

Research Article

Recharge Estimation of Andassa River Catchment, North-Western Ethiopia

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Abstract

Estimating the recharge amount of a given area is essential for sustainable management of groundwater resource. Andassa catchment which has area coverage of 609.68 square kilometer is located in north western Ethiopia. The area has flat, moderately slope and cliff topography. The rivers which have dendritic drainage pattern general flow south to north direction. Geological-geomorphological-structural feature suggest that the Andassa plain is a potential source of groundwater. The catchment has oligocene to miocene flood basalt with some deposit intercalation. There are tertiary and quaternary formations in the study area. The objective of this study was to estimate groundwater recharge of Andassa catchment using chloride mass balance, base flow separation, soil moisture balance, water balance methods were used to estimate the recharge value of the catchment. Meteorological, river discharge, pump tests, boreholes, springs and hand dug wells data together with well completion reports were used to estimate the recharge value. PET for the area was calculated using Penman gives annual potential evapo-transpiration value of 1335.26mm/year. Actual evapotranspiration (AET) for the area calculated using Turc and Thornthwaite Mather gives a value of 908.486mm/year and 1012.4 mm/year respectively. The recharge value is 370.68mm/y, 321.5 mm/y, 282.1mm/y and 255mm/year for base flow separation, soil moisture balance, water balance and chloride mass balance approaches respectively and the average recharge of the area is 307.3mm/year. The groundwater-bearing formation of the area is grouped as very low, low, moderate, high and very high aquifers based on transmissivity and yield of the borehole or springs. Very high productive aquifer in the low lands is recharged from regional groundwater flow and the middle elevated areas aquifer mainly shows local recharge.

Keywords

Base Flow, Catchment, Transmissivity, Hydro-geology, Groundwater

1. Introduction

1.1. Background

Water plays a vital role in all aspects of life: in the environments, our economy, food security, industries, agricultur-

al production and politics because of its value and importance, scientists deal about the resource's occurrence, recharge and hydro-geological characterization of ground water. Approximately 40% of the world's population uses groundwater and about 50% of the world's food production

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depends on irrigated agriculture linked to groundwater [11]. Ethiopia is located between latitudes 3-15°N and longitudes 33-48°E covering an area of about 1.12 million square kilometre at the horn of Africa and it has twelve basins [12]. The country has peculiar physiographic regions of the north-western, south-eastern and the rift valley that separates them. The surface elevation of the country varies between 120m below sea level in the Afar depression to 4620m above sea level in the north-western plateau. More than 100 million people are living within the three physiographic regions of the country [1]. Rainfall and temperature patterns vary across the country due to large topographic variations and differences in response to regional and global weather mechanisms [8]. Ethiopian land mass is covered with volcanic rocks with highly variable composition and stratigraphic set up, which provide one of the country best aquifer and fertile soil for agriculture [3]. The hydro-geological behaviour and hydraulic characteristics of rocks depend on their lithology, texture, structure and fracturing [7].

1.2. Statement of the Problem

Due to increasing in population with high migration of young people to Bahir Dar city, the demand for supply water is increasing, and a number of boreholes are drilled without detail investigation and without knowing the sustainability and environmental risks. So, understanding the hydrogeological dynamics and ground water recharge will help for a sustainable groundwater management practice. Unlike Tana basin at which most of the hydrogeological studies have been conducted, Andassa watershed has been given less attention, even though significant water supply activities are increasing dramatically in this area. Due to the expansion of Bahir Dar city and nearby small town the development of industries expansion of waste dump sites are affected in this catchment communities. Detail understanding of the hydrogeological system of the area will help for a better development plan.

1.3. Objectives

1.3.1. General Objective

The main objective of this study is to estimate groundwater recharge and characterize the aquifer of Andassa river catchment.

1.3.2. Specific Objectives

The specific objectives are:

- 1) To produce detail geological map of the area and its lithological cross section,
- 2) To characterize the water bearing condition of different lithological units and to produce hydrogeological map of the area,
- 3) To identify the groundwater flow direction of the study area,

- 4) To estimate groundwater recharge values,
- 5) To compare different recharge estimation methods.

2. Methodology

Catchment area delineation and drainage shapes file generation from topographic map and DEM have been carried out using Arc GIS 10.3 software. At field work, location of (springs, hand dug wells, swampy areas and rivers) have been observed geological units, geological structures and clearly observable contacts. There are a total of 116 hand dug wells, 24 springs and 30 rivers, swampy areas, other locations with descriptions and have been mapping carried out.

2.1. Data Collection

The collection of data takes place during pre-field work and field work. Secondary data is collected from various offices during pre-field work. These include meteorological data, river discharge data, pump test and well reported data. Meteorological data have been taken from meteorological agency, and consists of temperature, rainfall, wind speed, sunshine, and relative humidity for Bahir Dar, Adet, Meshenti, Kimbaba, Tisabay, Merawi and Sekela stations. These stations have 55, 30, 34, 29, 34, 29 and 28 years rainfall daily data respectively.

Fifteen boreholes were collected from Amhara Design and Supervise Work Enterprise and Water Well Drilling Enterprise offices. These wells are located on the study area and its surrounding. Addisalem (Sebatamit), Bahir Dar Horticulture, Bahir Dar university collage health Foreswega and Birakat wells are found in the catchment, but others are found near to the study area. All boreholes and springs are used to characterize the aquifer and determine groundwater flow direction map.

The 37 years daily river discharge data from 1974 to 2011 were taken from Bahir Dar branch of Abay Drainage Authority office. Missed daily data were filled using average similar days of data of the remaining years for all the meteorological data. Soil map were taken from previous work conducted by FAO integrated with MWIE [4], and land use/land cover map adapted from [6]. The necessary primary data, such as water samples (spring, hand dug well and precipitation), groundwater levels, structures, geomorphology etc. were collected from the field by direct observation, measurement and description of existing parameters.

2.2. Recharge Estimation Methods

2.2.1. Base Flow Separation and Run-off Estimation

The TIMEPLOT software uses daily flow and attenuation coefficient ranging between 0.9-0.995. The software separates total flow into base flow and run off component values

supplemented with hydrographs depicting the components. There are irrigation activities, mainly in the lower part of catchment, that take water from river by a small diversion and pumping engine from Abay and Andassa river. So, even if there is irrigation activity going on the amount is not significant to affect the assumption.

2.2.2. Water Balance Method

The water balance can be calculated as follows: Inflow= Outflow-change in storage

$$\text{These mean } P+Q_i=Rof+R+QO+AET\pm\Delta \quad (1)$$

Q_i is groundwater inflow; Q_o is groundwater outflow; Rof is surface runoff; AET is actual evapotranspiration; ΔS is change storage; R is recharge value.

But the area is considered a part of the regional groundwater flow system and it is not in closed system. Since groundwater inflow from neighboring basin is equal to out flow into other side of neighboring catchment, the net change of storage are nearly zero or can be put as zero.

Therefore:

$$R=P-(AET+Rof) \quad (2)$$

2.2.3. Chloride Mass Balance (CMB)

Ground water recharge estimation is very difficult to measure directly. In this study, CMB has been used. Recharge in this method is calculated by taking ratio of chloride concentration in rainfall sample to chloride concentrations in groundwater. The precipitation and aerosols are considered to be the only source of the chloride concentrations in groundwater.

To estimate recharge value in chloride mass balance approaches five precipitation samples, seven springs and eight hand-dug well samples are used. It can be calculate using the formula:

$$\text{Recharge}(R)=P_{EFC}\times Cl_{HAp}/Cl_{HAgw} \quad (3)$$

$$P_{EFC}=P_{mean}-Rof$$

P_{EFC} is mean annual effective precipitation (mm).

Cl_{HAP} is the harmonic average chloride concentration in precipitation (mg/l), Cl_{HAgw} is the harmonic average chloride concentration of groundwater (mg/l), P_{mean} is the mean annual precipitation (mm), R_{of} is mean annual run-off (mm).

2.2.4. Soil Moisture Balance (SMB) Method

Thornthwaite and Mather approach is used to calculate the recharge using this method. In addition to crop coefficient multiplied PET and rainfall data plant-available water, run off%, initial moisture of the catchment and time step is essential. Run off% can be calculated using run-off value from

base flow. The plant available water can be determined using land use/land cover, soil texture, water content, field capacity (%), permanent wilting point (%) and plant root depth. Land use/cover data for the catchment is taken from [6]. Soil texture data for the catchment is taken from [4]. Water field capacity (%), permanent wilting point and root depth are taken and integrated with [14, 2].

$$\text{Annual recharge}=\frac{\text{Total daily recharge data}}{\text{Total year}} \quad (4)$$

$$\text{Therefore, Runoff\%}=\frac{\text{Runoff}}{\text{rainfall}} * 100\% \quad (5)$$

2.3. Recharge Interpolation and Groundwater Flow

The groundwater flow map is determined by using ground water head. It can be calculated by subtracting static water level from surface elevation.

The recharge zones are calculated from precipitation of each station multiplied by the infiltration coefficient. Infiltration coefficient is calculated using the ratio recharge to precipitation of the whole catchment. Interpolation of each stations value divided the catchment in to three zones classified as high recharge zone, transitional zone and low recharge zone.

$$IC\text{ percent}C=RC/PC\times 100\% \quad (6)$$

Where ICpercent C is the infiltration coefficient of the catchment in present.

RC is annual recharge of the catchment; PC is annual precipitation of the catchment

Each stations of recharge value have been determined by using

$$\text{Reach stations}=IC\times\text{Peach stations} \quad (7)$$

Where Reach stations are recharge of each station,

IC is infiltration coefficient of the catchment:

P each stations are precipitation of each station.

3. Result and Discussion

3.1. Groundwater Recharge Estimation

Ground water recharge estimation is very difficult to measure directly. Therefore, in this research, it has been estimated using chlorine mass balance, base flow separation, soil moisture balance and water balance methods. There are seven meteorological stations and one river gauged station on the area. These are used to estimate the recharge value.

3.1.1. Soil Moisture Balance Method

Soil moisture balance method is mainly used as regional level recharge estimation [10]. The runoff is used to calculate runoff % and it is essential to get the recharge by soil moisture method.

$$\text{Runoff \%} = \text{Runoff} * \text{Rain fall} * 100\%$$

$$\text{Runoff \%} = 111.2\text{mm} * 1405.7\text{mm} * 100\% = 7.911\%$$

Then the PAW is calculated by using equation [13]

$$\text{PAW} = 10(\text{FC} - \text{PWP}) Z_r \quad (8)$$

Where PAW is plant available water, FC is water content field capacity.

PWP is permanent wilting point Z_r is root depth

The soil moisture mass balance method is become 321.5 mm/year.

3.1.2. Base Flow Separation Method

Base flow separation techniques use the time-series record of stream flow to derive the base flow signature. The base flow of groundwater recharge estimation value is 370.68mm/year, base flow and 111.2mm/year run off. The upper part of the area has large concentration of springs. But most of them have less discharge and are seasonal. The main source of ground water recharge in the study area is precipitation, with mean value of 1405.74 mm/year. This is calculated by:

$$\text{IC percent C} = \text{RCPC} \times 100\%$$

Where: IC percent C is the infiltration coefficient of the catchment in percent.

RC is annual recharge of the catchment; PC is annual precipitation of the catchment.

Each stations of recharge value have been determined by using:

$$\text{Reach stations} = \text{IC} \times \text{Peach stations}$$

Where: Reach stations are recharge of each station,

IC is infiltration coefficient of the catchment; Peach stations are precipitation of each station.

3.1.3. Water Balance Method

Based on the law of conservation, the hydrologic equation is essential to determine the water balance. Water balance approach were developed and revised by [14]. The method is important procedure, which estimates the balance between the recharge to and discharge from the catchment.

$$R = P - (\text{AET} + \text{Rof}) \quad R = 1405.74 - (1012 + 111.2)$$

$$R = 282.1\text{mm/year}$$

Since, the mean annual precipitation is 1405.74 mm/y; the actual evapotranspiration is 1012.4 mm/y, and the runoff is 111.2 mm/year. Thus, the recharge as calculated by the water balance equation is 282.1 mm/year.

3.1.4. Chloride Mass Balance Method

Sample is taken from aerial precipitation and groundwater. Five rainfall, seven spring water and eight hand dug wells of groundwater were sampled.

The harmonic average concentration of chlorine in precipitation is 0.42 mg/l.

The harmonic average concentration of chlorine in the groundwater is 2.13 mg/l.

$$R\text{Recharge}(R) = \text{PEFC} \times \text{ClHAp} / \text{ClHAgw},$$

$$\text{PEFC} = \text{Pmean} - \text{Rof} = (1405.7 - 111.2) \text{ mm/y} = 1294.5\text{mm/y}$$

$$R = 1294.5\text{mm/y} * 0.42\text{mg/l} / 2.13\text{mg/l}; \quad R = 255.25\text{mm/y}; \\ R = 255\text{mm/y}$$

Where R is the aerially averaged recharge flux to groundwater (mm/y)

As shown above, [5, 15] equation based on that recharge value is estimated to be 255 mm/y.

Recharge estimation in this research has been calculated by using four methods. These are base flow separation, soil moisture balance, water balance and chloride mass balance, with a value of 370.68mm, 321.5mm, 282.1mm and 255 mm per year, in respectively. Therefore, the total areal recharge estimation is calculated by taking mean of these values, which is going to be 307.3 mm. This means 22% of the total rainfall. Water balance method is the nearest value to the mean. Hence, the water balance method is the most appropriate to Andassa watershed.

3.2. Ground Water Flow

The static water level parameter is important and used to determine the groundwater flow direction. Topography, geology, structures govern groundwater flow. The general orientation of groundwater flow direction is towards NNE from high to low elevation area. The local topography has a contribution on local regime of groundwater flow. The low laying Tisabay area is feed from deep groundwater contributor of regional flow [10].

As groundwater flow not detected directly, different concepts were expressed to determine the occurrence and flow system, through the use of groundwater equipotential lines and flow directions [9]. The relationship between the same potential groundwater contour lines and the groundwater movement direction of Andassa catchment. The groundwater flow direction is clearly shown from south to north then to the east in the same trend as surficial river flow.

3.3. Hydrogeological Units and Aquifer Classification

The lower basalt is thick and strongly jointed by mostly N-S and NE-SW oriented joints and prominent lineaments channeling groundwater to the plains of Andassa. In the western part of the catchment, the quaternary basalts are exposed on top of the quaternary basalts, and sediments in the Meshenti area could also be potential zones for shallow groundwater sources in addition to deep groundwater sources in the underlying tertiary volcanic.

Table 1. Aquifer classification criteria [12].

| Aquifer Productivity | Transmissivity (m ² /day), mean | Yield (l/s), mean |
|----------------------|--|-------------------|
| Aquitard | < 1 | < 0.05 |
| Very Low | 1 to 10 | 0.05 to 0.5 |
| Low | 10 to 50 | 0.5 to 2 |
| Moderate | 50 to 100 | 2 to 5 |
| High | 100 to 500 | 5 to 25 |
| Very high | >500 | >25 |

Classification of aquifer zonal units were done based on lithological descriptions, hydraulic parameters, field observations of primary and secondary porosity, pumping tests and properties of well log data. The aquifer classifications are also determined and described by using transmissivity, yield, extent of surface and groundwater flow system and the continuity based on the data and fieldwork. Based on the aquifer classification criteria, the study area have been classified and mapped in to distinct aquifer units.

3.4. Hydro Stratigraphic Cross-section Maps

The area litho units have also been classified in to different aquifer unit by using the transmissivity data of the borehole and spring discharge capacity and other information like the distribution of hand-dug wells and geology. They are grouped in to; very high productive aquifer, high productive aquifer, moderate productive aquifer, low productive aquifer and very low productive aquifer.

As shown on the cross-section map, there is large variation of topography between the lower and higher part of the area. The lower part of the catchment has very high productive aquifer recharged from the higher elevated areas. The upper part of the area has a very low productive aquifer, which is mainly considered as a recharge zone. Very high productive aquifer is connected to regional groundwater flow, and high productive aquifer with intermediate and

local groundwater flow, low or very low aquifer with local groundwater flow.

4. Conclusion

The ground water recharge and discharge condition of the area is controlled by the topography, the existence of weathered and fractured of geology, the presence of geological structures and rainfall amount. The main recharge of catchment is from the highlands of Yinesa Lemirt, Abiyoteferi and tip of the catchment.

The mean annual groundwater recharge of the catchment is estimated using different methods and is calculated to be 307.3 mm, which is 22% of total rainfall.

The most productive aquifer is in the lower lying area, which is formed from scoraceous basalt, weathered and fractured formation of the lower basalt, middle basalt, and alluvial deposit. The productivity becomes lower within the upper basalt towards the high elevated area.

The deep boreholes have a transmissivity of 1.04 to 8380 m²/day, with a mean of 4190.52 m²/day. This indicates that the area has wide range of groundwater productivity. The alluvial deposit aquifer area coverage is very small and it has less recharge potential because clay formations overlay and reduce percolation. Very high productive aquifer in the lowlands is recharged from regional groundwater flow, and the middle elevated area mainly has a local recharge.

Abbreviations

| | |
|---------------------|------------------------------------|
| BMI | Body Mass Index |
| FAO | Food and Agricultural Organization |
| GIS | Geographic Information System |
| N | North |
| S | South |
| NE | North-Eastern |
| SW | South-Western |
| m ² /day | Square Meter Per Day |
| Km ² | Square Kilometer |
| l/s | Litter Per Second |
| mm | Milimeter |
| mm/y | Milimeter Per Year |
| mg/l | Miligram Per Litter |
| DEM | Digital Elevation Model |
| PET | Potential Evapo-transpiration |
| AET | Actual Evapo-transpiration |
| MWIE | Matt Webb Import/Export |
| % | Perecent |

Conflicts of Interest

The authors declare no conflicts of interest.

Appendix

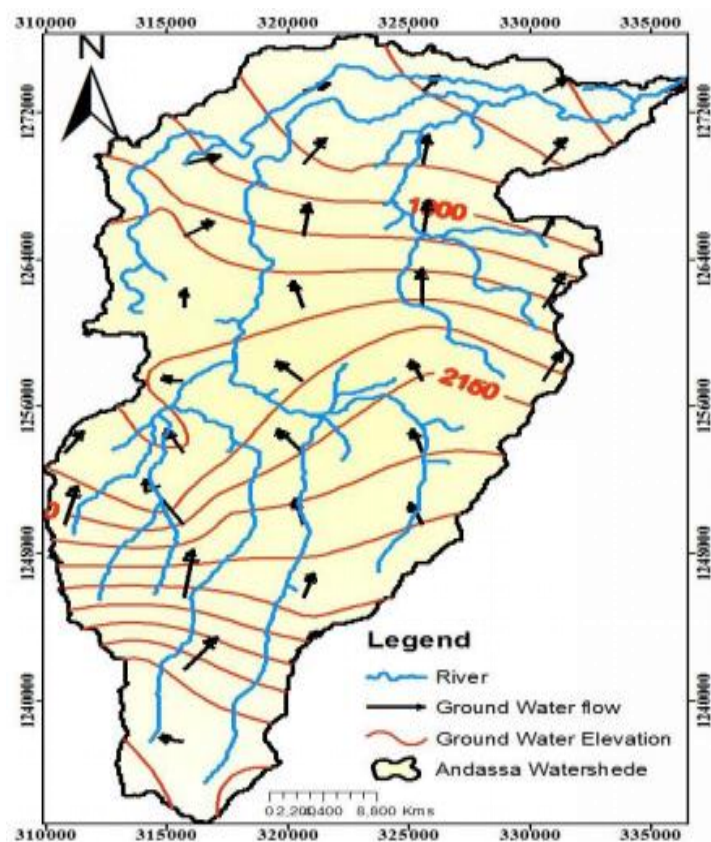


Figure 1. Groundwater contour and flow direction map.

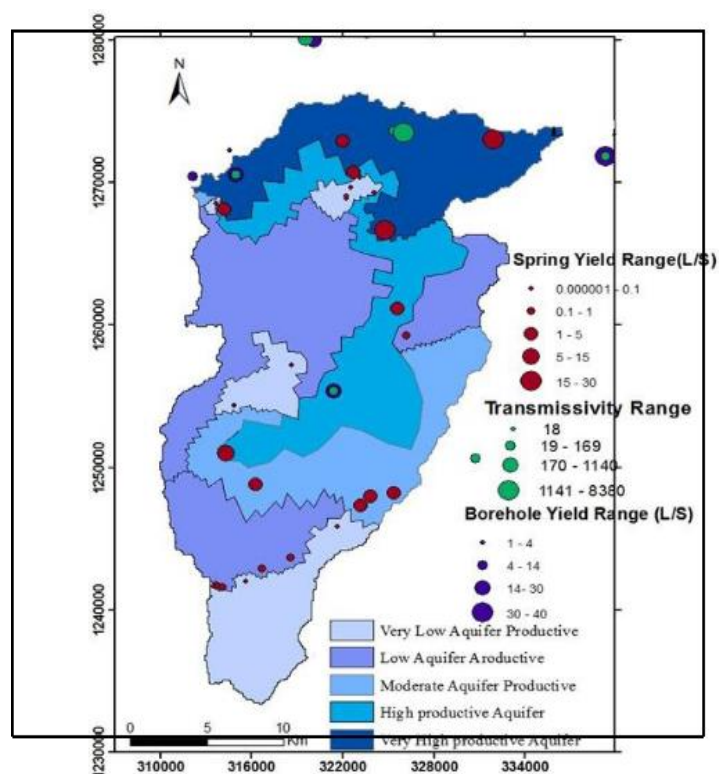


Figure 2. Aquifer classification of Andassa catchment.

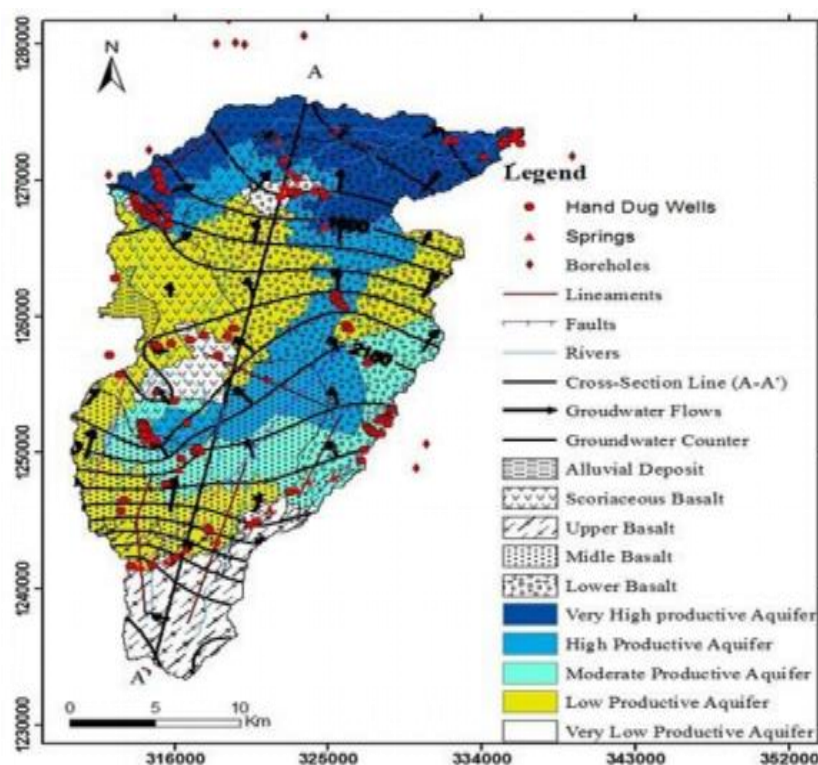


Figure 3. Hydrogeological map of Andassa river catchment.

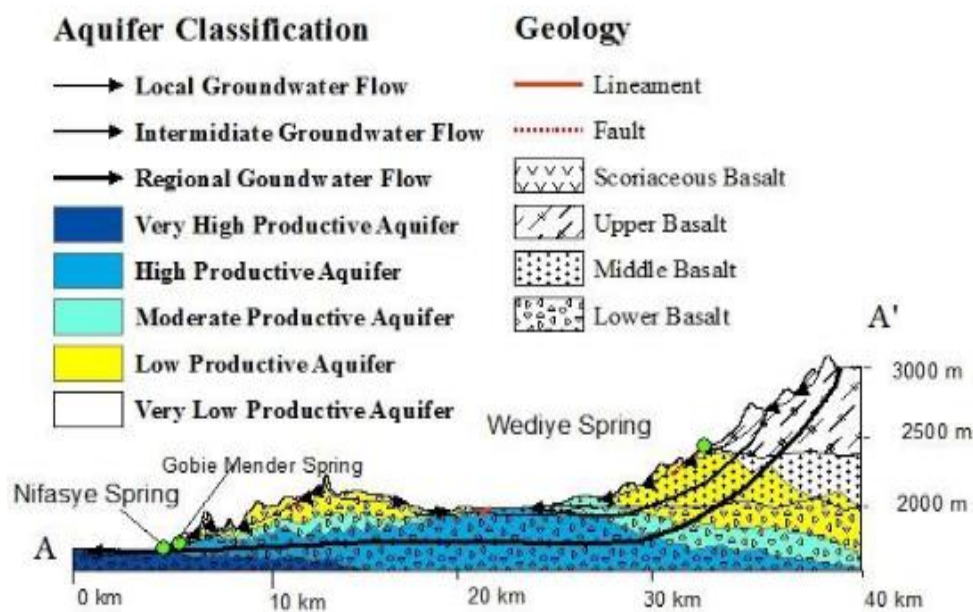


Figure 4. Geological, hydro stratigraphy and groundwater flow cross-section map.

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Biography

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