MEKELLE UNIVERSITY

COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCE

SCHOOL OF EARTH SCIENCE

HYDROGEOLOGY STREAM

GROUNDWATER POTENTIAL EVALUATION USING AN INTEGRATED HYDROGEOLOGICAL APPROACH

FOR

GETSKIMILESLEY CATCHMENT, TIGRAY, ETHIOPIA

BY: ATAKLTI GEBRETSADIK ALEMAYEHU

A Thesis submitted to the school of earth science in partial fulfillment of the requirements for the degree of masters in hydrogeology

MEKELLE, TIGRAY, ETHIOPIA

2025

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ABSTRACT

Groundwater is the main source of water for Abi-adi town and the people residing in its vicinity. The well field is found in Getskimlesley catchment located to the North of Abi-abi town. The potential of the well field was not estimated before and there is water exploitation each day. There is also high demand from different actors. So before creating social problems and damaging the aquifer due the excessive withdrawal, estimating the resource is mandatory.

The study is to estimate the groundwater potential of the catchment; the amount of water that is recharging the groundwater, the runoff and the water that is evapotranspired annually, to estimate the potential & manage & protect accordingly. Water balance, pump test, geophysical and hydrogeological approaches employed to estimate the resource and to characterize the aquifer of the well field.

The potential evapotranspiration is determined from the Penman-Monteith approach & its value is 2158.33mm per year. The actual evapotranspiration computed using Thornthwaite-Mather soil water balance method is 738.32mm per year. The value of runoff coefficient is 0.31 & this is affected by soil type, slope and vegetation of the study area. The amount of water that leaves the catchment as surface runoff & the water that merges to the groundwater system annually 363.88 & 71.60 mm/year respectively.

The main lithological formations of the area are basement rocks and sandstone & the source of groundwater is relatively thick; medium to coarse grained and sorted Enticho sandstone & fractured basement rocks.

There are a number of wells drilled in the basement rocks and sandstone formation in the catchment. The productivity of the wells ranges from dry well to 7 liters per second whereas the yield measured in the sandstone ranges from 5 – 30 liters per second.

The average minimum & maximum Transmissivity of the aquifers which is calculated from the pump test data are 1.3 & 834.8 m^2/day respectively. Then the catchment is categorized into three different zones of moderate, low and very low productivity. The maximum drilled depth in the sandstone formation is 194 meters and the thickness of this formation reaches 400 meters. The maximum depth drilled in the basement rocks is 120 meters.

The main water type of the catchment is Ca-Mg-SO_4-HCO_3 & the quality is within the allowable limit of the standards for irrigation & domestic use.

The amount of water that withdraws from this well field should be below the amount that is merging to groundwater.

Key words: Getskimlesley, Evapotranspiration, runoff, recharge, Transmissivity, water type

DECLARATION

I, the undersigned, declare that as far as my knowledge this thesis is my original work & has not been presented before for any degree at this and any other university.

All sources of materials used for this thesis have duly acknowledged.

ATAKLTI GEBRETSADIK ALEMAYEHU

Signature: ______________________

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2025

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ADVISOR′S THESIS APPROVAL SHEET

This is to certify that the Thesis entitled **"GROUNDWATER POTENTIAL EVALUATION USING AN INTEGRATED HYDROGEOLOGICA APPROACH FOR GETSKIMILESLEY CATCHMENT, TIGRAY, ETHIOPIA"** has been developed by **Ataklti Gebretsadik Alemayehu** under my supervision. All the comments and corrections the advisor gave were incorporated into the Thesis. Therefore, I confirm that the student has fulfilled the Thesis writing requirements and can submit the Thesis to the department.

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We, the undersigned, members of the board of examiners of the final open defense have read and evaluated her thesis entitled "**GROUNDWATER POTENTIAL EVALUATION USING AN INTEGRATED HYDROGEOLOGICA APPROACH FOR GETSKIMILESLEY CATCHMENT, TIGRAY, ETHIOPIA"** and examined the candidate's oral presentation. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the Master of Science degree in Hydrogeology.

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CHAPTER ONE

1.1 Background and Justification

Groundwater is the sub-surface water that is found in the saturated zone of fractured and/or between pore spaces of grains of rocks & unconsolidated materials with variable thickness and at different depths. Interconnected fractures and pores in rocks and unconsolidated materials make up a large underground reservoir where part of precipitation is stored. (Garg, 1997)

Groundwater is the largest source of fresh water in the world. In many parts of the world, especially where surface water supplies are not available; for domestic, agricultural and industrial water needs can be met by using the water beneath the ground. (Kumar, 1997)

Many major cities and small towns in the world depend on groundwater for water supplies, mainly because of its abundance, stable quality. Besides, it is inexpensive to exploit particularly in scarce surface water supply areas. (Morris & Lawrence, 2003)

It is basic to evaluate the groundwater potential of the area before any development begins or for management purposes. Evaluating the resource helps to determine the amount of water that can be pumped from the aquifers, & the type & number of water schemes that are going to be developed.

The basic aim of this study is to evaluate the groundwater potential & water quality assessment of Getskimlesly catchment that is found in Kola-tembien woreda, northern Ethiopia. The catchment is the main source of groundwater for Abi-adi town & villages surrounding it. There are a number of deep & shallow wells in the catchment mainly for domestic water supply purposes but also for bottling & industrial uses.

There are as many methods available for quantifying groundwater recharge as there are different sources and processes of recharge. Each of the methods has its own limitations in terms of applicability and reliability. The objective of the recharge study should be known prior to selection of the appropriate method for quantifying groundwater recharge as this may dictate the required space and time scales of the recharge estimates. (Fetter, 2001)

In this study, the water balance method is employed based on available data. This requires meteorological data such as precipitation, temperature, evapotranspiration. In addition the geological, geophysical, hydrogeological, hydrochemical, aquifer parameters from pumping test data are applied to characterize the aquifers & to classify the aquifers' productivity based on their transmissivity.

Generally groundwater resource evaluation is very important for appropriate utilization, proper management & planning.

1.2 General Description of the Study Area

The study area is found in the central zone of Tigray, Kola-Tembien woreda, Getskimlesley Tabia/Kebele and Getskimlesley water shade. It is located at Universal Transverse Merectar (UTM) value of 493529 – 510619 mE and 1506465 - 1517362 mN. The datum is Adindan UTM zone 37N. It is about a 6 – 7 km drive towards the North-west from Abyi-adi town which is the center of Kola-tembien woreda. The annual average rainfall is 1173.79mm per year, the maximum mean annual and the minimum mean annual temperature is 29.81 and 13.69 degree centigrade respectively. The maximum and minimum mean elevation of the area is 2552 & 1760 meters above mean sea level respectively. According to the Ethiopian climatic zone classification (Gemech, 1977) the area is grouped under sub-tropical (Weyna Degu'a) climatic zone. It is accessed through the asphalt road extending from Mekelle – Abyi-adi – Adwa, Mekelle – Hawzen – Abyi-adi and Mekelle – Abyi-adi – Tekeze main asphalt roads. The specific water shade is called Getskimlesley and its area coverage is 110 Km^2.

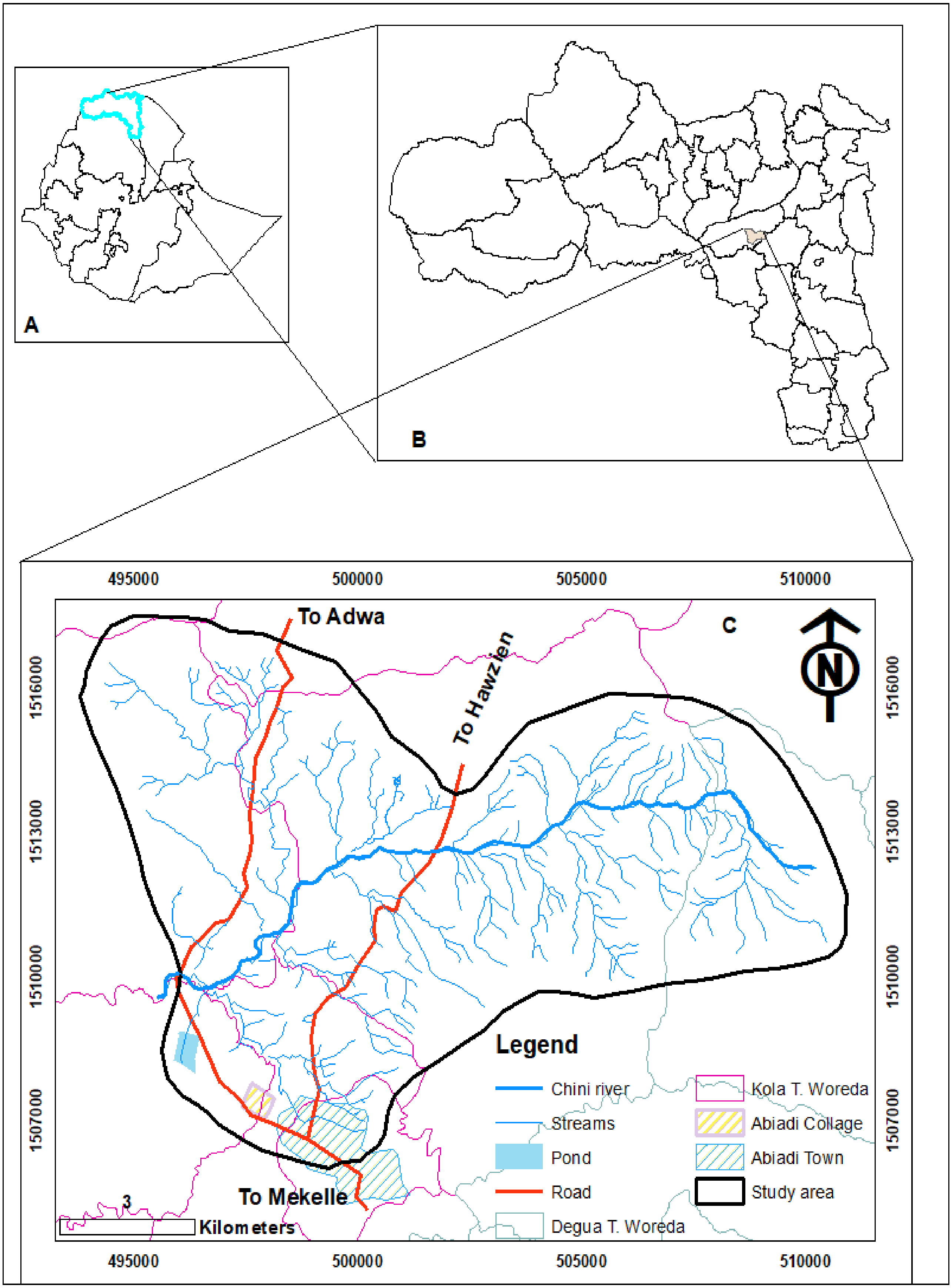


Figure 1. Location map of the study area

1.3 Physiography

The study area is surrounded by steep cliffs that reach up to 2550 meter elevation above mean sea level. There are a number of streams that originate from the cliffs and tributaries to the main river Chini. The lower area is relatively flat area that serves for farming and the lowest elevation is 1760 meter above mean sea level. There is an area between the cliffs and the flat lower area which is undulating in topography which is covered by bushes. These can be categorized according to their importance to groundwater development, recharge & discharge. The flat area is important to recharge groundwater through the big fractures found in the main river. Also this area is the main discharge area through drilling deep & shallow boreholes. The cliff is covered by different types of vegetation and this is the main area of recharge to the groundwater & source of runoff to the catchment.

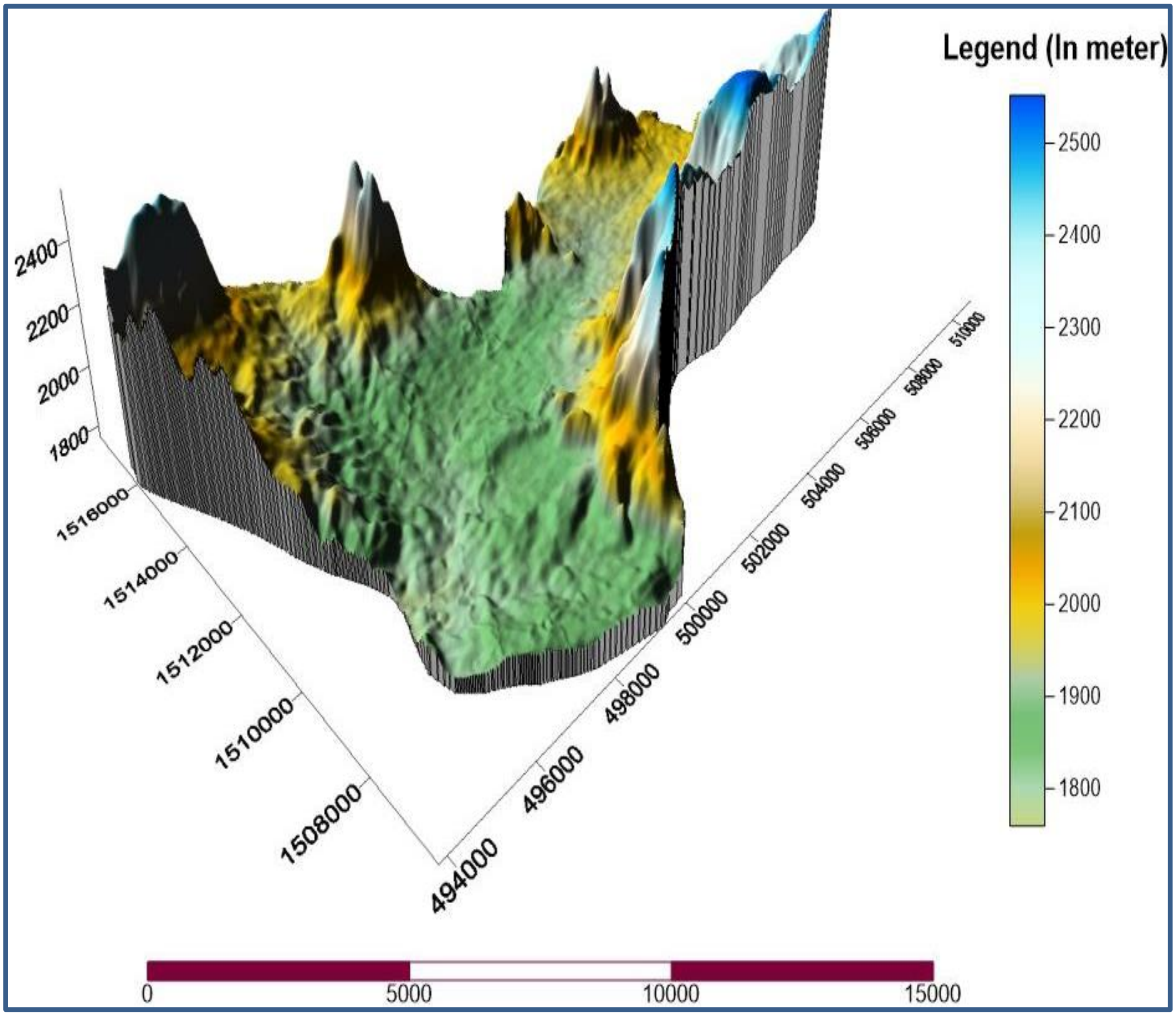


Figure 2. Physiographic map of the study area

1.4 Drainage

There is one relatively big river called Chini and is a perennial with moderate and small tributaries that supply runoff and base flow to it. The drainage system of the area is characterized by a dendritic pattern which is developed in geologically homogeneous areas.

The study area belongs to the Tekeze drainage basin and the drainage system flows to the west direction and joins to Tekeze River.

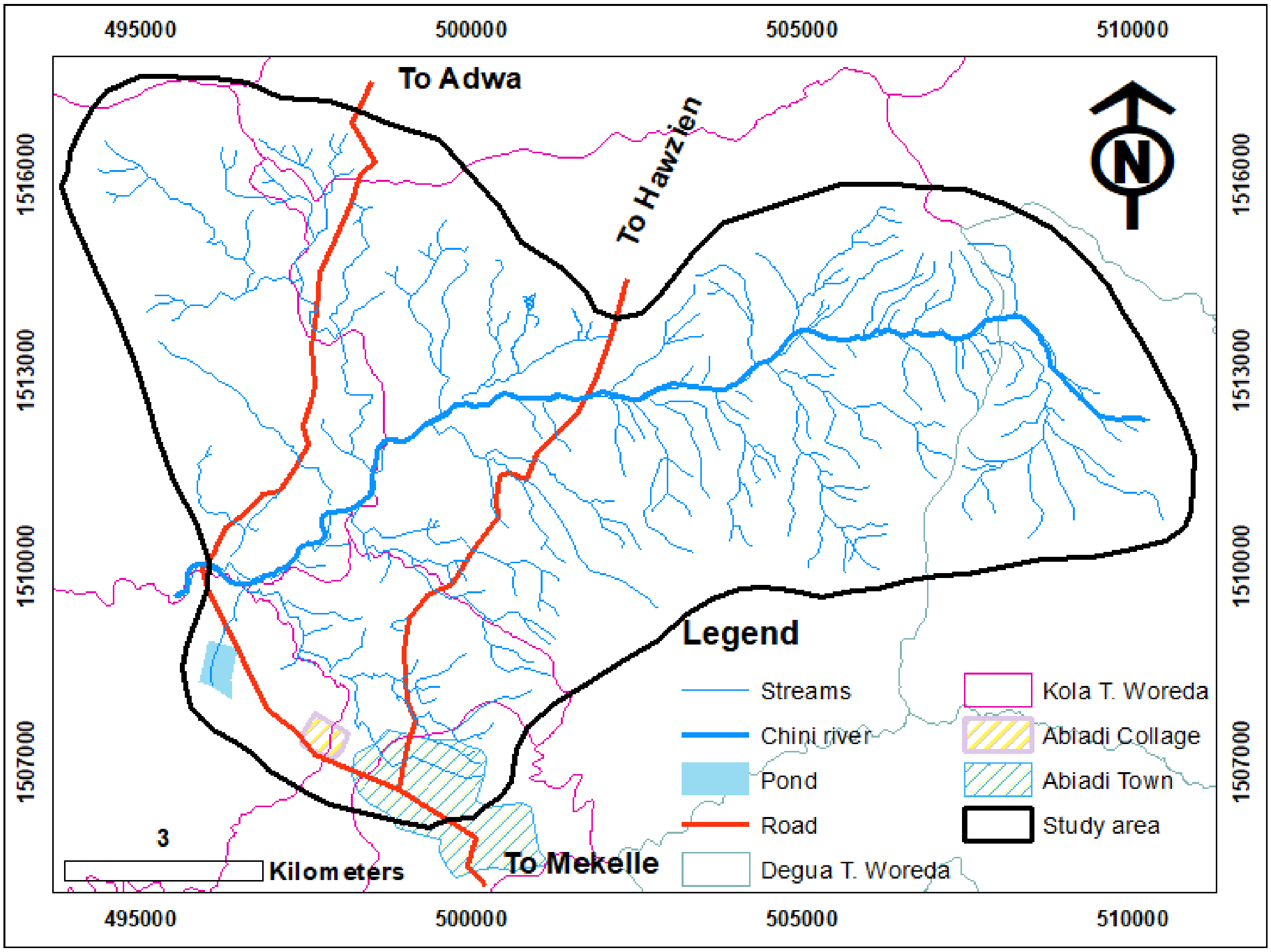


Figure 3. Drainage map of the study area

1.5 Vegetation

The study area is covered by different types of sparse vegetation such as Weyba (Combretum molle), Nefasha (Sibqana), Gaba (Zizipus spinachristi), Seraw (Acacia etbaica), Sagla (Ficus sycomorus), Kliaw (Euclea racemosa), Tahsas (Dodenia angustifolia), Lehay (Acacia lehai), Tambuukh (Croton macrostachyus), Tebeb (Becium grandiflorum), Awhi (Cordia africana), Hehot (Rumex usambarensis) etc.

1.6 Literature Review and Previous Works

Groundwater is the largest source of fresh water in the world. In many parts of the world, especially where surface water supplies are not available; for domestic, agricultural and industrial water needs can be met by using the water beneath the ground surface (Kumar, 1997).

There are a number of recharge estimation methods such as water table fluctuation, water budget, Darcy's law, empirical formula, groundwater modeling, tracer techniques (Scanlon, 2002).

There are a number of studies done in the study area, mainly for groundwater investigation for Abi-adi town& rural community water supply, bottling & industrial purposes. The study mainly focuses on groundwater searching using the conventional way that is, employing geological, hydrogeological and geophysical methods for the deep wells while for shallow and hand-dug wells done simply by observing the geology & hydrogeology of the area. The studies are done by Tigray water & energy bureau hydrogeology experts, freelancers & non-governmental organizations. These studies lack the main component that is the water balance, that is, the water that recharges the groundwater & the water that goes out of the catchment either naturally or artificially.

As can be evidenced by the previous studies in the area, there are a number of wells that become productive and dry as well. The documented reports include geology, hydrogeology, geophysical, lithological logging, hydrochemical, & pump test data etc.

These studies and activities are done for selecting sites for drilling & construction of wells and not to study the hydrogeological characteristics of the area, and no evaluation of the area has been done yet. The professionals who did the studies have recommended that it is mandatory to deal with the water balance of the catchment, geology, hydrogeology, characteristics, extent & depth of aquifer etc.

Then this study will provide enhanced information by collecting, analyzing & interpreting all the available primary & secondary data. Data from the previous works will deliver holistic information such as geological, geophysical, lithological logs & others which are crucial for the future investigation.

1.7 Problem Statement

Getskimilesley catchment is the main source of water supply for Abi-adi town & communities around the catchment, water bottling factory, and industrial use. The amount of water that is extracted daily from seven deep wells only exceeds 9000 cubic meters per day (Abi-adi water supply office). There are also tendencies to exploit more water from the catchment for other different purposes. The amount of water stored (reserve) in the sub surface is not evaluated and the amount of annual recharge not estimated yet. Therefore, the reserve and recharge of the aquifers need to be estimated for sustainable use of the groundwater resource of the area. The amount of water that is being extracted and the additional demands can play a major role in declining the groundwater amount & as a result damaging the aquifer system in addition to the huge environmental impact. In addition, this can affect the health, economy, energy and time of the community when water shortage is encountered. These can lead water offices to extra cost to solve the problem and create dissatisfaction among different stakeholders.

In order to minimize such types of problems it is essential to estimate the amount of water that is stored in the aquifers, the annual recharge annually to the aquifers; and the amount of water to be extracted from the aquifers in a sustainable way.

The aquifer nature of the catchment is fractured one, limited areal extent (its major part is covered by low yield or dry, the main aquifer has limited area extent, there is no any option for groundwater source in the neighboring catchments especially for Abi-adi town.

1.8 Scope of the Study

The study completed following conventional standard research methods starting from office work. From the literature acquire past experiences and methods of groundwater resource estimation methods that come up with reasonable results. Then it is by collecting relevant primary and secondary data from different sources.

Some of the data collected from different sources are meteorological, surface geology, lithological logging, hydrochemical, pumping test and others.

With the combination of the aforementioned data and applying appropriate and relevant groundwater resource evaluation methods and support of my advisors completed the study with good results.

1.9 Research Objective

1.9.1 General objective

To evaluate the groundwater potential of the study area using an integrated hydrogeological approach

1.9.2 Specific objective

The specific objectives of the research includes:-

- Estimate the groundwater recharge of the catchment
- Determine groundwater potential of the study area
- Characterize the hydrogeochemistry of the study area
- Evaluate groundwater quality for different purposes
- Map the geological and hydrogeological setting of the study area.

CHAPTER TWO

2.1. Regional Geology

The Precambrian basement forms a transition zone between the low-grade metamorphosed rocks (volcano-sedimentary succession and mafic-ultramafic complexes) of the northern East African Orogeny (Arabian Nubian Shield) and the high-grade metamorphosed and deformed rocks (schist, gneisses, migmatites, ophiolite fragments and granulites) of the southern East African Orogen (Miller, 2003).

In northern Ethiopia, the basement ages between 830 and 650 Ma and is characterized by deformation, metamorphism and intensive plutonism up to 520 Ma (Miller, 2003).

The Enticho Sandstones unconformably overlie Neoproterozoic basement rocks (Paleozoic planation surfaceand consist of eolian quartz arenites with a maximum thickness of 200 m. The upper part of the sandstones is locally heteropic with the EdagaArbi Glacials. (Beyth, 1972). The Enticho Sandstones are Ordovician in age on the base of fossil siphonoromid impressions (Saxena, 1983).

EdagaArbi Glacials consist of grey, black or purple clay and silt often containing dispersed pebbles or boulders up to 6 m in diameter (Beyth, 1972). Their thickness is variable but attains a maximum of 150 m in the northern portion of the Tekeze basin. The formation deposits in N–S trending glacial troughs and valleys up to several kilometers wide and tens of meters deep, carved into Precambrian basement and Early Paleozoic sediments (Beyth, 1972).

The Adigrat Sandstones increase their thickness from north to south and present the maximum values (∼600 m) aligned in a NNE–SSW trend, west of Mekele Outlier. They thin westward to ∼80 m and disappear north of Adigrat-Axum road (Beyth, 1972).

Since the abundance of ferruginous/lateritic beds and the presence of fossil wood fragments, (Beyth, 1972) interpret the sandstones as deposits of estuarine, lacustrine-deltaic or continental environments.

The age of the upper limit of Adigrat Sandstones is between Late Callovian – Early Oxfordian (Bosellini et al., 1997) whereas the lower boundary is thought to be diachronous and Triassic in age (Bosellini, 1997).

The thickness of the Antalo Limestone ranges from 300 m in the west to 800 m in the east. Four different facies can be identified (from bottom to top): (i) a sandy oolite limestone with low amount of marls, few chert beds and a fauna of corals, gastropods, and echinoids; (ii) an inter bedding of marls and limestone with brachiopods and algal and chert beds; (iii) reef limestone interbedded with marls and stromatolites; (iv) black to grey microcrystalline limestone interbedded with marls. (Bosellini, 1997).

A Late Callovian to Kimmeridgian age is assigned to the Antalo Limestone on the base of a benthic foraminifera fauna (Bosellini, 1997). Since the Adigrat Sandstones are continental, (Bosellini, 1997) hypothesize a Late Callovian sea transgression in northern Ethiopia.

The Agula Shales crop out only on top of the Antalo Limestone, reaching a maximum thickness of 300 m (Enkurie, 2010).nThey are composed, from bottom to top, of well-sorted, cross-bedded fine quartzarenites (tidal bars), laminated black shales and mudstones, dolomites and gypsum beds, and oolitic limestone (storm beds) (Beyth, 1972). This facies association is typical of peritidal, lagoonal and sabkha environments (Bosellini, 1997). The Agula Shales indicate the regression of the Jurassic sea from northern Ethiopia (Bosellini, 1997).

The AmbaAradam Formation has a maximum thickness of 200 m and lies unconformably (Cretaceous planation surface), on the Agula shales (Bosellini, 1997). The formation is made up of white or red sandstones with interbedded purple to violet silt- and mudstones, lateritic paleosols and lenses of conglomerates. The sandstones are interpreted as ‘point bar sequences’ deposited in a fluvial meandering river system (Bosellini, 1997). The lower- and uppermost parts of the formation are strongly lateritized.

Despite the absence of age diagnostic fossils, the formation is correlated with the Debre Libanos Sandstones, in the Blue Nile Basin (Assefa, 1991), and with the Aptian–Albian Upper Sandstone Unit, in the Harar region of southeastern Ethiopia (Bosellini, 1997)

The Tertiary Trap series of Ethiopia is associated with the Afar hotspot and covers most of Ethiopia, Eritrea and Yemen (Ebinger, 1998). Traps are characterized by a series of Late Eocene and Oligocene fissure basalts. Traps are covered by shield volcanoes (Mt. RasDashen, Mt. Guna, Mt. AbuneYosef) 30–10 Ma in age (Kieffer, 2004).

The Mekelle Dolerites are Oligocene in age. They consist of basaltic to gabbroid sills and dykes with aphanitic to phaneritic texture (Gebreyohannes, 2010). The thickness of the sills ranges from

80 to 130 m with a maximum area of 20 km2 ((Beyth, 1972); (Gebreyohannes, 2010)). The major conduits of the dolerites are the NW–SE faults and the NNE–SSW fractures (Gebreyohannes, 2010).

The Axum-Adwa Plugs are composed of silica-poor volcanic to hypabyssal rocks (phonolite–trachyte) 7–3 Ma in age (Beyth, 1972). Such plugs overlie Trap basalts and locally intrude and deform the basaltic flow layers.

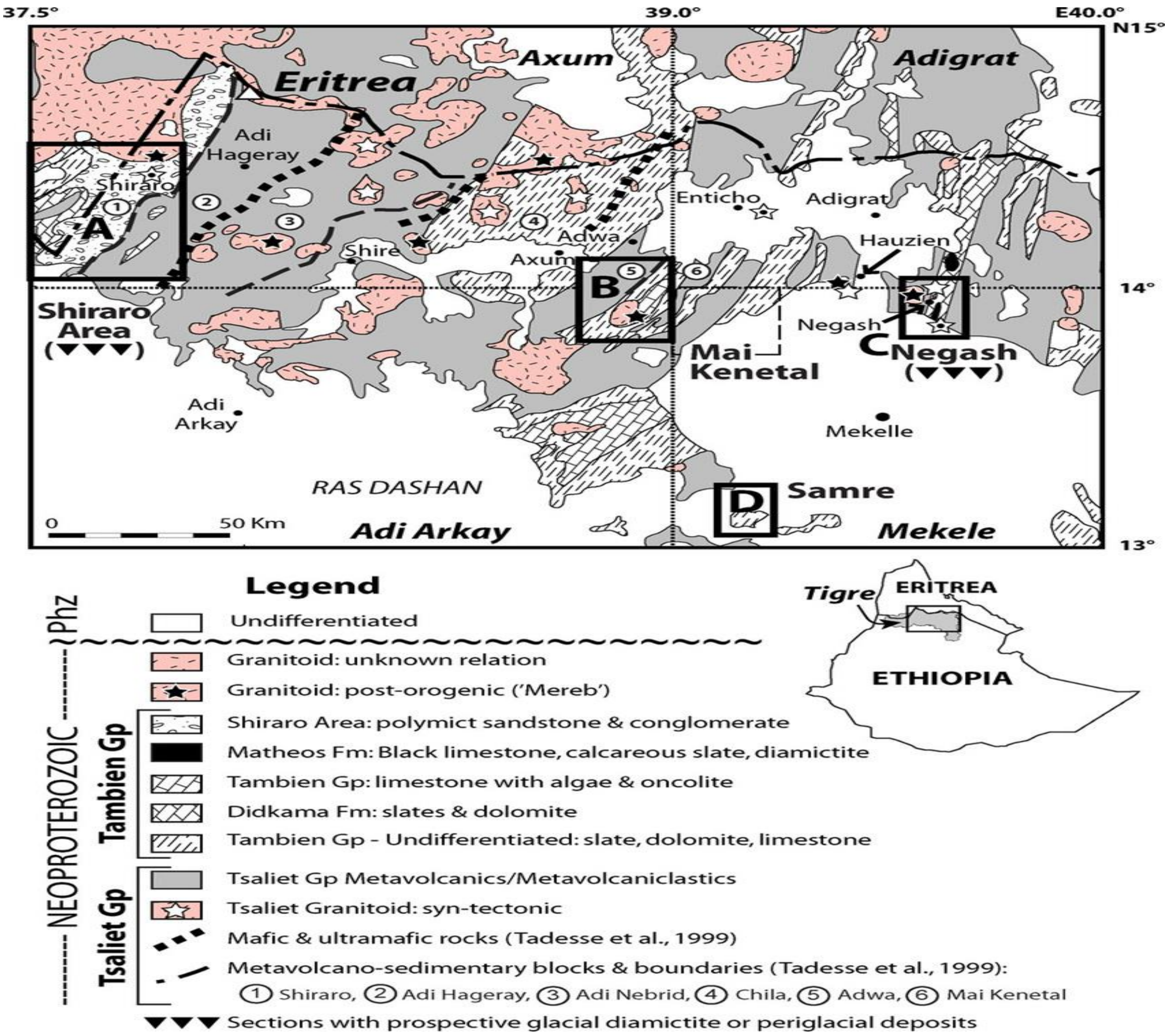


Figure 4. Geological map of northern Ethiopia (Tigre province) by N.R. Miller et al./Precambrian Research 170(2009) 129-156

2.2. Local Geology

The geology of the research area is mainly dominated by low grade metamorphic rocks (meta-volcanics), granite intrusion; the Paleozoic rocks (Enticho sandstone and Edga-arbi glacials) which form gentle slope; the Adigrat sandstone conformably lies over the glacials with very limited areal extent and the Tertiary volcanic rocks which form the highest elevated topography of the area. Quaternary alluvial deposits form flat land, mainly in the relatively flat areas and act as discharge area for groundwater.

2.2.1. Quaternary deposits (alluvial deposit)

This geologic unit is dominantly found in the river banks where mostly deposition of fine materials. Also there are areas with relatively thick in-situ deposition of clay soil and very fine grained sands. As it is observed in river cuts the thickness of this formation reaches 2-3meters.

2.2.2. Basalt

This formation is placed on the top of the Adigrat sandstone & is making the highest cliff in the area. It is also limited in aerial extent and coverage. It is part of the tertiary trap series basalts of Ethiopia. It is the source of black boulders found in the main river course in the study area.

2.2.3. Mudstone

This formation is part of the EdagaArbi Glacial and is found resting above the Enticho sandstone & below Adigrat sandstone. But in the study area the areal extent is limited and occurs as relative hill forming. It is reddish material & mainly found on the way to Getskimlesly from Abi-adi.

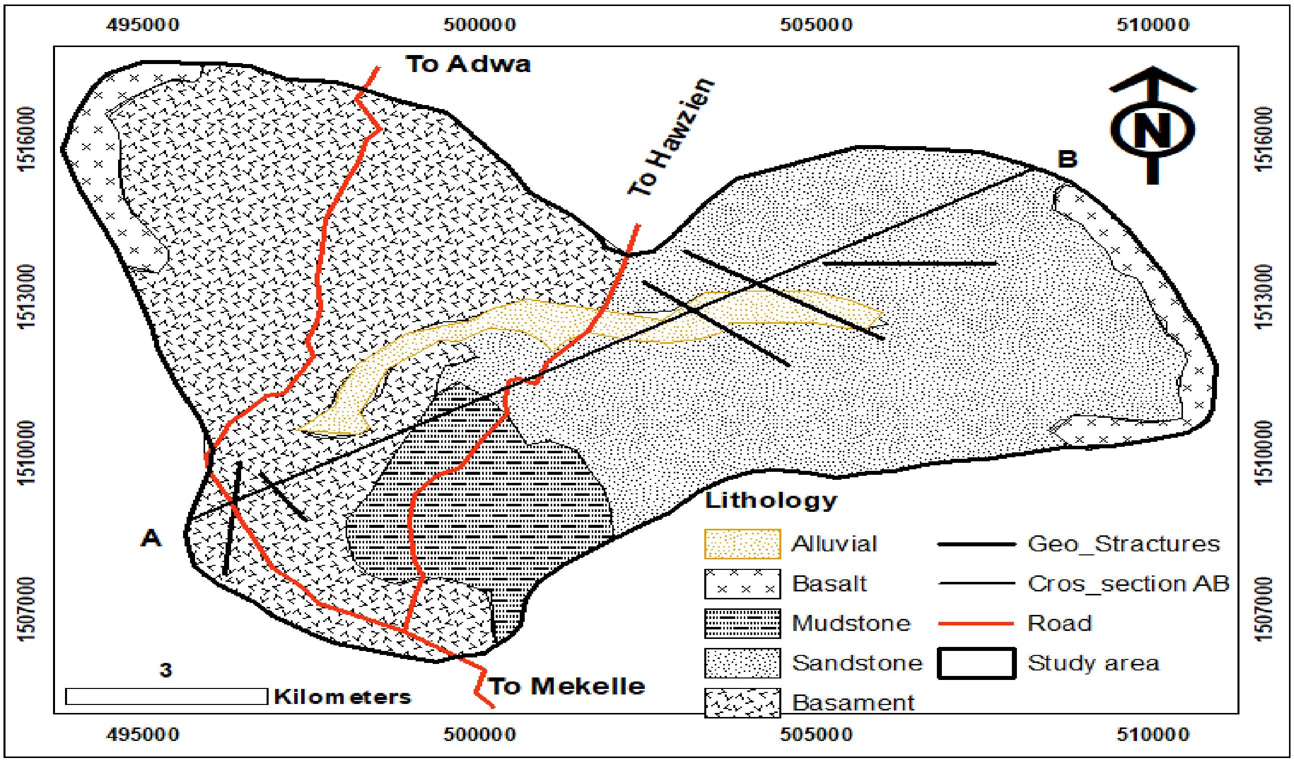
2.2.4. Sandstone

This lithologic unit is mainly found in the upper or eastern part of the water shade and is covered by fine grained sandstone or mudstone on the top. There are two layers of sandstone in the study area. One is the cliff forming which is called the Adigrat sandstone which rests above the Edga-arbiglacial.

The Enticho sandstone is reddish to pink in color. It is fine to medium grained and well sorted. It is highly fractured along the beds and are jointed, the aperture size of the fractures ranges from few centimeters to meters in the main Chini River. The orientation of the fractures is from South East to North West. The geophysical investigation results show that the thickness of this geologic unit is about 400 meter thick.

2.2.5. Basement rocks (meta-volcanic & mata-sediment)

These geologic units are dominantly found in the topographically lower part or south western part of the study area. In most cases they are weathered and fractured in their top part that reaches to the depth of 30-40m. This is proved from the drilled shallow & deep wells. These formations are intruded by quartz veins. In some areas they are highly fresh and become massive with depth. The upper part is weathered and fractured while its freshness increases with depth.



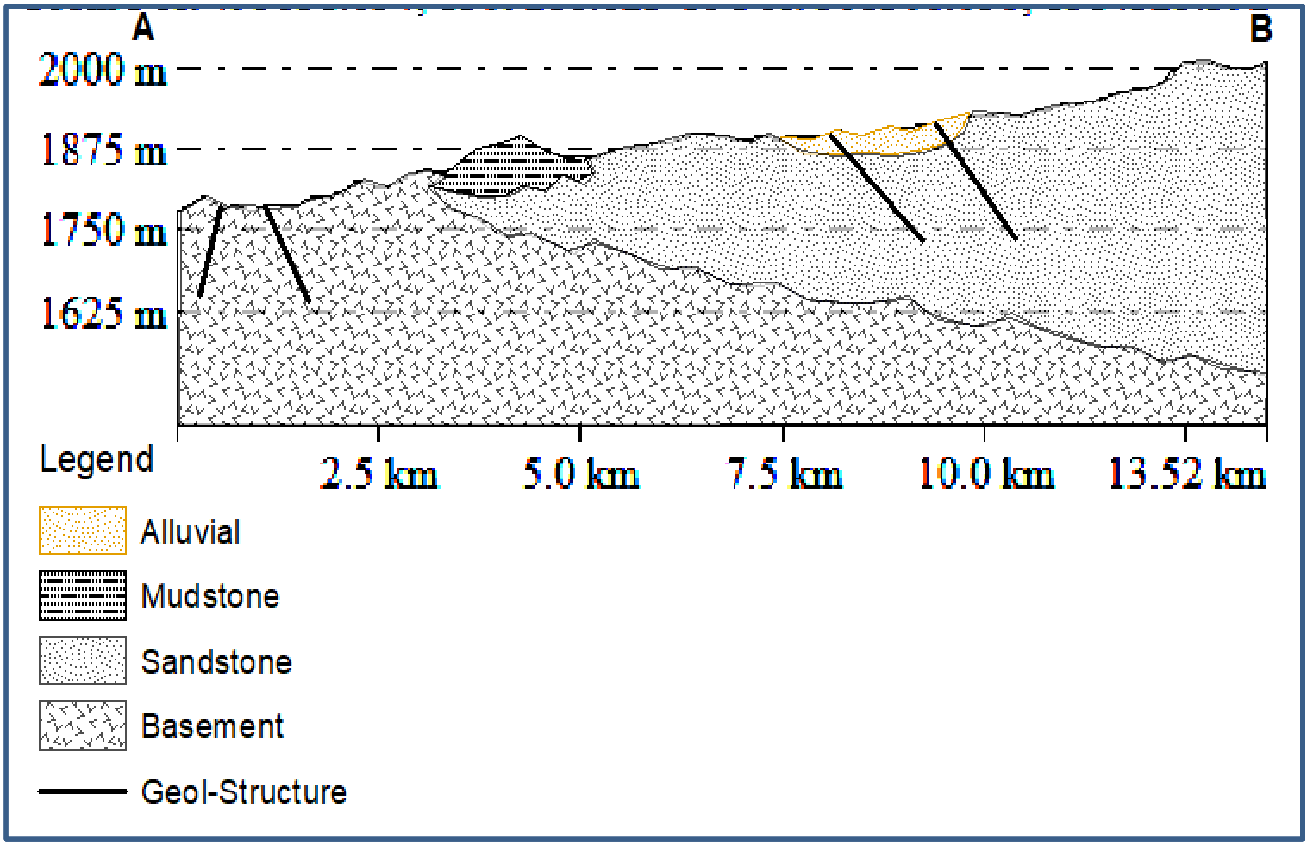


Figure 5. Geological map & geological cross-section of the study area

2.3. Geological Structures

The general orientation of the geological structures of the study area is almost the same. It is trending north south direction. The structures in the basement rocks are foliations (tightly spaced) due to the nature of rocks and how it is formed. Foliations are formed in meta-sediments between two thin layers. There are also contact structures between meta-sediment and meta-volcanic rocks. The meta-volcanic occur as dikes & sills but with small area extent. There are also geological structures that are filled with quartz veins.

The geological structures in Enticho sandstone are big fractures, lying along the main river. Its orientation is almost north south direction. Those clearly visible on the ground are found in the upper part of the catchment. There are a number of sets, persistence in both sides of the river and beyond, with different sizes of apertures. They are filled with sandy soil and gravel.

Figure 6. Photos of geological structures of the study area, in the sandstone formation & trending north-east to south west direction, near deep well of May Hutsa & Agamat

CHAPTER THREE

3.1. Materials and Methods

3.1.1. Materials used

The materials used in this study are Landsat satellite image (5m resolution), compiled regional geological (1:250,000), DEM (30m resolution), Garmin GPS, lithological log data, ArcGIS-10.8, Global Mapper-12, Surfer-13, geophysical data, IPI2 win software, hydrogeological map, pump test data, Strater software, Aquifer test software, pro version 8, Aqua chem 4.

3.1.2. Water budget method

The water budget methods are those that are based on the water budget equation. The water budget equation of a basin/catchment can be stated as

$$P + Qon = ET + Qoff + \Delta S \quad \text{---------- Equation 1}$$

Where,

P is precipitation (mm/month)

Q_{on} and Q_{off} is water flow onto and off the site (surface flow, interflow and groundwater flow) (mm/month)

ET is evapotranspiration (mm/month) and

ΔS is a change in storage (mm/month).

Based on the above water balance equation, (William, 1961) formulated the budget equation for recharge estimation as:

$$R = \Delta Sgw + ETgw + (Qgw\ off - Qgw\ on) + Qbf \quad \text{---------- Equation 2}$$

Where,

R is recharge

ΔSgw is change in subsurface storage

Qbf is base flow

ETgw is evaporation from groundwater and

Qgwoff - Qgwon is net surface flow from the basin

In the above model, all other parameters except R, can be measured or estimated. This method can be adopted for a wide range of spatial and temporal scales. However, a major limitation of this approach is that the accuracy of the recharge estimates depends on the accuracy with which other components of the water balance equation are measured (Scanlon, 2002).

Also the equation can be rearranged in this way and this is specific to the research area, by considering the change in storage is zero

$R = P - Roff - ET$ ------------ **Equation 3**

Where,

R is recharge

P is precipitation

R_{off} is surface runoff

ET is actual evapotranspiration

3.1.2.1. Precipitation

Precipitation is part of the atmosphere's water and derived from water vapor. Atmospheric water mostly exists as vapor, but briefly and locally it becomes a liquid (rainfall and cloud water droplets) or a solid (snowfall, cloud ice crystal and hails). But mostly in our case Precipitation is the amount of water in a liquid form that falls on the ground surface as rain.

Precipitation events are recorded by gauges at specific locations. Point precipitation data are used collectively to estimate aerial variability of rain and snow. The point location where the rainfall data gathered is Abi-adi metrological station, and the data are collected for this study from Ethiopian metrological agency, Mekelle branch located in Mekelle. The rainfall data are for about 24 years with few months data are missed and are recorded on daily bases. But these 24 years data are not taken because the other metrological components are not recorded equally at the same time. Then these were reduced to 15 years. These data are converted into monthly by adding each rainfall in each month and this monthly data are summed into yearly by adding each month in their respective year. After calculating each year data of 15 years, then average annual rainfall is also determined.

Accordingly the monthly average rainfall in mm is indicated below in the table 1. The annual average rainfall of the study area is 1173.79 mm/year.

TableTable 1. Average monthly rainfall in mm/month

Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Precipitation	2.79	5.73	11.88	27.43	42.19	136.6	345.5	457.1	128.9	11.88	3.78	0.0

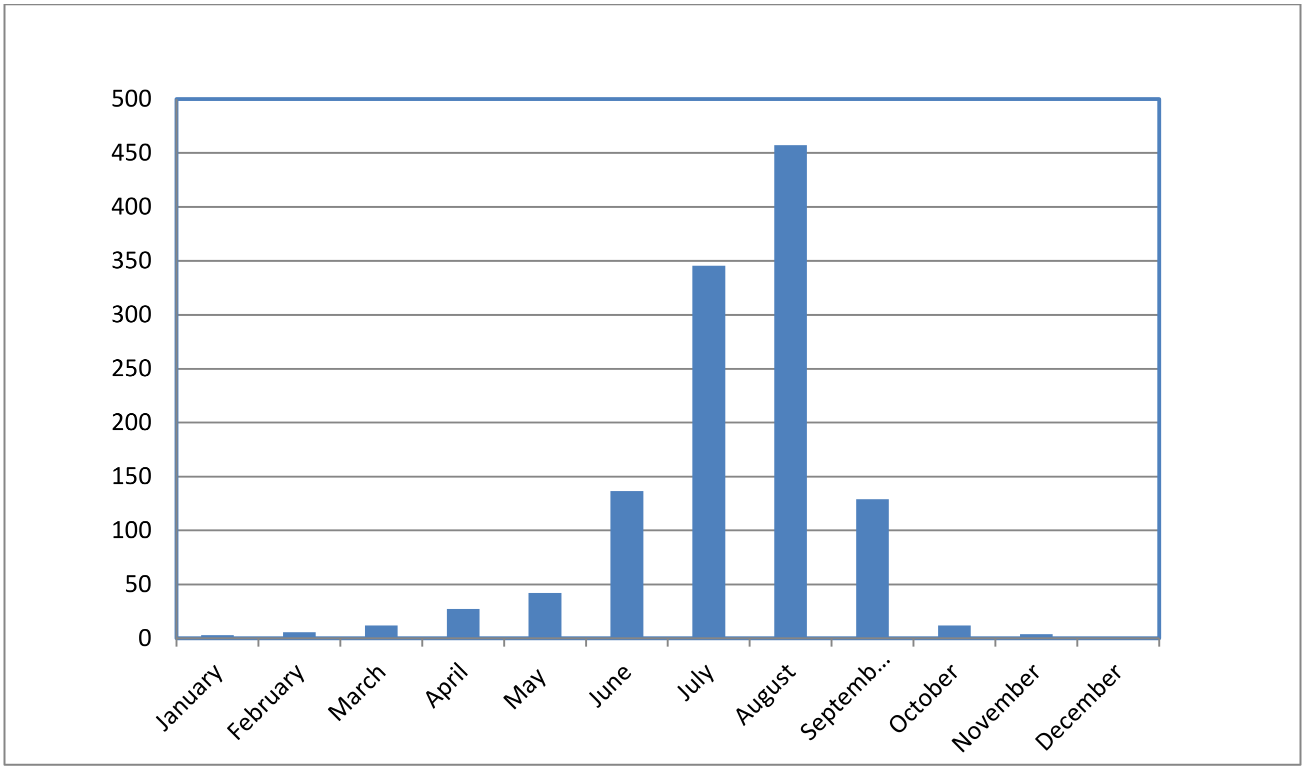


Figure 6. Mean monthly rainfall bar graph

3.1.2.2. Temperature

Temperature is a measurement of the hotness and coldness of a body. Temperature plays a critical role in determining the potential evapotranspiration and other important meteorological components. The maximum temperature is attained in the month of April which is 32.81 ^{o}C and the lowest is attained in the month of December which is 12.59 ^{o}C. The average maximum & minimum temperature per annum are 29.81 & 13.69 degree centigrade respectively. The average for both is 21.75 degree centigrade.

Table 2. Mean monthly temperature in ^{o}C

Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
T -Max	29.31	30.74	32.02	32.81	32.24	30.96	27.04	26.33	28.57	29.69	29.20	28.7
T- Min	12.67	13.35	14.49	14.63	14.83	14.19	13.05	13.15	13.97	14.15	13.24	12.6
T-Mean	20.99	22.04	23.26	23.72	23.53	22.58	20.05	19.74	21.27	21.92	21.22	20.7

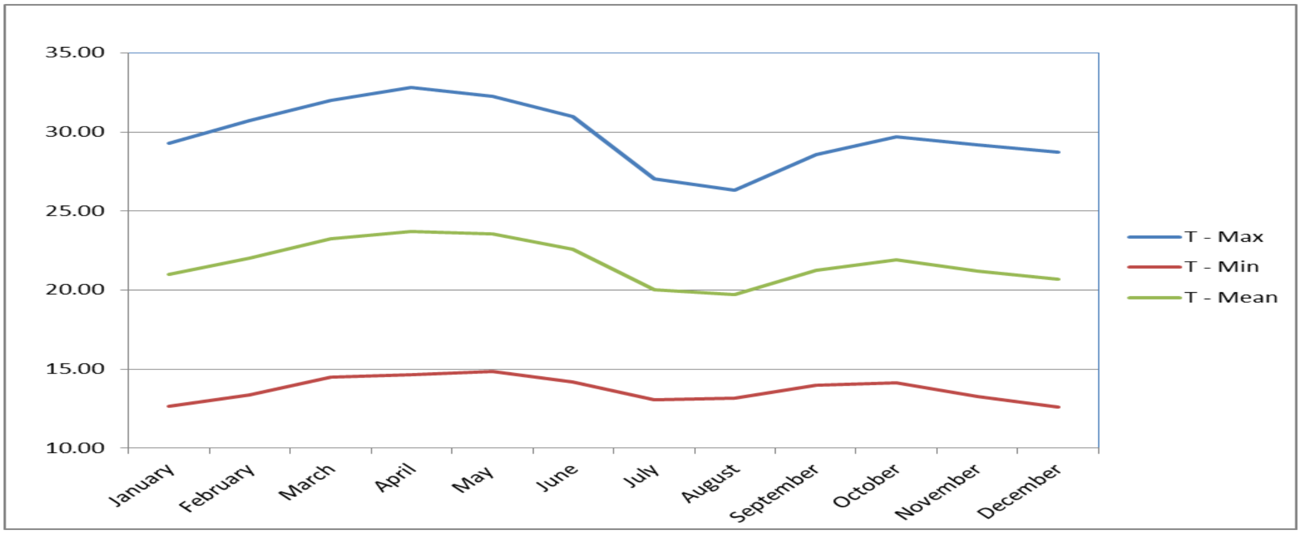


Figure 7. Mean, maximum & minimum temperature of the area

3.1.2.3. Relative humidity

Relative humidity is the amount of water vapor actually in the air, expressed as a percentage of the maximum amount of water vapor the air can hold at the same temperature. It is an important parameter in calculating potential evaporation. Relative humidity of an air mass is the percent ratio of the absolute humidity to the saturation humidity for the temperature of the air mass. The mean annual relative humidity is 48.21%. This parameter is collected from Adwa (nearby) metrological station.

Table 3. Mean monthly relative humidity in %

Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Relative Humidity (%)	39.50	34.75	34.99	34.85	37.02	48.26	72.19	78.83	65.01	45.21	45.32	42.63

3.1.2.4. Wind speed

Wind speed describes how fast the air is moving past a certain point. This may be averaged over a given unit of time. Wind helps in removing the saturated air and replacing it with the dry air. This facilitates evapotranspiration of an area. The movement of the air depends on the magnitude of the speed of the wind. Areas with high wind speed have high evapotranspiration and vice versa. The mean monthly wind speed is 0.94 m/sec. This parameter is collected from Adwa (nearby) metrological station.

Table 4. Mean monthly wind speed in meter per second

Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Wind speed	0.73	0.86	1.04	1.28	1.18	1.31	1.16	1.04	0.71	0.67	0.67	0.63

3.1.2.5. Sunshine hours

The sunshine hours are the maximum hours that the sun shines (sunshine) in a day. When there is no obstacle for the radiation of the sun to reach the earth surface. When it is rainy and cloudy the sunshine reaches on the earth surface is an obstacle and detected is a very small amount as a result the sunshine hours are so small. This parameter is the most important itself & also affects the other parameters directly & indirectly.

The mean monthly sun shine hour is 8.20 hours. This parameter is collected from Adwa metrological station.

Table 5. Mean monthly sunshine hours in Hours

Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Sunshine hours	9.40	9.88	9.15	9.15	8.26	7.28	5.11	4.34	6.96	9.45	9.59	9.80

3.1.2.6. Surface runoff

This is the amount of water that flows over the land surface as runoff after and/or during raining. This is the important parameter, determined using different methods as runoff coefficient to calculate the total volume of water moving as surface runoff from the catchment. Calculating the amount of surface runoff helps in calculating the amount of water that is going to recharge to the groundwater, the water lost by the process of evapotranspiration.

The runoff coefficient (C) is a dimensionless coefficient relating the amount of runoff to the amount of precipitation received. It is a larger value for areas with low infiltration and high runoff (pavement, steep gradient), and lower for permeable, well vegetated areas (forest, flat land).

The amount of surface runoff happens when the rainfall rate exceeds the infiltration capacity of the soil. The rate of infiltration, and therefore the possibility of surface runoff, is determined by such factors as soil type, vegetation, and the presence of shallow, relatively impermeable, soil horizons.

Saturated overland flow can occur when a temporary rise of the water-table inhibits infiltration and causes flow over the surface.

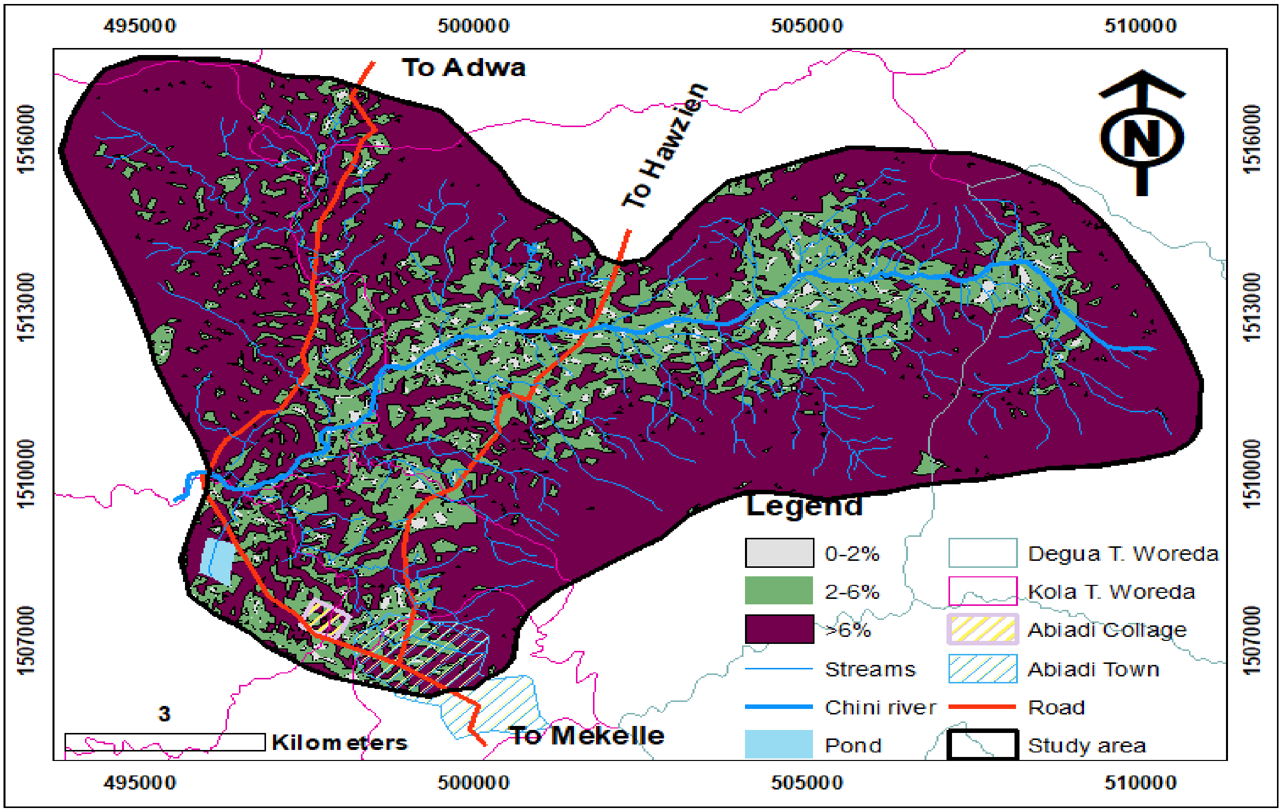


Figure 8. Slope map of the study area

Computation of accurate runoff rate or volume due to any storm from the watershed is a difficult task, because it depends on several factors related to the watershed and atmosphere. As mentioned above the runoff coefficient C is determined from the general catchment conditions of the catchment. These are land use, soil types, slopes and the vegetation cover of the area.

The area can be categorized into three parts. First the area covered by clay soil which covers the basement formation, the second one the sandy soil which covers the sandstone formation and the last one is the hill side that is covered by sparsely grown bushes and large trees. This area is covered by the sandstone & basement formations. The vegetation grows in the clay; sandy soil & hill side are Taff, maize & bushes/shrubs. The area that covers the large portion of the study area is the main source of runoff & has a large value of runoff coefficient.

The main important aspect to determine the runoff coefficient is slope. Areas with high slope have high runoff coefficient & vice versa. The slope of the study area is categorized into three parts and is in percent rise. These are 0 – 2, 2 – 6 & greater than 6 per cent.

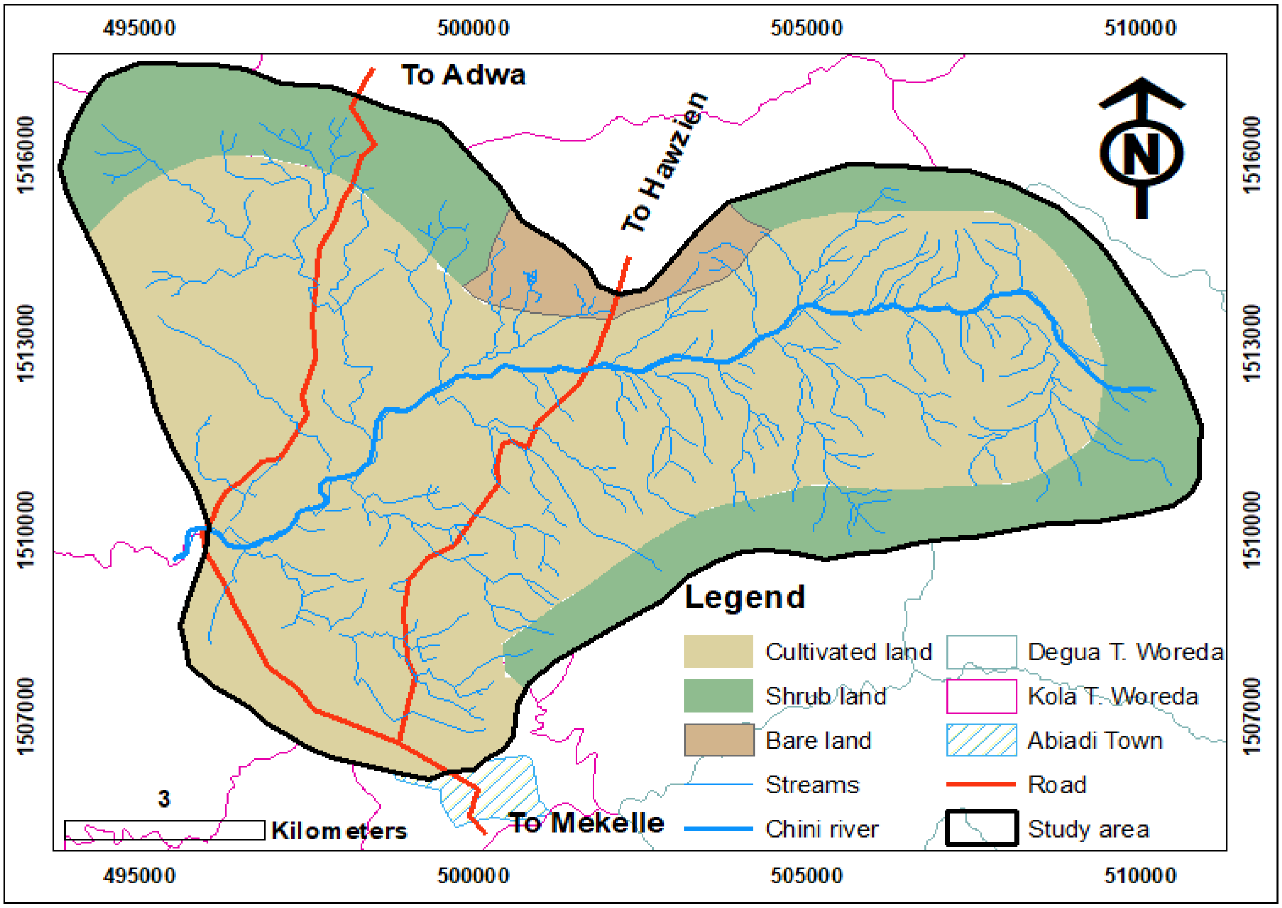


Figure 9 Land use map of the study area

Table 6 Table shows the result of the runoff coefficient for different slopes **(service, 1986)**

Land use type	Slope (%)	Area (Km^2)	Soil type	Runoff coefficient	Weighted runoff coefficient	Average
Cultivated	0 - 2	2	Sandy	0.2	0.4	0.4
	0 - 2	2	Clay	0.5	1	
	2 – 6	15	sandy	0.25	3.75	
	2 – 6	12	Clay	0.6	7.2	
	>6	30	Sandy	0.3	9	
	>6	19	Clay	0.7	13.3	

Shrub/Bush	0 - 2	0	Sandy	0	0	0.24
	0 - 2	0	Clay	0	0	
	2 – 6	1	sandy	0.1	0.1	
	2 – 6	0	Clay	0.3	0	
	>6	15	Sandy	0.15	2.25	
	>6	10	Clay	0.4	4	
Bare land	2 – 6	1	Sandy	0.25	0.25	0.29
	>6	3	Sandy	0.3	0.9	

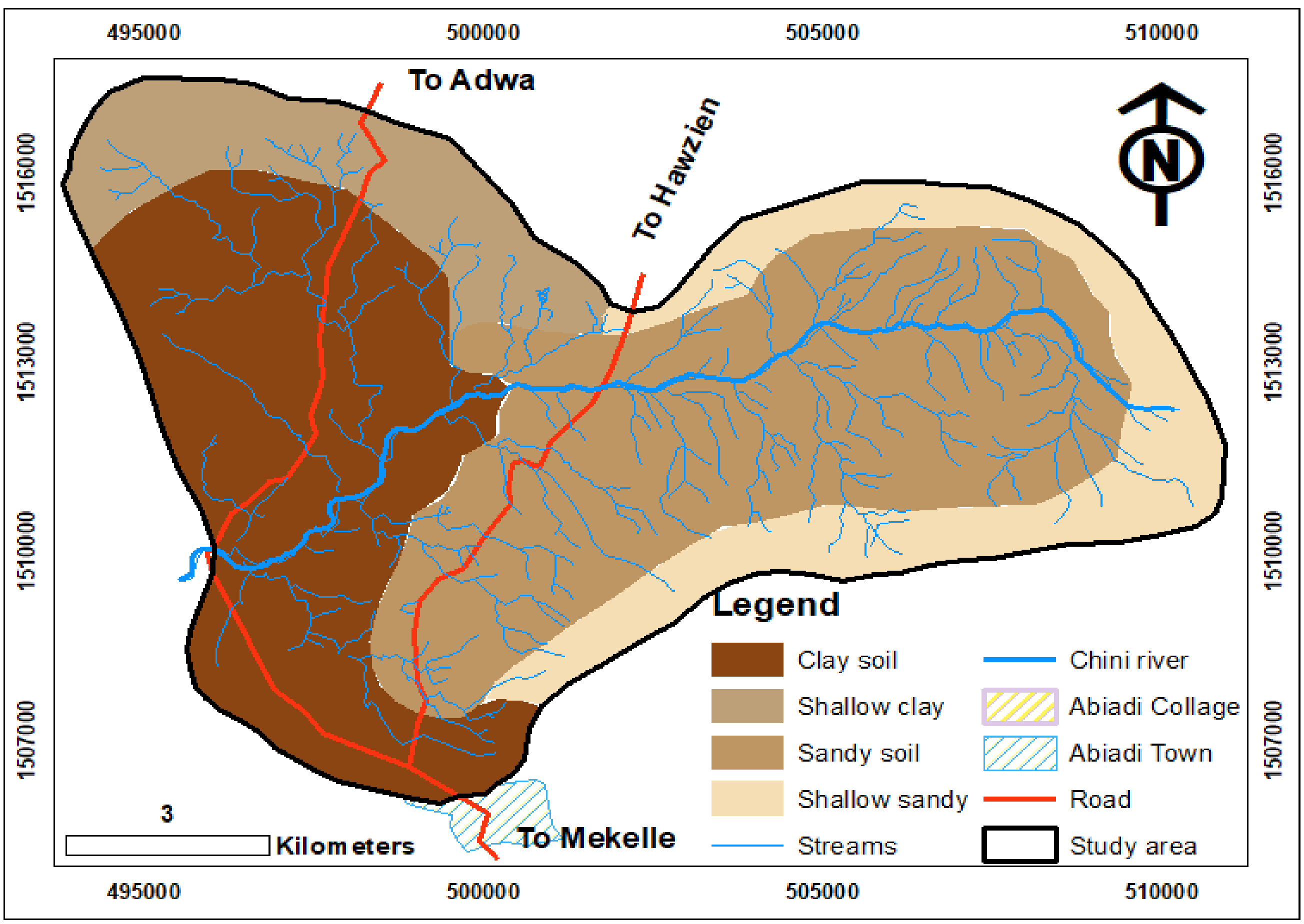


Figure 10. Soil map (relative to their thickness) of the study area

3.1.2.7. Potential evapotranspiration

Evapotranspiration is the process of chaining liquid water into gas from land surface, plants & from open air water bodies. It depends on solar radiation, air temperature, relative humidity, evaporating surface, wind speed.

Evapotranspiration is not easy to measure since it depends on many parameters such as crop type, soil type, and agricultural management. Expensive devices such as lysimeters can be used, but experienced researchers are required (Allen, Pereira, Raes, & Smith, 1998).

(Penman. & Monteith, 1965) Method is well known & recommended to calculate potential evapotranspiration & needs solar radiation, air temperature, humidity, and wind speed as input parameters. Wind speed, humidity & sunshine hours are from Adwa metrological station. (Priestley, 1972) developed an equation derived from the original (Penman, 1948) equation, and has been of interest to crop modelers due to lesser data requirements. It requires net radiation data & mainly applicable in humid areas. (Hargraves, 1985) developed an empirical equation for arid areas; & needs temperature & radiation data to calculate potential evapotranspiration. (Blaney, 1950) was also employed & mainly needs temperature & monthly percentage annual daytime hours. It is applicable in temperate and semi-arid areas. (Thornthwaite, 1948) also developed a method on empirical approach in order to estimate potential evapotranspiration & this mainly requires temperature & day length (hours based on latitude).

3.1.2.7.1. (Penman. & Monteith, 1965) Method

The FAO Penman-Monteith method equation is follows:

$$ETo = \frac{0.408\,\Delta\,(Rn-G)+\gamma\frac{900}{T+273}U2(es-ea)}{\Delta+\gamma(1+0.34U2)} \text{ ------------------ Equation 4}$$

Where,

ETo – potential evapotranspiration, mm/month;

Rn - net radiation, MJ m-2 d-1;

G - Soil heat flux density, MJ m-2 d-1;

T - Mean daily air temperature at 2 m height, ºC;

u2 - wind speed at 2 m height, m s-1;

es - saturation vapor pressure, kPa;

ea - actual vapor pressure, kPa;

es– ea is saturation vapor pressure deficit, kPa;

Δ - slope of the vapor pressure curve, kPa ºC-1;

γ − Psychrometric constant, kPa ºC-1.

Ra - Daily extraterrestrial radiation, MJ m-2 d-1;

Rns - Net solar/shortwave radiation

Rnl - Net long wave radiation

RH – Relative humidity in %

Table 7. Result of potential evapotranspiration from **(Penman. & Monteith, 1965)**

Parameters	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Ra	29.9	33.1	36.1	38.1	38.4	38.1	38.1	38	36.7	33.9	30.6	28.9
T mean	21.08	22.12	23.24	23.73	23.55	22.65	20.14	19.86	21.28	21.9	21.2	20.7
RH	39.50	34.75	34.99	34.85	37.02	48.26	72.19	78.83	65.01	45.2	45.3	42.6
W/s	0.73	0.86	1.04	1.28	1.18	1.31	1.16	1.04	0.71	0.67	0.67	0.63
N	11.3	11.6	11.9	12.3	12.6	12.8	12.8	12.5	12.1	11.7	11.3	11.2
n	9.4	9.88	9.15	9.15	8.26	7.28	5.11	4.34	6.96	9.45	9.59	9.8
N/n	0.83	0.85	0.77	0.74	0.66	0.57	0.40	0.35	0.58	0.81	0.85	0.88
es	2.78	2.98	3.20	3.32	3.25	3.06	2.55	2.49	2.75	2.88	2.78	2.71
Rso	23.50	26.02	28.37	29.95	30.18	29.95	29.95	29.87	28.85	26.7	24.1	22.7
Rs	19.91	22.37	22.90	23.70	22.19	20.36	17.13	16.10	19.73	22.2	20.6	19.9
Rs/Rso	0.85	0.86	0.81	0.79	0.74	0.68	0.57	0.54	0.68	0.83	0.86	0.87
G	0.1	0.1	0.1	0.0	0.0	-0.1	-0.1	0.1	0.1	-0.1	-0.1	0.0
Rns	15.33	17.23	17.64	18.25	17.08	15.68	13.19	12.39	15.19	17.1	15.9	15.3
Rnl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rn	15.33	17.23	17.64	18.25	17.08	15.68	13.19	12.40	15.19	17.07	15.88	15.30

ETo	171.2	184.6	212.3	223	214.2	192.5	150.9	135	155.4	185.6	167.6	166.1

The total amount of potential evapotranspiration from this method is 2158.33 mm/year.

3.1.2.7.2. (Hargraves, 1985) Method

Hargreaves (Hargraves, 1985) equation is expressed mathematically as:

$$ETo = 0.0023Ra(Tmean + 17.8)(Tmax - Tmin)^{.5}$$ ---------------------- **Equation 5**

Where ***Ra*** is the extraterrestrial radiation (mm/day), T-mean mean air temperature, T_{max} and T_{min} are mean maximum and mean minimum air temperature respectively. This mainly focuses on temperature & radiation.

Table 8. Result of evapotranspiration from **(Hargraves, 1985)**

Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Ra	12.20	13.50	14.73	15.54	15.67	15.54	15.54	15.50	14.97	13.8	12.5	11.8
Tmx - Tmin	16.64	17.39	17.54	18.18	17.41	16.77	13.99	13.19	14.59	15.54	15.96	16.15
T_mean	21.08	22.12	23.24	23.73	23.55	22.65	20.14	19.86	21.28	21.9	21.2	20.7
ETo	137.6	149.7	180.6	189.9	192.7	177.3	156.9	150.7	154.2	154.4	134.3	130

The total amount of potential evapotranspiration from this method is 1908.20 mm/year.

3.1.2.7.3. (Thornthwaite, 1948) Method

Thornthwaite equation, which is a method developed by (Thornthwaite, 1948) based on an empirical approach in order to estimate potential evapotranspiration.

$$ETP = 16\left(\frac{10*Tmean}{I}\right)^{a} * N/12$$ ---------------- **Equation 6**

Where ETP is potential evapotranspiration, T mean monthly average temperature, I is monthly heat index, ***a*** is a factor of I that is equal to 0.49+0.0179I-0.0000771I^2+0.000000675I^3 & N is the daylight hours from standard table with respective to latitude.

Table 9. Results of potential evapotranspiration from **(Thornthwaite, 1948)**

Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec

T_mean	21.08	22.12	23.24	23.73	23.55	22.65	20.14	19.86	21.28	21.9	21.2	20.7
I	8.78	9.45	10.25	10.56	10.43	9.80	8.19	8.00	8.95	9.37	8.92	8.57
a	2.46	2.46	2.46	2.46	2.46	2.46	2.46	2.46	2.46	2.46	2.46	2.46
N/12	0.94	0.97	0.99	1.03	1.05	1.07	1.07	1.04	1.01	0.98	0.94	0.93
ETo	71.89	83.22	97.40	105.74	106.19	97.40	72.69	68.35	79.51	82.82	73.82	68.56

The total amount of potential evapotranspiration from this method is 1007. 59mm/year.

3.1.2.7.4. (Priestley, 1972) Method

The Priestley-Taylor (1972) method can be expressed as:

$$ETo = \propto \frac{\Delta}{\Delta+\gamma}\frac{Rn-G}{\lambda}$$ ------------------- **Equation 7**

Where **α** is the empirically derived constant and was defined as 1.26 by Priestley and Taylor (1972), and k is the latent heat of vaporization (MJ/kg). This method is mainly focuses on net radiation.

Table 10.Results of potential evapotranspiration from **(Priestley, 1972)**

Parameters	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
α	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26
λ	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45
ɣ	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Δ	0.153	0.161	0.17	0.179	0.174	0.165	0.145	0.145	0.153	0.16	0.15	0.153
Rn	15.33	17.23	17.64	18.25	17.08	15.68	13.19	12.40	15.19	17.1	15.9	15.30
ETo	73.43	77.78	86.98	87.56	85.18	75.53	63.45	58.36	69.97	83.1	73.9	73.27

The total amount of potential evapotranspiration from this method is 908.58 mm/year**.**

3.1.2.7.5. (Blaney-Criddle-FAO24) Method

The FAO-24 Blaney-Criddle method (Doorenbos and Pruitt, 1977), referred to as FAO-24 BC hereafter, can be expressed as:

$$a + b[p(0.46Tmean + 8.13)]$$

$$a = 0.0043(RHmin) - \frac{n}{N} - 1.41$$

$$b = 0.82 - 0.0041(RHmin) + 1.07\left(\frac{n}{N}\right) + 0.066Ud - 0.006RHmin\left(\frac{n}{N}\right) - 0.0006RHmin$$

Where p is mean monthly daily percent of annual daytime hours (table), n sunshine hours, N possible maximum sunshine hours, a,b adjustment factors for local climate conditions.

Table 12.Results of potential evapotranspiration from Blaney-Criddle

Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
b	1.38	1.45	1.38	1.38	1.28	1.11	0.80	0.72	0.96	1.31	1.34	1.38
a	-2.07	-2.11	-2.03	-2.004	-1.91	-1.77	-1.5	-1.42	-1.71	-2.02	-2.06	-2.10
p	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69
T m	12.67	13.35	14.49	14.63	14.83	14.19	13.05	13.15	13.97	14.15	13.24	12.59
ETo	262.3	252.1	277.7	271.8	279.6	264.3	255.9	253.8	255.7	268.6	255.4	260.11

The total amount of potential evapotranspiration from this method is 3157.21 mm/year.

3.1.2.8. Actual evapotranspiration

Actual Evapotranspiration is defined as the amount of water that is removed from the earth surface due to the process of evaporation and transpiration under a natural condition of a given area with the actual amount of water supplied.

The actual evapotranspiration is calculated using the soil water balance (C.W. Thornthwaite, 1955). This method requires potential evapotranspiration calculated from the Penman - Monteith approach, mean monthly rainfall, available water capacity (AWC); and this provide us the most important component of the water balance, that is, actual evapotranspiration & others parameters such as deficit, surplus used to calculate the amount of water that is going to recharge to the groundwater.

The soil types of the study area are sandy & clay soils. The rooting depth of the crops (Cereals) is 0.8m. The AWC calculated below.

Table 11. Calculating average Available water capacity of the study area **(FAO, 2006)**

Soil type		AWC(mm)	Calculated AWC(mm)	Average (mm)
Clay	Clay	100 - 130	115	112.5
	Silt clay	90 - 130	110	
Sandy soil	Sand	25 - 50	37.5	50
	Loamy sand	50 - 75	62.5	

Table 12. Result of actual evapotranspiration for clay soil covered with cereal crops having rooting depth 0.8m & available water capacity is 112.5mm using soil & water balance (C.W. Thornthwaite, 1955), the potential evapotranspiration is from Penman - Monteith approach

Parameters	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
PPT	2.90	5.73	11.88	27.43	42.19	136.6	345.5	457.1	128.9	11.88	3.78	0.00
ETo	171.17	184.57	212.27	222.99	214.19	192.54	150.86	134.99	155.43	185.58	167.61	166.13
PPT- ETo	-168.27	-178.85	-200.39	-195.56	-171.99	-55.99	194.63	322.09	-26.55	-173.70	-163.83	-166.13
APWL	-698.49	-877.33	-1077.7	-1273.3	-1445.3	-1501.3			-26.55	-200.25	-364.09	-530.22
AWC	112.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5
ST	0.23	0.05	0.01	0.00	0.00	0.00	112.5	112.5	88.85	18.97	4.42	1.01
ΔSm	-0.78	-0.18	-0.04	-0.01	0.00	0.00	112.5	0.00	-23.65	-69.88	-14.55	-3.41
AET	3.68	5.91	11.92	27.44	42.19	136.55	150.86	134.99	152.53	81.76	18.33	3.41
D	165.62	177.98	200.12	195.49	171.98	55.99	0.00	0.00	2.27	89.02	138.85	157.94
S	0.00	0.00	0.00	0.00	0.00	0.00	194.63	322.09	0.00	0.00	0.00	0.00

Table 13. Result of actual evapotranspiration for sandy soil covered with cereal crops having rooting depth 0.8m & available water capacity is 50mm using Thornwthaite and Mather, 1957 soil Water balance, the potential evapotranspiration is from Penman - Monteith approach

Parameters	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
PPT	2.90	5.73	11.88	27.43	42.19	136.6	345.5	457.1	128.9	11.88	3.78	0.00
ETo	171.17	184.57	212.27	222.99	214.19	192.54	150.86	134.99	155.43	185.58	167.61	166.13
PPT-ETo	-168.27	-178.85	-200.39	-195.56	-171.99	-55.99	194.63	322.09	-26.55	-173.70	-163.83	-166.13
APWL	-698.49	-877.33	-1077.7	-1273.3	-1445.3	-1501.3			-26.55	-200.25	-364.09	-530.22
AWC	50	50	50	50	50	50	50	50	50	50	50	50
ST	0.00	0.00	0.00	0.00	0.00	0.00	50.00	50.00	29.40	0.91	0.03	0.00
ΔSm	0.00	0.00	0.00	0.00	0.00	0.00	50.00	0.00	-20.60	-28.49	-0.88	-0.03
AET	2.90	5.73	11.88	27.43	42.19	136.55	150.86	134.99	149.48	40.37	4.66	0.03
D	165.62	177.98	200.12	195.49	171.98	55.99	0.00	0.00	2.27	89.02	138.85	157.94
S	0.00	0.00	0.00	0.00	0.00	0.00	194.63	322.09	0.00	0.00	0.00	0.00

Where:-

PPT - Mean monthly precipitation (mm/month)

PET - Potential evapotranspiration (mm/month)

PPT - PET - The difference between precipitation and potential evapotranspiration

APWL - accumulated potential water loss is calculated as the cumulative sum of precipitation minus potential evapotranspiration is negative

AWC - available water capacity is the water that a soil can store & make available for plants

ST - Monthly Soil Moisture Storage calculated by $ST = AWC * e^{APWL}/AWC$ for the months which are the difference between precipitation & potential evapotranspiration is negative

ΔSm – The difference in soil moisture between consecutive months

AET - Actual Evapotranspiration

D - Soil moisture deficit is the difference between potential evapotranspiration and actual evapotranspiration

S - Soil moisture surplus is the difference between precipitations and potential evapotranspiration

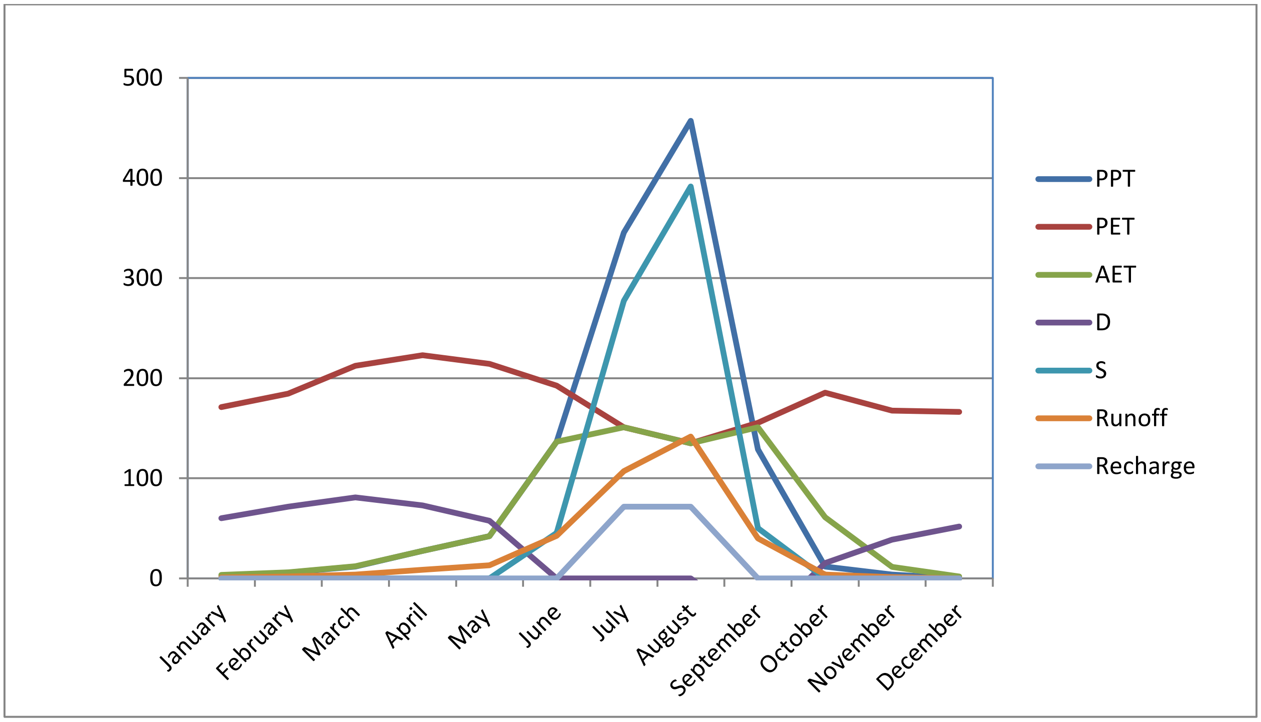


Figure 11. Graph shows the different parameters

3.1.3. Pumping test method

Groundwater is the most suitable source of water by digging deep & shallow boreholes & installs different pumps to bring the groundwater into the land surface.

Pumping test is a critical task where very important information and data are collected regarding the overall groundwater condition of a given area including borehole's efficiency and its optimal yield. The subsurface water condition may not be defined properly apart from conducting pumping test operations and the respective evaluation and analysis of results, considered as a middle point where the technical accomplishments and the management aspects inter-linked. Hence, it requires all commendable efforts and concentration to produce reliable results which would highlight the executed technical performances and the proposed borehole /aquifer management strategy.

From the pumping test it is possible to determine the different hydraulic properties of the aquifer, especially transmissivity and specific capacity of wells, from which the potentiality of the aquifer and productivity of the wells is evaluated. The results obtained can be used as input for mapping of areas with different yield and capacity accordingly and to give due attention in groundwater management.

In the study area, there are eleven (11) deep wells, out of which 6 have pump test data, 2 are dry, 1 has data quality problem, 1 with no pump test & log data but depth & yield,; and there is a well drilled for Sur construction plc (road construction), the well is dry but no data.

Six (6) deep wells drilled in the upper part of the catchment covered by the Enticho sandstone formation. The depth ranges from 100 – 194m and logged as Enticho sandstone with different grain and size, sorting. Out of the six deep wells five wells are taken into analysis but one well has data quality problems.

The other five (5) deep wells are drilled in the lower part of the catchment, covered by the Precambrian basement rocks. Their depth ranges from 78 – 120 meter. Out of the five deep wells only one well is found to be productive and it serves for Abi-adi town water supply. It yields 7 lit/second and its depth is 107 meter, but other data is not available (Abi-adi water supply office). This well is productive due to the existence of secondary structures developed and associated with quartz vein. The second well taken into analysis is Chini & it yields 1.5 liters per second. This yield is not economical to use as water supply source for towns like Abi-adi. The remaining three wells even have low yield that is below 1 liter per second and were considered as dry and abounded.

The total numbers of wells used for the pumping test data analysis are six deep wells which five wells are located in the sandstone & one well is in the basement rocks. The types of pumping test include step, constant and recovery tests. But the tests used for analysis are constant & recovery. One, two and three wells did constant tests for about 72, 48, and 24 hours respectively. The maximum and minimum attained drawdown for the constant test is 73.92m and 6.04m respectively. With respect to yield, the lowest yield tested 1.5 liters per second while the highest 30 liters per second. The lowest yield belongs to the basement rocks while the maximum yield is to the sandstone.

The transmissivity of the aquifer and specific capacity of the wells are determined from the pumping test analysis and classification of the aquifer & the wells based on the specified standards is made.

The method that is employed to determine Transmisivity is the Cooper-Jacob straight-line method; after (Cooper, 1946). A straight line is drawn through the field data points and extended backward to the zero drawdown axis. The slope should intercept this axis at some positive value of time. The value of the drawdown per log cycle *Δ (ho-h) is* obtained from the slope of the graph. The values of transmissivity and storativity may be found from the equations but in this study there is an observation well & don't calculate the aquifer storativity rather it calculates transmissivity values.

Transmissivity is calculated using Aquifer test pro-8 & confirmed using an excel spread sheet. The calculated results from both approaches are almost equal.

For constant test the formula is:

$$T = \frac{2.3*Q}{4\pi\Delta(ho-h)}$$ ---------------- **Equation 8**

Where

T is the transmissivity (m^2/day)

Q is the pumping rate (m^3/day)

Δ (ho-h) is the drawdown per log cycle of time (m)

For recovery test the formula is:

$$T = \frac{2.3*Q}{4\pi\Delta S'}$$ ---------------- **Equation 9**

Where

T is the transmissivity (m^2/day)

Q Is the pumping rate (m^3/day)

ΔS' is the residual drawdown per log cycle of time (m)

The specific capacity of a well is computed as:

$$Sc = \frac{Q}{\Delta S}$$ ------------------- **Equation 10**

Where: SC is specific capacity (lit/sec)/m

Q Is the pumping rate (lit/sec)

ΔS is the change in water level at constant test

Table14. Deep wells that are used for pumping test analysis

S. No	Site Name	Easting	Northing	Depth (m)	Water Strike (m)	Static Water level (m)	Yield (l/s)
1	Agamat	503286	1512729	130	46	30	25

2	May Hutsa	502813	1512624	100	28	20	30
3	Duramaba	502365	1512529	120	17	14	25
4	Bet-Hintset Pro	501088	1511589	120	32	23	6
5	Endabagumbah	500323	1511605	194	25	9	5
6	Chini	496470	1509804	78	9	8	< 1.5

Table17. Classification of wells based on their transmissivity and specific capacities **(Sen, 1995)** 1995)

Transmissivity (m^2/day)	Potentiality	Specific capacity (Q/sw) in [(l/s)/m]	Well productivity
T > 500	High	Q/sw> 5	Highly productive
50 < T < 500	Moderate	0.5 < Q/sw< 5	Moderately productive
5 < T < 50	Low	0.05 < Q/sw< 0.5	Low productive
0.5 < T < 5	Weak	0.005 < Q/sw< 0.05	Very low productive
T < 0.5	Very weak	Q/sw< 0.005	Very weak productive

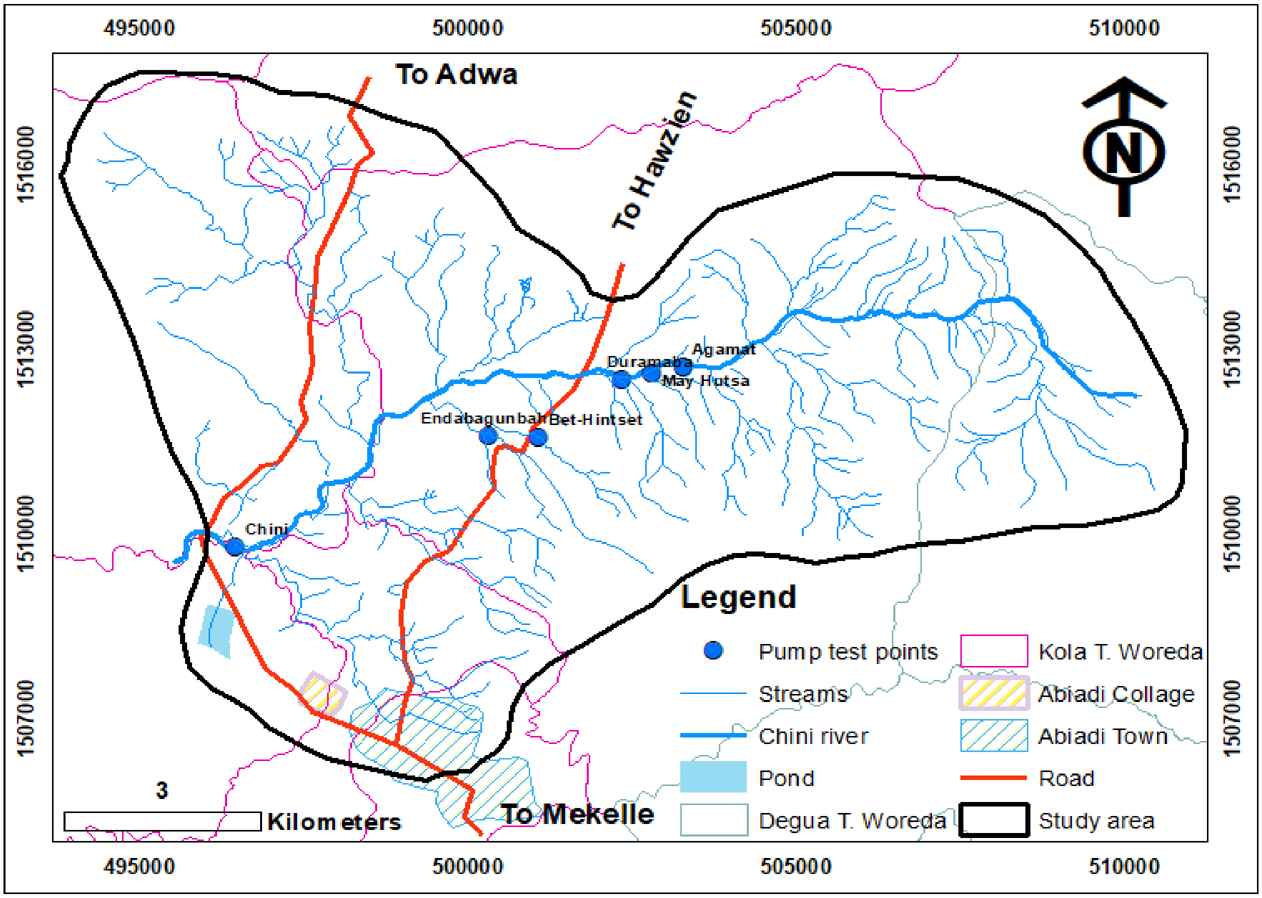


Figure 12. Map shows the points where pump test activities done

3.1.4. Geophysical method

The geophysical activity that is employed in the study area is electrical the method. In the electrical method surface geophysics, which is vertical electrical sounding (VES) technique was used. The method is crucial in determining the thickness of the saturated thickness of the aquifer, depth and thickness of the upper confined layer and depth of the lower confined layers, depth of the water table etc. which are very important in determine the groundwater resource evaluation.

The geophysical VES data is collected using SAS-4000 Tera-meter and the analysis and interpretation is done using the IPI win software.

The geophysical work was done on the three areas categorized differently by their productivity seven VES points were taken at relatively good interval and distance, it is almost covers the whole catchment. The first two points are in the basement formation; that is very low productive, and these two deep wells are drilled. The other four VES points collected from the sandstone formation which is moderately productive and out of the four points; the two are drilled. One VES is taken the low productive & the well was drilled. So the VES points taken are very representative to the area & can provide the full picture of the study area. The drilled boreholes were litologically and hydrogeologically logged and correlate with VES interpreted results.

Table15. Geophysical points taken (VES points)

VES No	Tabia	Local Name	Easing	Northing	Elevation(m)
VES-1	Dr. Ataklti	Chini	496470	1509804	1794
VES-2	Abi-iadi	Bet Hintset dry	498704	1508327	1836
VES-3	Geskimilesley	Agamat-1	503286	1512729	1899
VES-4	Geskimilesley	Agamat-2	503520	1512719	1898
VES-5	Geskimilesley	Quaya/May-Hutsa-1	502813	1512624	1890
VES-6	Geskimilesley	Quaya/May-Hutsa-2	502863	1512624	1885
VES-7	Limat	Adidokoy	501088	1511589	1883

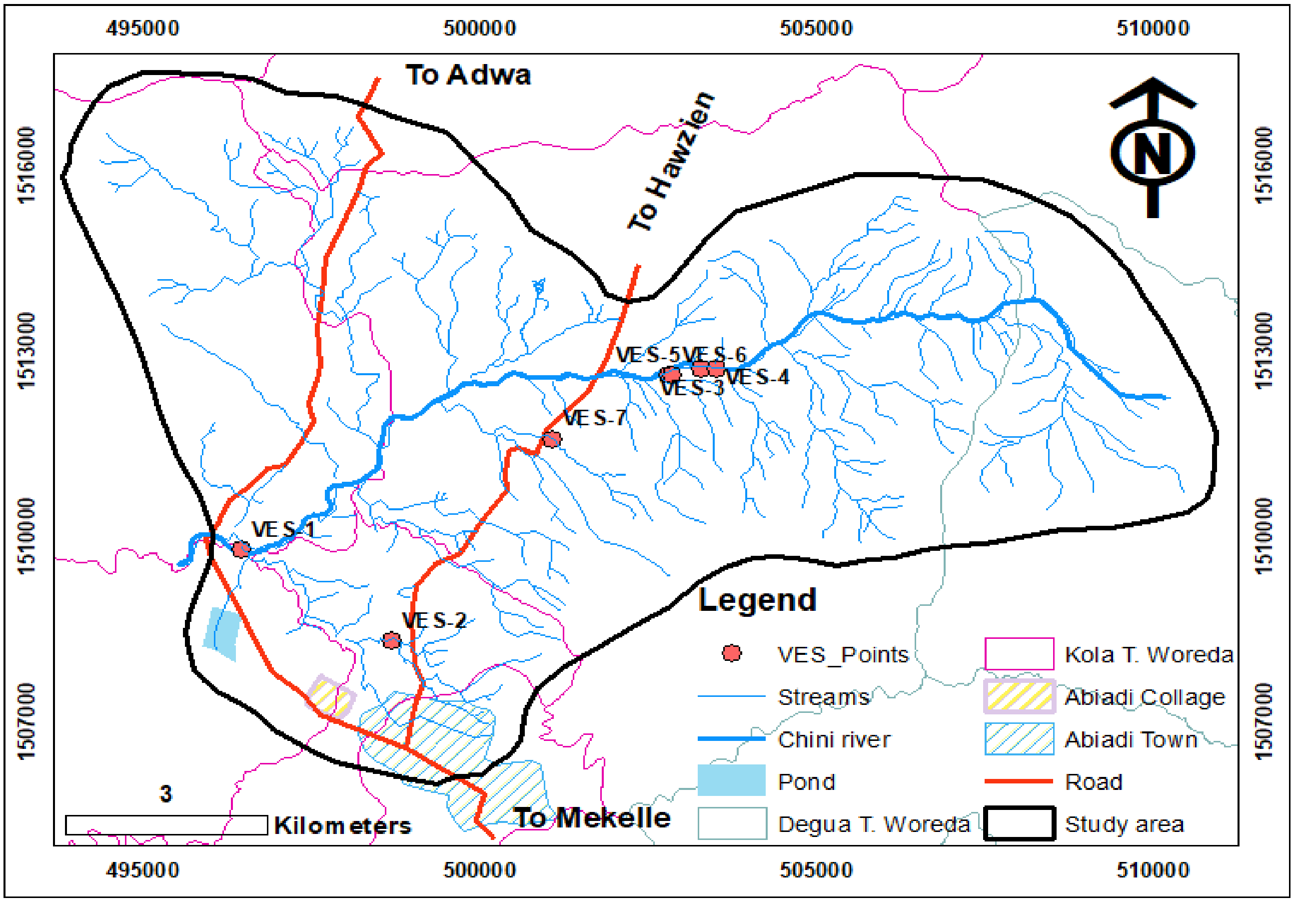


Figure 13. Map shows the geographical location of VES points of the study area

3.1.4.1 VES – 1 (Chini)

No.	VES Code	AB/2 spacing (m)	Direction	Site Name	UTM Coordinates		Elevation(m)
					Easting	Northing	
1	VES – 1	330	E-W	Chini	496470	1509804	1794

Table 16. Layer parameters and possible lithology at VES-1 (chini deep well)

Layers	Resistivity (Ω m)	Depth (m)	Possible Lithological description
1	50.4	0 – 0.252	Top sand and silty soil
2	191	0.252 – 15	Weathered and fractured basement, moist
3	1224	15 – 42.6	Slightly fractured basement

4	237	42.7 – 78.5	Fractured basement, saturated
5	25737	78.5	Massive basement rock

3.1.4.2 VES – 2 (Bet-Hintset dry)

No.	VES Code	Ab/2 spacing (m)	Direction	Site Name	UTM Coordinates		Elevation
					Easting	Northing	
1	VES – 2	500	E-W	Bet-Hintset dry	498704	1508327	1836

Table 23.Layer parameters and lithology of VES-2 (Bet-Hintset dry deep well)

Layers	Resistivity (Ω m)	Depth (m)	Possible Lithological description
1	8.51	0 – 1.52	Top sand and silty soil, moist
2	11.2	1.52 – 3.09	Weathered and fractured meta-sediment, moist
3	1.64	3.06 – 7.25	Highly moist meta-sediment
4	67.9	7.25 – 45.4	Graphite
5	15.2	45.4 – 288	Moist graphite
6	858	329	Meta sediment

3.1.4.3 VES –3 (Agamat-1)

No.	VES Code	AB/2 spacing (m)	Direction	Site Name	UTM Coordinates		Elevation
					Easting	Northing	
1	VES – 3	500	E-W	Agamat-1	503286	1512729	1899

Table 17.Layer parameters and possible lithology at VES-3 (Agamat-1)

Layers	Resistivity (Ω m)	Depth (m)	Possible Lithological description

1	37.4	0 – 1.09	Top sand and silty soil
2	81.7	1.09 – 5.07	Stiff mudstone, dry
3	529	5.07 – 53.4	Sandstone, dry
4	222	53.4 – 280	Sandstone, saturated, main aquifer
5	28130	280 -	Basement rock

3.1.4.4 VES – 4 (Agamat-2)

No.	VES Code	AB/2 spacing (m)	Direction	Site Name	UTM Coordinate		Elevation
					Easting	Northing	
1	VES – 4	500	E-W	Agamat-2	503520	1512719	1898

Table 18. Layer parameters and possible lithology at VES- 4 (Agamat-2)

Layers	Resistivity (Ω m)	Depth (m)	Possible Lithological description
1	46	0 – 3.46	Top sand and silty soil
2	2843	3.46 – 17.3	Stiff mudstone, dry
3	67.1	17.3 – 73.6	Mudstone, moist
4	304	73.6 – 412	Porous sandstone, saturated, main aquifer
5	7283	412	Massive basement rock

3.1.4.5 VES – 5 (May Hutsa-1)

No.	VES Code	AB/2 spacing (m)	Direction	Site Name	UTM Coordinate		Elevation
					Easting	Northing	
1	VES – 5	330	E-W	May-Hutsa-1	502813	1512624	1890

Table 19.Layer parameters and possible lithology at VES-5 (May-Hutsa-1)

Layers	Resistivity (Ω m)	Depth (m)	Possible Lithological description
1	252	0 – 0.507	Stiff sandstone, dry
2	21.66	0.507– 2.85	Moist mudstone
3	299	2.85 – 15	Hard mudstone, dry
4	1061	15 – 58.8	Hard sandstone
5	68	58.8 - 213	Porous sandstone, saturated, main aquifer
6	694	213	Relatively less porous sandstone, saturated

3.1.4.6 VES – 6 (May Hutsa-2)

No.	VES Code	Ab/2 spacing (m)	Direction	Site Name	UTM Coordinate		Elevation
					Easting	Northing	
1	VES – 6	500	E-W	May-Hutsa-2	502863	1512624	1885

Table 20.Layer parameters and possible lithology at VES-6 (May-Hutsa-2)

Layers	Resistivity (Ω m)	Depth (m)	Possible Lithological description
1	101	0 – 1.02	Stiff sandstone, dry
2	40.1	1.02 – 3.63	Mudstone, dry
3	863	3.63 – 14	Massive mudstone, dry
4	63	14 – 40.8	Porous sandstone, saturated
5	88.6	40.8 – 283	Porous sandstone, saturated, main aquifer
6	1.17	283	Porous mudstone, saturated, main aquifer

3.1.4.7 VES – 7 (Limaet)

No.	VES Code	Ab/2 spacing (m)	Direction	Site Name	UTM Coordinates		Elevation (m)
					Easting	Northing	
1	VES – 7	500	E-W	Adidokoy	501088	1511589	1883

Table 21.Layer parameters and possible lithology at VES-7 (Limaet)

Layer	Resistivity (Ω m)	Depth (m)	Possible Lithological description
1	242	0 – 1.49	Stiff sandstone, dry
2	37.4	1.49 – 3.01	Mudstone, dry
3	84.2	3.01 – 5.97	Mudstone, dry
4	3041	5.97 – 19.6	Massive mudstone, dry
5	25.5	19.6 – 144	Mudstone, saturated, main aquifer
6	14.7	144 – 332	Mudstone, saturated, main aquifer
7	1853	332 -	Basement

3.1.5. Hydrogeological method

The main water bearing formation of the study area is the Enticho Sandstone, which is medium to coarse grained and well sorted, layers unconformably overlaying the basement rock. None of the aquifers fully penetrated. The groundwater occurrence is in the inter-granular pore spaces of Enticho Sandstone and fractures of mudstone and sandstone. The top part of the sandstone is fine grained and mudstone and these acts as a confining layer as a result of which the nature of the aquifer is confined. The depth to the water table is higher in the upstream (eastern part of the catchment and it becomes closer to the surface as one goes towards the west). The depth of the water table/potentiometric surface ranges from 8 – 30 meters. The static water level in the wells is found above the water strike level. The deepest water strike level is 46 meters while the shallowest one is 9 meters. The yield of the wells increases when we go up and ranges from 1.5 liters per second in the lower part and reaches 30 liters per second in the upstream. The estimated thickness of the sandstone formation from the VES survey results is 400 meters. The lowland (western part of the study area), the main aquifer are the fractured Meta sediments & Meta volcanic. The secondary porosity is developed through the tectonic activity & the later coming quartz vein. Then the productivity of this formation is limited in certain areas where the fracture intensifies. And the degree of fracturing decreases with depth. These aquifers in the crystalline basement serve for the rural communities using hand pumps which need wells with yield from 0.3 lit/sec & above. There are three deep wells such as wells designated as Dr. Ataklti (was planned to serve for Tabia Dr. Ataklti), Bet Hintset (was planned to serve for Abi-adi prison center), there is also deep well along the Chini river with no data (was planned to serve for road construction, sur) become dry &/or low yield which is less than one liter/second. But there is one deep well which serves for Abi-adi water supply yields 7 liters per second when drilled along a quartz vein.

The flat laying area and the stream act as discharge area either naturally and/or using deep and shallow wells. The general groundwater flow direction follows the natural surface water flow & directed towards the west.

Table 23. List of wells with their respective well depth and heads

S.no	Well name	Easing	Northing	Elev. (m)	Head (m)	Depth (m)	Static water level (m)
1	Agamat	503286	1512729	1899	1869	130	30
2	May Hutsa	502813	1512624	1890	1870	100	20
3	Duramaba	502365	1512529	1872	1858	120	14
4	Bet-Hintset P.	501088	1511589	1876	1853	120	23
5	Endabagunbah	500323	1511605	1863	1854	194	9
6	Chini	496470	1509804	1794	1786	78	8
7	Bethintset_dry	498706	1508547	1824	1824	120	-

8	Chini_2	497790	1550674	1809	1809	110	-
9	Chini_3	496442	1509469	1796	1788	105	
10	Shallow well	502206	1513097	1876	1851	50	27

CHAPTER FOUR

4.1. Hydrochemistry

4.1.1. General

This hydrochemistry analysis is done to know the concentration of the laboratory measured chemicals, which are the cations (Na, K, Mg & Ca) & anions (So_4, HCo_3 & Cl), their possible sources & water type & the value of field measured parameters such as PH, electrical conductivity & total dissolved solids. Furthermore it compares the results against different water quality standards for different uses.

The sources of the data are secondary once collected from technical reports of five deep wells. The water quality analyses were done in Mekelle University, Geochemistry laboratory. The four samples are geologically from the sandstone & one sample is from the basement.

The samples are collected, analyzed & interpreted from five deep wells. The names of the deep wells are Agamat, May Hutsa, Duramba, and Bet-Hintset & Chini. The first deep wells are in the sandstone & the last one is in the basement rock respectively.

The collected samples are analyzed using the waterloo software called Aquachem 4.0. Before starting the water chemistry analysis the Electrical neutrality is checked & all samples are fulfilled the electrical neutrality & proceed to the next step. All the analysis is within the acceptable range that is below 5%. A variety of graphical methods are used such as Piper and Schoeller.

4.1.2. Field measured parameters

4.1.2.1 pH

The PH measurements of the four boreholes are ranging from 6.52 – 7.12, that is the lowest is Bet Hintset & the highest is May Hutsa respectively & this is within the range of weak acid while May-Hutsa's is weak base. Generally the range of the PH measurement is near to the neutral level.

According to the Ethiopian & World health organization water quality standard for pH is 6.5 - 8.5. Then the water in our analyses is in the acceptable limit.

4.1.2.2 Electrical conductivity

Electrical conductivity is the ability of a dissolved substance to transfer electric current &related to the ionic concentration to conduct electricity as fast as possible. Its unit is µS/cm. These measurements have similar values in Agamat, Duramba & Bet Hintset, 133.7, 136.6, 130.9µS/cm respectively. There is also expected result from Chini, that is 1206 this is due to the excessive amounts of cations & anions. May Hutsa 542µS/cm is something different from the same lithological setting & this is due the relative abundance of the cations & anions. The number of cations & anions directly related to lithology that is the mineral composition of the lithology made. Water from the basement formation such as Chini is quite different from Agamat, the sandstone. then the electrical conductivity directly related to Electrical conductivity.

4.1.2.3 Total dissolved solids (TDS)

Total Dissolved Solid is the amount of the solute that is dissolved in water. The measured value of TDS in the bore holes is the replica of the electrical conductivity. Bore holes with relatively high values of electrical conductivity have relatively high values of TDS.

The relation these parameters is expressed mathematically:

$TDS = EC*k$

Where EC electrical conductance in micromhos, TDS is the amount of total dissolved solids in mg/l and K is a conversion factor, its value is between 0.55 and 0.75. The measured values of Agamat, May Hutsa, Duramba, Bet Hintset & chini are 95.34, 386.51, 97.41, 93.34 & 860 mg/lit respectively. The value of k is 0.71 & this proves that the measurements are reliable & acceptable. According to the Ethiopian & World health organization water quality standard for TDS is 1000 & 1500 mg/lit respectively. The water in our analyses is in the acceptable limit & can be used for domestic water supply purposes.

4.1.3. Laboratory measured geochemical

4.1.3.1. Cations and anions with their graphical presentations

The measured Cations in this analysis are sodium ion (Na^+), potassium ion (K+), magnesium ion (Mg^{2+}), and calcium (Ca^{2+}). And the measured Anions are bicarbonate ion (HCO_3^-), sulphate ion (SO_4^{2-}), nitrate ion (NO_3^-) and chloride ion (Cl^-). Piper trilinear and Schoeller diagrams employed to determine the water type and to compare the ionic composition of the samples respectively.

4.1.3.1.1. Piper's trilinear diagram

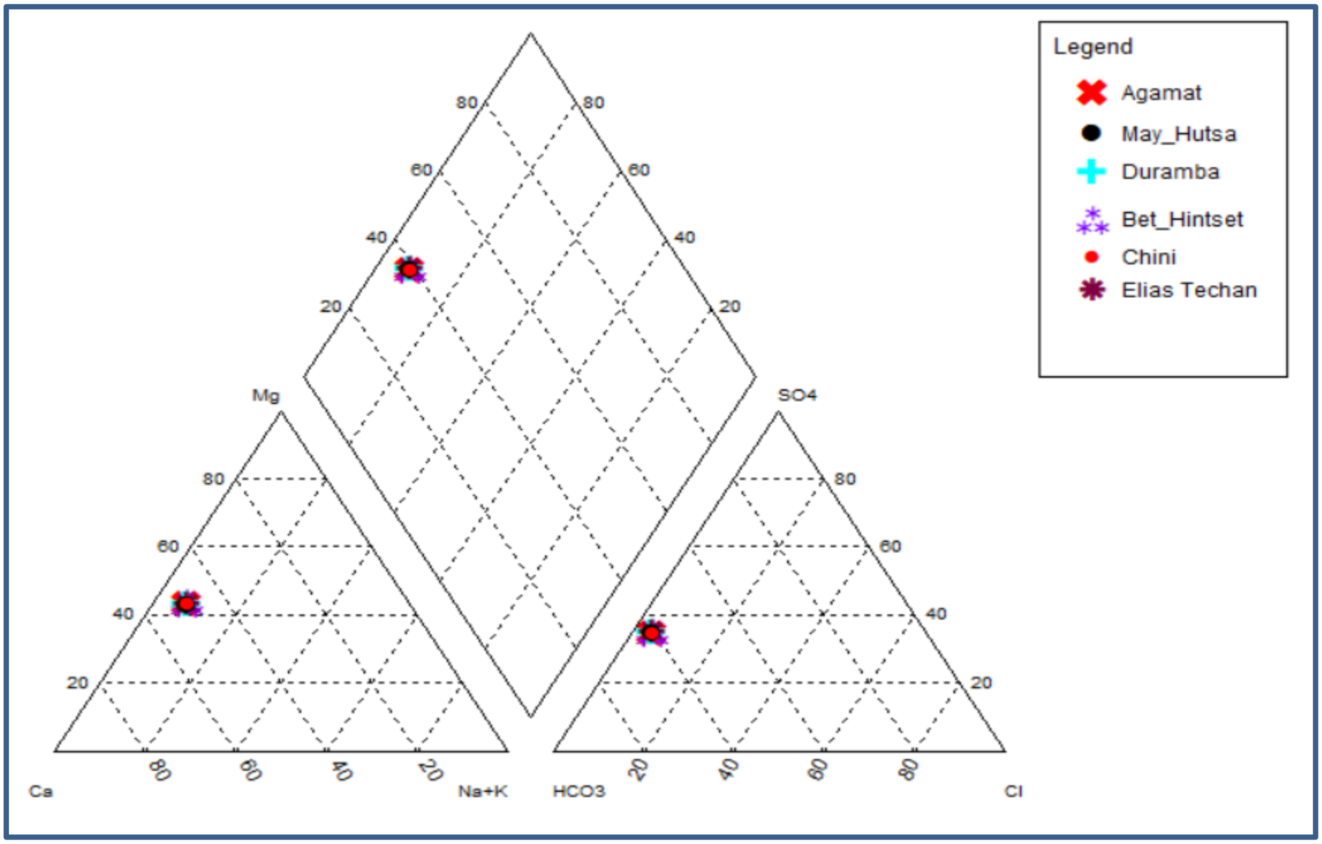


Figure 14 Piper Trilinear diagram of deep bore holes

As it is shown in the Piper Trilinear diagram all the samples fall in one type of water. That is Ca-Mg-HCO3-SO4 type of water. The difference among the samples is the magnitude of the chemical ions but the type of the water is similar. The Piper diagram takes the proportion percentage of the ions and regardless of the magnitude what it matters is the dominant ions in the sample. And this determines the type of water to which it belongs.

The main reason it may be to have such a type of water is the rocks which are in contact for a considerable amount of time. The basement rocks of the area driven from siliciclastic and carbonate sedimentation (Avigad, 2007). Therefore the Calcium and bicarbonates ions are driven from the dissolution of the carbonate rocks. When slightly acidic water reacts with carbon dioxide it forms carbonic acid (H_2CO_3). When calcium carbonate reacts with the carbonic acid is forms

$$CaCO_3 + H_2CO_3 \Longrightarrow Ca^{2+} + 2HCO_3^-$$

The source of magnesium ion is; it may be a dolomite because in this case dolomite commonly occurs together with limestone in carbonate sedimentary sequence. It is interlayered with limestone. And gypsum layers often overlie or alternate with carbonate rocks in sedimentary succession. The source for the sulphate ions is gypsum which is associated with the carbonate rocks.

4.1.3.1.2. Scholler diagram

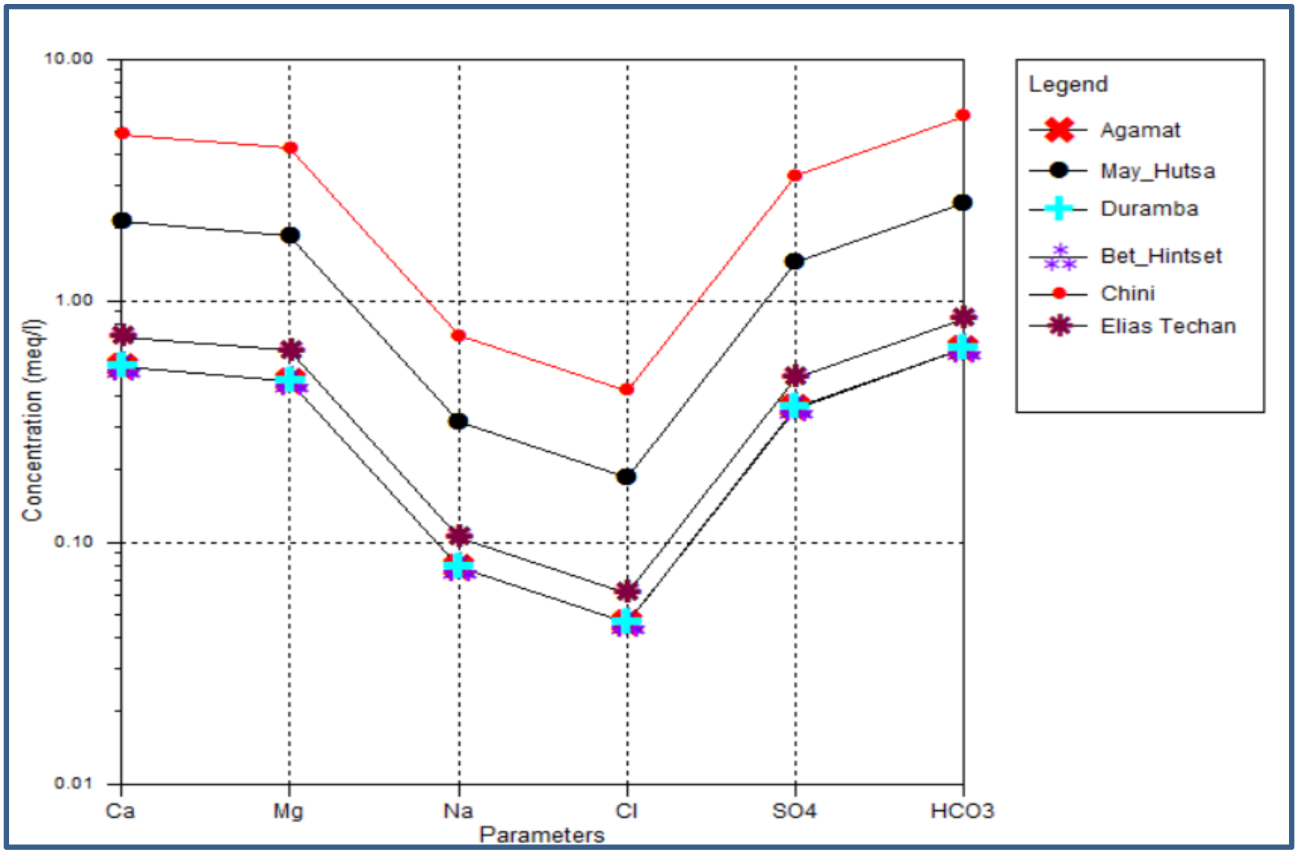


Figure 15 The Scholler diagram of deep bore holes

As shown from the Scholler diagram it is clearly visible that Chini well is with maximum amount or concentration of ions. This bore hole is constructed in the basement formation meaning the water is in direct contact with the source of ions. Then it is followed by the May-Hutsa bore hole and this is in the sandstone formation. Next is Elias T. and followed by the rest three deep wells. All these belong to the sandstone formation. The low concentration of ions is the water it may have in direct contact with the actual source of ions. The existing concentration is due to the movement of water among the lower and upper aquifers and the dissolution of certain minerals from the sandstone.

All these waters can be use for drinking and domestic purposes **((WHO), 2022)** because the measured values of the Cations & Anions are within the acceptable standards limits. But there is an exception of Chini bore hole with one parameter exceeding the standard limit. This is the total alkalinity as $CaCO_3$. The measured value is 590 mg/l while the allowable maximum permissible level in the guideline is 590 mg/l.

4.1.4. Total hardness

Total hardness is the sum of the calcium and magnesium concentration in water, both expressed as calcium carbonate, in milligram per liter. The value of total hardness for Agamat, Duramba & Bet Hintset is 49.90 mg/l. May Hutsa and Chini values are 199.59 and 457.40 mg/l respectively. According to the Hardness Classification of Water (Sawyer, 1967) the water from the first three deep wells is grouped under soft water, May Hutsa falls in hard water while Chini falls under very hard water.

Table 24 Hardness of water and their classification of hardness (Sawyer, 1967)

S.No	Name of Deep well	Hardness as $CaCO_3$ (mg/lit)	Classification	Hardness Values	Classification
1	Agamat	49.9	Soft	0 - 75	Soft
2	May Hutsa	199.59	Hard	75 – 150	Moderately Hard
3	Duramba	49.9	Soft	150 – 300	Hard
4	Bet Hintset	49.9	Soft	> 300	Very Hard
5	Chini	457.4	Very Hard		

CHAPTER FIVE

5.1. Result and Discussion

Combining all the important aspects, i.e. soil type, slope & land use the value of the runoff coefficient (C) is determined 0.31. The next step is calculating the amount runoff (mm) using the formula:

Q = C*p ------------ Equation 11

Where

Q is runoff (mm)

C is runoff coefficient (unit less)

P is precipitation of each month (mm)

The amount of runoff is 363.88mm per year (the sum of each 12 months) which is 31 persent of the total precipitation. Then monthly surface runoff yielded from the catchment is tabulated below.

Table 25. Mean monthly surface runoff in mm

Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Surface runoff	0.90	1.78	3.68	8.50	13.08	42.33	107.10	141.70	39.95	3.68	1.17	0.00

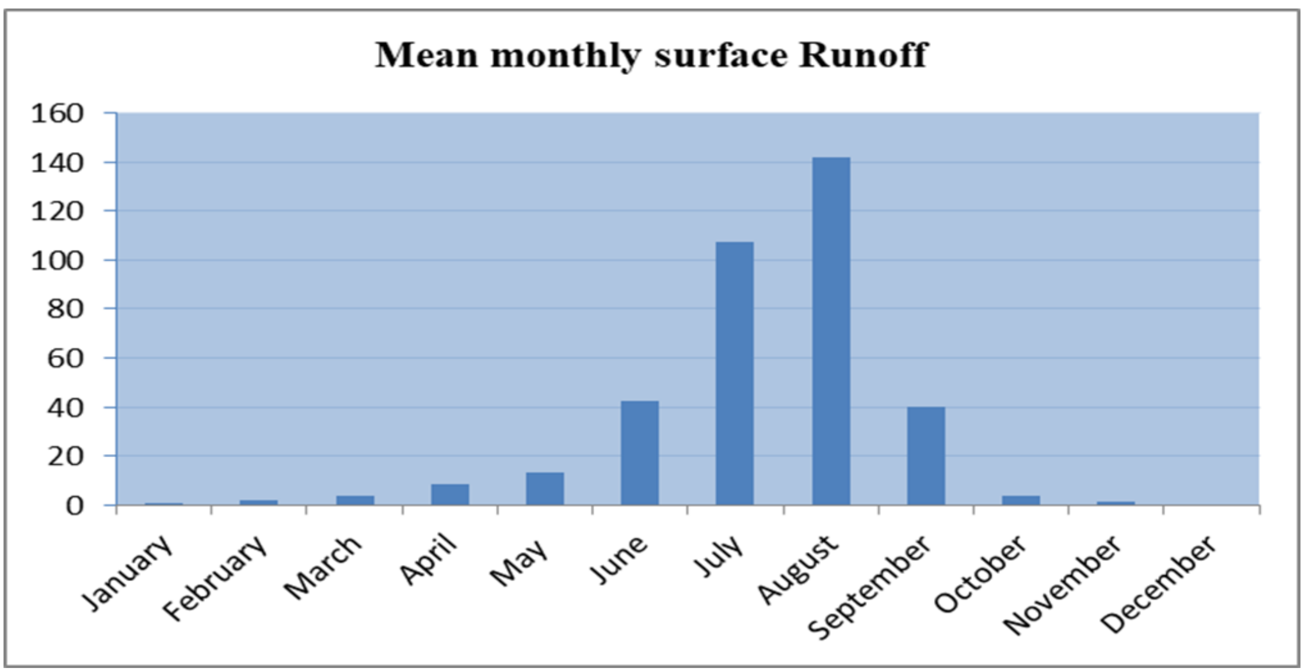


Figure 16. Mean monthly surface runoff in mm

Potential evapotranspiration is a crucial component to be determined using different methods. The different methods need different meteorological parameters and tabulated worldwide standards.

Table 26. Summary of potential evapotranspiration from different methods

S.No	Method	Amount (mm/year)
1	Blaney-Criddle (1950)	3157.21
2	Penman-Monteith (Allen et al., 1998)	2158.33
3	Hargreaves (1985)	1901.76
4	Thornthwaite (1948)	1007.59
5	Priestley-Taylor(1972)	908.58

As shown in the table the result of Blanley – Criddle is the maximum and more exaggerated. This method cannot be taken into account because its value is almost three times the rainfall and every drop is exhausted & nothing left for runoff and recharge. This approach is inapplicable for the study area. Penman - Monteith is in second place. This method is applicable in every corner of the world. It requires many metrological parameters. The result is reliable when it is compared with the other parameters that do not comply with the results on the ground. The value of the Hargraves is third place in this study but the method mainly works in arid areas such as Iran and the value is a little bit small. Thornthwaite & Priestly-Taylor approaches have values which underestimate the value of the potential evapotranspiration which cannot relate with semiarid areas. This may lead to wrong conclusions when we computed the recharge. The results of these approaches are not taken into consideration for further analysis.

The Penman - Monteith approach used for this area; and the result determined use for further practical works. Then the amount of potential evapotranspiration is 2158.33mm/year.

Actual evapotranspiration determined from potential evapotranspiration, available water capacity of soils. Actual evapotranspiration calculated by taking the average values of soils with different available water capacity 707.1 & 769.57mm/year respectively. Its average value is 738.32mm/year and is 63 percent of the total annual precipitation.

The annual recharge is calculated by the arithmetic of:

R= PPT – AET - Ro ------------------ Equation 12

Where

R - Annual recharge

PPT - Monthly Precipitation

AET - Monthly evapotranspiration

Ro – Runoff

The amount of water merging the groundwater system is 71.6mm per year & this 6.1 percent of the annual rainfall.

$$= (1173.79mm) - (738.32mm) - (363.88mm) = 71.6mm$$

The groundwater potential of the catchment is:

$$= Rechage * Area\ of\ the\ catchment$$

$$= 71.6 * 10\hat{}\ (-3)\ m * 110 * 10\hat{}6\ m\hat{}2$$

$$= 7.88\ \text{MCM}$$

From the pumping test method it is determined the transmissivity of the different aquifers of the catchment and the specific capacity of the wells. The table below expresses the value of transmissivity that is determined using aqua test software from constant and recovery tests. The other important parameter is specific capacity that is helpful to determine potentiality of the wells.

Table 27 Transmissivity & specific capacity values deep wells

Borehole Name	Transmissivity Values (m^2/day)								Average	Specific capacity (lit/sec)/m
	Using Excel spread sheet				Using Aquifer test pro8 software					
	Constant		Recovery		Constant		Recovery			
	Full Data	After ignoring the first 10 minutes	Full Data	After ignoring the first 10 minutes	Full Data	After ignoring the first 10 minutes	Full Data	After ignoring the first 10 minutes		
Agamat	656	826	261	400	654	823	261	401	739.0	2.5
May Hutsa	659	678	880	1023	657	676	876	1020	808.6	3.5
Duramaba	753	1005	622	965	752	1000	621	960	834.8	4.1

Bet-Hintset	28	25	41	133	28	25	41	133	56.8	0.5
Endabagunbah	5	4	3	2	5	4	2.68	2.68	3.5	0.07
Chini	1.28	0.9	1.42	2	1.28	0.94	1.42	1.42	1.33	0.03

The first three wells Agamat, May-Hutsa and Duramba have average transmissivity values 739, 808.6 and 834.8 m2/day respectively. The average value is taken from the constant & recovery test. The transmissivity result of recovery for Agamat is unique from others, and not consistent with the others, & this not represents what is on the ground and this indicates that there is an error in collecting and recording data during the recovery test. The value is taken from the constant test only for this well. The drawdown attained in the wells for 48 hours is 9.99, 8.54 & 6.04 meter respectively. The specific capacity of each well is 2.5, 3.5 and 4.1 (lit/sec)/meter respectively. The aquifer belongs to these wells classified as high potentiality aquifer and moderately productive wells.

The fourth well, called Bet-Hintset has average transmissivity value 56.8 m2/day. The average value is calculated from the constant & recovery tests as the above and therefore the aquifer potentiality classification is moderate. The drawdown attained for 24 hours is 12.9 meters. The specific capacity of the well is 0.5 (lit/sec)/meter, & its productivity is grouped under low productivity.

The fifth well, called Endabagumbah deep well has, an average transmissivity value of 3.5 m2/day. The drawdown attained for 72 hours is 73.89 meters. The aquifer potentiality classification is low. The specific capacity of the well is 0.07 (lit/sec)/meter and productivity of the well is grouped under low productivity.

The sixth well, called Chini deep well has, an average transmissivity value of 1.33 m2/day of the constant & recovery test. The drawdown attained for 24 hours is 54 meters. The aquifer potentiality classification is weak. The specific capacity of the well is 0.03 (lit/sec)/meter and the productivity of the well is grouped under very low productivity.

VES – 1 and VES - 2 done on the basement rocks and shows the hardness of the rocks increased with depth. This inhibits groundwater movement and storage. The wells drilled in the basement rocks are low yield and dry. When it is correlated the actual lithological logging with the VES is more or less analogous. The extent of fracturing in both wells is very limited to the top part and gradually decreases with depth & becomes totally massive. Generally the fractured and weathered thickness of the basement rock is so small to act as an aquifer to supply water in economic amounts. Groundwater investigation in the basement rock should rely on the image analysis combined with other methods in identifying areas deeply affected by geological structures such as faults, folds, quartz vein etc. From VES – 3 to VES – 7 done in the Enticho sandstone formation which clearly depicts the anomaly of the layers with and without water. The exception here is the yield difference because of the increase in thickness of the mudstone layer. The general thickness of this formation is beyond 200 meters and this confirmed through a drilled well located below downstream of these VES points. From these data the minimum and maximum thickness of the sandstone formation is 213 and 412s meter respectively. The drilled wells lithologically logged from the samples recovered and correlated with VES interpreted and analogous.

The main water bearing formation of the study area is the Enticho Sandstone, which is medium to coarse grained and sorted in the fractured sandstone and mudstone as well. None of the aquifers fully penetrated.

The catchment is different in geology, hydrogeology, productivity it needs to classify based on the well productivity & aquifer potentiality. It is divided into three categories; that is high, moderate & low potentiality. The aerial coverage of each potentiality zone is 30, 8 and 72 km^2 respectively. This helps to estimate the amount of water that could be exploited for different purposes & helps to focus on the area of interest for different reasons. The amount that can be harvested from the high & medium potential zones is 2.7 million cubic meters per annum.

Table 28 The volume of water that recharges in each potentiality zone

S. No	Potentiality	Area (Km^2)	Amount of recharge in each potentiality zone in cubic meter
1	High	30	2,147,906
2	Moderate	8	572,775
3	Weak	72	5,154,975

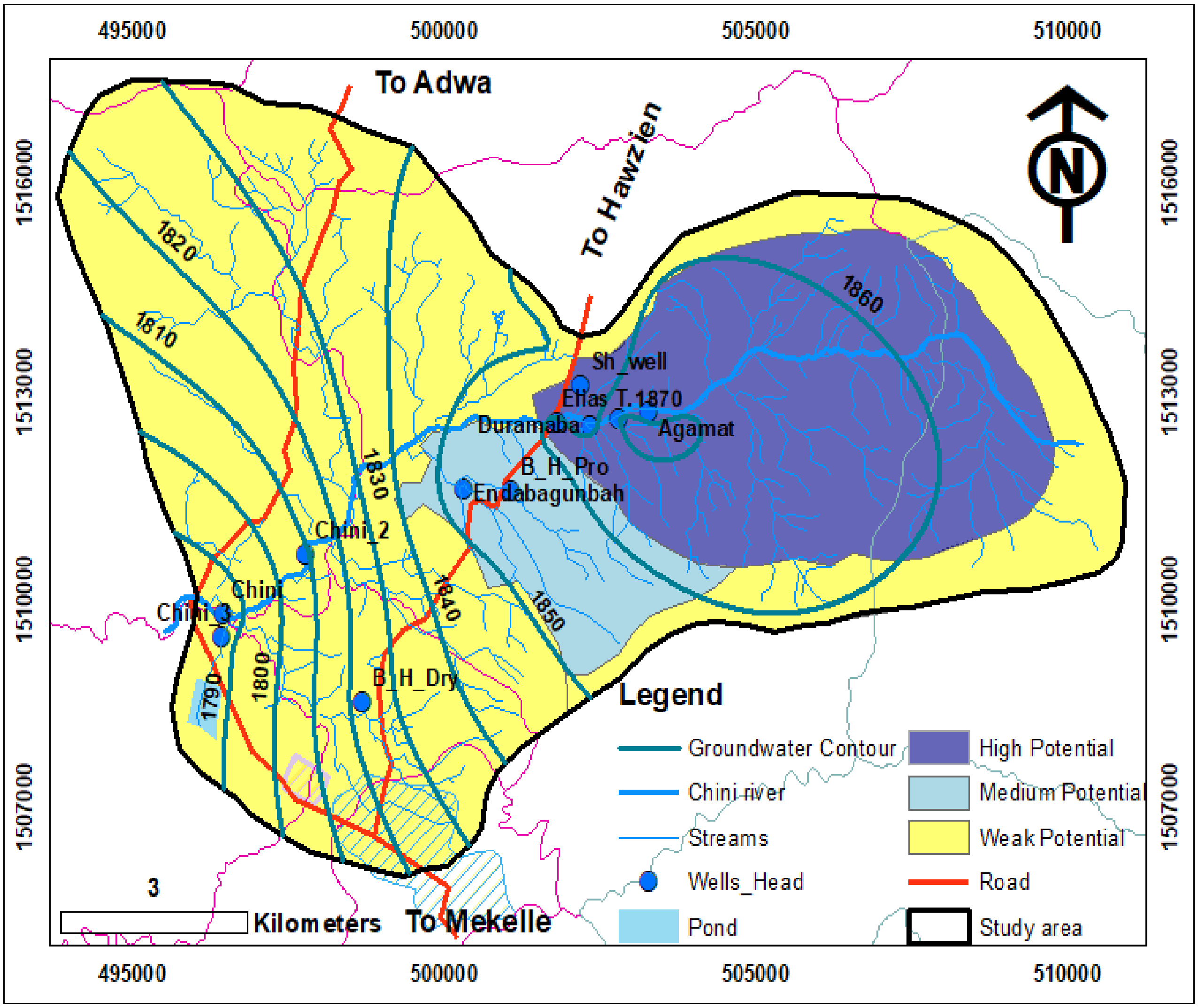


Figure 17. Hydrogeological & groundwater level contour map of the study area

CHAPTER SIX

6.1. Conclusions

The basic components in estimating the amount of water that recharges or water that merges to the groundwater system are precipitation, actual evapotranspiration and surface runoff.

The meteorological data such as precipitation, temperature, relative humidity, sunshine hours, wind speed collected from the Ethiopian metrological office Mekelle branch. Important parameters potential evapotranspiration is determined from different approaches but one reasonable & reliable value is taken & used to calculate the actual evapotranspiration. Other important parameters which are attempted to estimate in this paper are surface runoff and recharge. The total area of the project area is 110km^2. The average annual rainfall of the study area is 1173.79mm.

Potential evapotranspiration estimated using different approaches such as Thornthwaite, Penman-Monteth, Pristely-Taylor & Hargraves which require different meteorological & radiation parameters. It is found that the Penman-Monteth method which best expresses the area & its value is 2158.33mm/year.

The actual evapotranspiration is calculated using the soil water balance method called Thornthwaite-Mather approach. The annual actual evapotranspiration is 738.32mm/year & is 63 percent of the annual precipitation.

Surface runoff is estimated after deciding the value of the runoff coefficient. The runoff of coefficient is calculated after considering the slope of the area & categorized into different slope classification; soil type and land use of the area and its value is 0.31. Then the amount of water that goes as runoff from this watershed is 363.88mm annually.

The amount of water that merges to the groundwater system annually is 71.6mm/year & this is 6 percent of the total precipitation. This is the water that assumes it is evenly distributed and recharge to the whole catchment but the geology, hydrogeology is so different.

The maximum & minimum yield yet done is 1.5 & 30 litter per second respectively. Cooper-Jacob time drawdown is used to calculate transmissivity of the aquifer. Specific capacity of the wells also computed. The average minimum, medium & maximum of transmsivity values determined are 1.33, 56.8 & 834.8 m^2/day respectively. Accordingly the catchment is categorized into three parts as weak, medium & high potentiality. The aerial coverage of each category is 72, 8 & 30km^2 respectively. The water that can be exploited from the high & moderate potentiality zone should be less than 2.7 MCM per year. Also this categorization helps to focus on development & monitoring the resource. The specific capacity of the wells is ranging from the maximum 4.1, the medium 0.07 & the minimum 0.03 (lit/sec)/m then the wells are grouped as moderate, low & very weak productive respectively. The general groundwater flow direction is as of the surface water flow towards the south-west of the study area.

Geologically the area has basement formations (Meta sediment, Meta volcanic), sandstone (Enticho & Adigrat), mudstone, Tertiary basalt & the alluvial deposit. But the main and all the wells drilled are in the basement and sandstone formations. The maximum & minimum drilled depths are 194 & 78 meter respectively. According to the geophysics result the thickness of the sandstone reaches 412 meters. Most of the wells drilled in the basement formations are either dry or low yield but the wells drilled in the sandstone have yield 5 – 30 liters per second. The main aquifer is medium to coarse grained sandstone.

The nature of the main aquifer is confined; sorted, medium to coarse grained & fractured sandstone, while the basement rocks fractured and weathered on its top part only & can't yield enough water. The thickness of the aquifer is very shallow. However, there is a well that yields 7 liters per second and its depth is 105 meters. This is happening due to the high impact of the fractures created by quartz vein; but this is very limited experience in the study area. The secondary porosity only develops shallow wells for hand pumps.

The type of water in the catchment is $Ca\text{-}Mg\text{-}So_4\text{-}HCo_3$. The maximum value of the calcium ion is 97.90 mg/l & the maximum value of bicarbonate ion is 353.5 mg/l from the basement formation. The water can serve for agricultural & domestic purposes because it is in the allowable limit of the WHO standard.

6.2. Recommendations

The aquifer is partially penetrated that, is the deep wells drilled in the area are not totally penetrated the whole section of the geology that is considered as the main aquifer. So it needs wells to be drilled that penetrate the whole depth. And this helps to know the total thickness of the aquifer and the water that can yield from. The pumping tests done were with relatively low drawdown within

48 pumping hours. Then to know the maximum yield it should need wells with larger diameter and high capacity pumps with longer duration of pumping.

The amount of water extracted from this aquifer, mainly the high potential area (well field), should be less than the annual recharge. This not only favors the water supply but also preserves the aquifer from damage and unavoidable engineering problems.

It has not reached the lowest or the basement rock that is found below the main aquifer through the AB separation in resistive geophysical investigation. So to estimate the thickness of the aquifer or the depth to bed rock it is necessary to further geophysical works with greater AB separation.

Any investment, especially industries that take water as the main constituent should consider the total amount of water, before giving them a license on the catchment. Other activities placed on this well field should pass through water resource bureau and should evaluate its impact on the pollution of groundwater and its remedies.

There should be a strong monitoring system of the groundwater system that leads to easy understand and controlling of the groundwater system.

It is better to develop a model that helps as in monitoring, easy to understand and depicting the system. And this help in taking any additional bore holes and remedial measures when facing a problem.

Abi-adi municipality and water & sewerage service office should take the responsibility in keeping and controlling the well field. They should develop a controlling mechanism related to any action taken on the well field. It should design a mechanism to measure the groundwater level regularly & should not pump wells beyond the pumping hours stated on the design period.

It is better to design projects that enhance recharge to the groundwater & sustain the resource for the future without adversely impact.

Any development of well/wells that taking place on the basement rock needs a great emphasis, which traces mainly that, can identify geological structures. Because wells drilled in this formation is become very low yield & dry.

There should be strong natural resource conservation in the upstream highland of the catchment to enhance the recharge as a result it assures the continuity of the system and secured water supply to the community in general and Abi-adi town & other water based commercial activities done in particular.

The amount of recharge to the productive area of the catchment is so limited to satisfy the need of the people of Abi-adi & its vicinity, and then it needs a means to solve the water demand sustainably.

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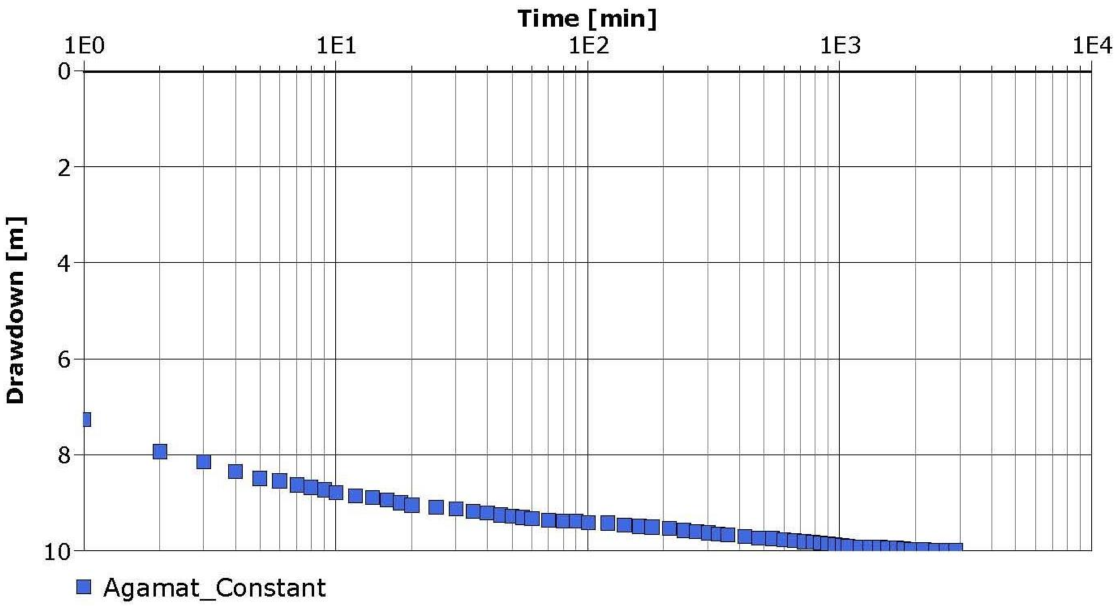
ANNEXES

Pumping Test Results

	Pumping Test Analysis Report
	Project: Gestkimilesley
	Number: 2
	Client:

Location: Kola Tembien	Pumping Test: Agamat_Constant	Pumping Well: Agamat_Constant
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Ataklti G/tsadik	Agamat	Analysis Date: 12/2/2021
Aquifer Thickness: 80.00 m	Discharge Rate: 25 [l/s]	



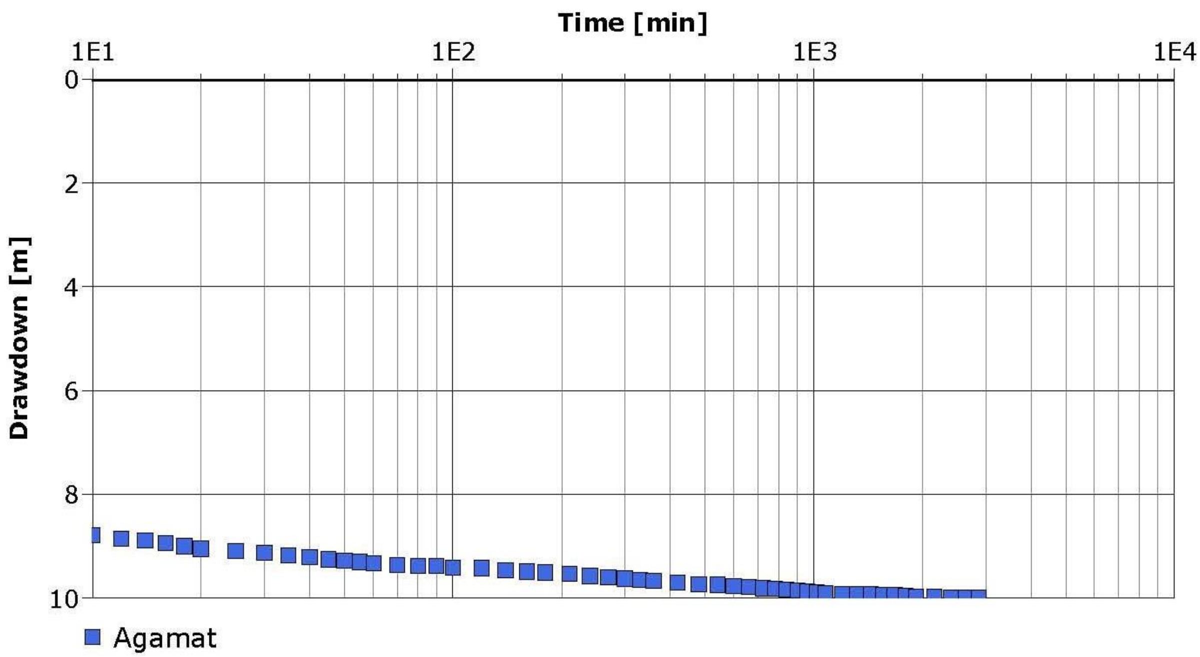
Calculation using COOPER & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Storage coefficient	Radial Distance to PW [m]	
Agamat_Constant	6.54×10^{2}	8.18×10^{0}	5.00×10^{-1}		

Figure 19. Graph of Agamat constant pumping test with transmissivity result for full data

	Pumping Test Analysis Report
	Project: Gestkimilesley
	Number: 2
	Client:

Location: Kola Tembien	Pumping Test: Agamat	Pumping Well: Agamat
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Ataklti G/tsadik	Agamat	Analysis Date: 12/2/2021
Aquifer Thickness: 80.00 m	Discharge Rate: 25 [l/s]	



Calculation using COOPER & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Storage coefficient	Radial Distance to PW [m]	
Agamat	8.23×10^{2}	1.03×10^{1}	5.00×10^{-1}		

Figure 20. Graph of Agamat constant pumping test with transmissivity result after ignoring the first 10 minutes

Table 29. Data of constant pumping test for Agamat deep well

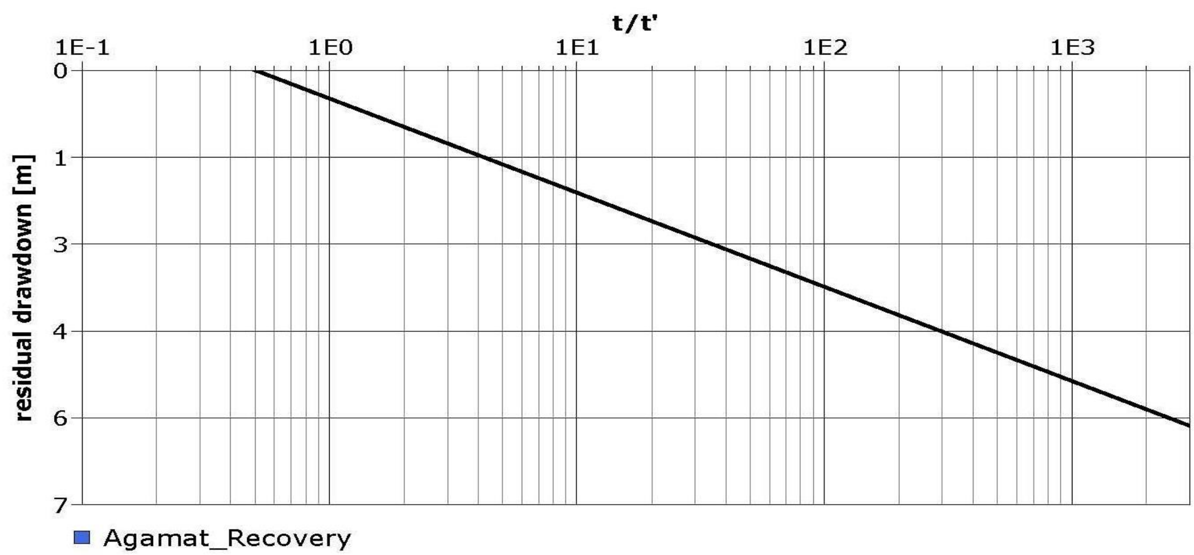
Pumping Test - Water Level Data	Page 1 of 2
Project: Gestkimilesley	
Number: 2	
Client:	

Location: Kola Tembien	Pumping Test: Agamat_Constant	Pumping Well: Agamat
Test Conducted by: Ataklti G/tsadik	Test Date: 12/2/2021	Discharge Rate: 25 [l/s]
Observation Well: Agamat	Static Water Level [m]: 30.29	Radial Distance to PW [m]: -

	Time [min]	Water Level [m]	Drawdown [m]
1	0	30.29	0.00
2	1	37.56	7.27
3	2	38.22	7.93
4	3	38.44	8.15
5	4	38.63	8.34
6	5	38.78	8.49
7	6	38.84	8.55
8	7	38.92	8.63
9	8	38.97	8.68
10	9	39.02	8.73
11	10	39.07	8.78
12	12	39.14	8.85
13	14	39.19	8.90
14	16	39.24	8.95
15	18	39.29	9.00
16	20	39.34	9.05
17	25	39.38	9.09
18	30	39.42	9.13
19	35	39.47	9.18
20	40	39.51	9.22
21	45	39.55	9.26
22	50	39.57	9.28
23	55	39.60	9.31
24	60	39.62	9.33
25	70	39.65	9.36
26	80	39.67	9.38
27	90	39.68	9.39
28	100	39.70	9.41
29	120	39.72	9.43
30	140	39.75	9.46
31	160	39.78	9.49
32	180	39.80	9.51
33	210	39.83	9.54
34	240	39.86	9.57
35	270	39.89	9.60
36	300	39.92	9.63
37	330	39.94	9.65
38	360	39.96	9.67
39	420	39.99	9.70
40	480	40.02	9.73
41	540	40.04	9.75
42	600	40.06	9.77
43	660	40.08	9.79
44	720	40.10	9.81
45	780	40.12	9.83
46	840	40.13	9.84
47	900	40.15	9.86
48	960	40.17	9.88
49	1020	40.19	9.90
50	1080	40.20	9.91
51	1200	40.21	9.92
52	1320	40.22	9.93
53	1440	40.23	9.94
54	1560	40.24	9.95
55	1680	40.24	9.95
56	1800	40.25	9.96
57	1920	40.26	9.97
58	2160	40.26	9.97
59	2400	40.27	9.98
60	2640	40.28	9.99
61	2880	40.28	9.99

	Pumping Test Analysis Report
	Project: Getskimilesley
	Number: 2
	Client:

Location: Kola Tembien	Pumping Test: Agamat Recovery	Pumping Well: Agamat_Recovery
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Ataklti G/tsadik	Getskimilesley	Analysis Date: 12/2/2021
Aquifer Thickness: 80.00 m	Discharge Rate: 25 [l/s]	



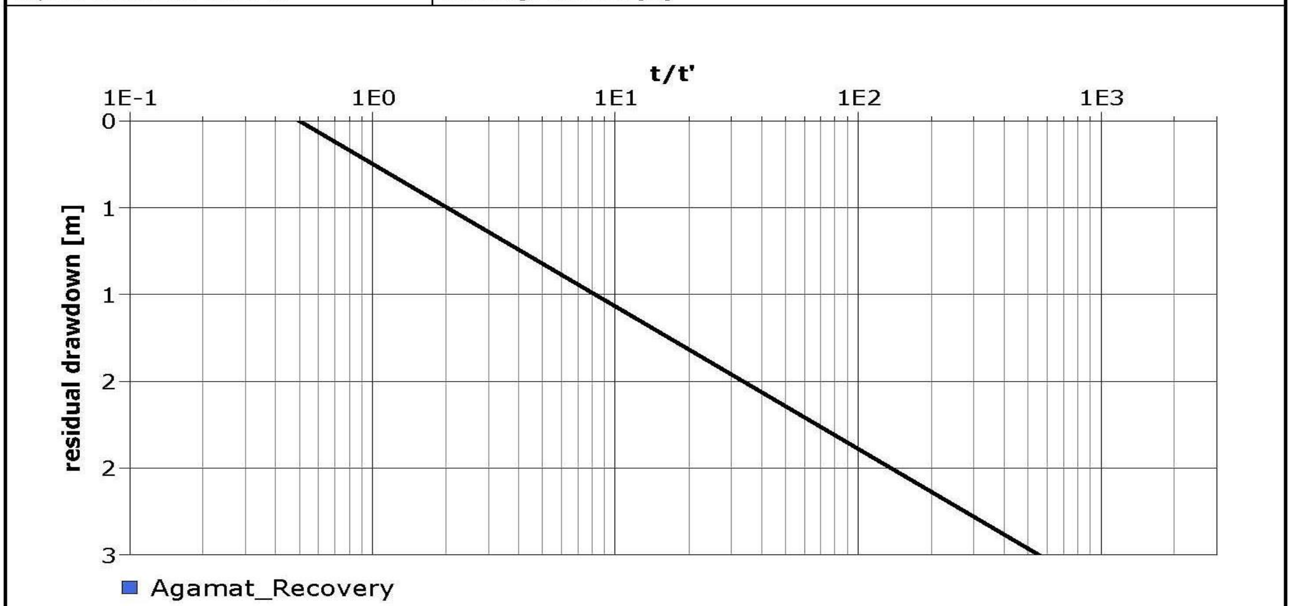
Calculation using THEIS & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Radial Distance to PW [m]	
Agamat_Recovery	2.61×10^{2}	3.26×10^{0}		

Figure 21. Graph of Agamat recovery test with transmissivity result for full data

	Pumping Test Analysis Report
	Project: Getskimilesley
	Number: 2
	Client:

Location: Kola Tembien	Pumping Test: Agamat Recovery	Pumping Well: Agamat_Recovery
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Ataklti G/tsadik	Getskimilesley	Analysis Date: 12/2/2021
Aquifer Thickness: 80.00 m	Discharge Rate: 25 [l/s]	



Calculation using THEIS & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Radial Distance to PW [m]	
Agamat_Recovery	4.01×10^{2}	5.01×10^{0}		

Figure 22. Graph of Agamat recovery test with transmissivity result after ignoring the first 10 minutes

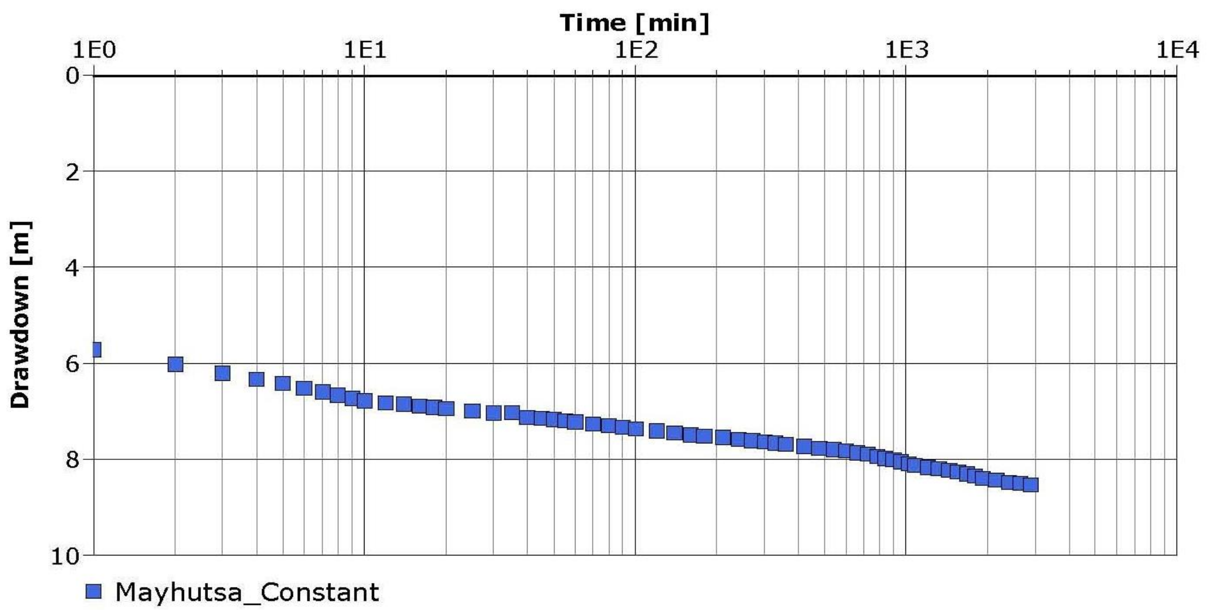
Table 30. Data of recovery test for Agamat deep well

	Pumping Test - Water Level Data		Page 1 of 2
	Project: Getskimilesley		
	Number: 2		
	Client:		
Location: Kola Tembien	Pumping Test: Agamat Recovery	Pumping Well: Agamat_Recovery	
Test Conducted by: Ataklti G/tsadik	Test Date: 12/2/2021	Discharge Rate: 25 [l/s]	
Observation Well: Agamat_Recovery	Static Water Level [m]: 30.29	Radial Distance to PW [m]: -	

	Time [min]	Water Level [m]	Drawdown [m]
1	2.875	30.60	0.31
2	3.0909	30.63	0.34
3	3.35	30.66	0.37
4	3.6667	30.68	0.39
5	3.8235	30.70	0.41
6	4	30.73	0.44
7	4.2	30.75	0.46
8	4.4286	30.77	0.48
9	4.6923	30.80	0.51
10	5	30.82	0.53
11	5.3636	30.84	0.55
12	5.8	30.86	0.57
13	6.3333	30.88	0.59
14	7	30.90	0.61
15	7.8571	30.93	0.64
16	9	30.95	0.66
17	9.7273	30.97	0.68
18	10.6	30.99	0.70
19	11.6667	31.02	0.73
20	13	31.08	0.79
21	14.7143	31.13	0.84
22	17	31.18	0.89
23	19	31.22	0.93
24	21.5714	31.27	0.98
25	25	31.32	1.03
26	29.8	31.36	1.07
27	33	31.40	1.11
28	37	31.45	1.16
29	42.1429	31.50	1.21
30	49	31.56	1.27
31	53.3636	31.62	1.33
32	58.6	31.70	1.41
33	65	31.79	1.50
34	73	31.86	1.57
35	83.2857	31.92	1.63
36	97	31.98	1.69
37	116.2	32.09	1.80
38	145	32.20	1.91
39	161	32.32	2.03
40	181	32.46	2.17
41	206.7143	32.54	2.25
42	241	32.62	2.33
43	289	32.72	2.43
44	321	32.80	2.51
45	361	33.16	2.87
46	412.4286	33.51	3.22
47	481	33.76	3.47
48	577	34.18	3.89
49	721	34.61	4.32
50	961	34.98	4.69
51	1441	35.19	4.90
52	2881	36.20	5.91

	Pumping Test Analysis Report
	Project: Getskimilesley
	Number:
	Client:

Location: Kola Tembien	Pumping Test: Mayhutsa_Constant	Pumping Well: Mayhutsa_Constant
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Ataklti G/tsadik	Mayhutsa_Constant	Analysis Date: 12/2/2021
Aquifer Thickness: 68.00 m	Discharge Rate: 30 [l/s]	



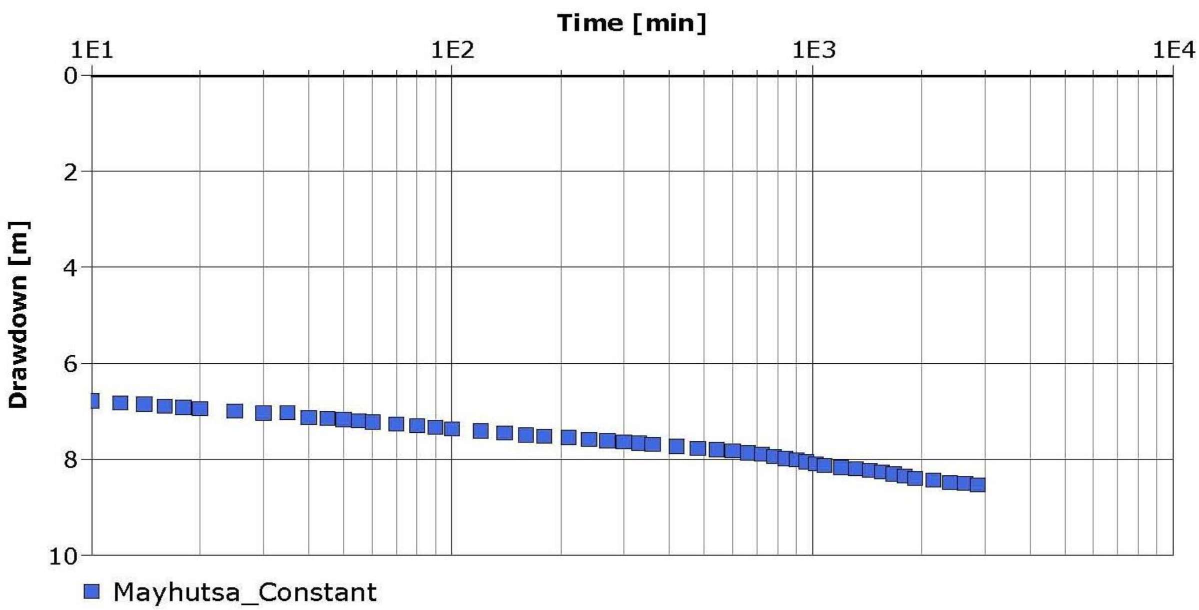
Calculation using COOPER & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Storage coefficient	Radial Distance to PW [m]	
Mayhutsa_Constant	6.57×10^{2}	9.66×10^{0}	5.00×10^{-1}		

Figure 23. . Graph of May-Hutsa constant pumping test with transmissivity result for full data

	Pumping Test Analysis Report
	Project: Getskimilesley
	Number:
	Client:

Location: Kola Tembien	Pumping Test: Mayhutsa_Constant	Pumping Well: Mayhutsa_Constant
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Atakl ti G/tsadik	Mayhutsa_Constant	Analysis Date: 12/2/2021
Aquifer Thickness: 68.00 m	Discharge Rate: 30 [l/s]	



Calculation using COOPER & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Storage coefficient	Radial Distance to PW [m]	
Mayhutsa_Constant	6.76×10^{2}	9.94×10^{0}	5.00×10^{-1}		

Figure 24. . Graph of May-Hutsa constant pumping test with transmissivity result after ignoring the first 10 minutes

Table 31. Data of constant pumping test for May-Hutsa deep well

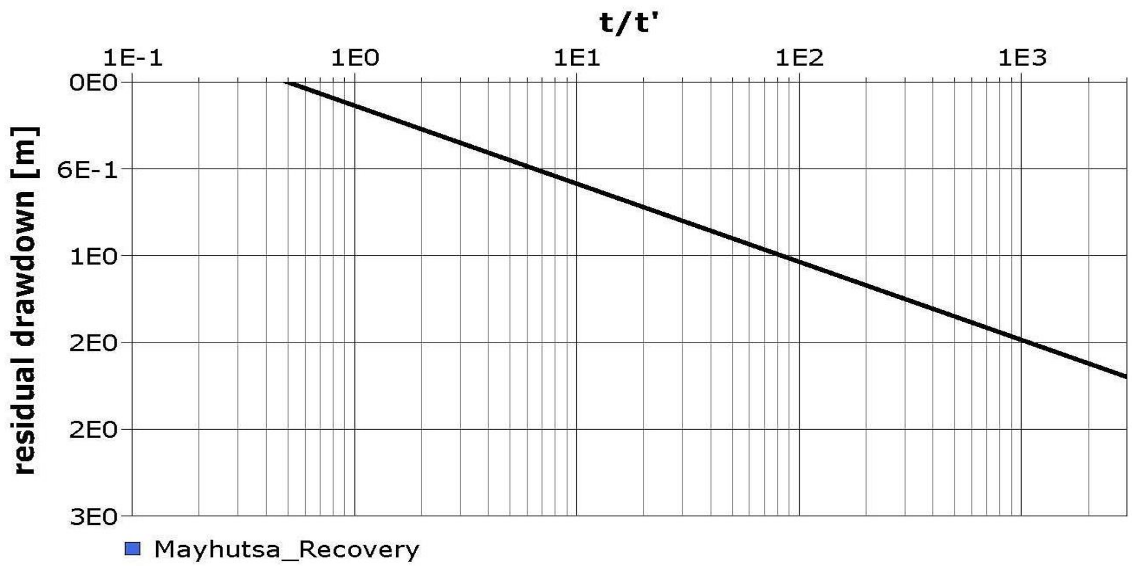
Pumping Test - Water Level Data	Page 1 of 2
Project: Getskimilesley	
Number:	
Client:	

Location: Kola Tembien	Pumping Test: Mayhutsa_Constant	Pumping Well: Mayhutsa_Constant
Test Conducted by: Ataklti G/tsadik	Test Date: 12/2/2021	Discharge Rate: 30 [l/s]
Observation Well: Mayhutsa_Constant	Static Water Level [m]: 23.68	Radial Distance to PW [m]: -

	Time [min]	Water Level [m]	Drawdown [m]
1	0	23.68	0.00
2	1	29.40	5.72
3	2	29.71	6.03
4	3	29.90	6.22
5	4	30.01	6.33
6	5	30.10	6.42
7	6	30.20	6.52
8	7	30.28	6.60
9	8	30.35	6.67
10	9	30.41	6.73
11	10	30.46	6.78
12	12	30.50	6.82
13	14	30.54	6.86
14	16	30.57	6.89
15	18	30.60	6.92
16	20	30.63	6.95
17	25	30.68	7.00
18	30	30.72	7.04
19	35	30.71	7.03
20	40	30.81	7.13
21	45	30.83	7.15
22	50	30.86	7.18
23	55	30.88	7.20
24	60	30.91	7.23
25	70	30.94	7.26
26	80	30.98	7.30
27	90	31.02	7.34
28	100	31.06	7.38
29	120	31.09	7.41
30	140	31.13	7.45
31	160	31.17	7.49
32	180	31.20	7.52
33	210	31.23	7.55
34	240	31.26	7.58
35	270	31.29	7.61
36	300	31.32	7.64
37	330	31.35	7.67
38	360	31.38	7.70
39	420	31.41	7.73
40	480	31.45	7.77
41	540	31.48	7.80
42	600	31.51	7.83
43	660	31.55	7.87
44	720	31.58	7.90
45	780	31.63	7.95
46	840	31.67	7.99
47	900	31.70	8.02
48	960	31.74	8.06
49	1020	31.77	8.09
50	1080	31.81	8.13
51	1200	31.85	8.17
52	1320	31.88	8.20
53	1440	31.91	8.23
54	1560	31.95	8.27
55	1680	31.99	8.31
56	1800	32.03	8.35
57	1920	32.08	8.40
58	2160	32.12	8.44
59	2400	32.16	8.48
60	2640	32.19	8.51
61	2880	32.22	8.54

	Pumping Test Analysis Report
	Project: Getskimilesley
	Number:
	Client:

Location: Kola Tembien	Pumping Test: Mayhutsa_Recovery	Pumping Well: Mayhutsa_Recovery
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Ataklti G/tsadik	Mayhutsa_Recovery	Analysis Date: 12/2/2021
Aquifer Thickness: 68.00 m	Discharge Rate: 30 [l/s]	



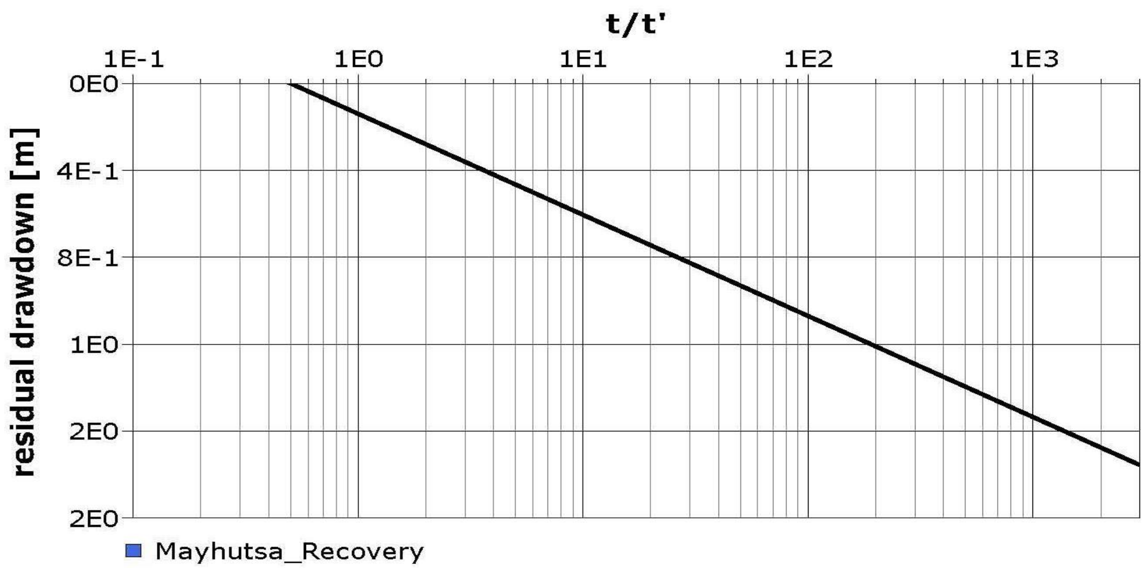
Calculation using THEIS & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Radial Distance to PW [m]	
Mayhutsa_Recovery	8.78×10^{2}	1.29×10^{1}		

Figure 25. Graph of May-Hutsa recovery test with transmissivity result for full data

	Pumping Test Analysis Report
	Project: Getskimilesley
	Number:
	Client:

Location: Kola Tembien	Pumping Test: Mayhutsa_Recovery	Pumping Well: Mayhutsa_Recovery
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Ataklti G/tsadik	Mayhutsa_Recovery	Analysis Date: 12/2/2021
Aquifer Thickness: 68.00 m	Discharge Rate: 30 [l/s]	



Calculation using THEIS & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Radial Distance to PW [m]	
Mayhutsa_Recovery	1.02×10^{3}	1.50×10^{1}		

Figure 26. Graph of May-Hutsa recovery test with transmissivity result after ignoring the first 10 minutes

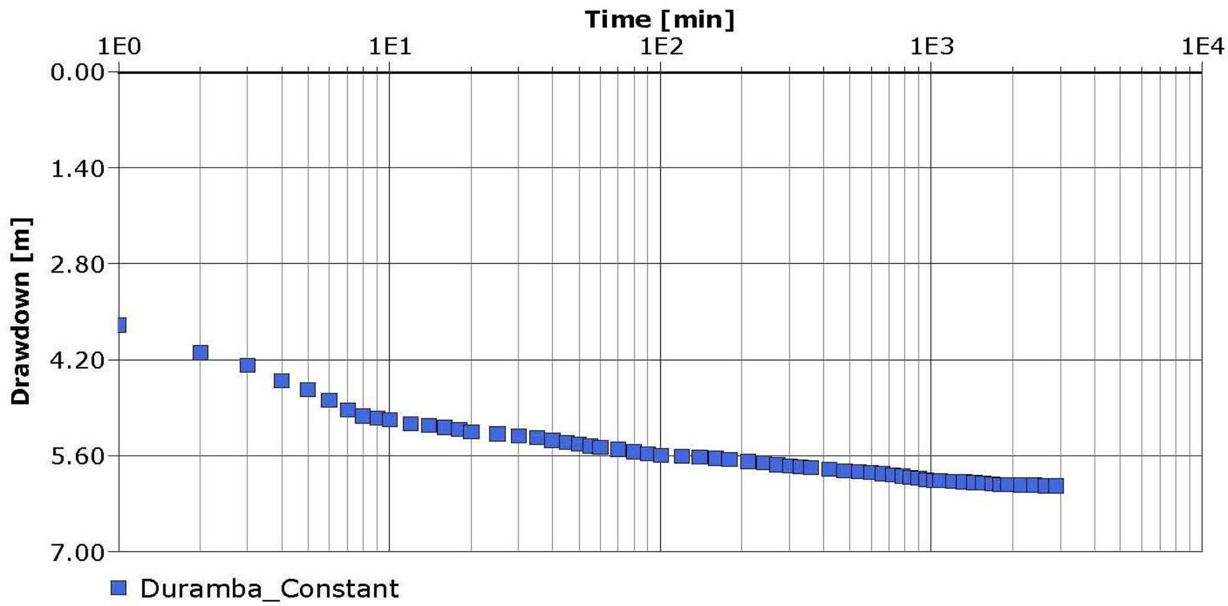
Table 32. Data of recovery test for May-Hutsa deep well

Pumping Test - Water Level Data			Page 1 of 2
Project: Getskimilesley			
Number:			
Client:			
Location: Kola Tembien	Pumping Test: Mayhutsa_Recovery	Pumping Well: Mayhutsa_Recovery	
Test Conducted by: Ataklti G/tsadik	Test Date: 12/2/2021	Discharge Rate: 30 [l/s]	
Observation Well: Mayhutsa_Recovery	Static Water Level [m]: 23.68	Radial Distance to PW [m]: -	

	Time [min]	Water Level [m]	Drawdown [m]
1	3	24.26	0.58
2	3.1818	24.27	0.59
3	3.4	24.28	0.60
4	3.6667	24.29	0.61
5	3.8235	24.30	0.62
6	4	24.32	0.64
7	4.2	24.34	0.66
8	4.4286	24.35	0.67
9	4.6923	24.36	0.68
10	5	24.37	0.69
11	5.3636	24.38	0.70
12	5.8	24.40	0.72
13	6.3333	24.42	0.74
14	7	24.43	0.75
15	7.8571	24.45	0.77
16	9	24.46	0.78
17	9.7273	24.48	0.80
18	10.6	24.50	0.82
19	11.6667	24.52	0.84
20	13	24.54	0.86
21	14.7143	24.56	0.88
22	17	24.58	0.90
23	19	24.60	0.92
24	21.5714	24.62	0.94
25	25	24.64	0.96
26	29.8	24.67	0.99
27	33	24.70	1.02
28	37	24.73	1.05
29	42.1429	24.76	1.08
30	49	24.80	1.12
31	53.3636	24.83	1.15
32	58.6	24.85	1.17
33	65	24.87	1.19
34	73	24.90	1.22
35	83.2857	24.93	1.25
36	97	24.97	1.29
37	116.2	25.00	1.32
38	145	25.03	1.35
39	161	25.06	1.38
40	181	25.10	1.42
41	206.7143	25.13	1.45
42	241	25.16	1.48
43	289	25.20	1.52
44	321	25.24	1.56
45	361	25.29	1.61
46	412.4286	25.35	1.67
47	481	25.40	1.72
48	577	25.48	1.80
49	721	25.53	1.85
50	961	25.61	1.93
51	1441	25.80	2.12
52	2881	26.18	2.50

	Pumping Test Analysis Report
	Project: Getskimilesley
	Number:
	Client:

Location: Kola Tembien	Pumping Test: Duramba_Constant	Pumping Well: Duramba_Constant
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Ataklti G/tsadik	Duramba_Constant	Analysis Date: 12/2/2021
Aquifer Thickness: 75.00 m	Discharge Rate: 25 [l/s]	



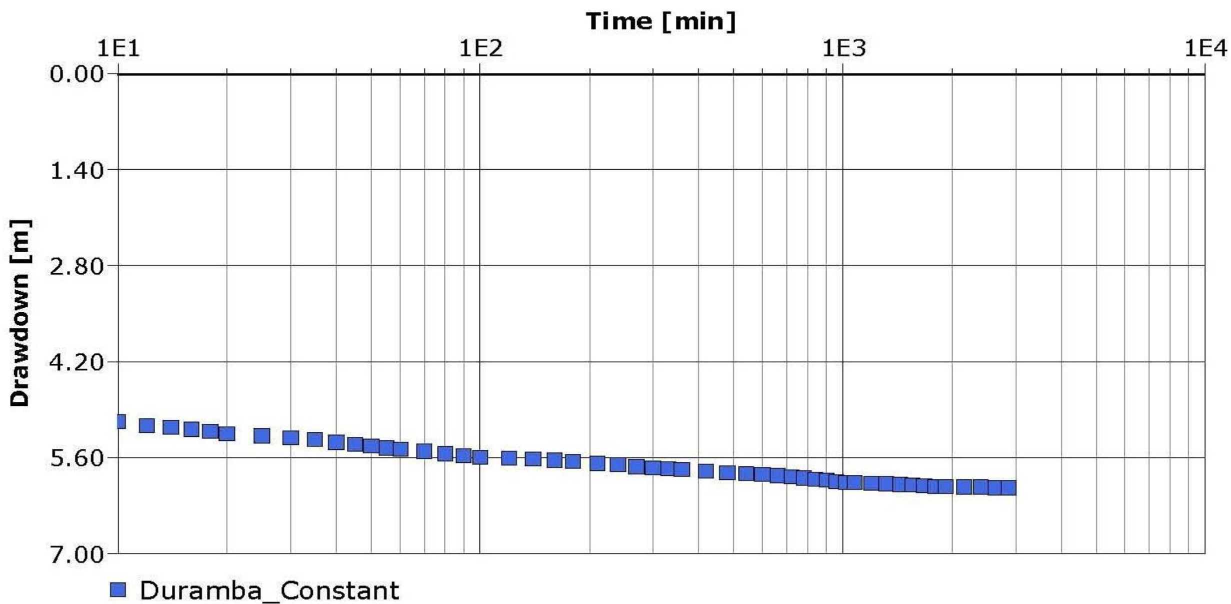
Calculation using COOPER & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Storage coefficient	Radial Distance to PW [m]	
Duramba_Constant	7.52×10^{2}	1.00×10^{1}	5.00×10^{-1}		

Figure 27. Graph of duramba constant pumping test with transmissivity result for full data

	Pumping Test Analysis Report
	Project: Getskimilesley
	Number:
	Client:

Location: Kola Tembien	Pumping Test: Duramba_Constant	Pumping Well: Duramba_Constant
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Ataklti G/tsadik	Duramba_Constant	Analysis Date: 12/2/2021
Aquifer Thickness: 75.00 m	Discharge Rate: 25 [l/s]	



Calculation using COOPER & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Storage coefficient	Radial Distance to PW [m]	
Duramba_Constant	1.00×10^{3}	1.34×10^{1}	5.00×10^{-1}		

Figure 28. Graph of duramba constant pumping test with transmissivity result after ignoring the first 10 minutes

Table 33. Data of constant pumping test for Duramba deep well

Pumping Test - Water Level Data — Page 1 of 2

Project: Getskimilesley

Number:

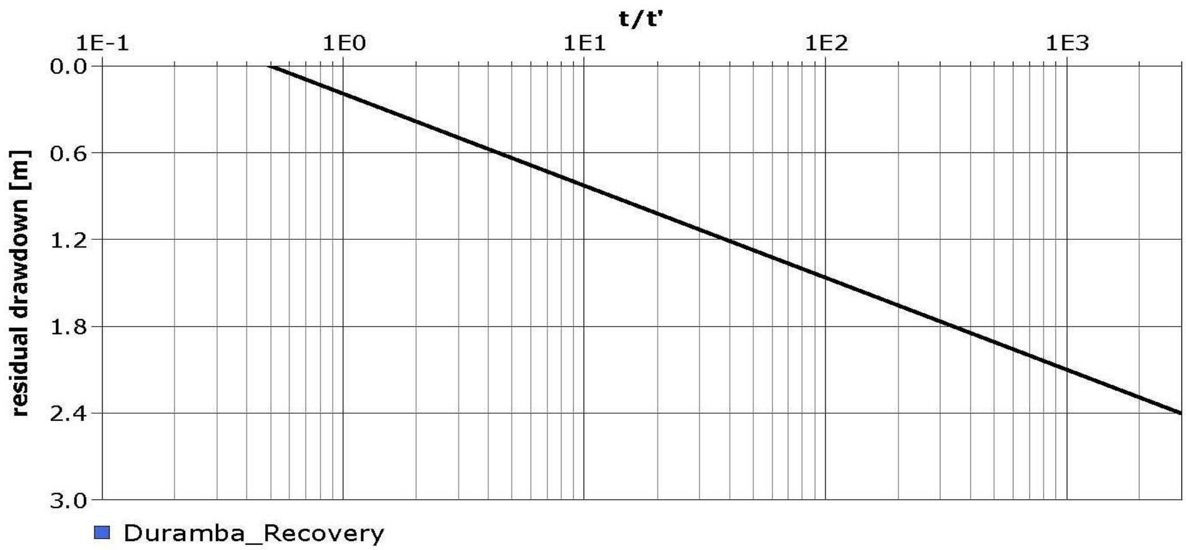
Client:

Location: Kola Tembien	Pumping Test: Duramba_Constant	Pumping Well: Duramba_Constant
Test Conducted by: Ataklti G/tsadik	Test Date: 12/2/2021	Discharge Rate: 25 [l/s]
Observation Well: Duramba_Constant	Static Water Level [m]: 13.92	Radial Distance to PW [m]: -

	Time [min]	Water Level [m]	Drawdown [m]
1	0	13.92	0.00
2	1	17.62	3.70
3	2	18.02	4.10
4	3	18.20	4.28
5	4	18.43	4.51
6	5	18.56	4.64
7	6	18.71	4.79
8	7	18.86	4.94
9	8	18.94	5.02
10	9	18.97	5.05
11	10	19.00	5.08
12	12	19.05	5.13
13	14	19.08	5.16
14	16	19.11	5.19
15	18	19.14	5.22
16	20	19.17	5.25
17	25	19.20	5.28
18	30	19.23	5.31
19	35	19.26	5.34
20	40	19.30	5.38
21	45	19.32	5.40
22	50	19.35	5.43
23	55	19.38	5.46
24	60	19.40	5.48
25	70	19.43	5.51
26	80	19.46	5.54
27	90	19.49	5.57
28	100	19.52	5.60
29	120	19.53	5.61
30	140	19.54	5.62
31	160	19.56	5.64
32	180	19.58	5.66
33	210	19.60	5.68
34	240	19.62	5.70
35	270	19.65	5.73
36	300	19.67	5.75
37	330	19.68	5.76
38	360	19.70	5.78
39	420	19.72	5.80
40	480	19.74	5.82
41	540	19.75	5.83
42	600	19.76	5.84
43	660	19.78	5.86
44	720	19.80	5.88
45	780	19.82	5.90
46	840	19.84	5.92
47	900	19.85	5.93
48	960	19.87	5.95
49	1020	19.88	5.96
50	1080	19.88	5.96
51	1200	19.89	5.97
52	1320	19.90	5.98
53	1440	19.91	5.99
54	1560	19.92	6.00
55	1680	19.93	6.01
56	1800	19.94	6.02
57	1920	19.94	6.02
58	2160	19.95	6.03
59	2400	19.95	6.03
60	2640	19.96	6.04
61	2880	19.96	6.04

	Pumping Test Analysis Report
	Project: Getskimilesley
	Number:
	Client:

Location: Kola Tembien	Pumping Test: Duramba_Recovery	Pumping Well: Duramba_Recovery
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Ataklti G/tsadik	Duramba_Recovery	Analysis Date: 12/2/2021
Aquifer Thickness: 75.00 m	Discharge Rate: 25 [l/s]	



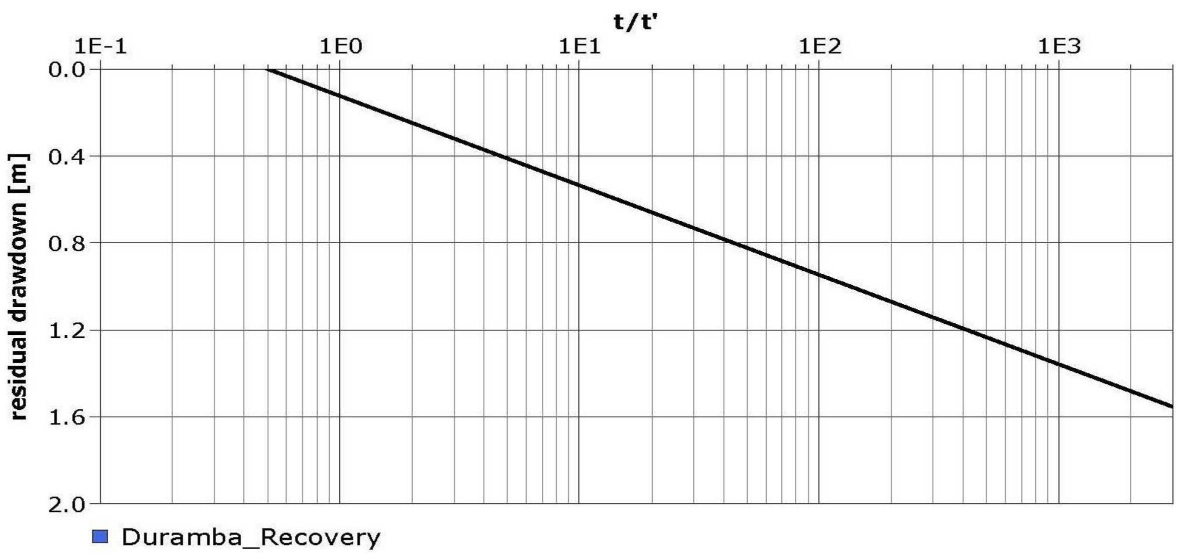
Calculation using THEIS & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Radial Distance to PW [m]	
Duramba_Recovery	6.21×10^2	8.28×10^0		

Figure 29. Graph of Duramba constant pumping test with transmissivity result for full data

	Pumping Test Analysis Report
	Project: Getskimilesley
	Number:
	Client:

Location: Kola Tembien	Pumping Test: Duramba_Recovery	Pumping Well: Duramba_Recovery
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Ataklti G/tsadik	Duramba_Recovery	Analysis Date: 12/2/2021
Aquifer Thickness: 75.00 m	Discharge Rate: 25 [l/s]	



Calculation using THEIS & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Radial Distance to PW [m]	
Duramba_Recovery	9.60×10^{2}	1.28×10^{1}		

Figure 30. Graph of Duramba constant pumping test with transmissivity result after ignoring the first 10 minutes

Table 34. Data of recovery test for Duramba deep well

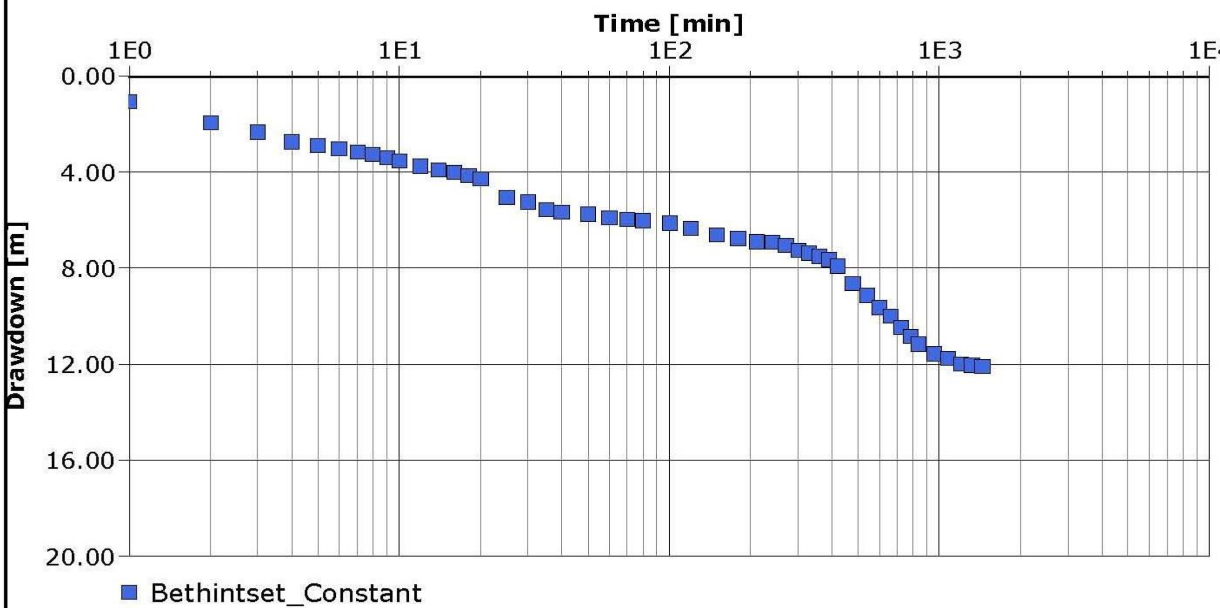
Pumping Test - Water Level Data	Page 1 of 2
Project: Getskimilesley	
Number:	
Client:	

Location: Kola Tembien	Pumping Test: Duramba_Recovery	Pumping Well: Duramba_Recovery
Test Conducted by: Atakltí G/tsadik	Test Date: 12/2/2021	Discharge Rate: 25 [l/s]
Observation Well: Duramba_Recovery	Static Water Level [m]: 13.92	Radial Distance to PW [m]: -

	Time [min]	Water Level [m]	Drawdown [m]
1	3	14.26	0.34
2	3.1818	14.27	0.35
3	3.4	14.28	0.36
4	3.6667	14.29	0.37
5	3.8235	14.30	0.38
6	4	14.31	0.39
7	4.2	14.32	0.40
8	4.4286	14.33	0.41
9	4.6923	14.34	0.42
10	5	14.35	0.43
11	5.3636	14.36	0.44
12	5.8	14.38	0.46
13	6.3333	14.39	0.47
14	7	14.40	0.48
15	7.8571	14.42	0.50
16	9	14.44	0.52
17	9.7273	14.45	0.53
18	10.6	14.47	0.55
19	11.6667	14.49	0.57
20	13	14.50	0.58
21	14.7143	14.52	0.60
22	17	14.53	0.61
23	19	14.54	0.62
24	21.5714	14.56	0.64
25	25	14.58	0.66
26	29.8	14.60	0.68
27	33	14.62	0.70
28	37	14.64	0.72
29	42.1429	14.65	0.73
30	49	14.66	0.74
31	53.3636	14.69	0.77
32	58.6	14.72	0.80
33	65	14.75	0.83
34	73	14.78	0.86
35	83.2857	14.81	0.89
36	97	14.84	0.92
37	116.2	14.87	0.95
38	145	14.90	0.98
39	161	14.95	1.03
40	181	15.00	1.08
41	206.7143	15.08	1.16
42	241	15.14	1.22
43	289	15.22	1.30
44	321	15.30	1.38
45	361	15.38	1.46
46	412.4286	15.48	1.56
47	481	15.59	1.67
48	577	15.70	1.78
49	721	15.82	1.90
50	961	15.96	2.04
51	1441	16.12	2.20
52	2881	16.88	2.96

	Pumping Test Analysis Report
	Project: Getskimilesley
	Number:
	Client:

Location: Kola Tembien	Pumping Test: Bethintset_Constant	Pumping Well: Bethintset_Constant
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Ataklti G/tsadik	Bethintset	Analysis Date: 12/2/2021
Aquifer Thickness: 42.00 m	Discharge Rate: 6 [l/s]	



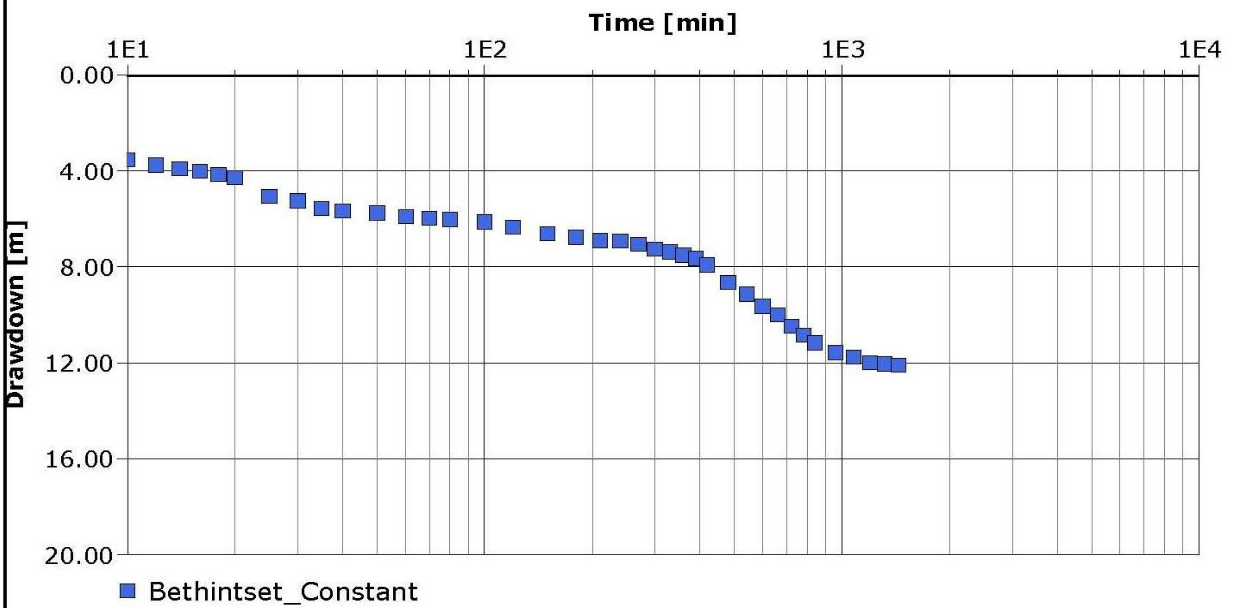
Calculation using COOPER & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Storage coefficient	Radial Distance to PW [m]	
Bethintset_Constant	2.84×10^{1}	6.76×10^{-1}	5.00×10^{-1}		

Figure 31. Graph of Bethintset constant pumping test with transmissivity result for full data

	Pumping Test Analysis Report
	Project: Getskimilesley
	Number:
	Client:

Location: Kola Tembien	Pumping Test: Bethintset_Constant	Pumping Well: Bethintset_Constant
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Atakldi G/tsadik	Bethintset	Analysis Date: 12/2/2021
Aquifer Thickness: 42.00 m	Discharge Rate: 6 [l/s]	



Calculation using COOPER & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Storage coefficient	Radial Distance to PW [m]	
Bethintset_Constant	2.54×10^{1}	6.04×10^{-1}	5.00×10^{-1}		

Figure 32. Graph of Bethintset constant pumping test with transmissivity result after ignoring the first 10 minutes

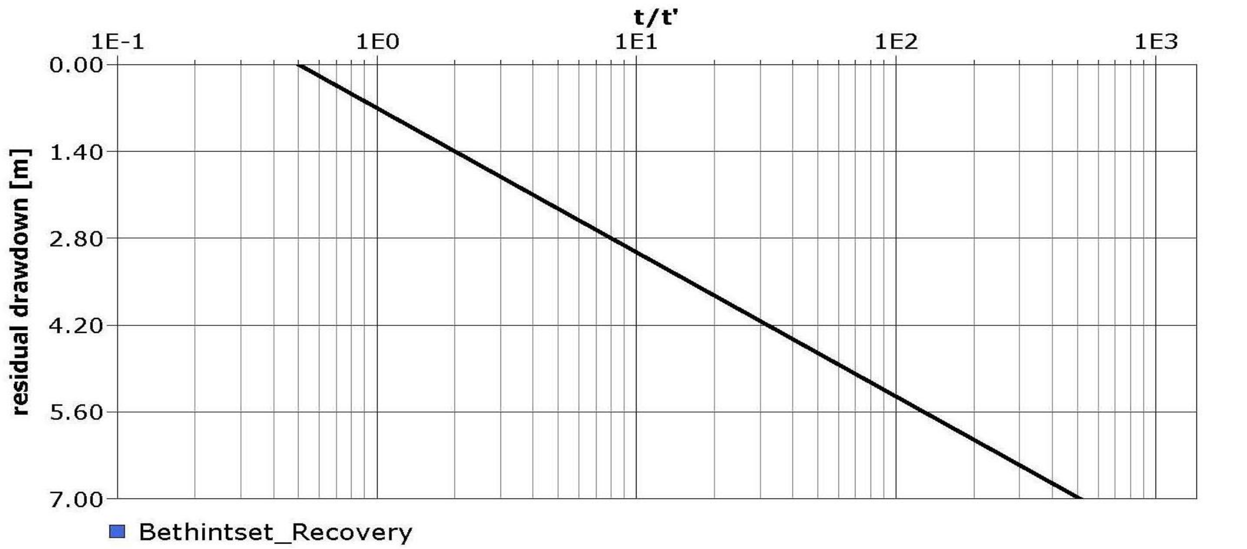
Table 35. Data of constant pumping test for Bethintset deep well

	Pumping Test - Water Level Data	Page 1 of 1
	Project: Getskimilesley	
	Number:	
	Client:	
Location: Kola Tembien	Pumping Test: Bethintset_Constant	Pumping Well: Bethintset_Constant
Test Conducted by: Ataklti G/tsadik	Test Date: 12/2/2021	Discharge Rate: 6 [l/s]
Observation Well: Bethintset_Constant	Static Water Level [m]: 23.95	Radial Distance to PW [m]: -

	Time [min]	Water Level [m]	Drawdown [m]
1	0	23.95	0.00
2	1	25.01	1.06
3	2	25.90	1.95
4	3	26.30	2.35
5	4	26.70	2.75
6	5	26.85	2.90
7	6	26.99	3.04
8	7	27.12	3.17
9	8	27.23	3.28
10	9	27.36	3.41
11	10	27.50	3.55
12	12	27.70	3.75
13	14	27.88	3.93
14	16	27.98	4.03
15	18	28.12	4.17
16	20	28.24	4.29
17	25	29.02	5.07
18	30	29.20	5.25
19	35	29.53	5.58
20	40	29.63	5.68
21	50	29.72	5.77
22	60	29.87	5.92
23	70	29.93	5.98
24	80	29.99	6.04
25	100	30.09	6.14
26	120	30.30	6.35
27	150	30.55	6.60
28	180	30.73	6.78
29	210	30.85	6.90
30	240	30.88	6.93
31	270	31.02	7.07
32	300	31.20	7.25
33	330	31.33	7.38
34	360	31.47	7.52
35	390	31.60	7.65
36	420	31.87	7.92
37	480	32.60	8.65
38	540	33.10	9.15
39	600	33.60	9.65
40	660	33.95	10.00
41	720	34.44	10.49
42	780	34.80	10.85
43	840	35.12	11.17
44	960	35.53	11.58
45	1080	35.70	11.75
46	1200	35.96	12.01
47	1320	36.01	12.06
48	1440	36.06	12.11

	Pumping Test Analysis Report
	Project: Getskimilesley
	Number:
	Client:

Location: Kola Tembien	Pumping Test: Bethintset_Recovery	Pumping Well: Bethintset_Recovery
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Ataklti G/tsadik	Bethintset_Recovery	Analysis Date: 12/2/2021
Aquifer Thickness: 42.00 m	Discharge Rate: 6 [l/s]	



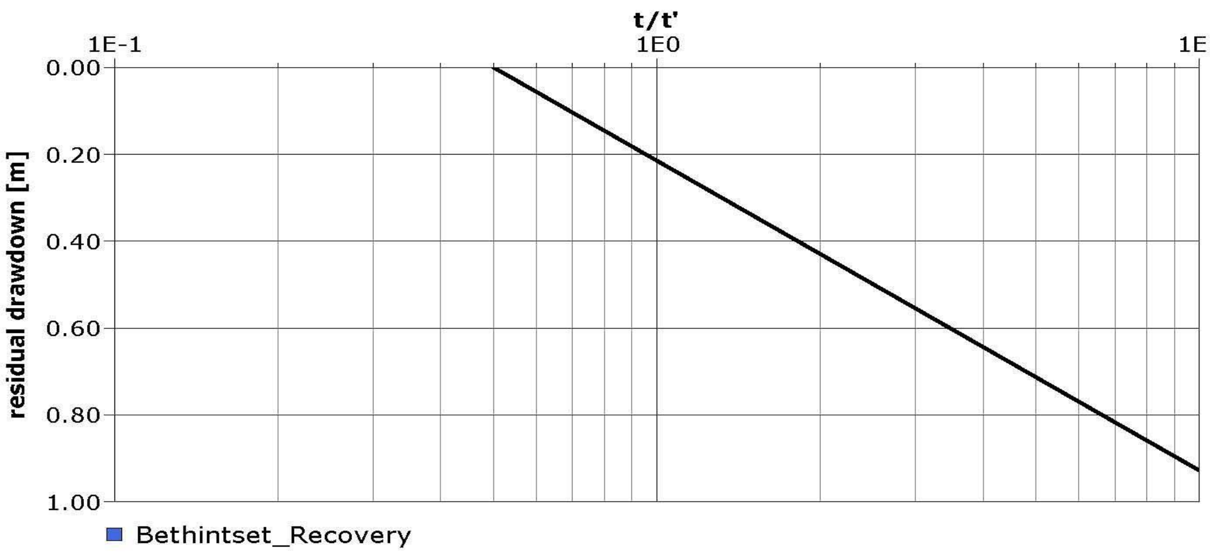
Calculation using THEIS & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Radial Distance to PW [m]	
Bethintset_Recovery	4.08×10^{1}	9.71×10^{-1}		

Figure 33. Graph of Bethintset recovery test with transmissivity result for full data

	Pumping Test Analysis Report
	Project: Getskimilesley
	Number:
	Client:

Location: Kola Tembien	Pumping Test: Bethintset_Recovery	Pumping Well: Bethintset_Recovery
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Ataklti G/tsadik	Bethintset_Recovery	Analysis Date: 12/2/2021
Aquifer Thickness: 42.00 m	Discharge Rate: 6 [l/s]	



Calculation using THEIS & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Radial Distance to PW [m]	
Bethintset_Recovery	1.33×10^{2}	3.17×10^{0}		

Figure 34. Graph of Bethintset recovery test with transmissivity result after ignoring the first 10 minutes

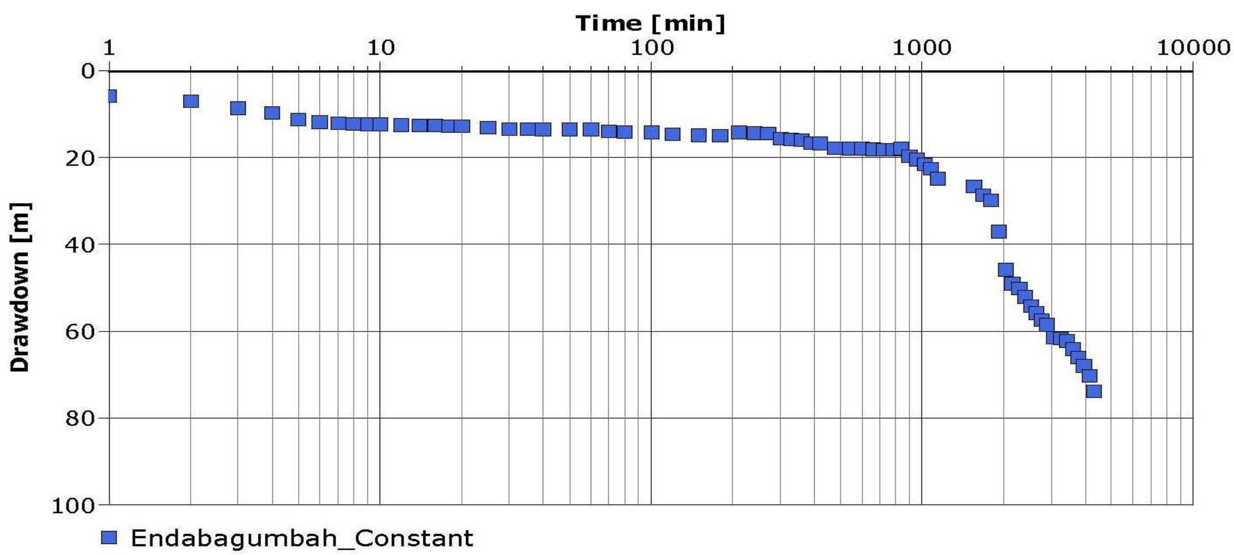
Table 36. Data of recovery test for Bethintsaet deep well

	Pumping Test - Water Level Data	Page 1 of 1
	Project: Getskimilesley	
	Number:	
	Client:	
Location: Kola Tembien	Pumping Test: Bethintset_Recovery	Pumping Well: Bethintset_Recovery
Test Conducted by: Ataklti G/tsadik	Test Date: 12/2/2021	Discharge Rate: 6 [l/s]
Observation Well: Bethintset_Recovery	Static Water Level [m]: 23.95	Radial Distance to PW [m]: -

	Time [min]	Water Level [m]	Drawdown [m]
1	7.8571	23.96	0.01
2	9	23.99	0.04
3	10.6	24.01	0.06
4	13	24.03	0.08
5	15.4	24.06	0.11
6	19	24.09	0.14
7	21.5714	24.15	0.20
8	25	24.21	0.26
9	29.8	24.23	0.28
10	37	24.26	0.31
11	42.1429	24.39	0.44
12	49	24.42	0.47
13	58.6	24.45	0.50
14	73	24.50	0.55
15	81	24.56	0.61
16	91	24.63	0.68
17	103.8571	24.76	0.81
18	121	24.80	0.85
19	145	24.86	0.91
20	161	24.90	0.95
21	181	25.01	1.06
22	206.7143	25.09	1.14
23	241	25.29	1.34
24	289	26.10	2.15
25	361	27.02	3.07
26	481	28.41	4.46
27	721	29.21	5.26
28	1441	30.70	6.75

	Pumping Test Analysis Report
	Project: Getskimilesley
	Number: 1
	Client:

Location: Kola Tembien	Pumping Test: Endabagumbah_Constant	Pumping Well: Endabagumbah_Constant
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Ataklti G/tsadik	Cooper & Jacob	Analysis Date: 12/2/2021
Aquifer Thickness: 84.00 m	Discharge Rate: 5 [l/s]	



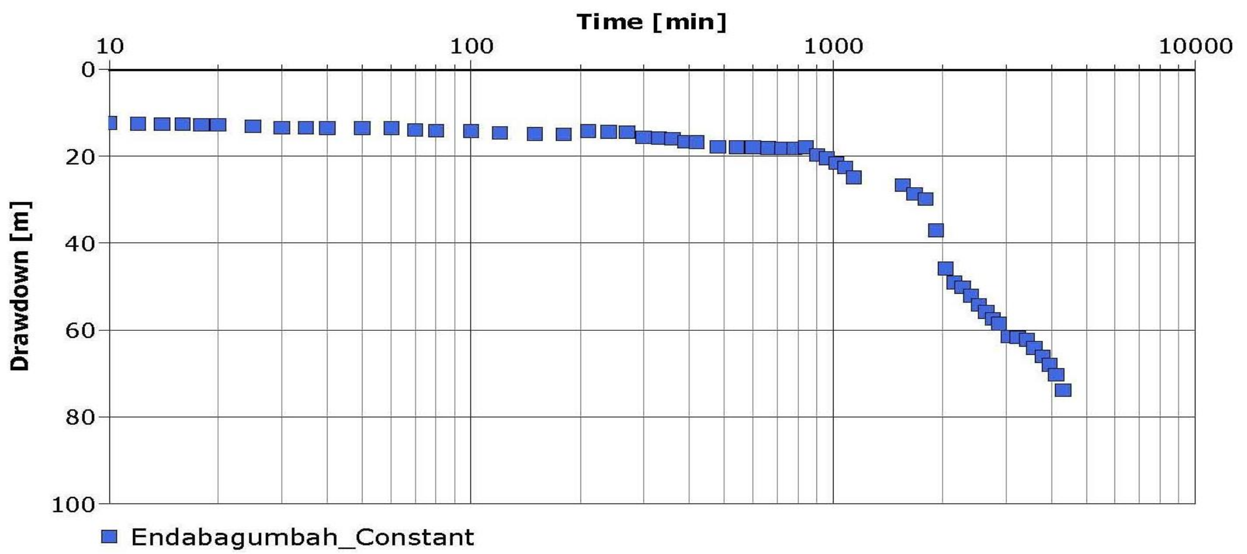
Calculation using COOPER & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Storage coefficient	Radial Distance to PW [m]	
Endabagumbah_Constant	5.34×10^{0}	6.35×10^{-2}	5.00×10^{-1}		

Figure 35. Graph of Endabagumbah constant pumping test with transmissivity result for full data

	Pumping Test Analysis Report
	Project: Getskimilesley
	Number: 1
	Client:

Location: Kola Tembien	Pumping Test: Endabagumbah_Constant	Pumping Well: Endabagumbah_Constant
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Ataklti G/tsadik	Cooper & Jacob	Analysis Date: 12/2/2021
Aquifer Thickness: 84.00 m	Discharge Rate: 5 [l/s]	



Calculation using COOPER & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Storage coefficient	Radial Distance to PW [m]	
Endabagumbah_Constant	4.02×10^{0}	4.79×10^{-2}	5.00×10^{-1}		

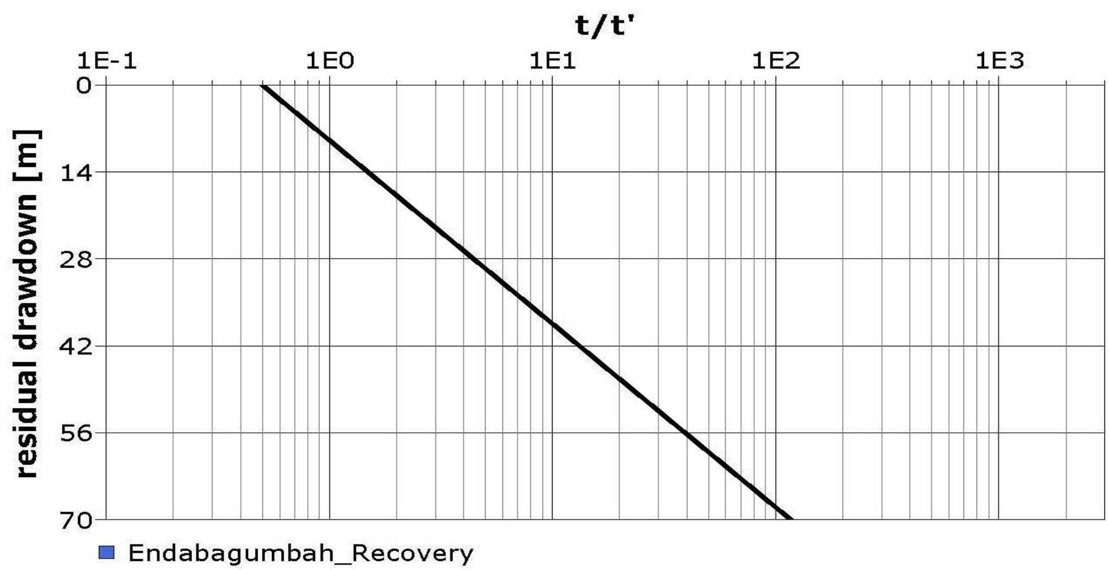
Figure 36. Graph of Endabagumbah constant pumping test with transmissivity result after ignoring the first 10 minutes

Table 37. Data of constant pumping test for Endabagumbah deep well

Pumping Test - Water Level Data			Page 1 of 2
Project: Getskimilesley			
Number: 1			
Client:			
Location: Kola Tembien	Pumping Test: Endabagumbah_Constant	Pumping Well: Endabagumbah_Constant	
Test Conducted by: Ataklti G/tsadik	Test Date: 12/2/2021	Discharge Rate: 6 [l/s]	
Observation Well: Endabagumbah_Constant	Static Water Level [m]: 9.34	Radial Distance to PW [m]: -	

	Time [min]	Water Level [m]	Drawdown [m]
1	0	9.34	0.00
2	1	15.19	5.85
3	2	16.43	7.09
4	3	18.05	8.71
5	4	19.11	9.77
6	5	20.67	11.33
7	6	21.16	11.82
8	7	21.44	12.10
9	8	21.60	12.26
10	9	21.68	12.34
11	10	21.79	12.45
12	12	21.86	12.52
13	14	22.02	12.68
14	16	22.06	12.72
15	18	22.09	12.75
16	20	22.11	12.77
17	25	22.53	13.19
18	30	22.82	13.48
19	35	22.87	13.53
20	40	22.90	13.56
21	50	22.93	13.59
22	60	22.99	13.65
23	70	23.28	13.94
24	80	23.44	14.10
25	100	23.62	14.28
26	120	23.96	14.62
27	150	24.23	14.89
28	180	24.38	15.04
29	210	23.62	14.28
30	240	23.79	14.45
31	270	23.88	14.54
32	300	25.06	15.72
33	330	25.27	15.93
34	360	25.38	16.04
35	390	26.03	16.69
36	420	26.17	16.83
37	480	27.24	17.90
38	540	27.33	17.99
39	600	27.39	18.05
40	660	27.48	18.14
41	720	27.56	18.22
42	780	27.63	18.29
43	840	27.29	17.95
44	900	29.11	19.77
45	960	29.85	20.51
46	1020	30.97	21.63
47	1080	32.05	22.71
48	1140	34.21	24.87
49	1560	36.07	26.73
50	1680	38.03	28.69
51	1800	39.16	29.82
52	1920	46.35	37.01
53	2040	55.18	45.84
54	2160	58.37	49.03
55	2280	59.52	50.18
56	2400	61.45	52.11
57	2520	63.62	54.28
58	2640	65.25	55.91
59	2760	66.87	57.53
60	2880	67.90	58.56
61	3060	70.86	61.52
62	3240	71.12	61.78
63	3420	71.54	62.20
64	3600	73.49	64.15
65	3780	75.41	66.07
66	3960	77.37	68.03
67	4140	79.62	70.28
68	4320	83.26	73.92

		Pumping Test Analysis Report
		Project: Getskimilesley
		Number: 1
		Client:
Location: Kola Tembien	Pumping Test: Endabagumbah_Recovery	Pumping Well: Endabagumbah_Recovery
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Ataklti G/tsadik	Endabagumbah_Recovery	Analysis Date: 12/2/2021
Aquifer Thickness: 84.00 m	Discharge Rate: 5 [l/s]	



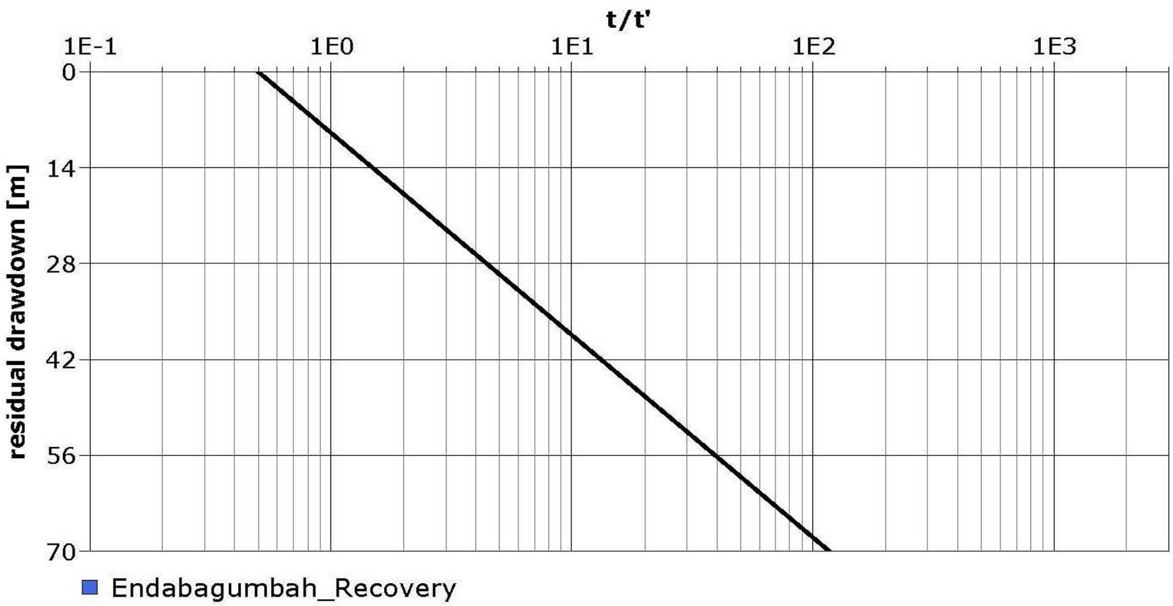
Calculation using THEIS & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Radial Distance to PW [m]	
Endabagumbah_Recovery	2.68×10^{0}	3.19×10^{-2}		

Figure 37. Graph of Endabagumbah recovery test with transmissivity result for full data

	Pumping Test Analysis Report
	Project: Getskimilesley
	Number: 1
	Client:

Location: Kola Tembien	Pumping Test: Endabagumbah_Recovery	Pumping Well: Endabagumbah_Recovery
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Ataklti G/tsadik	Endabagumbah_Recovery	Analysis Date: 12/2/2021
Aquifer Thickness: 84.00 m	Discharge Rate: 5 [l/s]	



Calculation using THEIS & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Radial Distance to PW [m]	
Endabagumbah_Recovery	2.68×10^{0}	3.19×10^{-2}		

Figure 38. Graph of Endabagumbah recovery test with transmissivity result after ignoring the first 10 minutes

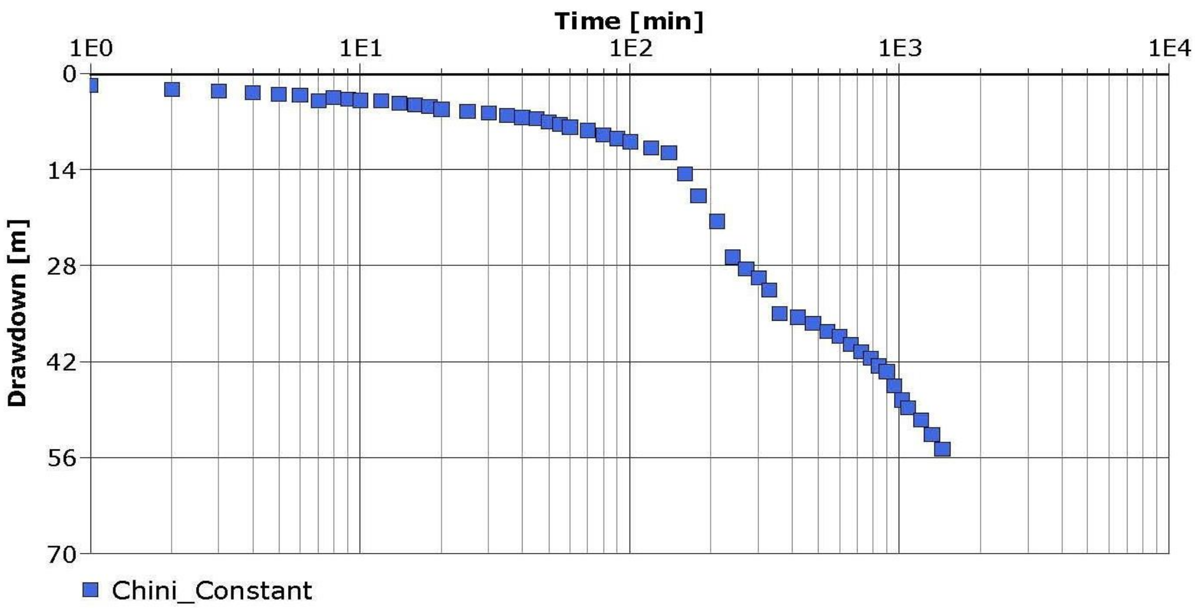
Table 38. Data of recovery test for Endabagumbah deep well

		Pumping Test - Water Level Data	Page 1 of 1
		Project: Getskimilesley	
		Number: 1	
		Client:	
Location: Kola Tembien	Pumping Test: Endabagumbah_Recovery	Pumping Well: Endabagumbah_Recovery	
Test Conducted by: Ataklti G/tsadik	Test Date: 12/2/2021	Discharge Rate: 6 [l/s]	
Observation Well: Endabagumbah_Recove	Static Water Level [m]: 9.34	Radial Distance to PW [m]: -	

	Time [min]	Water Level [m]	Drawdown [m]
1	14.0606	13.03	3.69
2	15.3667	13.45	4.11
3	16.963	13.98	4.64
4	18.9583	14.74	5.40
5	21.5238	15.71	6.37
6	24.9444	16.94	7.60
7	29.7333	18.71	9.37
8	36.9167	20.82	11.48
9	44.1	23.73	14.39
10	54.875	27.66	18.32
11	62.5714	31.47	22.13
12	72.8333	35.44	26.10
13	87.3	39.72	30.38
14	109	44.43	35.09
15	124.4286	47.08	37.74
16	145	49.86	40.52
17	173.8	52.72	43.38
18	217	55.77	46.43
19	241	56.93	47.59
20	271	58.15	48.81
21	309.5714	59.27	49.93
22	361	60.44	51.10
23	433	61.67	52.33
24	481	62.46	53.12
25	541	63.03	53.69
26	618.1429	64.07	54.73
27	721	64.93	55.59
28	865	65.97	56.63
29	1081	66.85	57.51
30	1441	68.08	58.74
31	2161	69.80	60.46
32	4321	74.15	64.81

	Pumping Test Analysis Report
	Project: Getskimilesley
	Number:
	Client:

Location: Kola Tembien	Pumping Test: Chini_Constant	Pumping Well: Chini_Constant
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Ataklti G/tsadik	Chini_Constant	Analysis Date: 12/2/2021
Aquifer Thickness: 30.00 m	Discharge Rate: 1.5 [l/s]	



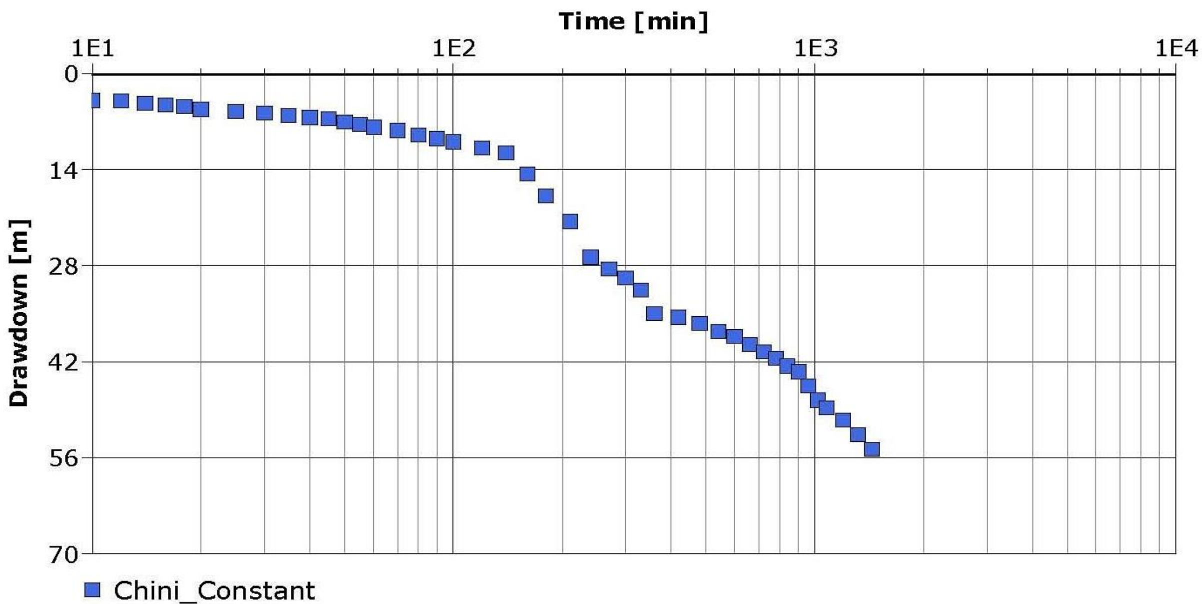
Calculation using COOPER & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Storage coefficient	Radial Distance to PW [m]	
Chini_Constant	1.28×10^{0}	4.26×10^{-2}	5.00×10^{-1}		

Figure 39. Graph of Endabagumbah constant pumping test with transmissivity result for full data

	Pumping Test Analysis Report
	Project: Getskimilesley
	Number:
	Client:

Location: Kola Tembien	Pumping Test: Chini_Constant	Pumping Well: Chini_Constant
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Ataklti G/tsadik	Chini_Constant	Analysis Date: 12/2/2021
Aquifer Thickness: 30.00 m	Discharge Rate: 1.5 [l/s]	



Calculation using COOPER & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Storage coefficient	Radial Distance to PW [m]	
Chini_Constant	9.42×10^{-1}	3.14×10^{-2}	5.00×10^{-1}		

Figure 40. Graph of Endabagumbah constant pumping test with transmissivity result after ignoring the first 10 minutes

Table 39. Data of constant pumping test for Chini deep well

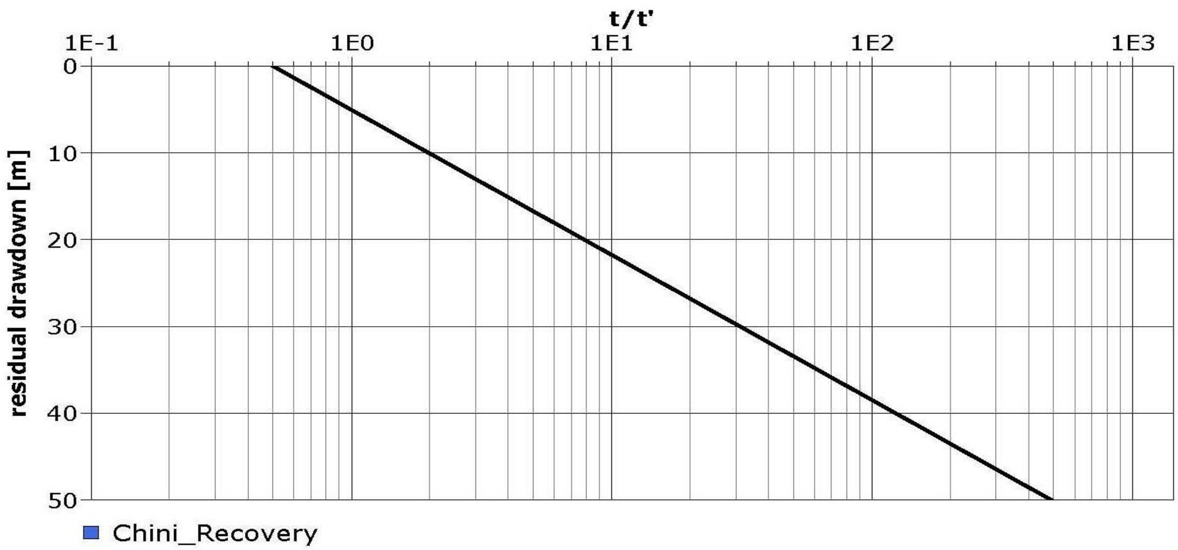
Pumping Test - Water Level Data	Page 1 of 2
Project: Getskimilesley	
Number:	
Client:	

Location: Kola Tembien	Pumping Test: Chini_Constant	Pumping Well: Chini_Constant
Test Conducted by: Ataklti G/tsadik	Test Date: 12/2/2021	Discharge Rate: 1.5 [l/s]
Observation Well: Chini_Constant	Static Water Level [m]: 8.72	Radial Distance to PW [m]: -

	Time [min]	Water Level [m]	Drawdown [m]
1	0	8.72	0.00
2	1	10.51	1.79
3	2	11.08	2.36
4	3	11.32	2.60
5	4	11.50	2.78
6	5	11.76	3.04
7	6	11.92	3.20
8	7	12.76	4.04
9	8	12.31	3.59
10	9	12.50	3.78
11	10	12.66	3.94
12	12	12.78	4.06
13	14	13.08	4.36
14	16	13.31	4.59
15	18	13.60	4.88
16	20	13.95	5.23
17	25	14.26	5.54
18	30	14.54	5.82
19	35	14.88	6.16
20	40	15.12	6.40
21	45	15.39	6.67
22	50	15.82	7.10
23	55	16.22	7.50
24	60	16.53	7.81
25	70	17.05	8.33
26	80	17.66	8.94
27	90	18.20	9.48
28	100	18.72	10.00
29	120	19.58	10.86
30	140	20.31	11.59
31	160	23.38	14.66
32	180	26.51	17.79
33	210	30.26	21.54
34	240	35.50	26.78
35	270	37.16	28.44
36	300	38.51	29.79
37	330	40.28	31.56
38	360	43.68	34.96
39	420	44.28	35.56
40	480	45.16	36.44
41	540	46.29	37.57
42	600	47.10	38.38
43	660	48.16	39.44
44	720	49.30	40.58
45	780	50.21	41.49
46	840	51.38	42.66
47	900	52.26	43.54
48	960	54.27	45.55
49	1020	56.36	47.64
50	1080	57.42	48.70
51	1200	59.26	50.54
52	1320	61.40	52.68
53	1440	63.52	54.80

	Pumping Test Analysis Report
	Project: Getskimilesley
	Number:
	Client:

Location: Kola Tembien	Pumping Test: Chini_Recovery	Pumping Well: Chini_Recovery
Test Conducted by: Atakلti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Ataklti G/tsadik	Chini_Recovery	Analysis Date: 12/2/2021
Aquifer Thickness: 30.00 m	Discharge Rate: 1.5 [l/s]	

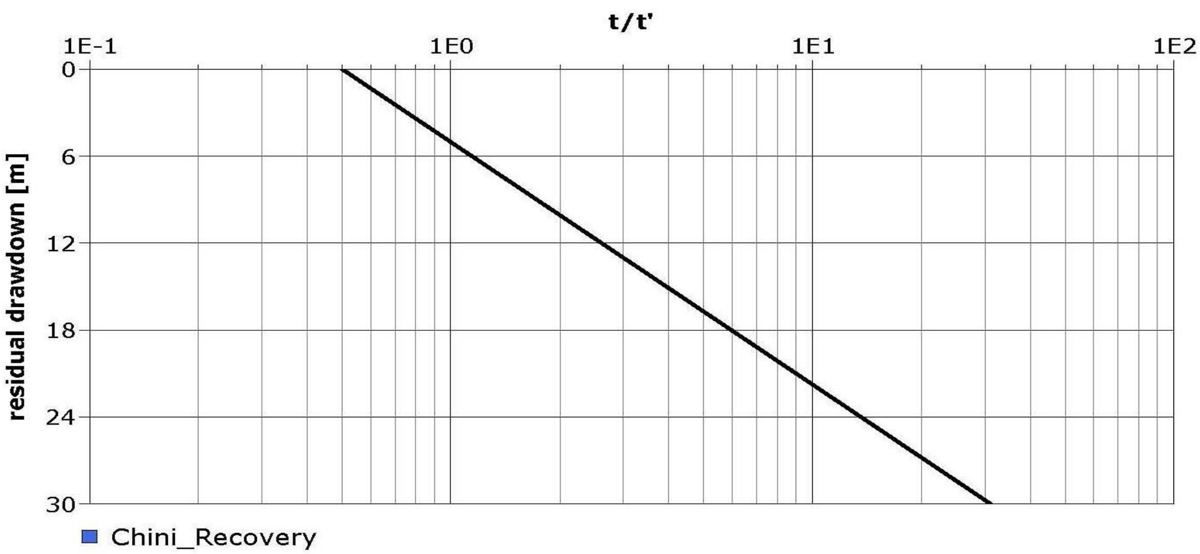


Calculation using THEIS & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Radial Distance to PW [m]	
Chini_Recovery	1.42×10^{0}	4.73×10^{-2}		

Figure 41. Graph of Chini recovery test with transmissivity result for full data

		Pumping Test Analysis Report
		Project: Getskimilesley
		Number:
		Client:
Location: Kola Tembien	Pumping Test: Chini_Recovery	Pumping Well: Chini_Recovery
Test Conducted by: Ataklti G/tsadik		Test Date: 12/2/2021
Analysis Performed by: Ataklti G/tsadik	Chini_Recovery	Analysis Date: 12/2/2021
Aquifer Thickness: 30.00 m	Discharge Rate: 1.5 [l/s]	



Calculation using THEIS & JACOB

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Radial Distance to PW [m]	
Chini_Recovery	1.42×10^{0}	4.73×10^{-2}		

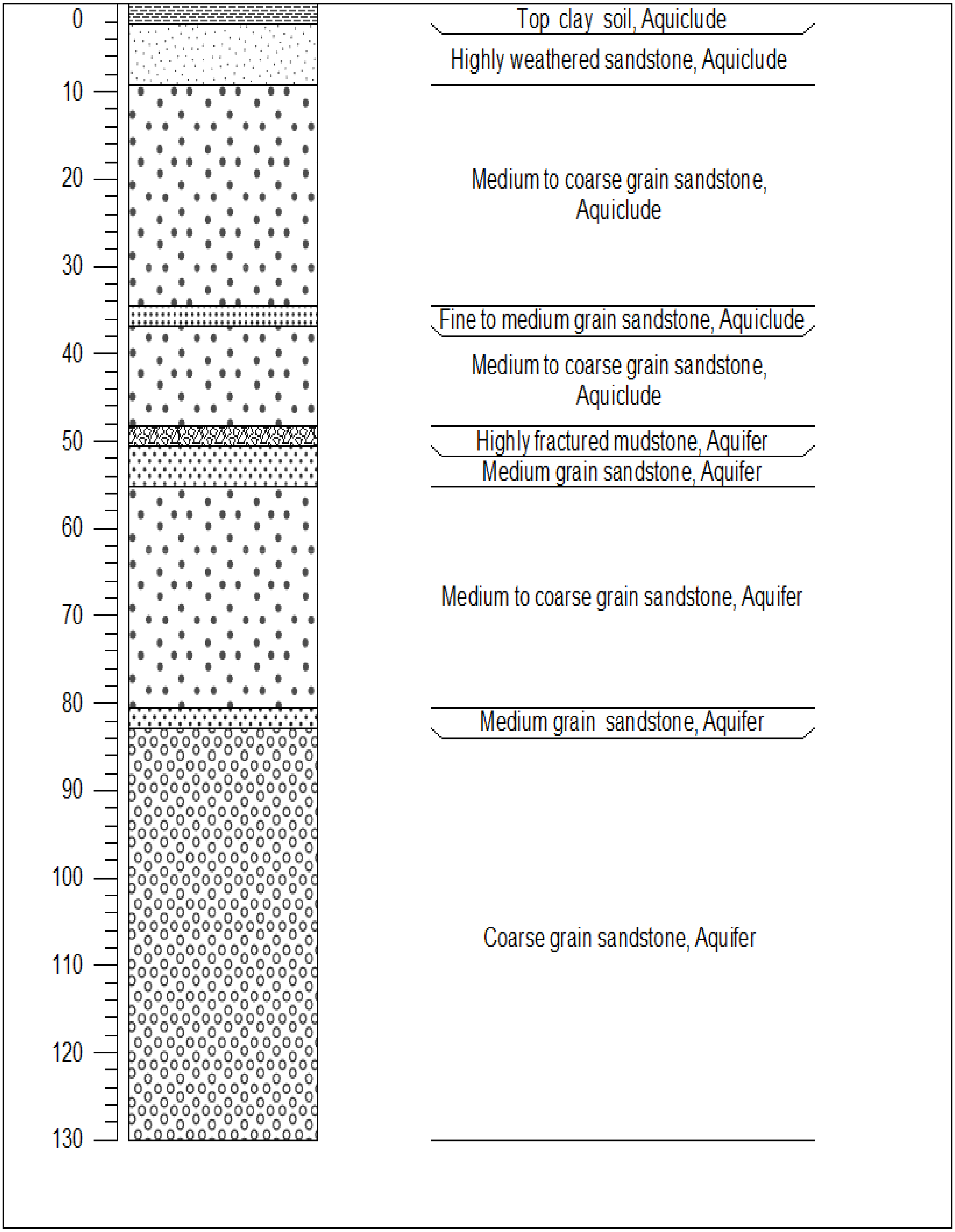
Figure 42. Graph of Chini recovery test with transmissivity result after ignoring the first 10 minutes

Table 40. Data of recovery test for Chini deep well

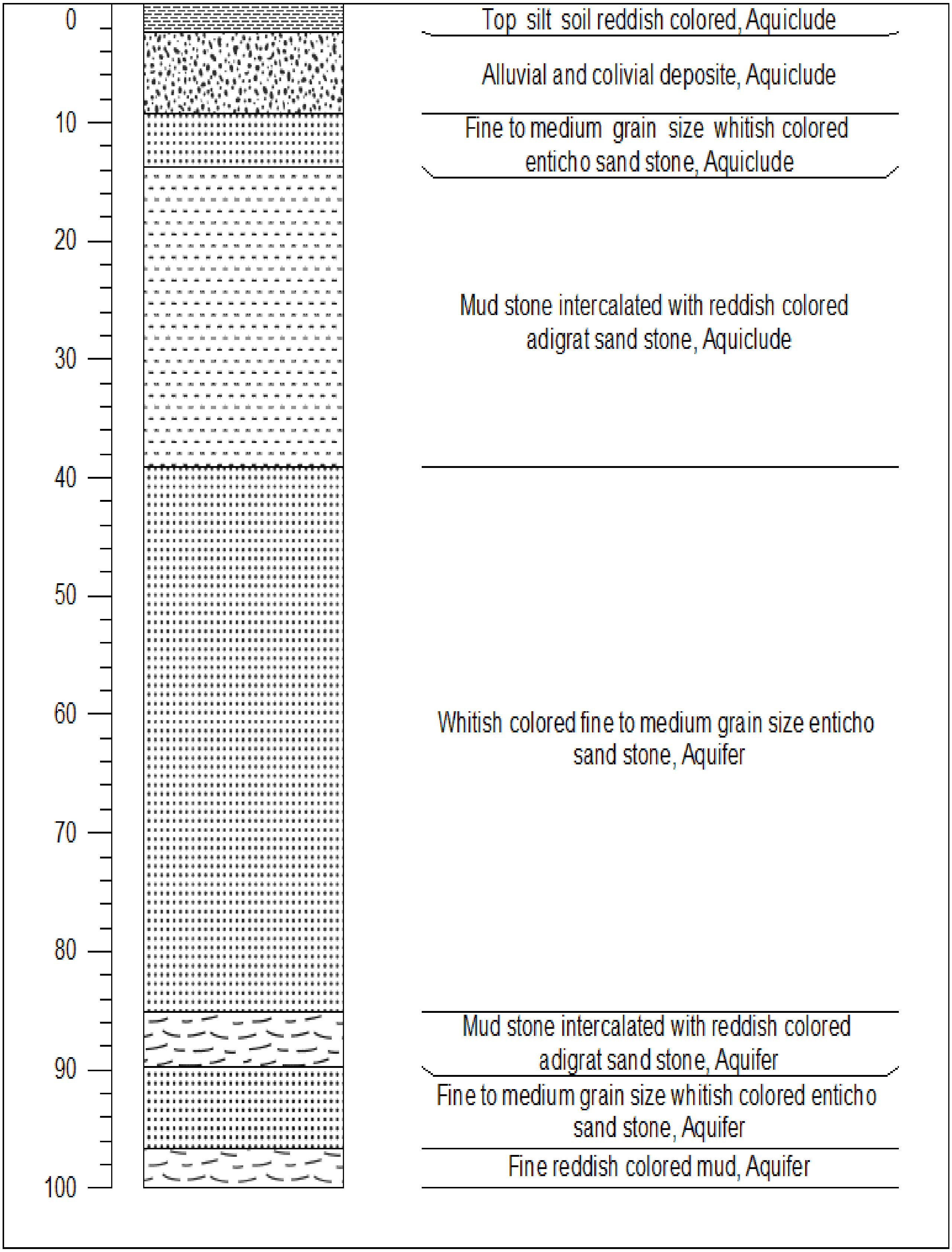
			Pumping Test - Water Level Data — Page 1 of 1
			Project: Getskimilesley
			Number:
			Client:
Location: Kola Tembien	Pumping Test: Chini_Recovery	Pumping Well: Chini_Recovery	
Test Conducted by: AtakIti G/tsadik	Test Date: 12/2/2021	Discharge Rate: 1.5 [l/s]	
Observation Well: Chini_Recovery	Static Water Level [m]: 8.72	Radial Distance to PW [m]: -	

	Time [min]	Water Level [m]	Drawdown [m]
1	3	12.28	3.56
2	3.1818	12.82	4.10
3	3.4	13.20	4.48
4	3.6667	13.69	4.97
5	4	14.26	5.54
6	4.4286	14.70	5.98
7	5	15.32	6.60
8	5.3636	15.82	7.10
9	5.8	16.29	7.57
10	6.3333	16.86	8.14
11	7	17.30	8.58
12	7.8571	17.72	9.00
13	9	18.29	9.57
14	10	18.78	10.06
15	11.2857	19.26	10.54
16	13	19.71	10.99
17	15.4	20.08	11.36
18	17	20.46	11.74
19	19	20.88	12.16
20	21.5714	21.39	12.67
21	25	21.80	13.08
22	27.1818	22.26	13.54
23	29.8	22.79	14.07
24	33	23.18	14.46
25	37	24.36	15.64
26	42.1429	25.42	16.70
27	49	26.19	17.47
28	58.6	26.80	18.08
29	73	27.42	18.70
30	81	28.51	19.79
31	91	29.46	20.74
32	103.8571	31.68	22.96
33	121	33.70	24.98
34	145	35.20	26.48
35	161	38.62	29.90
36	181	41.26	32.54
37	206.7143	42.88	34.16
38	241	45.30	36.58
39	289	48.26	39.54
40	361	50.36	41.64
41	481	51.78	43.06
42	721	54.42	45.70
43	1441	56.20	47.48

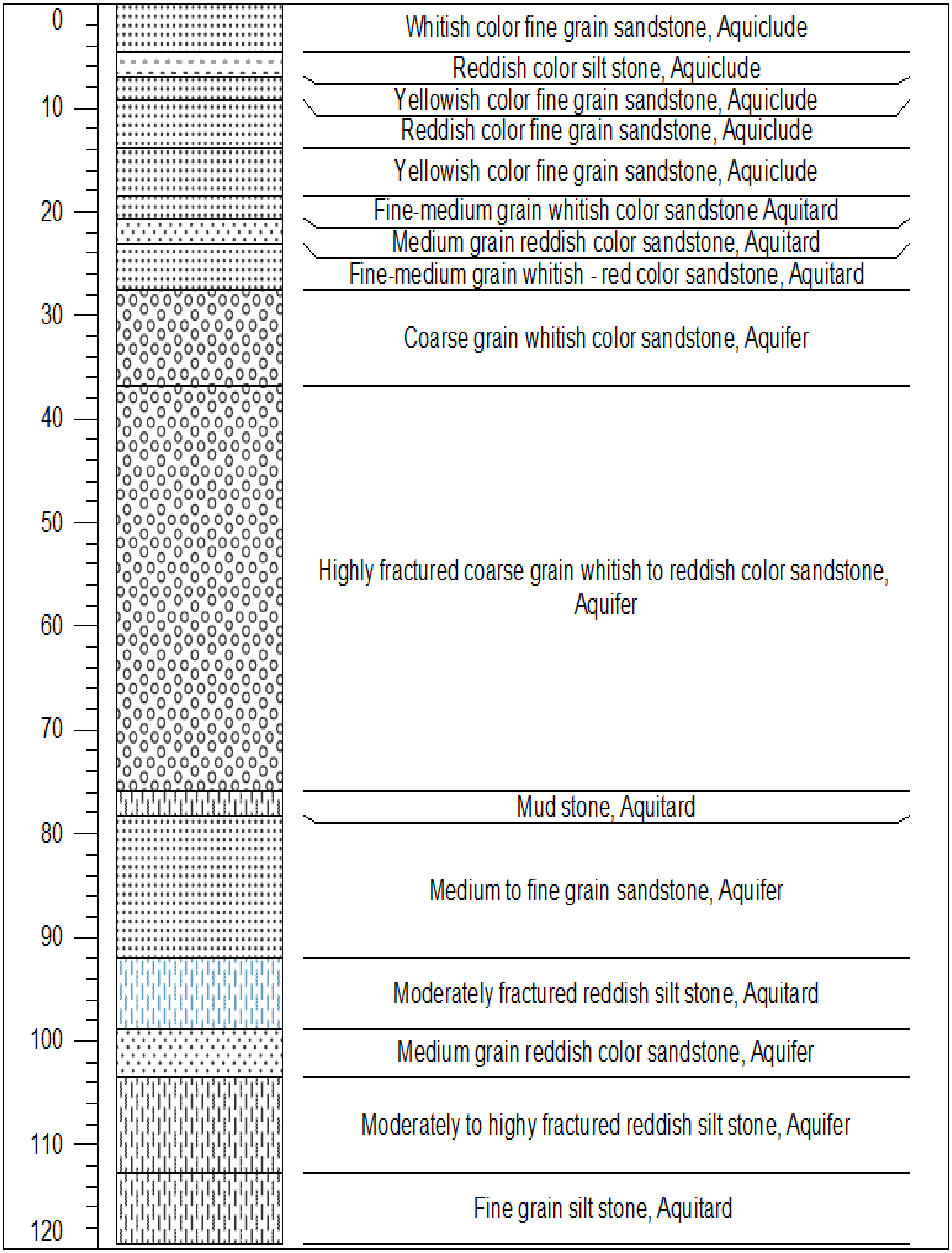
1. Geological log of Agamat deep well



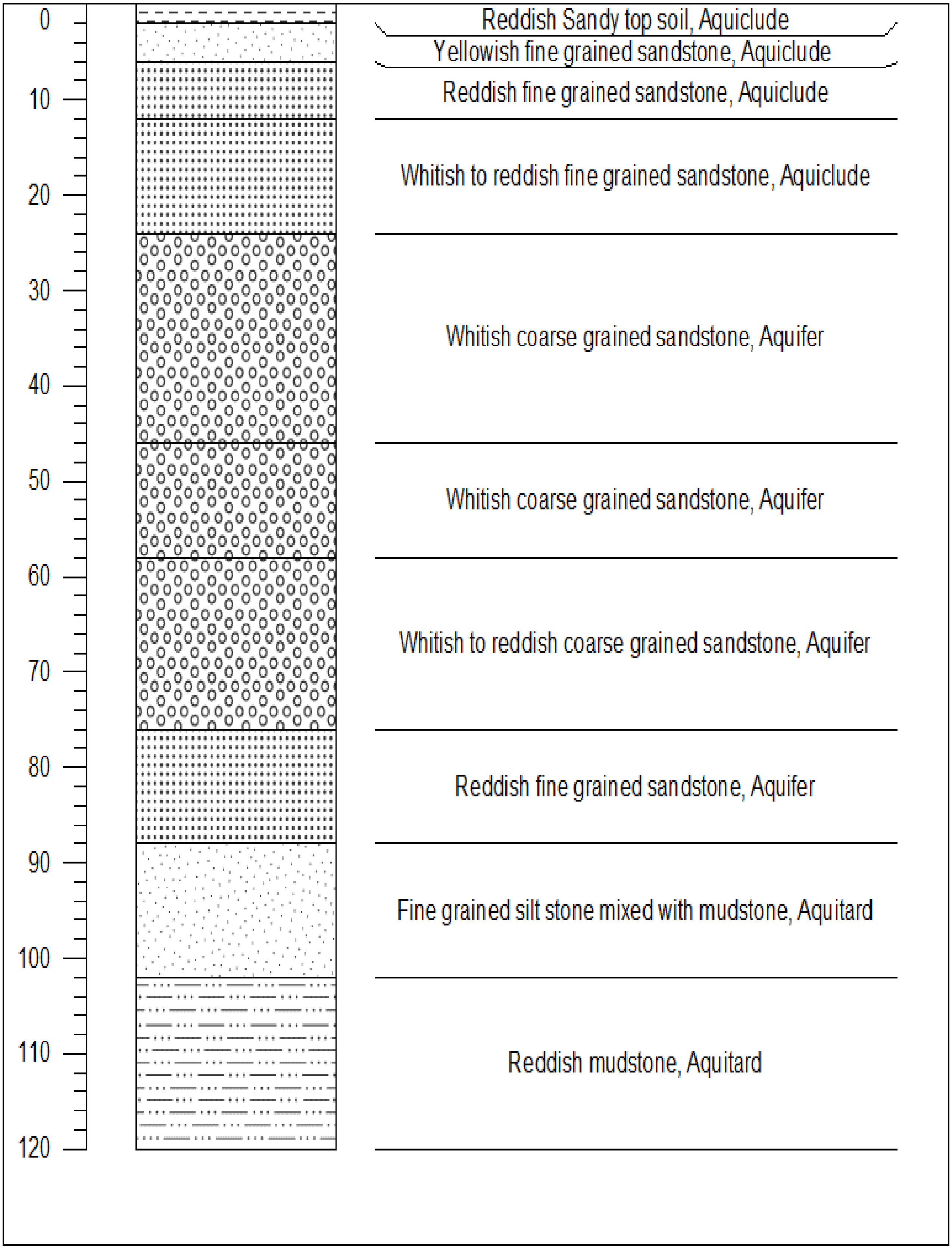
2. Geological log of Mayhutsa deep well



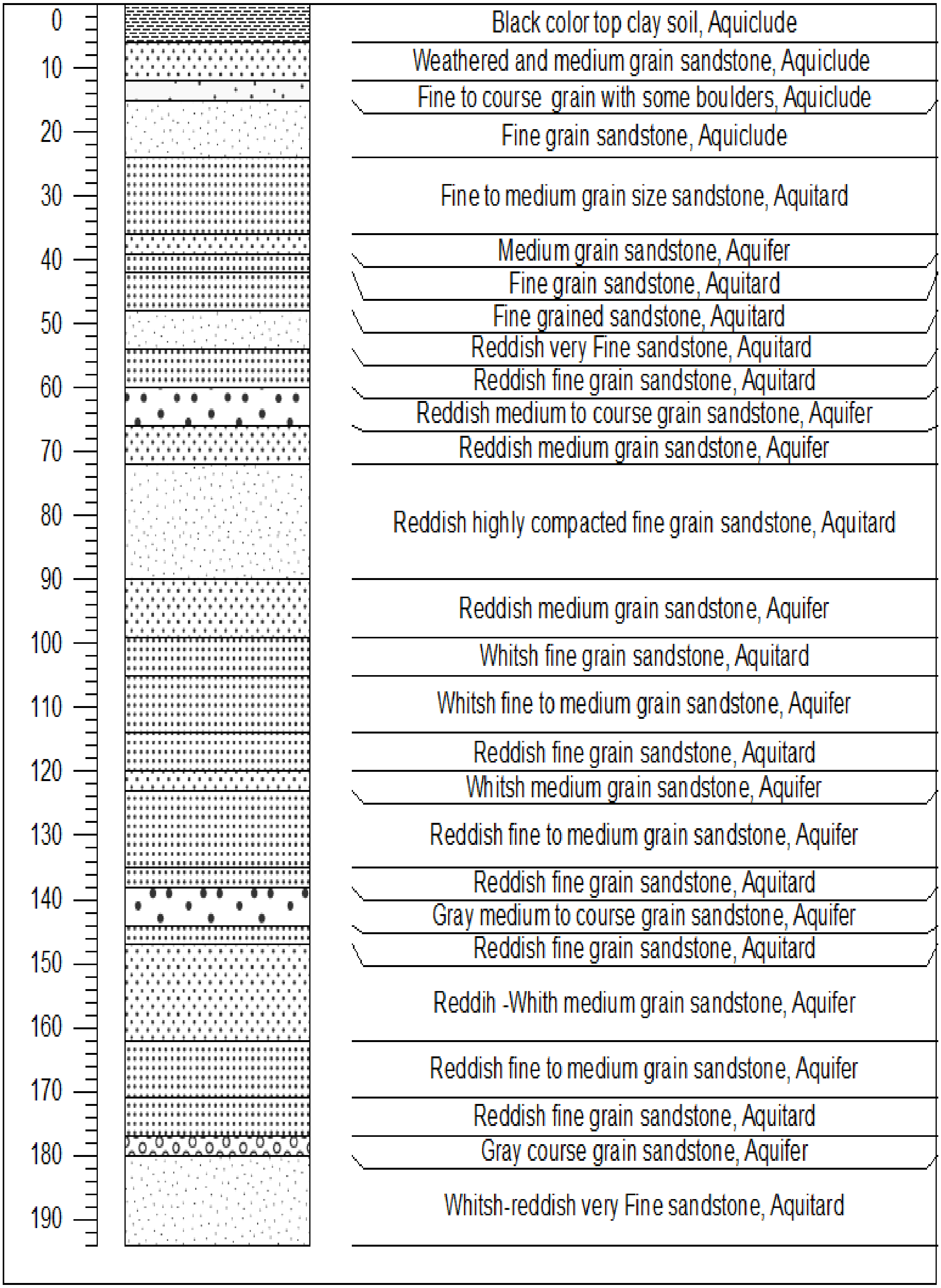
3. Geological log of Duramba deep well



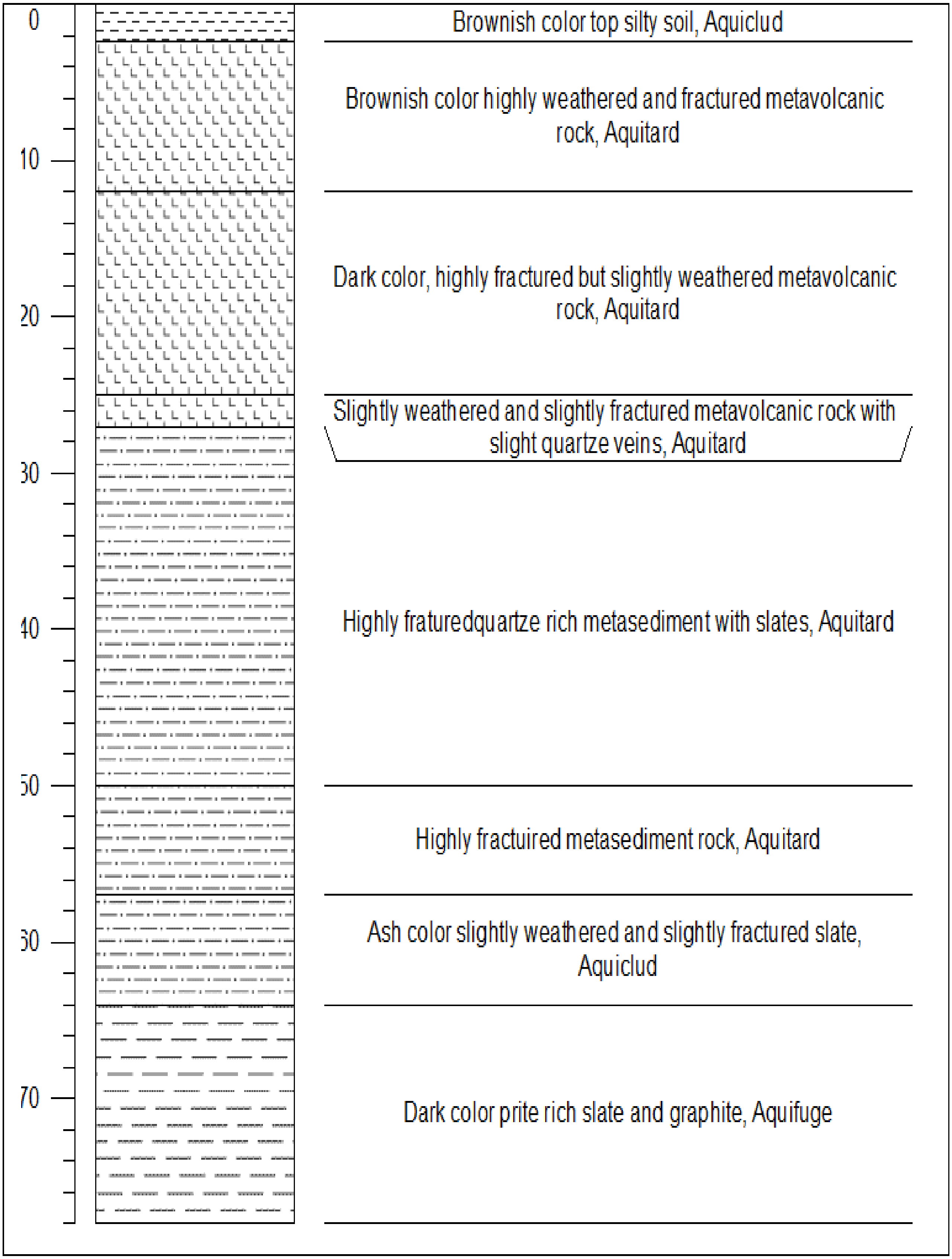
4. Geological log of Bet_hintset productive deep well



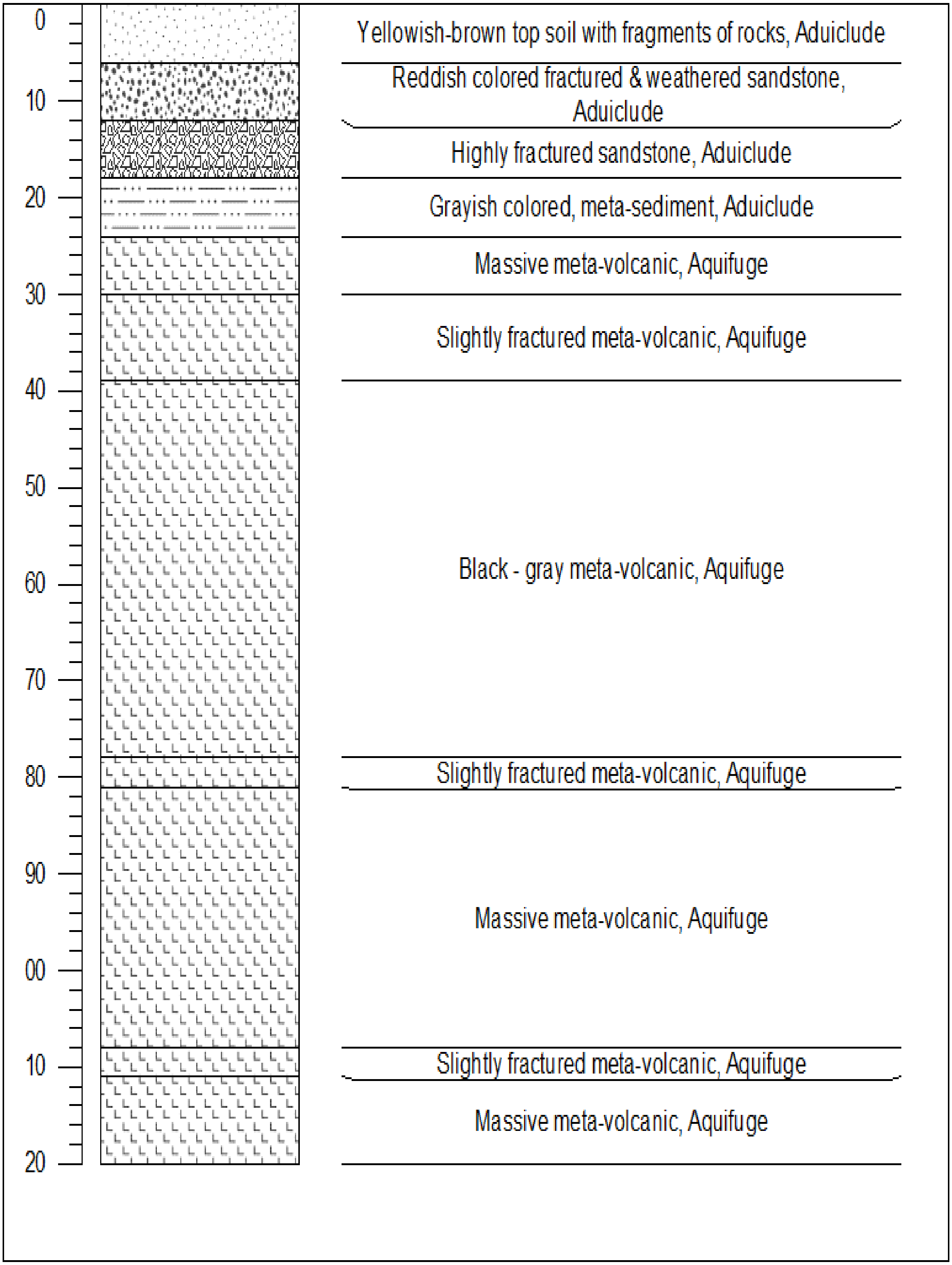
5. Geological log of Endabagunbah



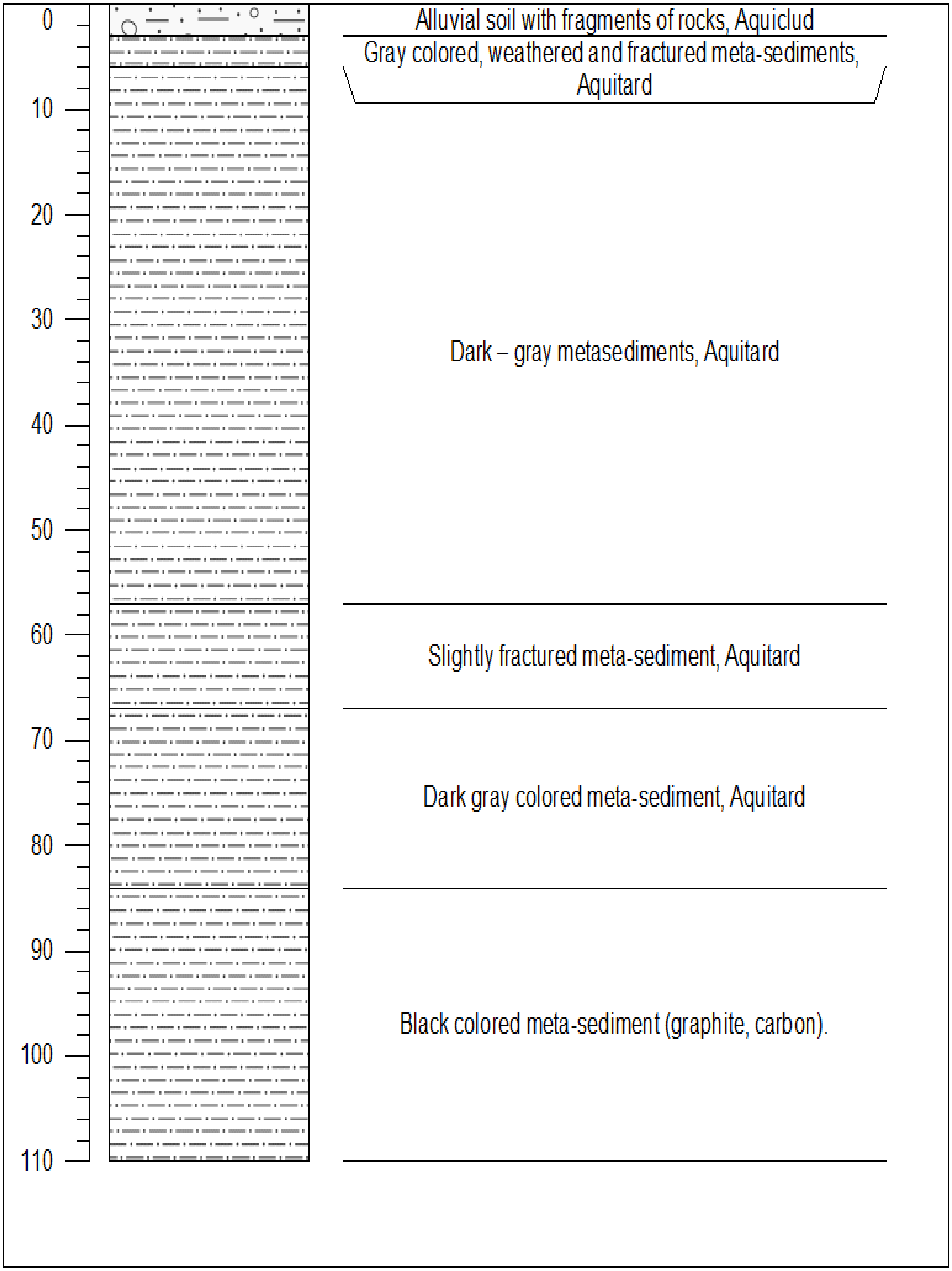
6. Geological log of Chini deep well



7. Geological log of Bethinset deep well dry



8. Geological log of Dr. Ataklti deep well dry



9. Bethintset deep well water quality data sheet

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Department of Earth Sciences
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E-mail: mekelle.university@telecom.net.et

Geo chemistry Laboratory Analytical Result Submission form

SELECTED PHYSIO CHEMICAL AND BACTERIOLOGICAL ANALYSIS RESULTS
Client/project : International Comitte of Red Cross

SOURCE OF SAMPLE	Borehole				WHO maximu allowable Concentration (mg/l)
Contractor	NOH Water Well Drilling				
Depth well	100 m				
Site Location	Abiy Adi Civina Prison				
DATE OF COLLECTION	11/09/2019				
DATE RECEIVED	11/09/2019				
LAB.ID,NO	01719/2011				
Fluoride (mg/l F^{-})	0.00				
Total Hardness (mg/l Ca CO_3)	16.95				
T. Dissolved Solid	93.34				1000
Electrical Conductivity (μS/Cm)	130.9				
P^H	6.52				6.5-8.5
Ammonium (mg/lNH4)	0.0001				2
Sodium (mg/lNa)	1.8				358
Potassium (mg/l K)	0.1176				12
Calcium (mg/l Ca)	10.68				200
Magnesium (mg/l Mg)	5.64				150
Total Iron (mg/l Fe)	0.0732				1.0
Manganese (mg/l Mn)	0.00				0.5
Chloride (mg/l Cl)	1.6404				45
Nitrate (mg/l NO_3)	0.7608				45
Chromium	0.00				0.5
Copper	0.0804				
Nitrite (mg/l NO_2)	0.0072				0.5
Alkalinity (mg/l $CaCO_3$)	16.2				-
Carbonate (mg/l $CaCO_3$)	0.04452				-
Bicarbonate (mg/l HCO_3)	38.5632				-
Sulphate (mg/l SO_4)	17.2488				400
phosphate (mg/l PO_4)	0.00024				2.0
Total Coliform Per 1 ml	0.00				
E.coil	0.00				
True color (Chromaticity)	0.65 TCU				22TCU
odor	No odor				No odor
Taste	Not unpleasant				Not unpleasan
Turbidity	0.04 NTU				7 NTU

REMARK: The test result can be compared with the WHO maximum allowable concentration (Mg/l) presented on the last column. T water sample was collected and submitted to our laboratory by client.

Checked by: Abadi Romha
Signature
Date: 14/09/2019

Approved by: ገብረስላሴ መብራህቱ
Signature Gebreslassie Mebrahtu
Date የስነ-ምድር ትምህርት ቤት ኃላፊ
Head. School of Earth Sciences

10. Duramba deep well water quality data sheet

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ቁጥር/Ref. No: Es/01/2012
ቀን/Date: 15/05/2012 E.C

Geo chemistry Laboratory Analytical Result Submission form

SELECTED PHYSIO CHEMICAL AND BACTERIOLOGICAL ANALYSIS RESULTS
Client/project : Tekeze Deep water Drilling PLC

		WHO maximum allowable Concentration (mg/l)
Source of water	Borehole	
Zone	Central	
Woreda	Kolla Tembian	
Site Name	Dramba	
DATE OF COLLECTION	15/01/2020	
DATE RECEIVED	15/01/2020	
LAB.ID,NO	00912/2012	
Fluoride (mg/l F^{-})	0.036	
Total Hardness (mg/l Ca CO_3)	16.95	
T. Dissolved Solid	97.41	1000
Electrical Conductivity (µS/Cm)	136.6	
pH	6.54	6.5-8.5
Ammonium (mg/lNH4)	0.00012	2
Sodium (mg/lNa)	1.8	358
Potassium (mg/l K)	0.1176	12
Calcium (mg/l Ca)	10.68	200
Magnesium (mg/l Mg)	5.64	150
Total Iron (mg/l Fe)	0.0732	1.0
Manganese (mg/L Mn)	0.00	0.5
Chloride (mg/L Cl)	1.6404	45
Nitrate (mg/l NO_3)	0.7608	45
Chromium	0.00	0.5
Copper	0.0804	
Nitrite (mg/l NO_2)	0.0072	0.5
Alkalinity (mg/l $CaCO_3$)	40	-
Carbonate (mg/l $CaCO_3$)	0.04452	-
Bicarbonate (mg/l HCO_3)	38.5632	-
Sulphate (mg/l SO_4)	17.2488	400
Phosphate (mg/l PO_4)	0.00024	2.0
Total Coliform Per 1 ml	0.00	
E.coil	0.00	
True color (Chromaticity)	0.65TCU	22TCU
Odor	No odor	No odor
Taste	Not unpleasant	Not unpleasant
Turbidity	0.15 NTU	7 NTU

REMARK: The test result can be compared with the WHO maximum allowable concentration (Mg/l) presented on the last column. The water sample was collected and submitted to our laboratory by client.

Checked by: Abadi Romha
Signature
Date: 24/01/2020

Approved by:
Signature
Date

School of Earth Sciences
College of Natural & Computational Sciences

11. Elias Techan deep well water quality data sheet

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Mekelle, Ethiopia

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E-mail: mekelle.university@telecom.net.et

Geo chemistry Laboratory Analytical Result Submission form

SELECTED PHYSIO CHEMICAL AND BACTERIOLOGICAL ANALYSIS RESULTS
Client/project : Eliase Tachana

SOURCE OF SAMPLE	Water				WHO maximum allowable Concentration (mg/l)
Wereda	Kola Tabin				
Tabia	Geske Melaselay				
Kushet	Geseke Melaselay				
DATE OF COLLECTION	05/06/2019				
DATE RECEIVED	06/06/2019				
Site Name	4007				
LAB.ID,NO	01167/2011				
Fluoride (mg/l F^{-})	0.00048				1.5
Total Hardness (mg/l Ca CO_3)	22.6				
T. Dissolved Solid	135.42				1000
Electrical Conductivity (µS/Cm)	189.9				
P^H	7.48				6.5-8.5
Ammonium (mg/lNH4)	0.00016				2
Sodium (mg/lNa)	2.4				358
Potassium (mg/l K)	0.1568				12
Calcium (mg/l Ca)	14.24				200
Magnesium (mg/l Mg)	7.52				150
Total Iron (mg/l Fe)	0.0976				1.0
Manganese (mg/L Mn)	0.00				0.5
Chloride (mg/L Cl)	2.1872				45
Nitrate (mg/l NO_3)	1.0144				45
Chromium	0.00				0.5
Copper	0.1072				
Nitrite (mg/l NO_2)	0.0096				0.5
Alkalinity (mg/l $CaCO_3$)	40				-
Carbonate (mg/l $CaCO_3$)	0.05936				-
Bicarbonate (mg/l HCO_3)	51.4176				-
Sulphate (mg/l SO_4)	22.9984				400
phosphate (mg/l PO_4)	0.00032				2.0
Total Coliform Per 1 ml	0.00				
E.coil	0.00				
True color (Chromaticity)	0.96 TCU				22TCU
odor	No odor				No odor
Taste	Not unpleasant				Not unpleasant
Turbidity	0.14 NTU				7 NTU

REMARK: The test result can be compared with the WHO maximum allowable concentration (Mg/l) presented on the last column. The water sample was collected and submitted to our laboratory by client.

Checked by: Abadi Romha
Signature
Date: 06/06/2019

Approved by: Gebreslassie Mebrahtu
Signature
Date

Head. School of Earth Sciences

School of Earth Sciences
College of Natural & Computational Sciences

12. Chini deep well water quality data sheet

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ቁጥር/Ref. No: Es/01/2012
ቀን/Date: 27/04/2012 E.C

Geo chemistry Laboratory Analytical Result Submission form

SELECTED PHYSIO CHEMICAL AND BACTERIOLOGICAL ANALYSIS RESULTS
Client/project :Tekeze Deep water Drilling PLC

Source of water	Borehole				WHO maximum allowable Concentration (mg/l)
Zone	Central				
Town	Abi Adi				
Site Name	Cheni				
DATE OF COLLECTION	18/12/2019				
DATE RECEIVED	18/12/2019				
LAB.ID,NO	00902/2012				
Fluoride (mg/l F⁻)	0.0033				
Total Hardness (mg/l Ca CO_3)	155.375				
T. Dissolved Solid	860				1000
Electrical Conductivity (μS/Cm)	1206				
P^H	6.84				6.5-8.5
Ammonium (mg/lNH4)	0.0011				2
Sodium (mg/lNa)	16.5				358
Potassium (mg/l K)	1.078				12
Calcium (mg/l Ca)	97.9				200
Magnesium (mg/l Mg)	51.7				150
Total Iron (mg/l Fe)	0.671				1.0
Manganese (mg/L Mn)	0.00				0.5
Chloride (mg/L Cl)	15.037				45
Nitrate (mg/l NO_3)	6.974				45
Chromium	0.00				0.5
Copper	0.737				
Nitrite (mg/l NO_2)	0.066				0.5
Alkalinity (mg/l $CaCO_3$)	590				-
Carbonate (mg/l $CaCO_3$)	0.4081				-
Bicarbonate (mg/l HCO_3)	353.496				-
Sulphate (mg/l SO_4)	158.114				400
phosphate (mg/l PO_4)	0.0022				2.0
Total Coliform Per 1 ml	0.00				
E.coil	0.00				
True color (Chromaticity)	4.21TCU				22TCU
odor	No odor				No odor
Taste	Not unpleasant				Not unpleasant
Turbidity	0.23 NTU				7 NTU

REMARK: The test result can be compared with the WHO maximum allowable concentration (Mg/l) presented on the last column. The water sample was collected and submitted to our laboratory by client.

Checked by: Abadi Romha
Signature ______
Date: 08/01/2020

Approved by: ______
Signature ______
Date ______

School of Earth Sciences
College of Natural & Computational Sciences

13. Mayhutsa deep well water quality data sheet

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ቁጥር/Ref. No: Es/01/2012
ቀን/Date: 26/06/2012 E.C

Geo chemistry Laboratory Analytical Result Submission form

SELECTED PHYSIO CHEMICAL AND BACTERIOLOGICAL ANALYSIS RESULTS
Client/project :Tekeze Deep water Drilling PLC

Source of water	Borehole				WHO maximum allowable Concentration (mg/l)
Zone	Centeral				
Worede	Kolla Tembien				
Tabia	G/Maleselye				
DATE OF COLLECTION	03/02/2020				
DATE RECEIVED	03/02/2020				
Site Name	Koia (May Heta) Borehole-3				
LAB.ID,NO	01181/2012				
Fluoride (mg/l F-)	0.00144				
Total Hardness (mg/l Ca CO_3)	67.8				
T. Dissolved Solid	386.51				1000
Electrical Conductivity (µS/Cm)	542				
P^H	7.12				6.5-8.5
Ammonium (mg/lNH4)	0.048				2
Sodium (mg/l Na)	7.2				358
Potassium (mg/l K)	0.470				12
Calcium (mg/l Ca)	42.72				200
Magnesium (mg/l Mg)	22.56				150
Total Iron (mg/l Fe)	0.292				1.0
Manganese (mg/L Mn)	0.00				0.5
Chloride (mg/L Cl)	6.56				45
Nitrate (mg/l NO_3)	3.04				45
Chromium	0.00				0.5
Copper	0.32				
Nitrite (mg/l NO_2)	0.03				0.5
Alkalinity (mg/l $CaCO_3$)	64.8				-
Carbonate (mg/l $CaCO_3$)	0.17				-
Bicarbonate (mg/l HCO_3)	154.25				-
Sulphate (mg/l SO_4)	68.99				400
phosphate (mg/l PO_4)	0.0096				2.0
Total Coliform Per 1 ml	0.00				
E.coil	0.00				
True color (Chromaticity)	0.89TCU				22TCU
odor	No odor				No odor
Taste	Not unpleasant				Not unpleasant
Turbidity	0.12 NTU				7 NTU

REMARK: The test result can be compared with the WHO maximum allowable concentration (Mg/l) presented on the last column. The water sample was collected and submitted to our laboratory by client.

Checked by: Abadi Romha
Signature
Date: 05/03/2020

Approved by:
Signature
Date

Head, School of Earth Sciences

School of Earth Sciences
College of Natural & Computational Sciences

14. Agamat deep well water quality data sheet

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ቁጥር/Ref. No: Es/01/2012
ቀን/Date: 25/06/2012 E.C

Geo chemistry Laboratory Analytical Result Submission form

SELECTED PHYSIO CHEMICAL AND BACTERIOLOGICAL ANALYSIS RESULTS
Client/project :Tekeze Deep water Drilling PLC

Source of water	Borehole				WHO maximum allowable Concentration (mg/l)
Zone	Centeral				
Worede	Kolla Tembien				
Tabia	G/Maleselye				
DATE OF COLLECTION	03/02/2020				
DATE RECEIVED	03/02/2020				
Site Name	Agamata				
LAB.ID,NO	01179/2012				
Fl[illegible]ide (mg/l F^-)	0.036				
T[illegible] Hardness (mg/l Ca CO_3)	16.95				
T. Dissolved Solid	95.34				1000
Electrical Conductivity (µS/Cm)	133.7				
P^H	6.55				6.5-8.5
Ammonium (mg/lNH4)	0.00012				2
Sodium (mg/l Na)	1.8				358
Potassium (mg/l K)	0.117				12
Calcium (mg/l Ca)	10.68				200
Magnesium (mg/l Mg)	5.64				150
Total Iron (mg/l Fe)	0.073				1.0
Manganese (mg/L Mn)	0.00				0.5
Chloride (mg/L Cl)	1.64				45
Nitrate (mg/l NO_3)	0.76				45
Chromium	0.00				0.5
Copper	0.08				
Nitrite (mg/l NO_2)	0.01				0.5
Alkalinity (mg/l $CaCO_3$)	16.2				-
Carbonate (mg/l $CaCO_3$)	0.04				-
Bi[illegible]bonate (mg/l HCO_3)	38.5				-
S[illegible]ate (mg/l SO_4)	17.2				400
phosphate (mg/l PO_4)	0.024				2.0
Total Coliform Per 1 ml	0.00				
E.coil	0.00				
True color (Chromaticity)	0.52TCU				22TCU
odor	No odor				No odor
Taste	Not unpleasant				Not unpleasant
Turbidity	0.05 NTU				7 NTU

REMARK: The test result can be compared with the WHO maximum allowable concentration (Mg/l) presented on the last column. The water sample was collected and submitted to our laboratory by client.

Checked by: Abadi Romha
Signature
Date: 04/03/2020

Approved by:
Signature
Date

School of Earth Sciences
College of Natural & Computational Sciences

Vertical Electrical Sounding (VES)

VES Data collection format

1. VES Code: VES - 1 Site name: Chini UTME: 496470 UTMN: 1509804 Elevation: 1794 meter AB spacing: 330m Direction: E-W

AB/2	MN	K	ρ	K*ρ
1.5	1	6.28	21.0230	132.024
2.1	1	13.07	11.785	154.030
3	1	27.49	5.5828	153.471
4.2	1	54.63	3.0603	167.184
6	1	112.31	1.5927	178.876
9	1	253.68	0.73026	185.252
13.5	1	571.77	0.34481	197.152
20	1	1225.215	0.19504	238.966
20	12	95.24666667	2.0828	198.380
30	1	2825.215	0.11987	338.659
30	12	226.08	1.2601	284.883
45	12	520.455	0.6954	361.924
66	12	1130.4	0.3347	378.345
100	12	2607.246667	0.17203	448.525
150	12	5878.08	0.08921	524.384
150	90	714.71	0.53965	385.693
220	12	12655.24667	0.059958	758.783
220	90	1618.79	0.3649	590.696
330	90	3730.64	0.16187	603.879
500	90	8656		

2. VES Code: VES - 2 Site name: Bet-Hinset dry UTME: 498704 UTMN: 1508327 Elevation: 1836 meter AB spacing: 500m Direction: E-W

AB/2	MN	K	ρ	K*ρ
1.5	1	6.28	1.4635	9.19078
2.1	1	13.07	0.72547	9.4746382
3	1	27.49	0.3412	9.379588
4.2	1	54.63	0.16346	8.9298198
6	1	112.31	0.064331	7.22501461
9	1	253.68	0.02124	5.3881632
13.5	1	571.77	0.0096701	5.529073077
20	1	1225.215	0.0050557	6.349200845
20	12	95.24666667	0.071673	6.82972017
30	1	2825.215	0.0037883	10.7081982
30	12	226.08	0.040487	9.15775453
45	12	520.455	0.026027	13.55277944
66	12	1130.4	0.018026	20.38686522
100	12	2607.246667	0.0067797	17.68532203
150	12	5878.08	0.0031613	18.59179498
150	90	714.71	0.035963	25.70311573
220	12	12655.24667	0.0022363	28.31527026
220	90	1618.79	0.014386	23.28791294
330	90	3730.64	0.0061447	22.92366361
500	90	8656	0.0034658	29.99982617

3. VES Code: VES - 3 Site name: Agamat-1 UTME: 503286 UTMN: 1512729 Elevation: 1899 meter AB spacing: 500m Direction: E-W

AB/2	MN	K	ρ	K*ρ
1.5	1	6.28	7.1878	45.139384
2.1	1	13.07	3.6836	48.107816
3	1	27.49	1.9977	54.916773
4.2	1	54.63	1.1114	60.715782
6	1	112.31	0.6796	76.325876
9	1	253.68	0.38737	98.2680216
13.5	1	571.77	0.2449	140.026473
20	1	1225.215	0.15596	195.862366
20	12	95.24666667	1.521	144.93609
30	1	2825.215	0.089489	252.9540819
30	12	226.08	0.86308	195.2200652
45	12	520.455	0.46795	243.670924
66	12	1130.4	0.23726	268.3339422
100	12	2607.246667	0.080354	209.6090338
150	12	5878.08	0.044944	264.3183606
150	90	714.71	0.39194	280.1234374
220	12	12655.24667	0.01149	145.4824734
220	90	1618.79	0.15884	257.1286036
330	90	3730.64	0.070471	262.9019314
500	90	8656	0.045809	396.5208716

4. VES Code: VES - 4 Site name: Agamat-2 UTME: 503520 UTMN: 1512719 Elevation: 1898 meter AB spacing: 500m Direction: E-W

AB/2	MN	K	ρ	K*ρ
1.5	1	6.28	7.9043	49.639004
2.1	1	13.07	3.5144	45.898064
3	1	27.49	1.8743	51.524507
4.2	1	54.63	1.1446	62.529498
6	1	112.31	0.74395	83.5530245
9	1	253.68	0.4488	113.851584
13.5	1	571.77	0.2729	156.036033
20	1	1225.215	0.17184	215.805264
20	12	95.24666667	1.9989	190.475181
30	1	2825.215	0.11465	324.0754225
30	12	226.08	1.1621	262.855399
45	12	520.455	0.65958	343.4564976
66	12	1130.4	0.41001	463.7090097
100	12	2607.246667	0.15568	406.1021776
150	12	5878.08	0.048997	288.1542968
150	90	714.71	0.41831	298.9703401
220	12	12655.24667	0.0199324	252.3772718
220	90	1618.79	0.16613	268.9295827
330	90	3730.64	0.056971	212.5382914
500	90	8656	0.027957	241.9946737

5. VES Code: VES - 5 Site name: Mayhutsa-1 UTME: 502813 UTMN: 1512624 Elevation: 1890 meter AB spacing: 300m Direction: E-W

AB/2	MN	K	ρ	K*ρ
1.5	1	6.28	11.138	69.94664
2.1	1	13.07	2.8675	37.44955
3	1	27.49	1.1145	30.637605
4.2	1	54.63	0.73542	40.1759946
6	1	112.31	0.44751	50.2598481
9	1	253.68	0.26258	66.6112944
13.5	1	571.77	0.14494	82.8723438
20	1	1225.215	0.093191	117.0339174
20	12	95.24666667	1.2877	122.704933
30	1	2825.215	0.061405	173.5704433
30	12	226.08	0.80058	181.0831902
45	12	520.455	0.52905	275.486916
66	12	1130.4	0.34457	389.6983329
100	12	2607.246667	0.11125	290.2034125
150	12	5878.08	0.062744	369.0012286
150	90	714.71	0.43751	312.6927721
220	12	12655.24667	0.02764	349.9682824
220	90	1618.79	0.19405	314.1261995
330	90	3730.64	0.05874	219.1377936
500	90	8656		

6. VES Code: VES - 6 Site name: Mayhutsa-2 UTME: 502863 UTMN: 1512624 Elevation: 1885 meter AB spacing: 500m Direction: E-W

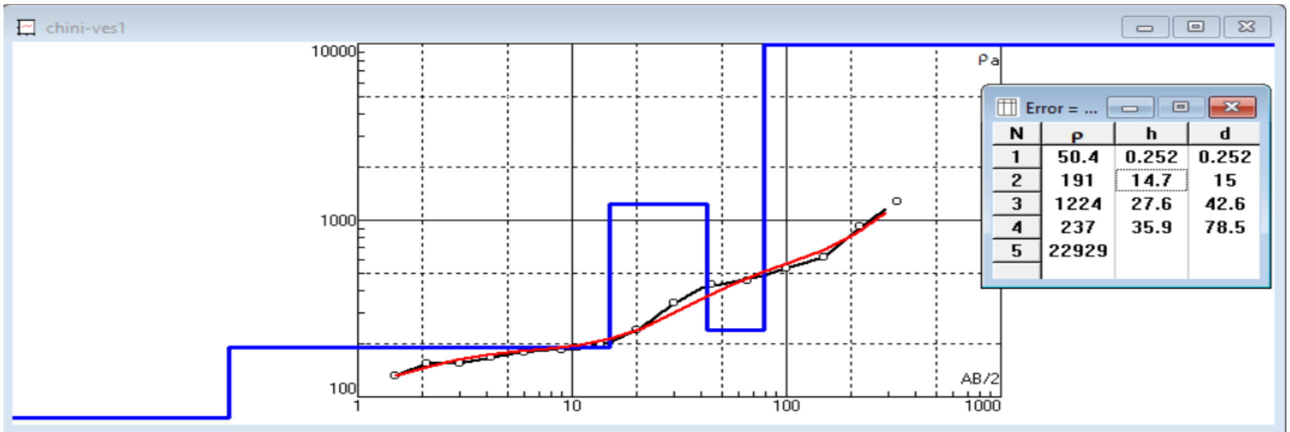
AB/2	MN	K	ρ	K*ρ
1.5	1	6.28	13.5410	85.03748
2.1	1	13.07	5.8131	75.919086
3	1	27.49	2.3247	63.906003
4.2	1	54.63	1.1768	64.288584
6	1	112.31	0.64469	72.4051339
9	1	253.68	0.41226	104.5821168
13.5	1	571.77	0.24182	138.2654214
20	1	1225.215	0.13974	175.492479
20	12	95.24666667	1.932	184.10028
30	1	2825.215	0.083775	236.8026038
30	12	226.08	1.1184	252.970896
45	12	520.455	0.63022	328.1681584
66	12	1130.4	0.17961	203.1335217
100	12	2607.246667	0.061696	160.9383347
150	12	5878.08	0.018378	108.0821207
150	90	714.71	0.28133	201.0693643
220	12	12655.24667	0.0080029	101.3299988
220	90	1618.79	0.097868	158.4277397
330	90	3730.64	0.036195	135.0305148
500	90	8656	0.0067663	58.56882215

7. VES Code: VES - 7 Site name: Adi_Dokoy UTME: 500752 UTMN: 1511205 Elevation: 1883 meter AB spacing: 500m Direction: E-W

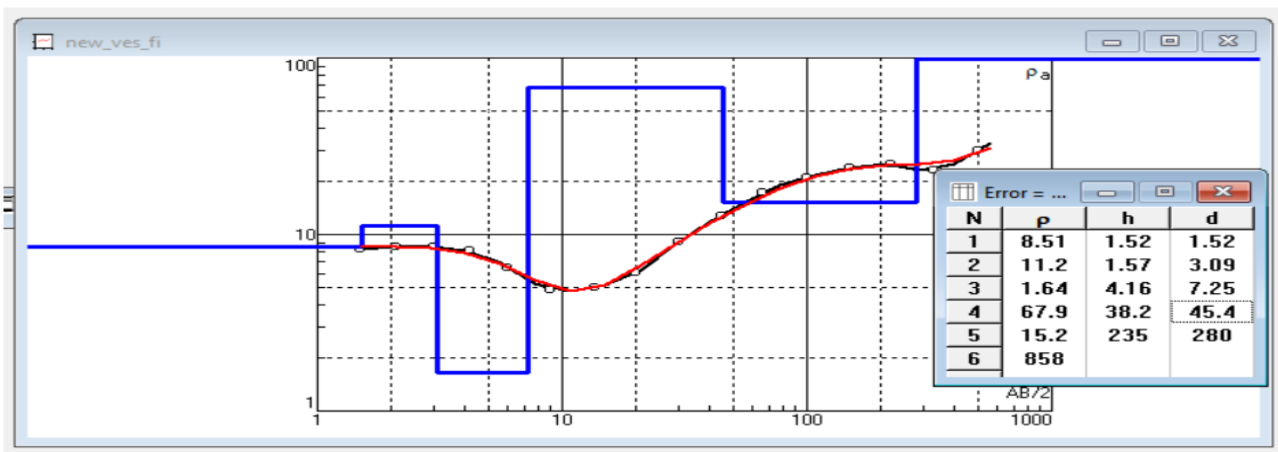
AB/2	MN	K	ρ	K*ρ
1.5	1	6.28	94.071	590.76588
2.1	1	13.07	55.01	718.4306
3	1	27.49	32.77	900.8473
4.2	1	54.63	19.604	1070.96652
6	1	112.31	11.604	1303.24524
9	1	253.68	6.2028	1573.526304
13.5	1	571.77	2.6685	1525.768245
20	1	1225.215	0.96994	1218.099149
20	12	95.24666667	11.711	1115.94119
30	1	2825.215	0.39348	1112.230242
30	12	226.08	4.4621	1009.282399
45	12	520.455	1.7294	900.533168
66	12	1130.4	0.73491	831.1611627
100	12	2607.246667	0.17895	466.8036015
150	12	5878.08	0.069784	410.403891
150	90	714.71	0.51143	365.5241353
220	12	12655.24667	0.016108	203.9540193
220	90	1618.79	0.10825	175.2340175
330	90	3730.64	0.017584	65.59957376
500	90	8656	0.0083759	72.50145536

Curve Matching

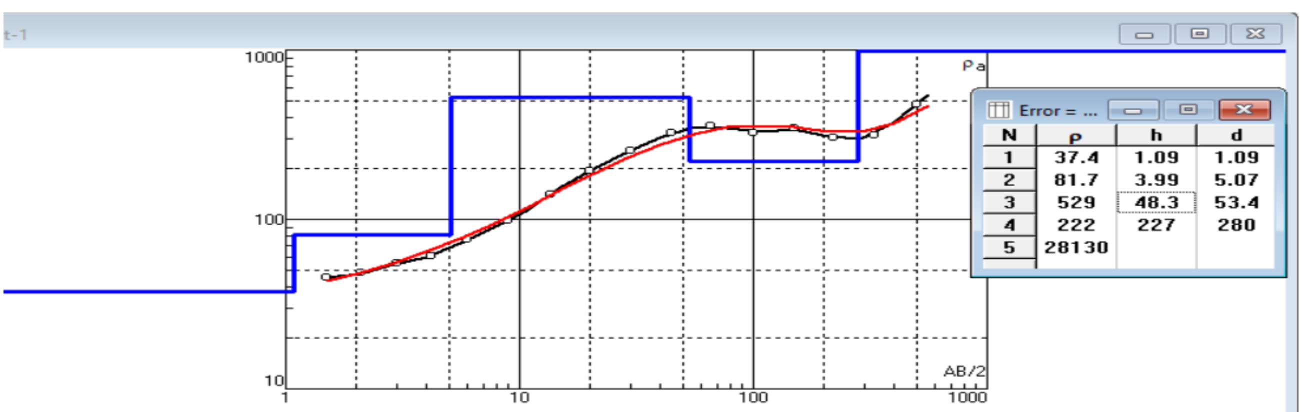
1. VES – 1 (Curve matching and interpreted layer parameters of VES-1 (chini deep well))



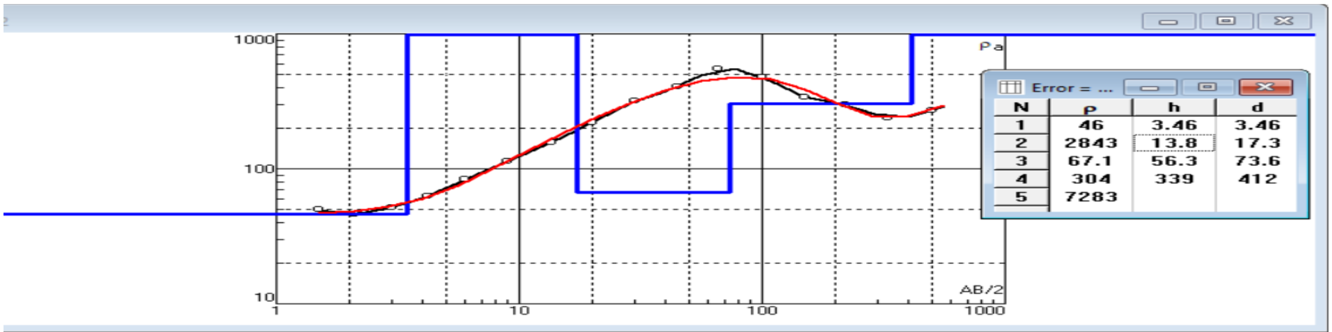
2. VES – 2 (Curve matching and interpreted layer parameters of VES-2 (Bet-Hintset dry deep well))



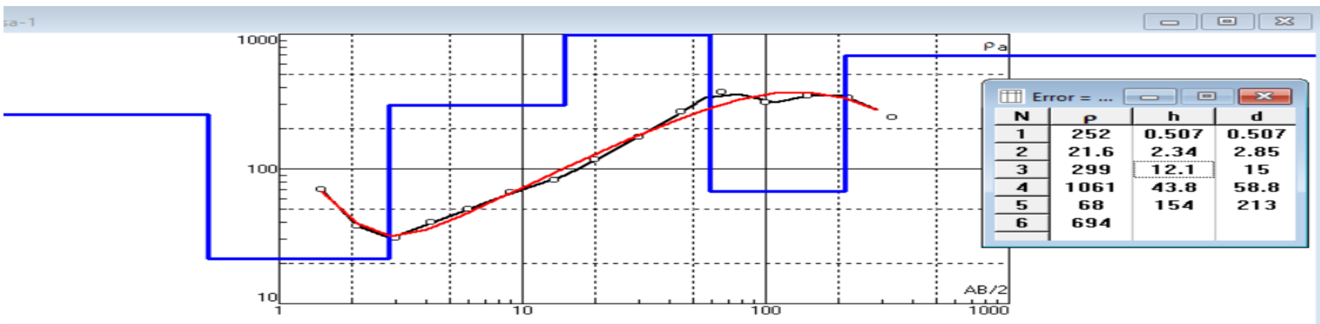
3. VES – 3 (Curve matching and interpreted layer parameters of VES-3 (Agamat-1))



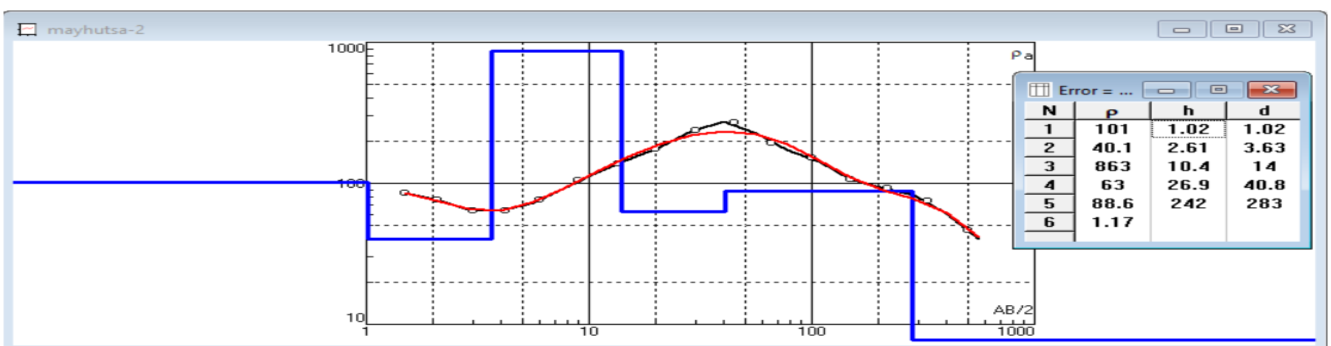
4. VES – 4 (Curve matching and interpreted layer parameters of VES-4 (Agamat-2))



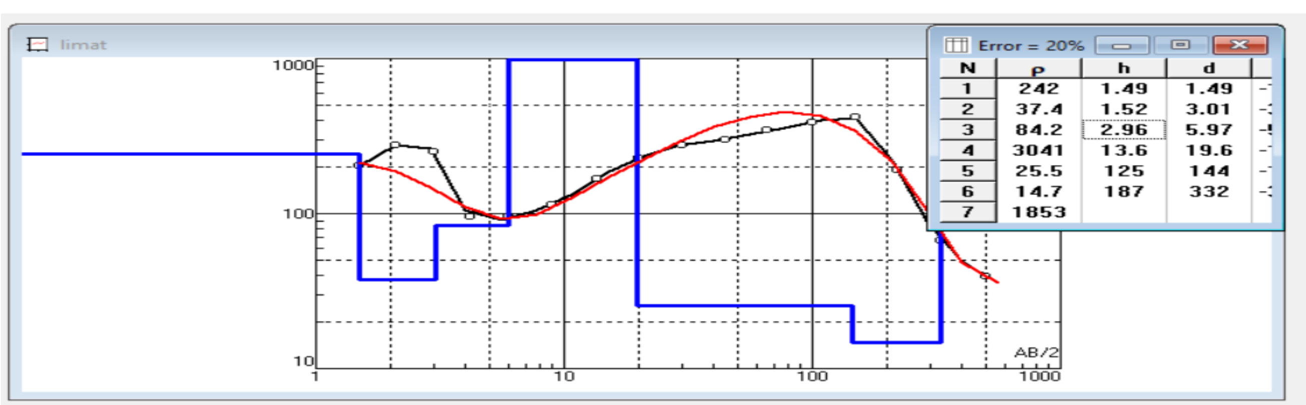
5. VES – 5 (Curve matching and interpreted layer parameters of VES-5(May-Hutsa-1))



6. **VES – 6 (**Curve matching and interpreted layer parameters of VES-6 (May-Hutsa-2)



7. VES – 7 (Curve matching and interpreted layer parameters of VES-7 (Limaet))



Lithological logs of 8 deep wells

Deep well Drilling & Lithological log Format

1. **Deep well name: Bet-Hintset Productive**

Location: Gps location:

Woreda: Kolla Tembien East: 501088

Tabia: Limat North: 1511589

Site name: Adidokoy Elev: 1883m

Depth: 120m

Status: Productive

Drilling Diameter: 12 $^{1/2"}$

From(m)	To(m)	Lithological Description
0	2	Reddish Sandy top soil
2	6	Yellowish fine grained sandstone
6	12	Reddish fine grained sandstone
12	24	Whitish to reddish fine grained sandstone
24	46	Whitish coarse grained sandstone
46	58	Whitish coarse grained sandstone
58	76	Whitish to reddish coarse grained sandstone
76	88	Reddish fine grained sandstone
88	102	Fine grained silt stone mixed with mudstone
102	120	Reddish mudstone

Deep well Drilling & Lithological log Format

2. Deep well name: Dr. Ataklti

Location:

Woreda: Kolla Tembien

Tabia: Dr. Ataklti

Site name: Dr. Ataklti

Depth: 110m

Status: Dry

Drilling Diameter: 12 1/2"

Gps location:

East: 497790

North: 1550674

Elev: 1809m

From(m)	To(m)	Lithological Description
0	3	Alluvial soil with fragments of rocks.
3	6	Gray colored, weathered and fractured met sediments.
6	57	Dark –gray met sediments.
57	67	Slightly fractured met sediment.
67	84	Dark gray colored met sediment.
84	110	Black colored met sediment (graphite, carbon).

Deep well Drilling & Lithological log Format

3. Deep well name: Bet-Hintset Dry

Location:

Woreda: Kolla Tembien

Tabia: Abi-adi

Site name: Bet-Hintset

Depth: 120m

Status: Dry

Drilling Diameter: 12 1/2"

Gps location:

East: 498706

North: 1508547

Elev: 1824m

From(m)	To(m)	Lithological Description
0	6	Yellowish-brown top soil with fragments of rocks.
6	12	Reddish colored fractured & weathered sandstone.
12	18	Highly fractured sandstone.
18	24	Grayish colored, met sediment.
24	30	Massive met volcanic.
30	39	Slightly fractured met volcanic.
39	78	Black gray met volcanic.
78	81	Slightly fractured met volcanic.
81	108	Massive met volcanic.
108	111	Slightly fractured met volcanic.
111	120	Massive meta volcanic.

Deep well Drilling & Lithological log Format

4. Deep well name: Chini

Location:

Woreda: Kolla Tembien

Tabia: Dr. Ataklti (Dildl)

Site name: Chini

Depth: 78m

Status: Low yield

Drilling Diameter: 12 1/2"

Gps location:

East: 498706

North: 1508547

Elev: 1794m

From(m)	To(m)	Lithological Description
0	2.3	Brownish color top silty soil, *Aquiclud*
2.3	12	Brownish color highly weathered and fractured metavolcanic rock, *Aquitard*
12	25	Dark color, highly fractured but slightly weathered metavolcanic rock, *Aquitard*
25	27	Slightly weathered and slightly fractured metavolcanic rock with slight quartze veins, *Aquitard*
27	50	Highly fraturedquartze rich metasediment with slates, *Aquitard*
50	57	Highly fractuired metasediment rock, *Aquitard*
57	64	Ash color slightly weathered and slightly fractured slate, *Aquiclud*
64	78	Dark color prite rich slate and graphite, *Aquifuge*

Deep well Drilling & Lithological log Format

5. Deep well name: Agamat

Location:

Woreda: Kolla Tembien

Tabia: Getskimlesley

Site name: Agamat

Gps location:

East: 503286

North: 1512729

Elev: 1899m

Depth: 130m

Status: Productive

Drilling Diameter: 12 1/2"

From(m)	To(m)	Lithological Description
0	2.3	Top clay soil, *Aquiclude*
2.3	9.2	Highly weathered sandstone, *Aquiclude*
9.2	34.5	Medium to coarse grain sandstone, *Aquiclude*
34.5	36.8	Fine to medium grain sandstone, *Aquiclude*
36.8	48.3	Medium to coarse grain sandstone, *Aquiclude*
48.3	50.6	Highly fractured mudstone, *Aquifer*
50.6	55.2	Medium grain sandstone, *Aquifer*
55.2	80.5	Medium to coarse grain sandstone, *Aquifer*
80.5	82.8	Medium grain sandstone, *Aquifer*
82.8	130	Coarse grain sandstone, Aquifer

Deep well Drilling & Lithological log Format

6. Deep well name: May-Hutsa

Location:	Gps location:
Woreda: Kolla Tembien	East: 502813
Tabia: Getskimlesley	North: 1512624
Site name: May_hutsa	Elev: 1890m

Depth: 100m

Status: Productive

Drilling Diameter: 12 $^{1/2"}$

From(m)	To(m)	Lithological Description
0	2.3	Top silt soil reddish colored, *Aquiclude*
2.3	9.2	Alluvial and colivial deposite, *Aquiclude*
9.2	13.8	Fine to medium grain size whitish colored enticho sand stone, *Aquiclude*
13.8	39.1	Mud stone intercalated with reddish colored adigrat sand stone, *Aquiclude*
39.1	85.1	Whitish colored fine to medium grain size enticho sand stone, *Aquifer*
85.1	89.7	Mud stone intercalated with reddish colored adigrat sand stone, *Aquifer*
89.7	96.6	Fine to medium grain size whitish colored enticho sand stone, *Aquifer*
96.6	100	Fine reddish colored mud, *Aquifer*

Deep well Drilling & Lithological log Format

7. Deep well name: Duramba

Location: Gps location:

Woreda: Kolla Tembien East: 502365

Tabia: Getskimlesley North: 1512529

Site name: Duramba Elev: 1872m

Depth: 120m

Status: Productive

Drilling Diameter: 12 1/2"

From(m)	To(m)	Lithological Description
0	4.6	Whitish color fine grain sandstone, *Aquiclude*
4.6	6.9	Reddish color silt stone, *Aquiclude*
6.9	9.2	Yellowish color fine grain sandstone, *Aquiclude*
9.2	13.8	Reddish color fine grain sandstone, *Aquiclude*
13.8	18.4	Yellowish color fine grain sandstone, *Aquiclude*
18.4	20.7	Fine-medium grain whitish color sandstone *Aquitard*
20.7	23	Medium grain reddish color sandstone, *Aquitard*
23	27.6	Fine-medium grain whitish - red color sandstone, *Aquitard*
27.6	36.8	Coarse grain whitish color sandstone, *Aquifer*
36.8	75.9	Highly fractured coarse grain whitish to reddish color sandstone, *Aquifer*
75.9	78.2	Mud stone, *Aquitard*
78.2	92	Medium to fine grain sandstone, *Aquifer*
92	98.9	Moderately fractured reddish silt stone, *Aquitard*
98.9	103.5	Medium grain reddish color sandstone, *Aquifer*
103.5	112.7	Moderately to highy fractured reddish silt stone, *Aquifer*
112.7	120	Fine grain silt stone, *Aquitard*

Deep well Drilling & Lithological log Format

8. Deep well name: Endabagunbah

Location:

Woreda: Kolla Tembien

Tabia: Getskimlesley

Site name: Endabagunbah

Depth: 194m

Status: Productive

Drilling Diameter: 12 1/2"

Gps location:

East: 500323

North: 1511605

Elev: 1863m

From(m)	To(m)	Lithological Description
0	6	Black color top clay soil, *Aquiclude*
6	12	Weathered and medium grain sandstone, *Aquiclude*
12	15	Fine to course grain with some boulders, *Aquiclude*
15	24	Fine grain sandstone, *Aquiclude*
24	36	Fine to medium grain size sandstone, *Aquitard*
36	39	Medium grain sandstone, *Aquifer*
39	42	Fine grain sandstone, *Aquitard*
42	48	Fine grained sandstone, *Aquitard*
48	54	Reddish very Fine sandstone, *Aquitard*
54	60	Reddish fine grain sandstone, *Aquitard*
60	66	Reddish medium to course grain sandstone, *Aquifer*
66	72	Reddish medium grain sandstone, *Aquifer*
72	90	Reddish highly compacted fine grain sandstone, *Aquitard*
90	99	Reddish medium grain sandstone, *Aquifer*
99	105	Whitsh fine grain sandstone, *Aquitard*
105	114	Whitsh fine to medium grain sandstone, *Aquifer*
114	120	Reddish fine grain sandstone, *Aquitard*
120	123	Whitsh medium grain sandstone, *Aquifer*
123	135	Reddish fine to medium grain sandstone, *Aquifer*
135	138	Reddish fine grain sandstone, *Aquitard*
138	144	Gray medium to course grain sandstone, *Aquifer*
144	147	Reddish fine grain sandstone, *Aquitard*
147	162	Reddih -Whith medium grain sandstone, *Aquifer*
162	171	Reddish fine to medium grain sandstone, *Aquifer*
171	177	Reddish fine grain sandstone, *Aquitard*
177	180	Gray course grain sandstone, *Aquifer*
180	194	Whitsh-reddish very Fine sandstone, *Aquitard*