ADDIS ABABA UNIVERSITY

School of Earth Sciences

Groundwater Surface water Interaction along the main course of Awash River; Integrated approach

A Thesis Submitted to School of Graduate Studies of Addis Ababa University
In Partial Fulfillment of the requirements for Degree of Master of Science in Hydrogeology

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Abstract

In river basin hydrology the role of groundwater for being an integral part of the river basin water resources is often unrecognized. This is true in Ethiopia. Groundwater has multiple roles in river basins. It serves as source of water for socioeconomic activity, it maintains river flows during dry seasons and it could be the main pathway for solute and heat migration. In existing Awash Basin Master Plan groundwater is not accounted as one of the factor for increasing and imposing stress on existing surface water resources. There is increasing discussion among policymakers to learn more about the role of groundwater in the Awash Basin Hydrology.

Through multiple methods, namely stable isotope of water (δ^2H and $\delta^{18}O$), isotope of Radon (^{222}Rn), piezometeric evidences as well as field physico-chemical characteristics, investigation of groundwater surface water interaction along the main channel of Awash River has been carried out. The analysis of isotopic compositions of groundwaters from Upper Awash generally signifies, the groundwaters have similar isotopic composition to that of the present day rainfall. Whereas from middle and Lower Awash groundwaters here are mostly of older origin- because of lack of ^{14}C data estimating the age of groundwater in the lower Awash Basin was not possible. From ^{222}Rn measurements groundwater discharge into the river is observed, in Upper Awash, in the lower and middle Awash. There are some specific spots where groundwater discharge is noticed in the lower and middle Awash (e.g. around irrigation areas of-Wonji, Metahara and Amibara; and along thermal spring discharge zones downstream-e.g. Meteka). The Pizeometeric evidence also supports this observation. In which Upper Awash is generally a gaining river and the downstream river segments are generally loosing. Most of groundwater loss that occur in the lower part of Awash, takes place between Amibara and Mile and groundwater flows towards North Easterly direction and probably discharges into Lake Abe or into the sea or into other lower areas in Ethiopia. Evidences form various methods clearly indicate the presence of aquifer hydraulic link in the basin. This work generally showed that deep groundwater in the middle and Lower Awash can be considered as separate water resources, whereas, deep groundwaters in Upper Awash are hydraulically connected to Awash River. Therefore, areas where this interaction taking place is mapped based on the obtained results. This has a practical implication in finding way for water resource management, which can solve the current unbalanced usage of water resource. Key Words: - ♦Awash Basin ♦Groundwater-Surface Water interaction ♦ ^{222}Rn ♦Stable Isotopes ♦Pizeometeric evidence ♦ Groundwater Management

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Acronyms

AAWSA	Addis Ababa Water and Sewerage Authority
BHs	Boreholes
Bq/m^3	Becquerel per Meter cube
DEM	Digital Elevation Model
EARS	East African Rift System
EC	Electrical Conductivity
FAO	Food Agricultural Organization
GMWL	Global Meteoritic Line
GSE	Geological Survey of Ethiopia
GPS	Global Positioning system
IAEA	International Atomic Energy Agency
ITCZ	Inter Tropical Convergence Zone
LMWL	Local Meteoritic Water Line
MER	Main Ethiopian Rift
MOWIE	Ministry of Water Irrigation and Energy
MWR	Ministry of Water
NMSA	National Metrological Service Agency
R-	River/Reach
T-	Tributary streams
UNDP	United Nation Development Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
USGS	United States Geological Survey
VSMOW	Vienna Standard Mean Ocean Water
WT-	Wet land
WFB	Wonji Fault Belt
WWDSE	Water Works Design and Supervision Enterprise
YTVL	Yere Tulu Volcanic Lineament

1. Introduction

1.1 Background

In river basin hydrology role of groundwater, for being an integral part of the river basin water resources is often unrecognized. This is true in Ethiopia. The contribution of groundwater to the surface water, in Awash Basin hydrology is not largely known. Various published and unpublished studies have been carried out in different parts of Awash Basin. Policy makers consider these two water resources as if they are separate from one another but, few studies have addressed the concept and the presence of groundwater surface water interaction. Some previous works discuss the basic concept of groundwater surface water interaction, but does not notifying the possible consequences the can happen as a result of the interaction of these resources.

So many worldwide scholars have put forward the concept of groundwater and surface water interaction. Such as, Sophocleous, (2002) noted that groundwater and surface water are considered as if they are separate entities, but these two waters interact with each other in so many ways. Winter (1998) also tried to explain the association of groundwater and surface water. The study states that nearly all surface water features (streams, lakes, reservoirs, wetlands, and estuaries) interact with groundwater. These interactions take many forms, in many situations; surface water bodies gain water and solutes from groundwater systems. In others the surface water body is a source of groundwater recharge and causes changes in groundwater quality. From quantity point of view withdrawal of water from streams can deplete groundwater and constantly pumping of groundwater can reduce the volume of water from surface water bodies like streams, lakes, or wetlands. Quality wise contamination of surface water can affect the quality of groundwater. On the other hand depletion or over pumping of groundwater can affect the sustainability of surface water bodies during dry seasons.

The role of groundwater in the surface water bodies is well observed during dry seasons. On drier periods where there is no source of replenishment, the volume of flowing river water is usually sustained by groundwater contribution. By being part of the base flows of rivers, the groundwater supports the river in the ecosystem (Seifu Kebede et.al 2009) which in turn supports living organisms. Such role of groundwater for the endurance and maintenance of the ecosystem is also observed on wetlands and springs.

The ever growing population and climate changes have extremely increased the pressure in the demand of water in Awash Basin. The increment of population in the basin has brought the spreading out of urban areas, expansion of small and large scale industries and irrigation sites. Such expansion and development has brought stress on demand of water. Shortage of water is commonly observed in arid regions, which is usually as a result of low and irregular precipitation. Thus, conducting groundwater surface water interactions studies in arid and semi-arid regions, especially in regions where there is scarcity of water has its own significance for proper utilization of both resources. In addition to minimizing the resource risk, taking groundwater and surface water as a single source has a great significance for balancing and maintaining the ecosystem.

Investigation of groundwater surface water interaction provides vital information for water resource management sectors to evaluate water resource allocation, needs and impacts on groundwater ecosystem (Sophocleous 2002). In addition to effective land and water management, it requires a clear understanding of the linkages between groundwater and surface water, as it will be applied to any given hydrologic setting.

The flow of groundwater to surface water and the flow of surface water to groundwater can be estimated indirectly by balancing the environmental tracers. Environmental tracers (stable and radiogenic isotopes) measured in surface water and groundwater which provides important information for understanding the process of these interactions.

For this research an integrated framework is presented for delineating areas where, groundwater surface water interaction is taking place. The investigation utilizes measurement of Radon (^{222}Rn in air) on both season and analyzing stable isotopes results of Hydrogen and Oxygen (δ^2H and δ^{18}O). These environmental tracers are recognized tools to examine the bidirectional flow of water. But in some cases environmental tracers may not be useful in differentiating groundwater from surface water. Sometimes groundwater can be a simple flush that cannot be differentiated from the surface water (Tenalem Ayenew et.al, 2007). In such cases piezometeric evidences are helpful to observe the direction or flow condition and identify areas where groundwater surface water interaction is taking place.

Therefore, conducting groundwater and surface water interaction studies provide useful information for the sustainable utilization of both groundwater and surface water resources. Sustainable utilization of these water resources, in turn assists to protect the fragile ecosystem from various adverse factors, that can be caused by natural process or anthropogenic factors.

1.2 Literature review

Several researches on various topics have been conducted concerning Awash River and the river basin in general. But there is no sufficient work done on these methodologies which can give a clear picture of the hydraulic linkages in the river basin. From previous studies, there are indications where surface water groundwater mixing is observed.

On Environmental isotopes and hydrochemical study applied to surface (Tenalem Ayenew, et.al 2007). Surface water and groundwater interaction in the Awash River basin is observed around wonji area, in which areas where irrigational activities are being carried out. In this case Awash River is feeds the groundwater. The other observation is, as the river approaches to middle valley the groundwater gets its recharge from evaporated Awash River. In lower part of Awash Basin, much river water feeds the aquifer. In addition piezometeric evidences show that groundwater head merges with the river close to Gamari and Lake Abhe. Similar but an in-depth sampling under the current work intends to validate the above conclusions.

A study is held, to evaluate the groundwater resource potential of Ada'a and Becho plains by WWDSE, (2007). The investigation result is presented based on the comparison between $^{2}\delta H$ and $^{18}\delta O$ content of the groundwater of the upper Awash Basin. The rainfall data shows, the shallow aquifers recharge takes place principally from summer rain and this seasonal rainfall have minor importance in recharging the deep aquifer. In addition the result showed the deep groundwater is much more depleted in $^{2}\delta H$ and $^{18}\delta O$ with respect to modern day rainfall. The study suggests that recharge to these aquifers must have taken place at higher altitude. However shallow groundwater in the highlands are more enriched than deep groundwater in their $^{2}\delta H$ and $^{18}\delta O$ contents. From this it can be concluded that recharge to the upper Awash Basin aquifers must have taken place under cold climatic condition or at higher altitude. Likewise comprehensive work has to be carried out in order to clearly identify the recharge sources of both deep and shallow groundwaters of Upper Awash.

On chemical and isotopic groundwater hydrology as Mazor, (2004) explained, for studying such interactions between these water resource environmental isotopes paly a great role. Radon (^{222}Rn) is a radioactive isotope of Uranium, which is very helpful in determining areas where there is a groundwater discharge to rivers. Presence of Radon in waters can be used as a sign of active groundwater circulation.

Portions of unpublished MSc. thesis of Asfaw Aymeku, (2006), indicate the presence of groundwater surface water interaction in the middle Awash. The study utilizes, base flow separation to observe this interaction. This approach is helpful in order to observe the amount of water that contributes from Awash River and its variation downstream.

From the result the long term coincidence of the two hydrograph regimes shows, the shallow groundwater system and the Awash River have strong hydraulic connection. In which Awash River directly feed the aquifer system. This interaction is observed on the upper and lower reaches of the Awash River at Awash Sebat and Melka Worer.

The other evaluation carried out in Awash Basin is, Groundwater Resources of Teru area and its environs held by WWDSE (2011). The investigation was carried out on a limited data in order to demonstrate the presence of groundwater surface water interaction in the lower plain of Awash Basin. For this study certain isotope data were analyzed, from some rivers and the intermittent tributaries and groundwater's, in order to assess the groundwater recharge source of the area. The existing data generally imply the sampled river waters have distinct $^{2}\delta H$ and $^{18}\delta O$ content compared to majority of groundwater. This put forward that aquifer recharge from losing streams plays a minor role in the overall groundwater system.

The isotopic depletion of ground water in the Teru and Digdiga zone indicates that, there is no evaporative enrichment prior to recharge, i.e. infiltrating waters did not undergo significant evaporation prior to recharge. This indicates that recharge commonly takes place rapidly through fractures.This also suggest that the groundwater may have a high altitude source followed by deeper circulation path way. This study generally determines the recharge source of the aquifer system of the lower plain is from unevaporated Awash River. Thus in-depth sampling in the lower plain and even further out of the basin has to be carried out in order to observe and confirm the recharge sources of the plain.

1.3 Objectives

1.3.1 General objective

- The general objective of this research is to delineate and map areas where groundwater surface water interaction is taking place.

1.3.2 Specific Objective

- Delineate Recharge & discharge zones,
- Determine the isotopic signature and characteristics of water samples,
- Determine groundwater flow conditions from pizeometeric evidences,
- Determine groundwater origin in major aquifers & major well fields in Awash Basin.

1.4 Statement of the Problem

Many researches and studies have been carried out in different parts of Awash Basin concerning various groundwater issues. These previous studies are mostly done on different part of the basin not in the river basin Scale. Consequently, this research is aimed to be carried out in Awash Basin to observe and understand the aquifer hydraulic link in a large scale.

Studying surface water groundwater interaction is important for better understanding of the interactions between these two water resources. That in turn assists proper utilization of both groundwater and surface water.

1.5 Significance of the research

Carrying out this research has its own significant in a large scale. The most important part of this research is showing or validating areas where this interaction is taking place.

After confirming the presence of groundwater surface interaction between the water bodies, it assists to create effective management of water resources that in the latter case balance the demand and supply of water in the basin.

In addition to minimizing the resource risk, understanding groundwater surface interaction has also a great ecological significance for organisms living in the basin.

1.6 Materials Used and Sampling

Different materials were used for the research such as;

- Geological map, hydrogeological map and DEM (digital elevation model)
- Software's;
    - Arc-GIS 10.2.2,
    - Global Mapper 17,
    - Plot.ly online graph plotter,
    - AutoCAD, 2016
    - Starter 4,
    - Microsoft Office, (MS-word, MS-excel),
- GARMIN GPS- Vista (hand GPS)
- Bottles for collection of Borehole and spring water samples
- EC meter (for measurement of temperature, electrical conductivity and PH) and
- RAD-7 with its accessories, including, the desiccants /drying unit (for extracting the humidity from the gas loop before entering to the RAD-7 instrument)

1.6.1 Sampling sites, collection and measurements

Groundwater, spring and river water samples are collected on both major seasons of the country i.e. during the wet and dry season. The wet season survey was carried out from August 19 up to September 9, 2017 and dry season measurements are held from February 19 to March 8, 2018.

^{222}Rn on site concentration measurement is carried out at several selected river segments. The river segments were selected based on the geographical set up of the river and based on accessible ways to Awash River. In addition ^{222}Rn was measured at selected tributaries from upper Awash and wetlands from the middle Awash Basin.

Groundwater samples are collected from wells and springs (For ^{18}O and ^{2}H analysis) near the river segments where ^{222}Rn measurements have been taken place. While sampling water, for ^{18}O (oxygen-18) and ^{2}H (deuterium) analysis, no filtration or preservation is required in order stabilize the sample and minimize the interaction with the atmosphere. The sample bottles are 30ml in volume with a double capped polyethylene. The bottles are directly filled from the river and from borehole taps. In order to avoid sampling of stagnant water that is exposed for evaporation for longer time, the sample bottles are directly filled from areas where flow was observed.

In order to avoid exchange of gas with the atmosphere, after filling the bottles with the required amount, the bottle caps are checked if they are tightly capped. Then after, the bottles are properly and carefully labeled. The label includes sample ID, Sampling date, sampling position and the local area where the sample is taken. Later then the samples were sent to university of Oxford and then the sealed bottles are sent to laboratory of CNESTEN in Morocco.

Oxygen and hydrogen analysis were performed at laboratory of structural and isotopic analyzes in Morocco with a Picarro L2130i laser spectroscope. The results are reported in per mil (‰) relative to VSMOW (Vienna Standard Mean Ocean Water) with a standard deviation of ±0.2‰ for δ^{18}O and ±1‰ δ^{2}H.

While carrying out measurements for radon (^{222}Rn) a simple portable radon-in-gas monitor RAD-7 (Durridge Company, Inc.) is used for measuring radon in air (Burnett and Dulaiova, 2003). The RAD7 command list has four command groups: Test, Data, Setup and Special. The Test group of commands controls the collection of new radon data. The Data group retrieves data from memory, outputs them, and gets rid of old, unwanted data.

The RAD-7 setup allows radon extraction from the bottle into a closed gas loop which is connected with the RAD-7 detection chamber. Radon extraction is accomplished by spraying the water into a closed air tight plastic cylinder that is part of the closed gas loop.

The RAD7 radon monitor works most effectively when the incoming air sample has a low relative humidity, usually the measurement is held when the RH reach ranging between 10-11%. The DURRIDGE pile transfers moisture from the incoming air to the air being pumped out of the RAD7. As the air enters a drying unit, on its way to the RAD7, it will have already lost most of its moisture, greatly extending the life of the desiccant in the drying unit.

Figure1.1 On site Radon measurement

2. Methodologies

2.1 Radon (^{222}Rn)

Radioactive isotopes are unstable nuclides that decay with time to a more stable configuration by the emission of alpha particles and gamma radiation. There are many radionuclides that have been identified so far. Over 900 radionuclides with a half-life longer than one hour have been reorganized so far. Between the known radioisotopes, only few have a half-life that is well suited for conducting groundwater studies (Clark and Fritz, 1997). This radioactive noble gas (Radon), have three naturally occurring radioactive isotopes ^{219}Rn (Actinon), ^{220}Rn (Thoron) and ^{222}Rn (Radon). Among these isotopes the most stable one is ^{222}Rn with a half-life of 3.82 days.

Radon (^{222}Rn) is a radioactive isotope that naturally originates from the Uranium-238 decay series through the alpha decay of Radium-226. ^{222}Rn is found in, phosphate rocks, Shale's, Igneous and metamorphic rocks such as Granite, Gneiss, and Schist, and to a lesser degree, in some common rocks such as Limestone. Apart from the radioactive decay of Radium-226 and the Radon bearing host rocks which are the main source of Radon, river bed sediments can also be the other source of Radon. This soluble noble gas (^{222}Rn) emitted from rocks or from dissolved sediment grains join the groundwater and move with the groundwater. This radionuclide is partly carried out to the surface either as a gas or dissolved in water. Several factors play a great role in the concentration and in bringing up ^{222}Rn on surface water bodies, Geological structures are the predominate factor that brings out ^{222}Rn on surface water bodies and climatic conditions also play a great in the concentration of ^{222}Rn in surface water bodies (Eilers et.al, 1995).

Concentration of Radon in groundwater varies according to the content of these radioactive isotopes in the aquifer matrix. Aquifer characteristics such as, aquifer mineralogy, fracture characteristics in hard rocks, porosity of sediments and degree of metamorphism can determine the concentration of ^{222}Rn in groundwaters (Veeger and Ruderman, 1998). Such radionuclides are normally measured by Becquerel's (Bq). Becquerel is equal to the disintegration of a radionuclide per second. This reading is then normalized to a given sample size using units of Bq/l or Bq/m^3 It is usually <2Bq/l in calstic sediments and >200Bq/l in igneous and metamorphic rocks (Wu Y., et.al, 2000) in addition, these isotopes can also be expressed like stable isotopes by their abundance ratio.

In Mostly radon activity is lower at higher temperate areas and higher radon activity is usually noted in areas with lower temperature conditions. These can be as a result of the favored fractionation of radon into the vapor phase upon higher temperature zones. ^{222}Rn transport is controlled by diffusion and it is very condensable at low temperature (George, 1900).

The various features of ^{222}Rn make this radioactive isotope for a qualitative indicator of groundwater surface water interaction (IAEA, 2000). Such as, a result of the volatile nature of ^{222}Rn, it is present in much higher concentration in groundwater than surface waters, thus concentration gradients between surface waters and groundwaters is created which in turn assists, to determine if discharge of groundwater has taken place at that certain point. Therefore, despite the existence of other more short-lived radon isotopes, this nature of ^{222}Rn makes it particularly well suited for studying and determination zones where the fluxes between river water and the groundwater has taken place. Thus, High concentration of ^{222}Rn detected in river water can be regarded as an indicator of high influx of groundwater to the surface water.

After a discharge of groundwater, to surface water there will be high concentration of ^{222}Rn in surface water. Even after a high concentration of ^{222}Rn is noticed in surface water bodies, outgassing of ^{222}Rn to the atmosphere can occur as a result of various reasons. Such as, rapid exchange of water between river bed sediment and river water, in addition turbulent conditions in rivers may facilitate the degassing of ^{222}Rn. In a flowing water bodies ^{222}Rn activities decline downstream from zones of groundwater inflow (Cartwright et.al. 2011).

Generally the presence of Radon is an indicator of actively circulating groundwater. In addition, the presence of radon in surface water always means the groundwater is feeding the river at the measured river segment. By using measurements of ^{222}Rn one can identify groundwater discharge zones in surface water bodies. Moreover Radon can be used as an indicator of active groundwater circulation where it is also possible to drive hydraulic information such as rock permeability’s and fluid movement in a certain geologic formation (Mazor, 2004).

2.2 Stable Isotopes

Environmental tracers are frequently used in many geological and hydrogeological studies. The word environmental tracer is the commonly used name, in order to differentiate these tracers from artificial tracers. Environmental tracers could be isotopes or other tracers that are broadly spread in the environment more dominantly in the hydrosphere (Werner, 2006). Mostly tracers are substances which only exist in a small concentration. Stable isotopes that are used for various purposes are nearly tracers such as isotopes of Hydrogen and Oxygen. Isotopes of Oxygen and hydrogen of water are extensively used tracers to understand the natural hydrogeological process (Clark, 2015). The hydrogeological processes that are mainly investigated under these stable isotopes are precipitation, groundwater recharge and groundwater-surface water interactions.

Stable isotopes are those isotopes that do not undergo radioactive decay; so their nuclei are stable and their masses remain the same. However, they may themselves be the product of the decay of radioactive isotopes. In hydrological studies, the stable isotopes of interest generally relate to hydrogen, carbon, nitrogen and oxygen. In terms of the water molecule itself, oxygen has three stable isotopes, ^{16}O, ^{17}O, and ^{18}O; and hydrogen has two stable isotopes, ^{1}H and ^{2}H (deuterium). The relative abundances of the lighter isotopes of hydrogen (^{1}H=0.999) and oxygen (^{16}O =0.997) are naturally high that is mainly related with the weight of the isotopes. The stable isotopes of ^{18}O (oxygen-18) and ^{2}H (deuterium) are the commonly used isotopes that provide information on hydrological processes, including groundwater-surface water interactions.

There are some basic hydrogeologic processes that usually affect the distribution of isotopes through the hydrogeologic cycle. These are (1) evaporation and formation of vapor, (2) condensation and rainout with decreasing temperature, (3) mixing during recharge and groundwater flow and (4) rarely isotope exchange during mineral-water and gas-water reactions (Clark, 2015). Stable isotopic compositions of water are considered to be conservative but, it can be hardly affected by water-rock reactions under moderate temperatures (McCarthy et al., 1992; Gat, 1996).

The combination of isotopes of oxygen ^{18}O and Hydrogen ^{2}H is usually constant under normal temperature of the groundwater. This is for these reasons that stable isotopes of ^{18}O and ^{2}H are used as a conservative tracer. The values these isotopes remain constant unless otherwise there is a phase change or fractionation along the flow path.

The isotopic content of groundwater usually retains the primary meteoric isotopic signature that is originally received from precipitation and recharge (Clark, 2015) but this is with some exception of deep geological settings like brines and geothermal settings.

The concentration of stable isotopes are measured as a ratio of the rare to abundant isotope and it can be expressed the difference in the ratio between the sample that has been taken and a known reference (Clark, 2015). It is given as the following mathematical formula;

$$\delta^{18}O_{Sample} = \frac{(^{18}O/^{16}O)_{Sample} - (^{18}O/^{16}O)_{reference}}{(^{18}O/^{16}O)_{reference}}$$

The above expression helps to regulate the difference between the sample and the reference it is then multiplied by 1000, that defines the measurement in permil (‰). Where δ or delta notion defines the ratio from the standard given by VSMOW. This standardizes measurements to a reference material for accurate measurements (Clark, 2015).

$$\delta^{18}O_{Sample} = \left(\frac{(^{18}O/^{16}O)_{Sample} - 1}{(^{18}O/^{16}O)_{VSMOW}} \right) x1000‰\ VSMOW$$

In 1961, Craig put in to the knowledge of science about earliest measurement of ^{18}O and ^{2}H from freshwater. The well-known principles of Craig become the base for isotope hydrology. These principles are; the concentration of ^{18}O and ^{2}H in freshwater are enriched in warm area and it is depleted in colder regions. The other principle state there is a strong linear correlation between for $\delta^{18}O$ and δD in meteoric waters with a slope of 8 with a deuterium intercept of 10‰.

Several factors can affect the correlation between ^{18}O and D; climate is one of the factors that mainly influence the strong correlation between ^{18}O and D in precipitation. Dansgaard W. (1964) quantified this apparent climatic influence that exhibits the strong correlation between $\delta^{18}O$ and δD for the mean annual air temperature. The other ideology that describes the correlation between $\delta^{18}O$ and δD provides the behavior of meteoric water line (MWLs).

This provides information of recharge of groundwater. Craig in 1961 express's the regression line obtained from the values of ^{18}O and D that provides Global Meteoric Water line (GMWL). GMWL is obtained from the average of numerous regional or local meteoric water lines (MWLs). Local meteoric water lines differ from global line in both deuterium intercept and slope of the line. This regression line for global meteoric water line is defined as; $\delta D = 8\delta^{18}O + 10‰$

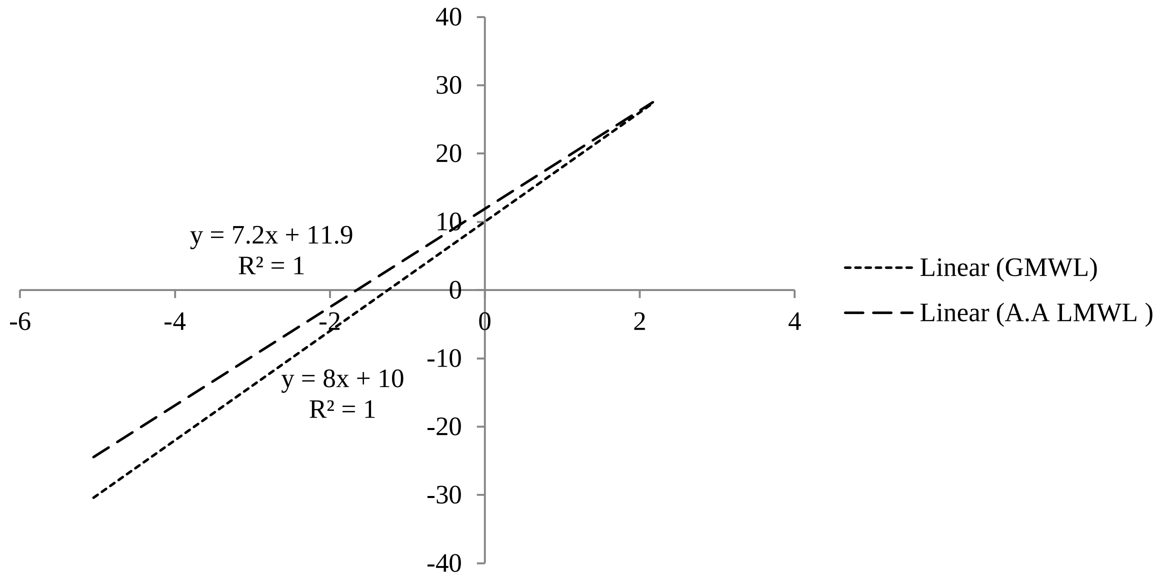


Figure 2.1 Regression lines for GMWL and LMWL

The regression line for global precipitation data gives the same line to that of GMWL. Therefore GMWL can be used as a benchmark to compare the isotopic composition of groundwater and surface water (Clark, 2015). By using the regression line one can determine the recharging degree of a groundwater. One of the recharge sources of groundwater is rainfall; Clark (2015) noted that when a rain water contribution is minimal; to the recharge of groundwater the slope becomes closer to 8.

Various studies have been carried out to determine areas where groundwater surface interaction is occurring along the stretch of Awash River. The investigation was carried out on various bases, for instance based on their geographical distribution for hydrogeological analysis. Only limited samples are incorporated during the study, to provide the summary and conditions of groundwater surface interactions.

Generally, among the most important applications, applications of environmental isotopes are useful in groundwater system; flow path, interconnection between aquifers and groundwater. Moreover, studying stable isotopes of oxygen and hydrogen can help in identifying different groundwater recharge zones (Hsin-Fu et.al, 2009).

2.3 Pizeometeric Evidences

Groundwater is a wide spread and inaccessible resource compared to surface waters. Surface water bodies are essential parts of groundwater flow system that can be accessed easily. These days as a result of the growing population and urbanization, water supply shortages are observed in different regions of the country. Consequently in order to balance the demand and supply of the water requirements, a number of boreholes are drilled to access the groundwater. Depending on the type and purpose of wells, there are various types of boreholes, such as production wells, observation wells and Piezometeric wells.

Piezometeric wells are generally boreholes that are not designed for water supply purpose. Hence the primary purpose of these wells is to control; the flow direction, volume of water as well as these wells is used to estimate the velocity of groundwater movement. Generally, these wells provide information of the timely groundwater level at a certain area.

Regardless of limitation of the Piezometeric data it has a time to time increasing support for scientifically observe and understand groundwater flow system. In a hydrogeological studies using a Piezometeric well data as one of the methodology makes hydrogeological studies possible to identify where the groundwater is recharging the river segments and the vice versa.

Since groundwater and surface water bodies are interrelated to each other in so many ways, any changes that occur on either of the water resource can affect both systems. Changes in groundwater quantity and quality are often very slow processes, as a result of the slow movement and the less exposure of groundwater to the external environment.

Consequently, due to such factors changes that occur in subsurface water cannot be determined by simple surveys, rather it requires an integrated and detail work that includes well-organized monitoring networks and a time series data with a systematized database.

Groundwater head variation and distribution assist to identify areas with high and low hydraulic head. By using the head distribution and topographic variation along a catchments or basin a water table contour map can be generated. A contour map is a graphical representation of hydraulic gradient of the water table or potentiometric surface.

Producing contour map is a very important technique in which groundwater flow and movement direction can be clearly determined. Groundwater contours form a ‘V’ shape pointing upstream whenever the line came across a gaining stream or river. At the same time contour lines bend downstream when the lines cross a losing stream. In the two aforementioned cases the existence of the interconnection between surface water and aquifer system can be easily determined. In some other cases where there is no hydraulic connectivity between surface water and groundwater the potentiometric surface contour lines are not affected by the presence of a river. This phenomenon is mostly observed on the potentiometric surface of confined aquifers. In addition areas with shallow gradient of water table the groundwater contours will be spaced in a pronounced way. Conversely if the hydraulic gradient is steep, the groundwater contours will be very closer to each other. This suggests that groundwater is flowing in the direction that the water table or potentiometric surface is sloping.

The main importance of carrying out this research by supporting with piezometeric evidences is to cover the data and knowledge gap that is created by lack of information as a result of various reasons.

3. Characteristics of Awash Basin

3.1 Location

The Awash River Basin is the essential and the 4th largest river basin in Ethiopia. The basin is found lying between the catchment of the wabi Shebelle River to the south, the catchment of the Blue Nile to the west, the depressions of the Danakil desert to the north, and border of Somali land to the east (FAO, 1965). The basin comprises of the western and the eastern catchment. The western catchment covers 64,000km^2 and the eastern catchment covers 46,000Km^2. The eastern part of the catchment does not contribute any surface runoff to the main river rather it drains to a desert area (Halcrow, 1989). The river flows in an easterly direction through 5 regional states namely Amhara, Oromiya, Afar, SNNP and Somali. The river flows from the head water down to the lower plain with a total length of 1,250km and with an area of 110,000km^2 (FAO, 1965).

The Awash River Basin has been the most extremely studied river basin in the country. This is as a result of its good access for various facilities, for its strategic location and also the availability of land water around the river. Awash Basin is the most developed portion of Ethiopian river basin in terms of its irrigational activity since Halcrow (1989) carried out the basin master plan

Awash basin is divided into main subdivisions as upper valley, middle valley, lower valley and the lower plain (Tenalem Ayenew et.al, 2007)

- Upper basin: extends from the origin of Awash River to Koka dam
- Upper valley: extends from Koka dam and Metahara
- Middle valley: part of the valley between Metahara and Mile
- Lower plain: includes the downstream of Tendaho up to the termination point of Afambo.

Besides the major sub-divisions Awash Basin is also divided into a number of sub-catchments. The western sub-catchment of the basin includes important left bank tributaries such as Kesem, Kebena, Ataye, Awadi, Negeso, Borkena Jara, Mille and Logiya that rises from the north-western highlands and drains to Awash Valley. The eastern catchment extends from Hararghe down to the vast plain. This portion of the catchment is considered to be a closed sub-basin since it doesn't contribute any surface runoffs to the main stream of Awash river.
The other is the Ayisha sub-basin. This sub-basin is relatively dry and it is located in the Eastern part of Awash Basin i.e. adjacent to eastern catchment (Gedion Tsegaye, 2009).

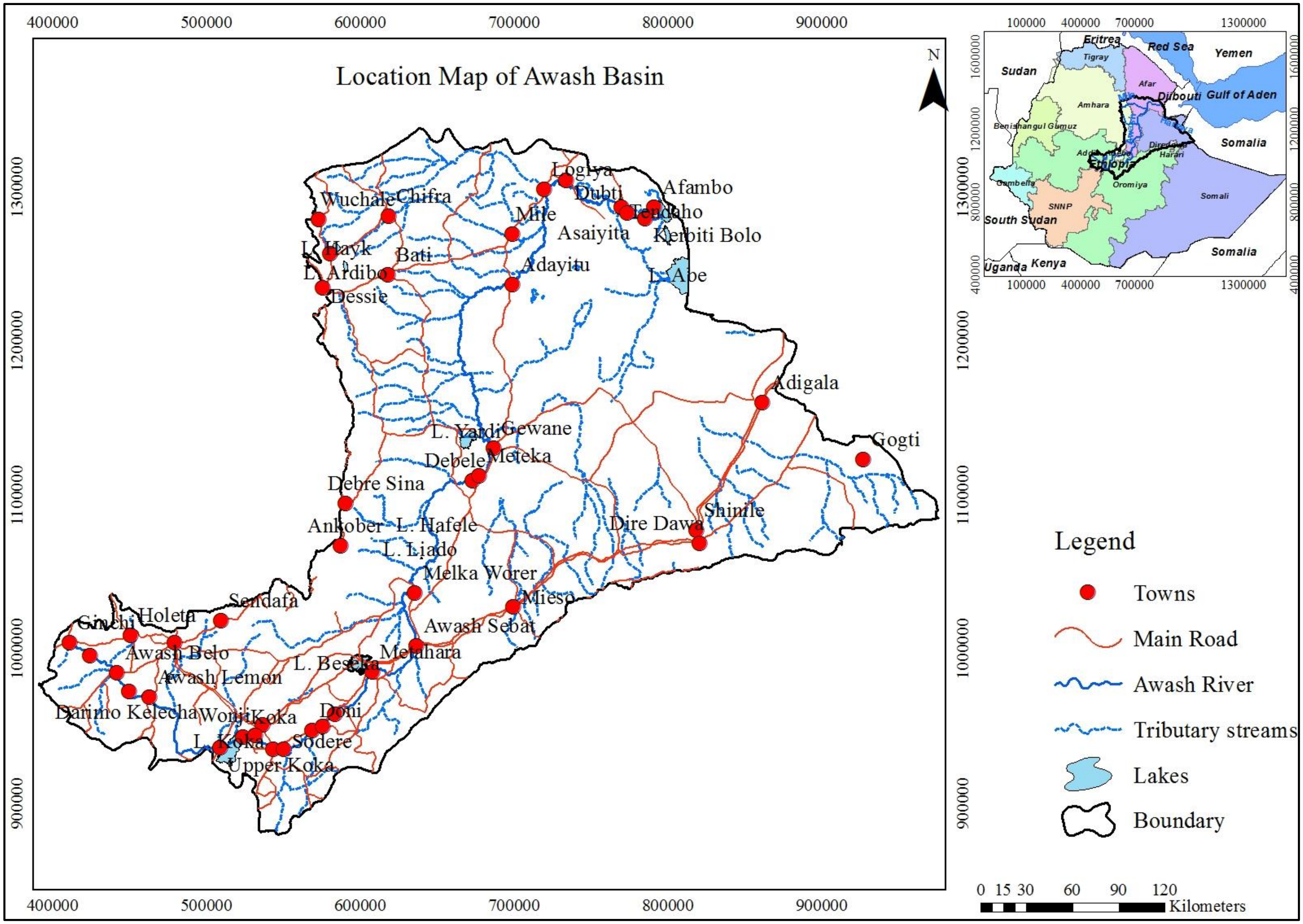


Figure 3.1 Location map of Awash Basin

3.2 Physiography

Mohr on 1961 on the book of the Geology of Ethiopia expresses the physiography as '… more perhaps than in any other country of Africa, the physiography of Ethiopia is an intimate expression of the underlying geology.' The two main physiographic parts of the Awash Basin are the Ethiopian plateau and the rift valley, which expands to the north into Afar triangle (Halcrow, 1989). From the physiographic point of view Awash River Basin can also be classified as upper, middle and lower. The upper most part of the basin is dominated by chain of volcanic mountains forming the water shed divide. This chain of volcanic mountain is bounded, in the north by east west trending rift escarpment and the Entoto mountain range. The upper portion of Awash Basin physiography is mainly shaped by volcano, tectonic and erosional process. And it is characterized by very steep slope in the northern, eastern and western part. The undulating topography in the central and gentle to flat in the southern part. The recognized major volcanic centers and ridges with in the upper basin are Wechecha, Fuji, Guji, Bedegebaba, Ziquala and Yerer (Andarge Yitbarek, 2009).

In the middle part of the basin, there are three distinct slices of geomorphic series in central Ethiopia recognized as plateau, escarpment and the rift floor. These configurations create three distinct river basins bordering the middle Awash. The intermittent volcano-tectonic process of the rift forms land deformations into successive stratum land mass arranged one after the other. (Wagari Furi, 2010). Middle Awash is bounded to the west by graben or valley of Awash river course where the river dropped 100m from the plain. A north south trending horst separates the plain from this graben and it is believed that this structure diverts the Awash River course to the present valley direction. (Asfaw Aymeku, 2006).

According to the survey of the Awash River basin carried out by FAO, the lower portion of the basin composed a number of hills which is associated with recent volcanic activities. The distribution of these hills is related with the secondary faults. These faults are generally aligned in west - east direction. Near Tendaho village, the river has cut a gorge through a volcanic range that is most likely associated with a series of faults parallel with the main fault i.e. North-south. In addition to this gorges begin in this plain, which were probably once covered by lakes. The other is in the lower plain of Awash there are recent volcanic activities, with manifestations of geyser and several mud-volcanoes.

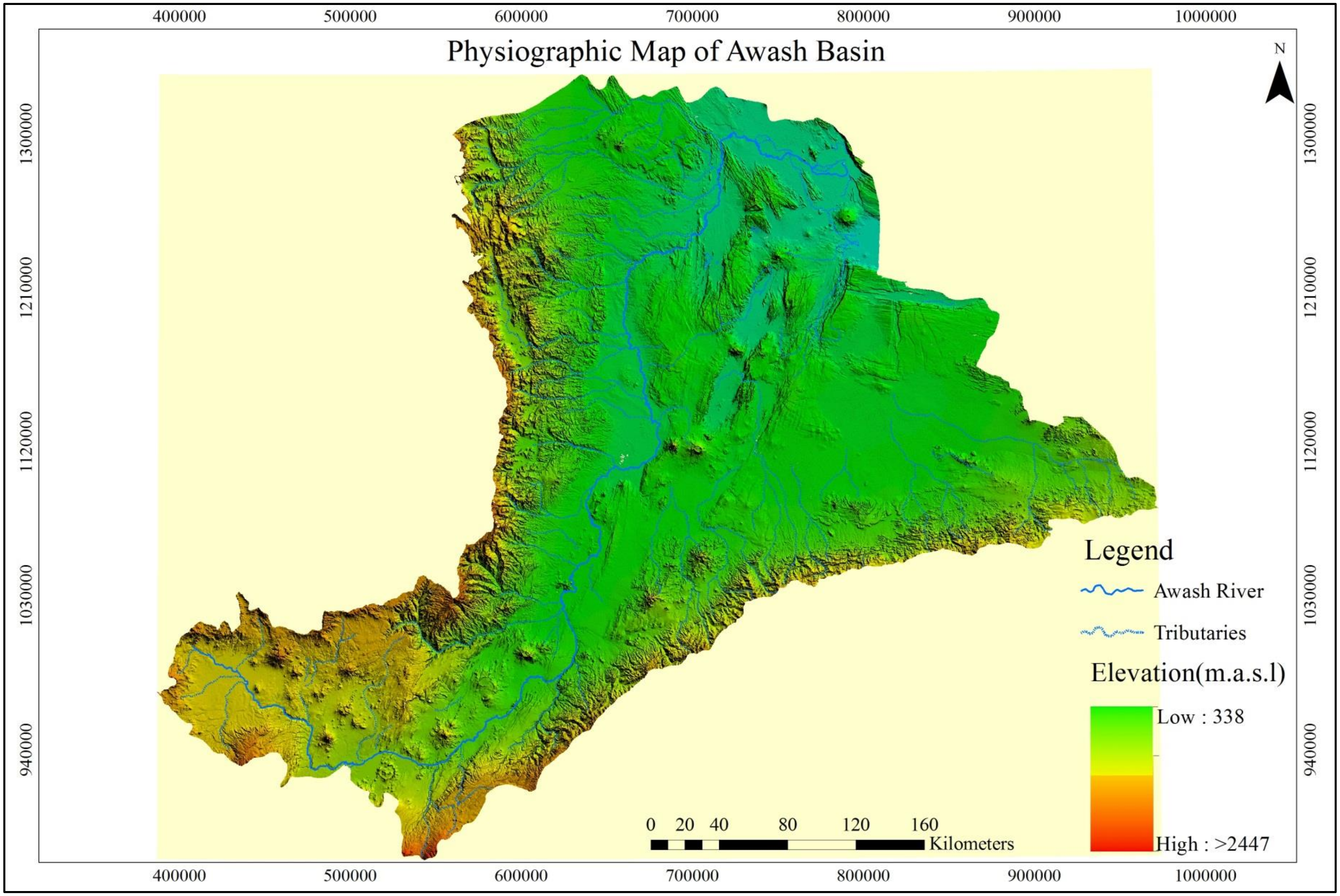


Figure 3.2 Physiography map of Awash Basin

3.3 Climate

Metrological data were collected from online data source of National Metrological services agency (NMSA). One of the main factors that can determine the climatic conditions of a certain area is altitude variation. In Ethiopia it is customary to classify climate conditions based on altitude and agricultural activity. According to the altitude variations and to some extent based on the natural vegetation, the climatic conditions of Awash Basin can be classified on four major climatic zones. These classifications are namely, Dega, Woina Dega, Kolla and Bereha (FAO, 1965). Basically there are some dominant leading factors for the variations of climatic condition at a given area. These factors are precipitation, temperature and evaporation variations occurring within the basin. These factors can also affects surface water and groundwater availability from one region to another region.

The climate of the Awash River Basin is mostly affected by the movement of inter tropical convergence zone (ITCZ). ITCZ creates two rainy seasons in the river basin. The shorter rainy season is around March, it is called ''Belg". The longer rainy season is the one between June and September, which is called "Kiremt". The rainy-season in Awash Basin is considered to be bimodal towards eastern part of the basin and almost uni-modal towards western Ethiopia. The other season of the river basin is, the time between October and March, which is a dry season, called "Bega".

As per the physiographic setup of Awash Basin, the north-western and south-eastern highlands of Awash Basin including the upper basin are dominantly Woina Dega and partly Dega (Gedion Tsegaye, 2009).

Woina Dega is the tropical to sub-tropical plateau generally considered to be found at an altitude from 2,500m to 1,800m.

Dega is a name given to the tropical highlands above 2,500m with a cool and wet climate. Areas with Dega climate are humid especially at the highlands. The natural condition of this zone makes the area well suited for rain dependent agricultural activities (FAO, 1965). These regions generally have average annual temperature of about 22^0C and an annual rainfall of between 510 and 1530 millimeters.

Going down to the valley, the climatic condition is changed to Kolla. Kolla region covers areas between 1,800-1,500m (FAO, 1965). These are areas that generally fall under the semi-arid or semi-desert climatic zone (Asfaw Aymeku, 2006). That commonly has an average annual temperature of about 27^0C and 510 millimeters of rainfall per year.

The dominate part of Awash Basin lies in the category of Bereha. This designation is given to semi-arid and sub-desert lowlands at an altitude below 1,500m. It includes rocky and hilly lands and also alluvial plains. In this area because rainfall is very scarce agriculture without irrigation is not possible (FAO, 1965). Below on the isohyets map of Awash Bain it is clearly indicated that the amount of precipitation decreases while going down to the lower plain of the basin.

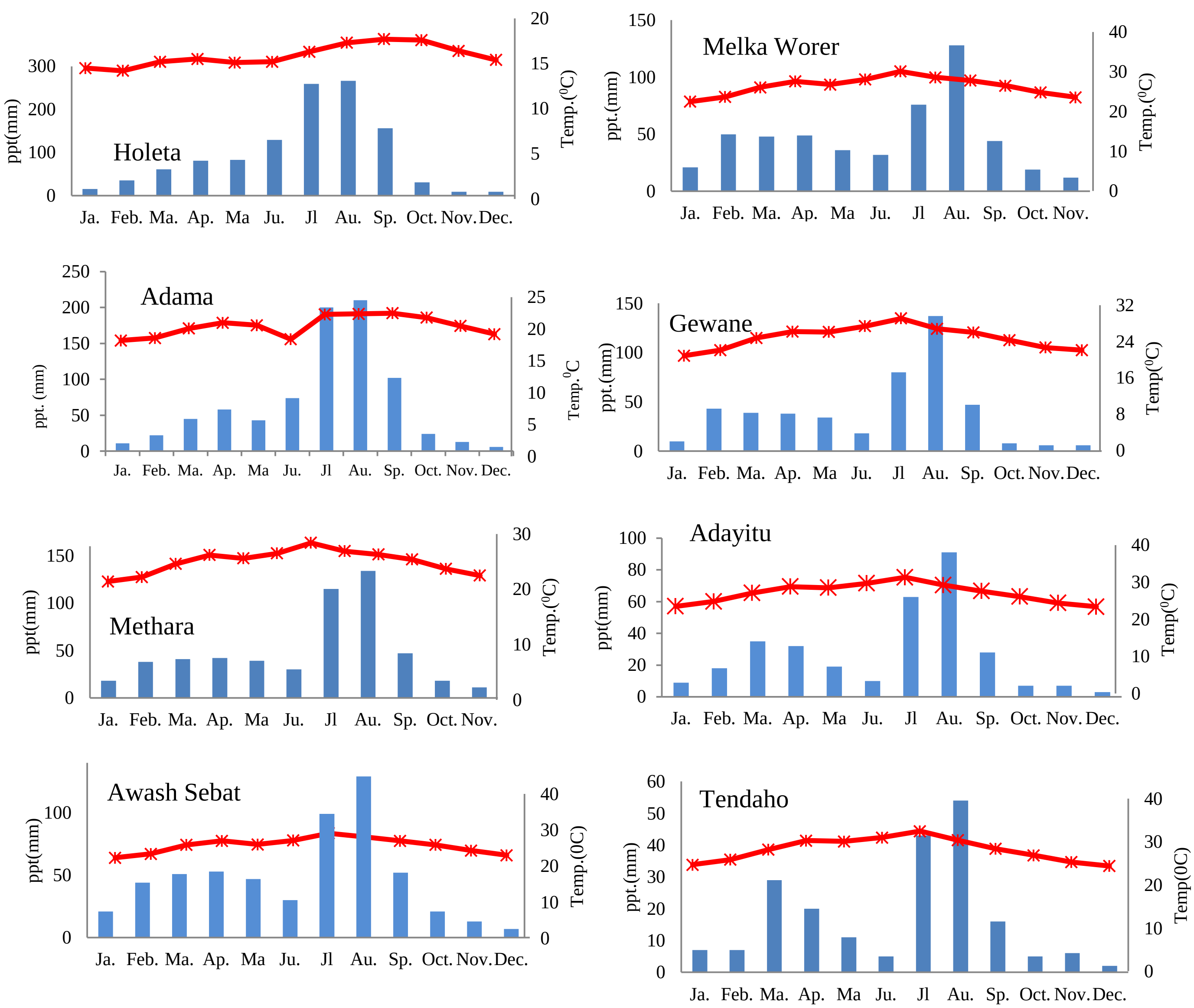


Figure 3.3 Graphs showing mean annual precipitation and temperature at selected stations

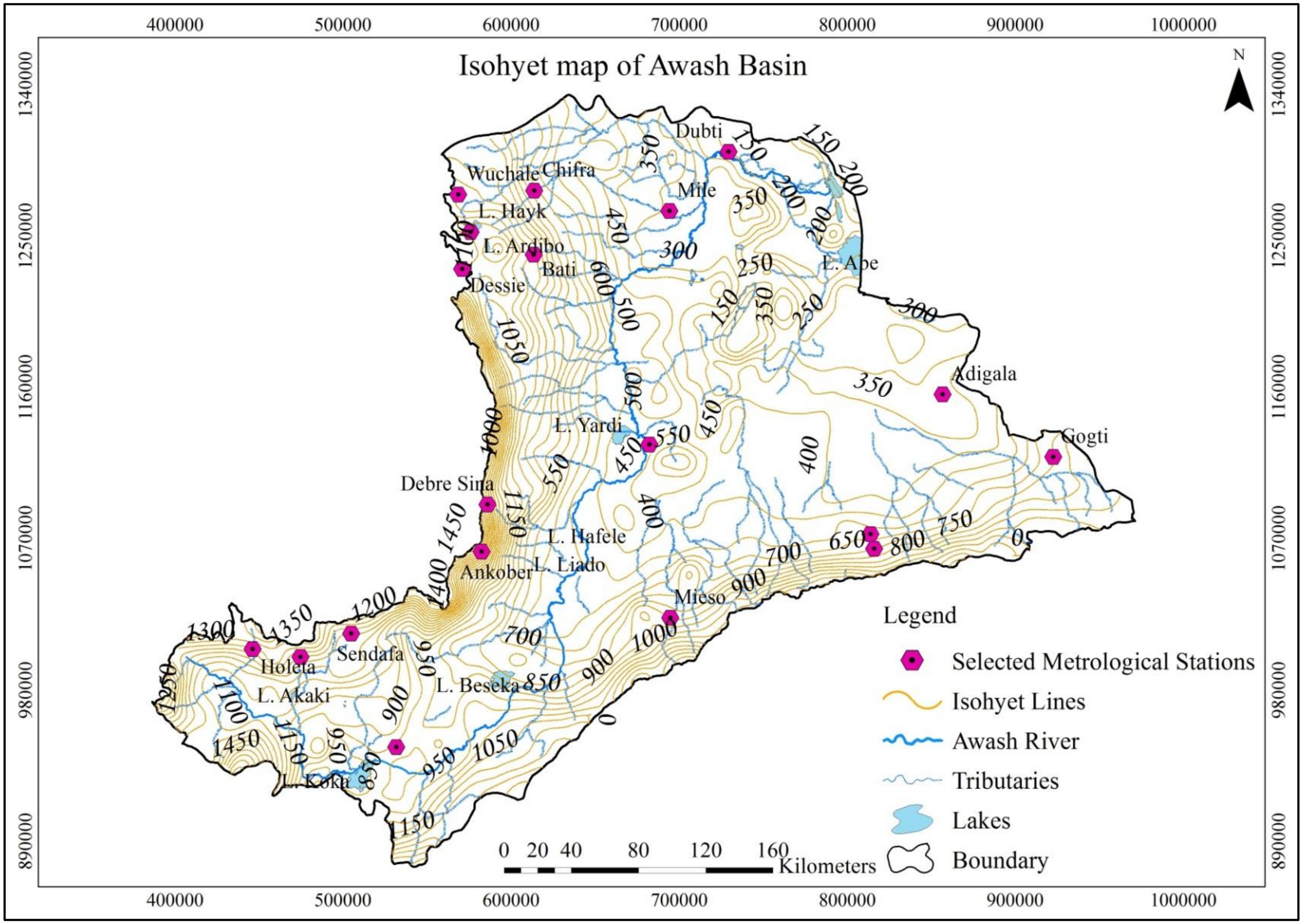


Figure 3.4 Rainfall distribution map of Awash Basin

3.4 Land use land cover

Land use land cover of a certain area shows how a region is covered by forests, wetlands, agriculture, and other land and water types. Water types may include marsh areas, open water bodies and reservoirs. It also shows how people use the landscape whether for development, conservation, or mixed uses.

The common land use types in Awash River Basin include cultivated agricultural lands, grasslands, croplands with shrub land, forests, woodland, bare land, Swamps and marsh areas. Besides the status of the usage and coverage of the basin land, it is covered with main cities and people i.e. upper basin and in the upland areas above the 1,500m elevation is a highly populated region of the basin.

Cropland and Cultivated lands dominantly cover most of the upper Awash Basin, north-western and south-eastern highlands including some parts of the upper valley are intensively cultivated (Gedion Tsegaye, 2009). This is as a result of the natural climatic condition of upper Awash Basin that makes the region well suited for rain fed agricultural activities.

In addition to rain dependent agricultural activities, the Awash Basin is known for its irrigated agriculture activities. Among the irrigation estates found in the valley, Wonji sugar factory and Metahara sugar Estate including the Abadir and Merti irrigation areas are the well-known irrigation scheme sites found in the most part of upper Awash Basin.

The north-western highlands of the upper valley contain lakes like Hayk and Hardibe. There are also lakes in the rift valley of Awash river Basin these mentionable lakes include Lake Bishoftu, Hora, Beseka, Le Ado, Hertale, Yardi, Gamari, Adobed, Afambo and Lake Abe. In addition there are artificial lakes like Koka and Aba Samuel are reservoirs in the upper part of the valley. These reservoirs are primarily constructed for hydro-power generation. Similarly Geffersa, Legedadi-Dire reservoirs are found at the upper portion of the valley. The reservoirs are constructed for water supply for the city of Addis Ababa and its vicinity (Gedion Tsegaye, 2009).From the land use land cover map of the Awash Basin it can be seen that part of the rift valley is mainly bare lands. These bare lands include exposed rocks and sands and soils with small vegetation. Some part of the rift is semi-desert covered by grassland with shrubs that stretches along the mainstream of Awash.

Moving to the main part of the rift the basin is rich in several wetlands of various types like open water, springs and seasonal swamps/marshes. Meteka wetland is one of the well mentionable wetland found in Gewane wereda, the wereda is known by its marshy nature. These various types of water (springs and wetlands) sources are the only source of water for both domestic and livestock. Most people living in southern Afar are pastoralists who reside there life almost entirely dependent on the wetland. They use these water sources for car washing and for locally made mattress called Jeba.

From the land use land cover map of Awash Basin, except some areas the lower plain is dominantly bare land covered by young volcanic rocks. Most people residing in the lower plain are nomadic people. These people are pastoralists, living with the herd of camels, sheep's and goats. Since the lower plain is not favorable for agricultural activities the Afar people lead their life by following river flows or any other water sources.

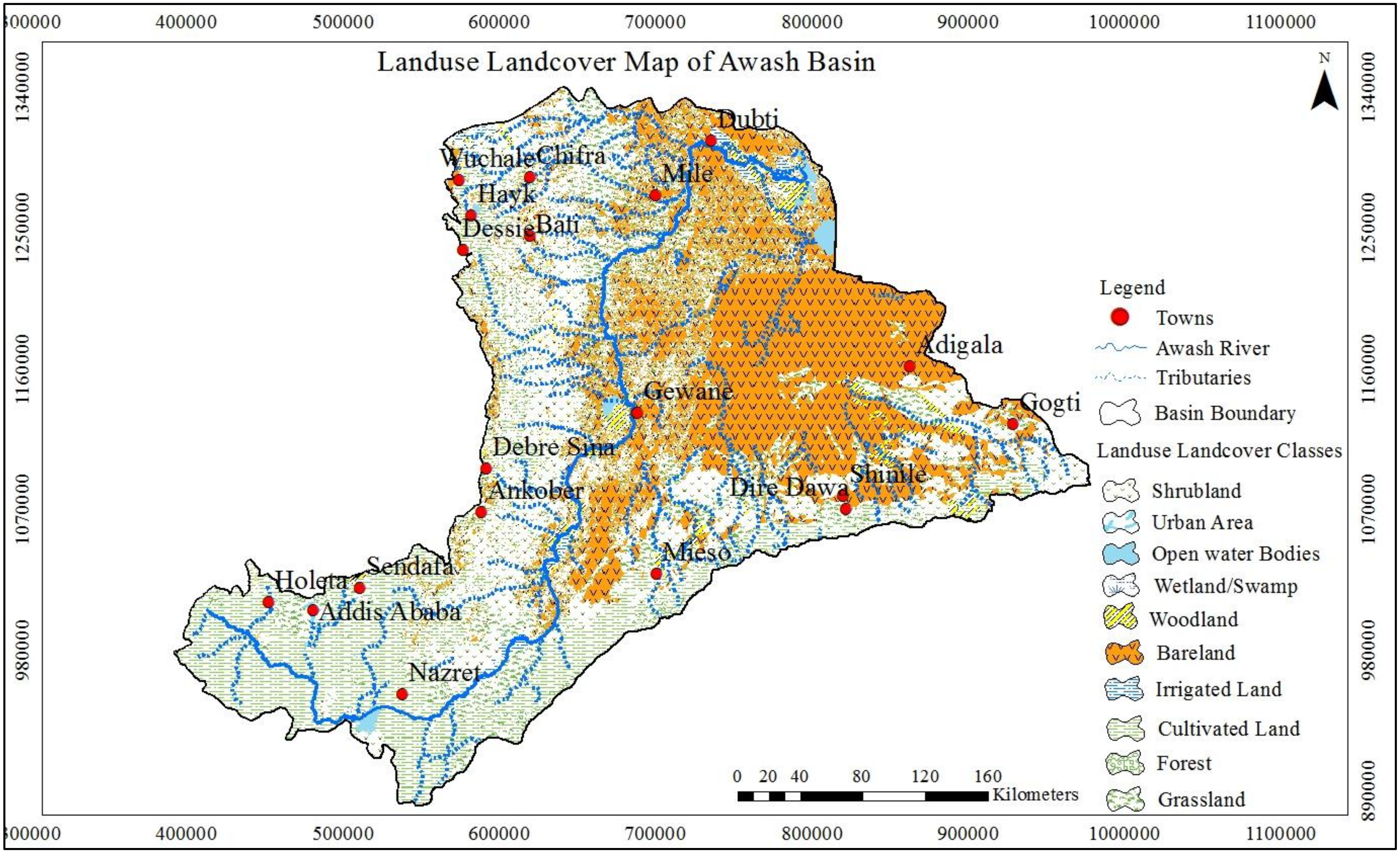


Figure 3.5 Land use land cover map of Awash Basin (modified from WWDSE, 2017)

3.5 Geology

3.5.1 Geology of Awash Basin

Miocene is a period where Ethiopian rift is formed. During this period the eastern and western highlands were separated forming the great Ethiopian rift system (Andarge Yitbarek, 2009). The Western and North Western plateau of upper Awash is mainly covered with early Cenozoic Trap Series group. This group mainly composed of Rhyolites, Ignimbrites, Basalts and Trachytes. From Figure 3.6 some patches of Alkali Olivine basalts and tuff with Rhyolite covers the north western escarpment of upper Awash Valley. In addition Cenozoic volcanics that include the Ashenghe Group basalts interbedded with pyroclastics and rare Rhyolites intruded by dolerite sills, acidic dykes and gabbro-diabases cover the upper part of the basin (Tenalem Ayenew et.al 2007).

As a result of various geo-tectonic activities, there are complex geological formations in the rift floor of the basin. The rift floor is widely covered by Afar group of Pleistocene to Holocene volcanic age deposits. These formations are basalts that are subordinated with acidic lavas and Ignimbrites. Small patches of the Magdala group can also be observed along the middle and lower part of the Awash Basin. On the top of the presence of rift volcanics, the region is covered with thick lacustrine and alluvial deposits and with limited Mesozoic sedimentary rocks that exist in the east. These include the Adigrat Sandstone and the Hamanlei Formations consisting of dolomites, limestones, the Amba Aradam sandstones and shale and marl formations (Tenalem Ayenew et.al 2007). The acidic volcanics of the Nazreth Group is relatively younger basic volcanics of the Afar Group (Zanettin et al., 1980). In addition to Afar group there is a recent formation called Wonji Group. This group extends from Nazreth to Welenchit and even further to Metahara area.

Holocene conglomerates, sands, silts, clays and reef limestones dominantly cover the basin from the middle Awash Valley up to the lower plains of Afar. These formations extend to the eastern shoulder of the basin. Lower plain of Afar is dominantly covered by rhyolite and ignimbrites with volcanic ejecta and fumarole deposits of the Afar Group, generally these Afar Group are interbedded with the alluvio-colluvial deposits (Tenalem Ayenew et.al, 2007)

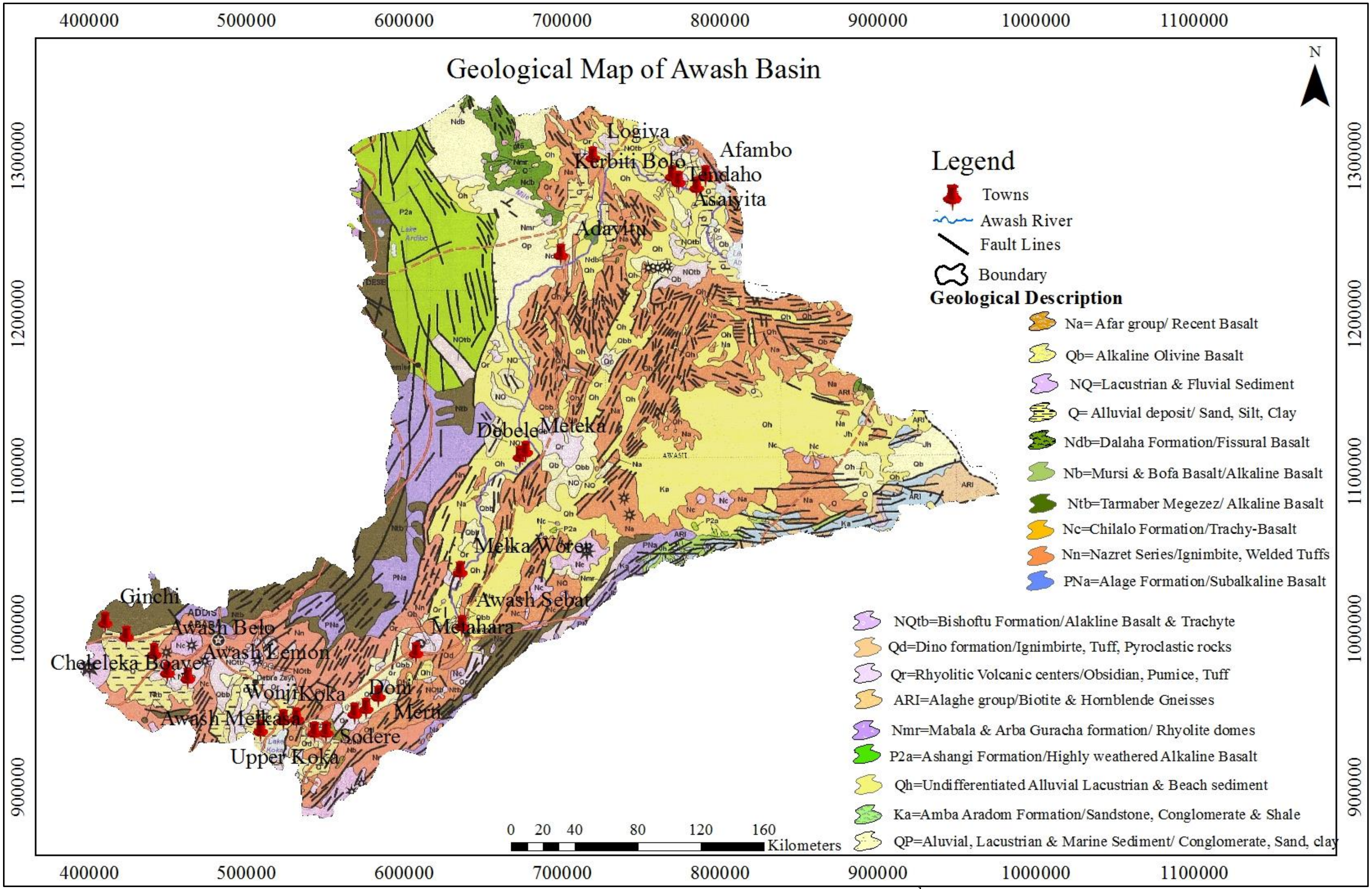


Figure 3.6 Geological map of Awash Basin (Modified from GSE, 2[nd] edition, 1996)

3.5.2 Geomorphology of Awash Basin

In order to fully understand and describe a certain region's morphology there are some morphometric elements, that must be taken into consideration. These elements include the physiographic setup with its component such as slope variability and various observable features caused by various geo-tectonic activities. To have the clear picture of groundwater surface water interaction and to conceptualize groundwater flow systems, as side to other factors that control the groundwater flow system, it is best to deal with the geomorphologic set up of the basin.

The geomorphology of the present day landscape of Awash Basin is built up through uplift and volcanism, faulting, denudation and also some degree of erosion. On the later time this denudations produces sediments that is transported and deposited in the low energy area within the lower plain. The data or information used here to explain the geomorphology of Awash Basin is prepared by (Curry, 1972).

The basin exhibits landscapes ranging from a very high relief (3200masl) to lower areas (250masl). The natural landscape of any region can determine groundwater or surface water flow system. Elevation of the basin generally decreases from the central mountainous plateau to north east following the flow of Awash River.

Much of Upper Awash area mainly constitutes flat lands where that can be observed around the North West, South East and South West, specifically the Becho plain at the south western and the Ada'a plain at the North Eastern part of the Upper Awash section (WWDSE, 2016).

Heading to the rift escarpment there is slightly raised land forms on the upper plateau region. A bit far from this raised land forms, there is low scarp forming gorges and shallow faults. These areas form a minor depression that generally seems excavated to create these features (Curry, 1972).

The rift floor is dominated by north east trending swarm of en-echelon transitional faults which commonly produces horst and graben. The wonji fault belt is one of the features formed during the last stage of graben faulting. As per the study held by FAO, (1972) it is this graben which is now occupied by the Awash River. This faulting resulted in the formation of two major grabens in the middle valley; these are the Alidegie plain and the Awash Valley.

The gravel deposit of the plain of the center of the basin is derived from the breakdown product of the elevated area materials towards the center of the basin to form extensive out wash gravel plains. While carrying out the master plan study on 1989, the outwash gravels were penetrated during the drilling of shallow boreholes. These formations are also observed during the very deep borehole drillings of Alidegie plain. These outwash gravels are also exposed on each flank of Awash River at the left side of plain.

The present day valley of Awash River valley is formed, firstly by erosion of the valley to a certain depth deep through the horst in a position where the Alidegie plain exists. The depth of the alluvium deposited during this stage of the valley development is not known, but it might be in filled to the nearest elevation of its present flood plain.

In the middle valley of the basin there exists enormous number of swampy areas. Gedebassa swamp is one of the swampy areas in the middle valley. The fans at this region caused a blockage in this portion of the river result in the absence of normal river flows. The blockage of the river leads to create a big swamp and form a breakthrough for out wash fan deposits to encroach on to the flood plain below Gedebassa. This blockage below Lake Gedebassa resulted in the formation of a basin of internal drainage.

In the lower valley there are two distinct features of the river. These are the section from Logiya to Dit Bahari in a river flood plain and the other section is from Asayita to the delta of the basin lakes. The land surface of the lower plain is made up of certain geomorphological units. The oldest unit is the older lava and sedimentary block faulted hills, these are partly covered by newer lavas which have been extruded from the volcanic vents located in the hills.

Dunes which occur intermittently across the desert surface are formed from materials wind eroded from the sea or lake floor sediments. Minor braided streams have eroded courses along the fault lines of the block faulted hills. The streams Travers the desert to the flood plain, transporting the materials eroded from both volcanic hills and marine lake sediments of the desert. At this section Awash River is bounded by natural levees formed and added to during each flood events. Breakaway streams occur along the secondary streams and the complex stream systems and levees disrupt the flood plain drainage resulting in the formation of swamp areas and minor depression behind and between the raised land forms.

The other feature in the lower plain is the desert, which has been formed on the sea like floor sediments. These sea lake floor sediments have been divided into two parts by the Awash River flood plain.

These are the most westerly part extending from the north of Mahadi Hubri to Awash River and continuous to the east past of Dubti town, along the southern edge of the Tendaho plantation.

There is dune filed between the southern boundary of the Tendaho plantation and the Awash River, which has been modified along its southern edge by flood waters these dune fields continues approaching the town of Asayita.

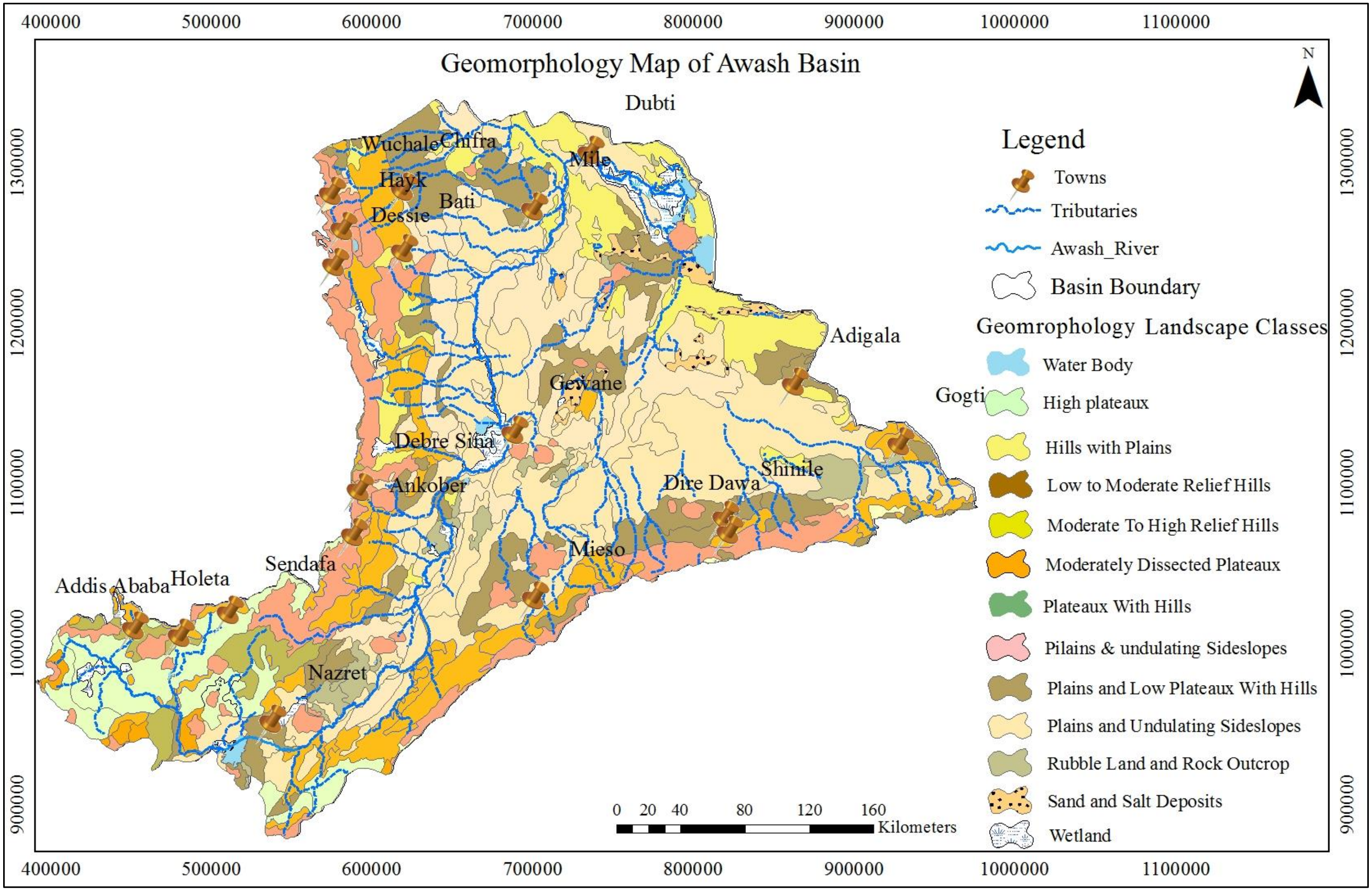


Figure 3.7 Geomorphology of Awash Basin (modified from WWDSE, 2016)

3.5.3 Geological structures in Awash Basin

Geological structures are results of tectonic forces, which result in the formation of faults, folds joints and any of the aforementioned combinations. These structures can affect the nature of a landscape, and can also modify the hydrological and hydrogeological nature of any given region.

Certain structural features or conditions favor the accumulation groundwater in an aquifer; other acts as a drain. Natural geological conditions that are vital for groundwater accumulation are equivalently necessary like reservoirs are important on the surface. Such natural or geologic dams or traps can be tectonic structures, which bring about differences in water bearing capabilities among various strata's.

Geological structures play a great role in changing the physicochemical compositions of water by allowing surface water and groundwater interaction. In order to understand the hydrogeological system of the area it is very crucial to understand the location, orientation and density of faults and lineaments.

The East African rift system (EARS), accommodating the active opening between Africa (Nubia) and Somalia plates, is one of the largest tectonic feature of the earth crust. The Main Ethiopian Rift (MER) in the northern part of the EARS extends from Lake Chamo in the south to Afar in the North (Mohr, 1964).

Based on information's on the recent structural geology investigations (Williams's et.al, 2004), the kinematic and geophysical observations show that deformation in the MER propagates from rift border faults (accommodating NW-SE extension) to rift floor fault (accommodating E-W opening).

Since about 2 Ma, deformation concentrates along 20 km wide, 60 km long in en-echelon rift floor faults, called the Wonji Fault Belts (WFB). This old tectonic phase controls the majority of Awash River flows, generally trending NW-SE direction (Guilanme et.al, 2004) with a strike direction of NE-SW.

The upper most part of the basin is found at the intersection of major regional structures that are NNE-SSW trending MER faults to the East West trending Yerer-Tuluwele volcanic lineament (Andarge Yitbarek, 2009).

The other major fault found in upper Awash is the Filwuha fault. Filwuha fault is a well-known fault that is found at the capital city where many hot springs and thermal wells exits. This fault trends NE-SW and it dips to the southern direction of the basin (Seifu Kebede, 2013). From the structural map on section 3.5.1 (Figure.3.6) lineaments density gets denser following the trend of the rift. This shows that the density of the faults increases while going down to the rift floor of the basin. Faults related to WFB dominate the rift floor and are oriented NNE-SSW direction and locally modify the drainage pattern in the MER (Corti et al., 2009).

At the most center of the rift surface disconnection take place in large scale. That is in response to the tensional force that produce a large number of fissures of various sizes that are aligned NNE-SSW (Morgan and Ramberg, 1987). These fissures allow exchange of subsurface materials, such as groundwater emerging on the surface, in a later case joining surface water bodies.

The Fantalle young ignimbrites and various volcanic domes are the product of young volcano tectonics found in the rift floor of Awash Basin (Williams's et.al, 2004). Several studies have shown that there are ongoing geological processes in the basin. In these active geological processes the fissures are modifying now and then which allows groundwater and surface water interaction within the basin center, besides the exchange of subsurface materials (Wagari Furi, 2009). The other main tectonic structure that trends to the rift margin and bound the rift floor is the Yere Tuluwelele volcanic lineament (YTVL). This volcanic-tectonic lineament is oriented in to the E-W direction and joins the MER around 9^0N. This area of the basin is well known by its dense minor duplicate rift system called the rift-in-rift that dips one another (keep and McClay, 1997). All in all the geological structure of Awash River basin gained most of its structures during the oldest tectonic phase that generally trend WE and NW-SE structural directions.

3.6 Hydrology

3.6.1 Awash River and Tributaries

A river is a naturally flowing water course that flows towards an ocean, sea, lake or to another river. In some cases a river flows into the ground without reaching another water body, becoming the main source of recharge for the aquifer. Such phenomenon when a river is accumulated without reaching any other water body makes the river to be an Endorheic river in the basin.

An Endorheic basin is a closed drainage basin that preserves water and do not allow any outflow to other external water bodies, like Awash River. The flow of Awash River is principally governed by certain natural factors (like geology, physiography and climate). River flows can also be dependent on various human activities such as agricultural practices. Such factors play a great role in influencing the flow characteristics of a river as well as the interaction with the groundwater.

Awash River originates from the high plateau of Mount Warqe, west of Addis Ababa, close to the town of Ginchi, within an altitude of about 3,000 masl. Then it follows the course of south-east and east down to the point where the river turns north wards along the line of the rift. It travels for about 250Km to enter the Great Rift Valley. Awash River and its tributaries form a dendritic drainage pattern (Figure 3.1) as they follow the line of the rift. In between the River is fed by several major and minor tributaries. Awash River has twelve main tributaries, among them Akaki river is the largest tributary (Andarge Yitbarek, 2009) found on the upper part of the basin. Other tributaries of the Awash River include: Logiya, Mille, Borkana, Ataye, Hawadi, Kabenna and Durkham Rivers. These rivers are found in the middle and lower part of the basin.

Going down to the rift the river follows the course northwards to the point downstream of Mile River. In this section the river crosses bars of igneous rocks, between which occur reaches of the flood plain and wet lands in so many places (FAO, 1965). As result of climatic variations (dry and wet season) and hydrologic characteristics of Middle Awash there is a discontinuous stream flow systems.

The plateau and escarpment of the middle valley is marked by dense drainage system in which many tributaries come up together creating a large stream. On the other hand on the rift floor that covers most of the area has a dispersed drainage system (Wagari Furi, 2009).

Reaching to the lower plains of Afar, the river is forced to turn south-east across the alluvial plain that is as a result of series of faults aligned north-west to south-east. In the lower plain the river flows in meandering, deltaic pattern. In this plain several lakes exist, of which the largest is Lake Abe, which receives the remaining flows of Awash is among them.

3.6.2 Lakes and reservoirs

It is very important to understand groundwater influences in a lake system as well as the effect of lake to the groundwater flow. Groundwater influences the water budget of a lake like other water bodies. Most studies that are carried out around the world try to simulate lake-groundwater interaction but very few address the importance this interaction. Since now over pumping water from groundwater preceded without basic understanding of the interconnection of the hydrodynamics between surface water and groundwater. Therefore, conducting a research on lake-groundwater system is very important on the water management as well as, it benefits in maintaining the ecology of any given region.

Awash River basin comprises lakes and reservoirs with various size and purposes. Hayk and Hardibe are lakes that are found at the north-Western highlands of Awash Bain. Lake Hayk is around 23 km^2 in surface; found at an altitude of around 2,000 masl. Lake Hayk is one of the freshwater Lake in Ethiopia. This indicates that there is a Substantial amount of surface inflow recharge from the surrounding shallow and deep aquifer system of the lake (Marco et.al, 2015). The capital city Addis Ababa and its surrounding area is part of the Awash River basin, the city and the nearby areas use two main surface water sources: the Legedadi-Dire and Geffersa reservoir for water supply (Bathymetric survey, 1999).

There are also artificial lakes in the upper portion of Awash River basin, like Koka and Aba Samuel. Koka is found in south-central Ethiopia. This reservoir is primarily constructed for hydro-power generation, constructed across the Awash River with an area of 180km^2.

At the outlet of Koka the overall catchment area is around 11,500km^2. Generally reservoirs can result seasonal river flow variability. Particularly in Awash River, where there are highly variable seasons, the reservoir can sustain dry season flow. In which the river discharge can fall to zero during the dry season (Halcrow, 1989).

In the rift valley of the river basin there are some mentionable lakes like, Lakes Bishoftu, Hora and Lake Beseka. Lake Beseka is an Endorheic lake located in the middle Awash River Basin. Unlike the other Ethiopian Lakes this lake is expanding from time to time in an alarming rate. The total surface area of the lake is around 46km^2. Some studies showed that the expansion of the lake is as a result of the flow of groundwater to the lake.

For instant the study that is carried out by Megersa on 2009, takes Beseka Lake as a permanent lake. Permanent lakes usually interact with surrounding groundwater in three ways (1) some receive groundwater inflows (2) some have seepage loss to the groundwater and (3) some receive and from and lose to the groundwater system. On this study quantification of the groundwater flux has also been conducted and the study clearly put that groundwater changes are positive (inflow > outflow). From previous studies it is very clear that groundwater surface water interaction is taking place at Lake Beseka, in which groundwater contribution to the lake is more than 50% of the total inflow (Megersa Olumana, 2017).

Lake Yardi, Gamari, Afambo and Lake Abhe are parts of the lower plain in which Awash River terminate after the long journey it made starting from the head water at Ginchi. Lake Abhe is a salt lake, lying on the Ethiopia-Djibouti border. It is a place where groundwater level and the surface water match (Halcrow, 1989). Lake Abhe is one of a chain of six connected lakes, which also includes (from north to south) lakes Gargori, Laitali, Gummare, Bario and Afambo (https://en.wikipedia.org/wiki/Lake_Abbe).

3.6.3 Springs and wetlands

Springs are normally found at the foot of mountains and hills, in lower areas of a valley, and similarly near the bank of major rivers (Zeyede Kebede and Tesfaye Gobena, 2009). Springs can also occur when the artesian or aquifer pressure exceeds hydrostatic pressure. There are three types of springs (1) seasonal spring, (2) Main spring/gravity spring and (3) Thermal or hot spring.

Seasonal springs are one kind of springs that are dependent of the season; those springs are most likely disappears during dry season. Main springs are those springs that emerge on the surface of the ground by the help of the gravity related to the topographic setup of the region.

The other kind of spring is the thermal or hot springs. Thermal springs are springs that occur on the surface of the earth with high temperature. These springs are heated deep down before they reach the surface of the ground (Zeyede Kebede and Tesfaye Gobena, 2009).

Thermal springs in Awash Basin occur in both high and low precipitation regions of the basin. Annual precipitation across the river basin goes from high to low. This indicates that these thermal springs are not influenced by the amount of precipitation or the elevation of the basin. There are well known thermal springs in upper Awash these are the Filwuha spring of Addis Ababa and the Sodera thermal spring of west showa.

Previous studies showed that Filwuha has the most depleted oxygen 18 and Deuterium composition. From this it can be inferred that the water of Filwuha can be described by, intense degree of rock water interaction compare to the nearby groundwater’s (Seifu Kebede, 2013). The natural origin of high temperature springs can be as a result of geothermal gradient with deep circulation of groundwater. The circulation of groundwater through faults, chemical reactions and the mixing of meteoric water with the magmatic water made the springs to have a higher temperature (Mohammadzadeh H. and Kazemi M., 2017). The other characteristics of hot springs in orogenic region are usually due to the interaction between water with the lithosphere and environmental conditions, such as lithology pathways and residence time (Kebede Beyene, 2000). Besides all various scientific explanations on the presence of thermal springs in the highlands, the main reason for the presence of thermal springs can be due to the E-W fault that acts as a barrier for the N-S groundwater flow (Seifu Kebede, 2013).

Several springs mostly warm springs come about downstream of Lake Koka. These springs get their recharge from deep well sources and seepage from Koka reservoir through the NE – SW fault lines (Tamiru Alemayehu, 2008).

Going down along the river course there is a spring called Hippo pool. On the study that is held by Kibret Beyene in 2000, the hippo pool spring is treated as groundwater.

This spring showed similar isotopic composition to that of Wonji and Nazareth cold groundwater. This indicates that the spring shares the same aquifer system with the deep wells around the spring.

Even if further and additional studies are not done on the Hippo pool spring the study that is held by UNDP in 1973 showed that this spring is supplied by shallow aquifer with only minor contribution from deep sources.

The Gergedi thermal spring is the other hot spring found along the river of Awash. It is located close to the city of Nazareth and Wonji adjacent to the Awash River. The normal faults and the wonji fault belt are considered as the sources of the Gergedi hot spring (Yahya Ali, 2011). The discharged temperature of the Gergedi spring ranges between 41^0C - 47^0C, for the springs that are away from Awash River. Whereas, the springs located close to the river has a lower temperature that is as a result of the cooling effect of Awash River (Theodrose Solomon, 2008). From this it can be clearly understood that the springs has interaction with Awash River. From various studies that are aforementioned and from observation almost all existing cold and hot springs are mostly located along tectonically active zones and in areas where there exists a normal fault and elongated fractures.

Ethiopia is continuously referred as the water tower of North East Africa. This is as a result of the wide variety of landforms and climatic conditions; that leads to an extensive wetland system throughout the country (Dugan, 1990).

Like streams and rivers wetlands can get water from groundwater or they can recharge the groundwater from the accumulated water. There are two types of wetlands these are the fens and the bogs. The fens are those wetlands that are found on sloppy areas these wetlands constantly get their recharge from groundwater. Since the Fens continuously get their recharge from groundwater they have similar chemical composition to that of the groundwater. The bogs are wetlands that are usually found on flat areas. These wetlands commonly receive most of the water from rainfall (Winter T. 1998).

Meteka is one of the wetland found in the middle valley of Awash basin. The village has numerous springs and wetlands that are door step to one another. During in situ measurement theses springs have a discharging temperature greater than 50^0c.

Previous studies revealed that the Isotopic and chemical composition of Meteka spring has no significant difference for the major cations and anions analyzed from the boreholes (Kibret Beyene, 2000). From this study it can inferred that the springs of Meteka emerge from deep aquifer system.

Normally wetlands produce an ecological equilibrium in any given environment by maintaining the integrity of life by supporting the system for sustainable socio-economic development. Most people living in Meteka village support their life depending on these wetlands and springs. They use the springs for car washing, for domestic purposes as well as for their cattle's.

Naturally there are several types of springs. Fracture springs are the type of springs that are most likely occurs around Meteka area. These springs are considered discharging through faults or joints. The yield and the presence of these springs are largely controlled by the presence of hydro-structures. From the structural map provided on figure 3.6 the lineaments are dense in the middle of the river basin. This contributes for the occurrence of a number of springs in the village.

The largest perennial wetland in Awash River basin is the Gedebassa swamp. This swamp is found bordering Yardi near Gewane. The other swamp is Borkena swamp. It is found within the structural graben on the north-western highlands, and lower plains swamps near the terminal lakes (Gedion Tsegaye, 2009).

3.7 Hydrogeology

3.7.1 Aquifer characterization

The volcanic aquifer of East Africa is the most complex and the least understood in the hydrogeologic system compared to other aquifers found in Africa (UNESCO, 2006). Concerning the groundwater resource of east Africa, the groundwater is being utilized in a most limited amount, mainly due to the quality limitations. As Kassa (2007) noted around 80% of groundwater failure and abandonment of the well is associated with poor water quality. Consequently, local people living in a poor water quality zone are forced to use other sources of water such as nearby flowing rivers.

Mirroring the geological set up of an area, lithostratigraphic succession of deep boreholes can best explain the hydrogeologic system, aquifer geometry and configurations of the water bearing formations. Likewise Awash Basin has a closely related hydrogeologic structure with the geological feature of the basin. The aquifer configuration and characteristics of Awash Basin is discussed based on the compiled information's from deep and very deep borehole in such a way that is suitable for further discussion of this research.

The geologic formation that mostly covers Upper Awash region is the Ashenghe Group; this group mostly contains fractured volcanic rocks that are mainly the basalts. As MWR (2007) study showed most of Upper Awash aquifer system composed of basalts that are covered with ignimbrites and volcanic Ashes. From the lithological description of the very deep boreholes of Upper Awash Figure 3.8 (BTW-2) the dominate formation is the volcanic rocks, specifically the basalts that is covered with Tuff.

One of the factors that determine the recharging rate of an aquifer is the presence of fractures, joints and openings. The degree of fracturing and the presence of pore spaces that are interconnected determine the capacity of a rock to transmit water. As per the study of MWR (2007) the aquifer system of western part of Upper Awash is under confined and semi-confined conditions, these aquifers can yield up to 200l/s. Thus the main hydrogeologic formations of Upper Awash are the Ashenghe group that is considered to be the most favorable geologic formation for highland recharge (Tenalem Ayenew et.al, 2007).

The intersection of existing rift faults with the pervious E–W trending structure of the Yerer Tulu Volcanic lineament (YTVL) has formed impermeable volcanic layers. The impermeable layer caused by the intersection of these lineaments regionally impedes the vertical movements of Water and reduces deeper recharge. Consequently the formation of springs in the escarpments of upper Awash and at some parts of the region is as a result of the intersection of these two features. On the upper rift escarpment, since the deep aquifer system is not recharging fast enough, the shallow groundwater's frequently discharges in the form of cold springs (Seifu Kebede, 2007).

In Ada'a and Becho plains most of the recharge to the groundwater is from flood plain and from seasonal rainfall. The Litho-stratigraphic information's of very deep boreholes of Becho plain exhibits the aquifer system of this plain is mainly tuff overlaid by the alluvio lacustrine deposit (BPW-18).

Away from Ada'a plain, some previous works explains that, Awash River is hydraulically associated with upstream of the Koka aquifer system, and this link become less at the downstream of Koka. Some spring discharge manifestations have been encountered by some scholars. In which some explain that the spring waters are from the leakage of the reservoir and some discuss by notifying that these springs are discharging from the groundwater.

Within and around Wonji area there are several shallow wells, in which the groundwater level of these boreholes is much lower than the Awash River. Riverine alluvium formations (Tenalem Ayenew et.al, 2007) fractured Basalts and Ignimbrites which are highly associated with the faulted terrain are present within Nazreth, wonji area and even further north east ward to Welenchit (Abera Taye, 2007). The source and accumulation the riverine alluvium is, as a result of the erosion of the up land volcanic rocks down to the rift floor. Lithostratigraphic data of shallow wells of this region signify that, the main aquifer of this area is alluvial and lacustrine deposits found sandwiching the ignimbrite formation.

Water bearing formations in Lake Beseka area mainly composed of fractured Basalts and Scoriaceous Basalts as well as pyroclastic deposits such as pumice, tuff and volcanic breccia (Ayalew, 2008).

Besides the occurrence of favorable formations of the fractured basalt the presence of faults in the valley forms a very deep groundwater that goes up to 274m (Seifu Kebede, 2007).

The present day hydrogeological system of Alidegie plain takes after the recent geomorphic sessions; it is mostly characterized by the alluvial formation. There are two water bearing formations within the Alidegie plain; these are the unconsolidated sediment aquifer and the volcanic aquifer formations. The volcanic aquifer formations can be observed from the lithostratigraphic description below on ALPW-38. Based on this description the main aquifer of the area is fractured Basalts overlaid by thick clay. The alluvial plain includes gravel, graveled sand and the pebbles. These formations are the most favorable formations that facilitate the groundwater recharge condition of the system. In addition to the good aquifer system at some points the plain, the aquifer gets its recharge from the leakage of Awash River (Seifu Kebede, 2007).

In the floor of the basin both shallow and deep groundwater are available. Besides the groundwater system, there are areas, where marsh lands are present within different altitudes. The occurrence of these marsh areas is attributed to flat plains in line with the presence of dense fault lines. Thus water in the middle valley is assumed to be collected on the low permeability ignimbrites of the Magdala Group (Tenalem Ayenew et.al, 2007).

Reaching to the lower plain the hydrogeological units found in the lower Awash are mostly the alluvial fan, the Alluvium and Lacustrine deposit, recent basalts, Acidic rocks and also older basalts. The lithological description of TCTW-27 best explains the aquifer characteristics of the area. The Alluvial fans are distributed at the western and southern parts of the Graben where seasonal streams emanate from Megenta ridges and drain towards Awash River.

According to the study carried out on the lower plain, held by WWDSE (2014), the Magdala groups are also distributed around Asayita area where runoff generates from Borawle ridge then accumulate at the foot of the scarp. Coarser materials, which are an immediate deposit of fans, can contribute considerably for occurrence of groundwater. Like the alluvial fan, the alluvium mainly consists of sand silt and clay and some fine rock fragments. This is distributed along the Awash River and its previous courses and along non-perennial streams. Mostly the alluvium formation gets recharge from the river in the form of seepage, which would contribute for groundwater deposit in shallow depths. The entire lacustrine deposit is not important for groundwater development owing to high salinity problems.

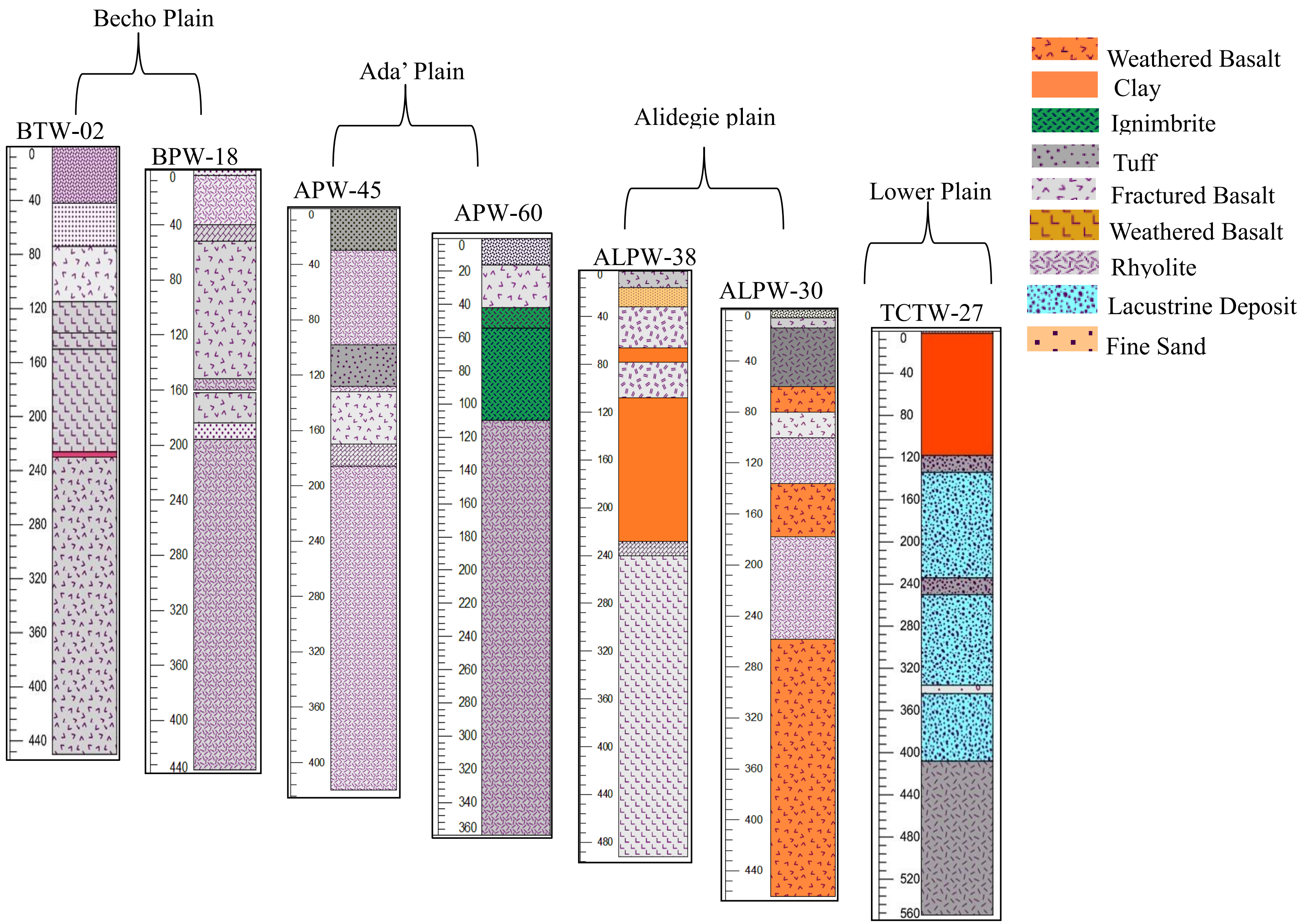


Figure 3.8 Lithostratigraphic descriptions of selected boreholes

3.7.2 Recharge and Discharge conditions

Recharge is one of the elements of a hydrologic process that determines deep drainage or deep percolation in an aquifer. It is generally defined as the process of the movement of water from the surface through the saturated zone (Balek, 1988). In recharge areas, there is often a rather deep unsaturated zone between the water table and the land surface. In discharging areas, the regions are found either close to or at the land surface of the water table. There are physical manifestations in which when the groundwater is released to the surface it can take the form of springs, lakes or streams (Fetter, 1988).

The occurrence and distribution of groundwater at a certain area depends on certain variables. These factors include the amount of precipitation, physiography, geological structures, geological formations and the type of land use and land cover of the region. Rain fall is the main source of recharge for both surface water bodies and groundwater.

In Awash Basin the highlands (upper Awash) receives high annual rainfall compared to the other parts of the basin. Generally areas which encounter long lived and high amount of rainfall will have a high recharge to the groundwater.

The principal geological formation in upper Awash is the Ashenghe group, which mainly comprises fractured volcanic rocks. The main sources of recharge in volcanic rocks on highlands are direct recharge from precipitation (Guppta, 2010). Seepage from streams and return flow from irrigation are also other sources of recharge to the groundwater. In addition, distribution and orientation of geological formation play a vital role in determining the ability of an aquifer to store and transmit water.

Physiographic setup is another aspect that determines the recharging and discharging condition of an area. It can assist either infiltration to the ground or it promotes runoff. Upper Awash is characterized by a chain of ridges in East-West direction and as Ketema Wogari (2003) noted 80% of upper Awash Basin is characterized by flat topography. By and large flat topography plays a vital role in promoting recharge to the groundwater than creating runoff. By taking in to consideration the Litho-hydro-stratigraphy, the rainfall amount and the physiographic setup of upper Awash, is rich in groundwater potential.

The main lithological formations hosting groundwater in middle valley of the basin are Pumice, Rhyolites, fractured Basalts and Ignimbrites. As Wagari Furi sited (2010) the volcanic rocks in the middle Awash Valley are generally massive rocks which are considered to have low primary porosity, whereas the volcanic pyroclastics in the rift floor have a higher primary porosity. Massive formation by nature hampers groundwater movement which makes them to be a poor aquifer.

There are various mechanisms in which aquifers can get recharge such as diffuse (direct) or preferential (localized/indirect) recharge (Andarge Yitbarek, 2010). Diffuse recharge occurs when water is added to the groundwater due to excessive soil moisture. Whereas the preferential occurs when there is a concentrated percolation of water to the water table (Lerner et.al, 1990). At some places of the middle valley the presence of fractured rock exposure in wide areas favor a direct and localized recharge from an inflow of rainfall that fall on plateau area (Wagari Furi, 2010). Escarpments are the intermediate segments between the rift floor and the highlands of the middle Awash. On the rift escarpment, direct recharge from precipitation is expected to be lower compared to highland areas because of lower rain fall and higher evapotranspiration of the region. The dense fault systems and joints in the middle valley play a significant role for fast vertical recharge of the aquifer that flows from the plateau.

From hydrochemistry result and Isotope analysis that Wagari Furi (2010) carried out, aquifers in the rift floor get their recharge mainly from rain that falls on the mountains bounding the rift as in flow compared to local vertical recharge. The groundwater continuity and inflow to the rift floor is facilitated by the nature of the bounding fault (Seifu Kebede et.al, 2008) and hydraulic gradients. The presence of depressional valleys (Welenchit and Wonji) in the rift floor makes the surface water to enter to the ground, through volcanic carks and joints. Since these depressional valleys are often occupied by seasonal ponds and occasional surface runoff are observed.

In the middle Awash Valley there are also additional recharging possibilities other than surface runoff percolation and rain fall infiltration. The percolation of river bed of Awash and seepage from irrigational canals are the other sources of recharge to the middle valley aquifer. This usually occurs whenever the groundwater level is lower than the river beds. In such phenomena the aquifers can receive significant amount of water from rivers.

The lower plain of Awash Basin lies between 500m and 250m, from physiographic point of view the area is generally consider as a discharging zone. This plain has a mean annual rainfall that is less than 200mm. As UNESCO (1975) noted in arid regions of different parts of the world the groundwater recharge in a basaltic terrain is reported to be about 10% of the annual rainfall. From this, it can be inferred that the area has low precipitation that the groundwater can not only get recharge from rainfall. The major recharge sources of groundwater in the lower plain of Awash River are the subsurface seepage from the fracture openings of the volcanic rocks and unconsolidated sediments of the catchment and seepage from Awash River irrigation.

According to the study that was carried out for groundwater potential assessment study for Teru area showed that there are two zones with respect to recharge and discharge of the groundwater. The first zone covers areas of western Dubti and partly Logiya town. These areas receive most of their recharge from seepage of Awash River and groundwater that flows adjacent to the bedrock. The other zone comprises eastern part of Dubti that mainly covers all irrigation area and bare plain area up to the lake Afambo. These areas receive most of their recharge from groundwater of the first zone, seepage from Awash River and outflow from irrigation. In these areas discharge by subsurface groundwater flow towards the east is high.

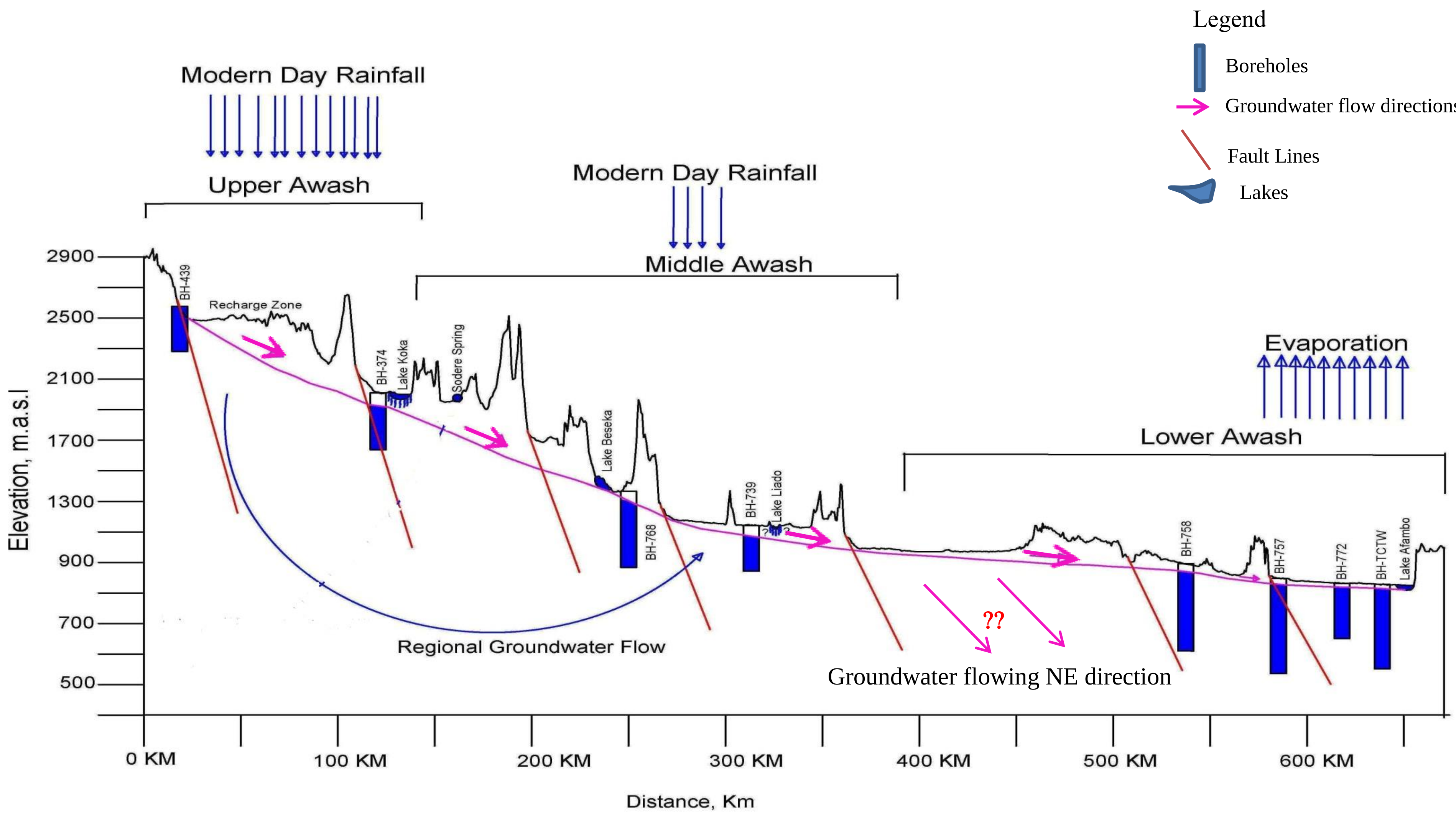


Figure 3.9 Cross section of Awash Basin hydrologic system (Profile line on Figure 4.13)

4. Results

4.1 ^{222}Rn in Awash River

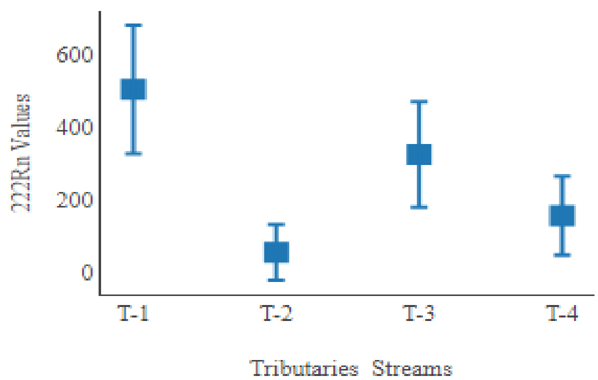
A total of 78 ^{222}Rn measurements were carried out on the two events of the field work, i.e. during wet and dry season. On both occasions of the measurements, 68 of the measurements are taken from Awash River segments, 8 of them are obtained from the tributary streams of upper Awash and the rest of the 4 readings are taken from the wet lands of Meteka (middle Awash).

Since the wet season measurements were carried out in the course of the rainy season the river level was very high. In order to clearly observe the groundwater contribution to the surface water the dry season measurement is held, when the river level of Awash is lower than its average height.

^{222}Rn concentration measurements along Awash River are assumed to give important information if there is groundwater surface water interaction. That in turn will suggest both gaining and losing activities is happening along the river stretch. For this section the results is reported in a way that is suitable for discussion for the coming section.

The Wet season measurements are carried out from August 19 – September 9, 2017. During this season the ^{222}Rn concentrations changes significantly along the river segments. In the highlands of the basin i.e. in upper Awash, from river segment R_1 (Ginchi) to R_7 (Koka Reservoir), the ^{222}Rn concentration in the river water increases on the first encounter i.e. at R_1 and R_2 and decreases on the following river segments of R_3, R_4 and R_5. Then it increases slowly again at R_6.

^{222}Rn measurements were also taken from the tributary streams of upper Awash. At T1, T3 and T4 higher ^{222}Rn readings are obtained. The values of ^{222}Rn at T2 is lower compare to the other tributaries value (56.0 ± 77.3).



At R_{10} ^{222}Rn showed a pronounced increment from the previous segments (168 ± 112). Following the river path at R_{11} and R_{12}, the measurement showed a lower concentration of 44.8 ± 72.5 and 56.0 ± 77.3 respectively. Going down to the rift escarpment readings of ^{222}Rn obtained from R_{13}, R_{14} and R_{15} are very low compared to the highland measurements.

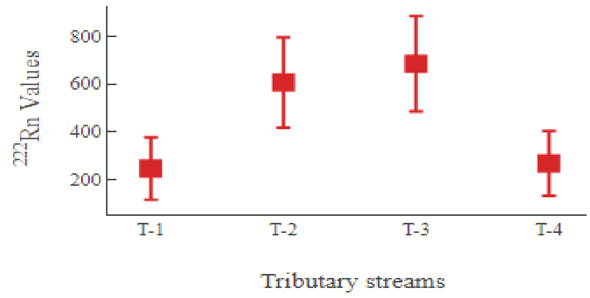
Moving to the middle basin from R_{16} (Metahara) to R_{24} (Meteka) the ^{222}Rn at R_{16} is very low that, it is about 0.00 ± 44.8. The river segments below R_{16} the value of ^{222}Rn ranges from 22.4 - 112Bq/m^3. In the middle Awash there exist wet lands specifically at Meteka area. The ^{222}Rn measurements provide a higher value that goes up to 12,000Bq/m^3.

The selected river segments from lower basin begins from R_{25} (Adayitu) to R_{32} (Lake Afambo). The lower reaches generally exhibits very low ^{222}Rn concentrations compared to the other river segments of Awash River. The value of ^{222}Rn at the lower Awash River segment oscillates from 11.2 to 67.2Bq/m^3.

Similarly the dry season measurements were carried out along the same river segments in which the wet season measurements have been taken place. The dry period measurements held from February 23 to March 8, 2018.

^{222}Rn measurements of this season demonstrate higher values compared to the wet season survey. The increment is observed on the River segments, tributary streams as well as on the wetlands. The readings go up to 605 Bq/m^{3}on the main course of the river. On the first encounter ^{222}Rn concentration increases from R_1 to R_{15}. The readings first increase then slowly decreases at R_2, R_3 and R_4. A distinctive spike in ^{222}Rn activities were observed at R_5 (605 ± 189 Bq/m^3). It decreases very slowly again from R_8 to R_{12}. From R_9 – R_{15} the readings abruptly decreases going down to 33.6Bq/m^3 at R_{15}. All in all the values that are obtained from Upper Awash ranges from 605 -200 Bq/m^3.

All the measured tributaries of upper Awash also showed a higher ^{222}Rn concentration. The values range from 685 – 247 Bq/m^3, with average value of 466 Bq/m^3.



The middle valley of Awash River segment begins with an elevated concentration of ^{222}Rn at R_{16} (393 ± 157). It then suddenly decreases at the following river segment of R_{17} (44.8 ± 72.5). Most readings that are obtained from R_{19} to R_{22} provide higher ^{222}Rn concentrations ranging from 752 - 291 Bq/m^3. The rest of the measurements at R_{23} and R_{24} showed lower values of ^{222}Rn.

During the dry season survey two additional segments were measured in middle Awash specifically at Gewane. Both these segments demonstrate a lower concentration of ^{222}Rn which is 22.4 Bq/m^3 at R_{33} and 44.8 Bq/m^3 at R_{34}.

The previously measured wetlands during the wet season were also measured during the dry season. The wetlands exhibited higher ^{222}Rn concentration that goes up to 10,000 Bq/m^3.

The results obtained from lower Awash Basin i.e. segments from R_{26} to R_{32} demonstrates a very lower ^{222}Rn measurements that ranges from 101 – 11.2 Bq/m^3.

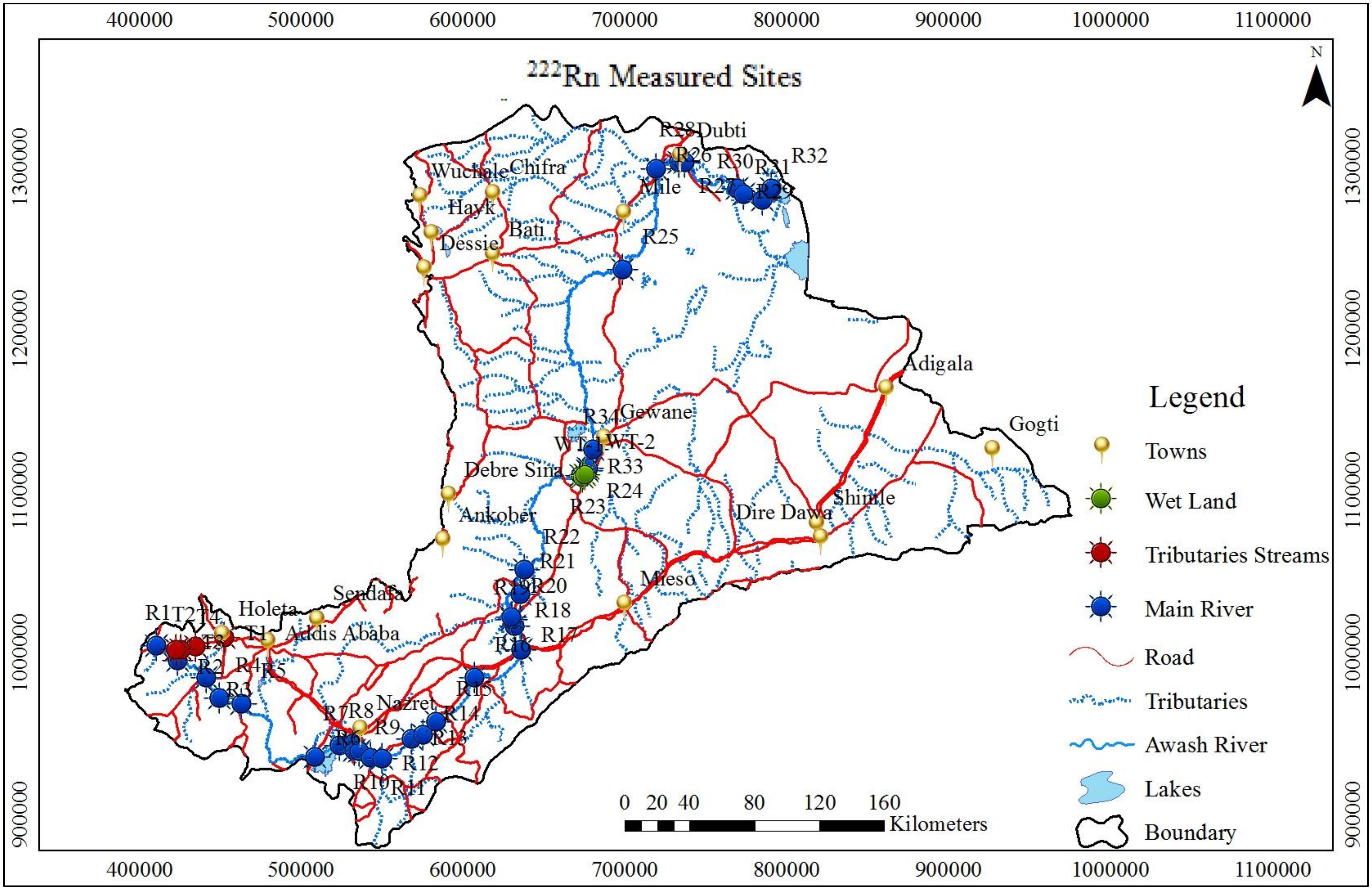


Figure 4.1 ^{222}Rn measuring sites

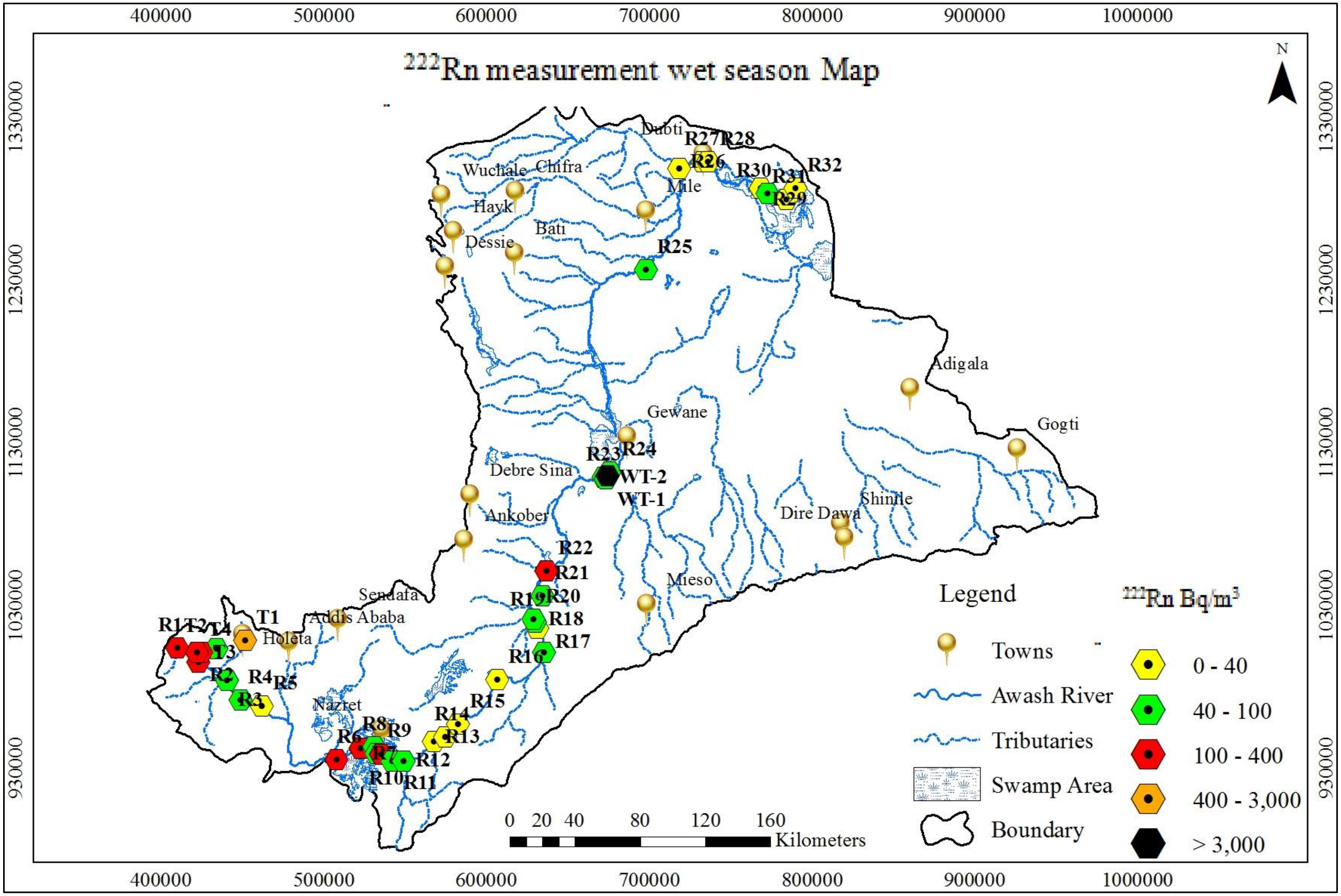


Figure 4.2 ^{222}Rn values during wet season

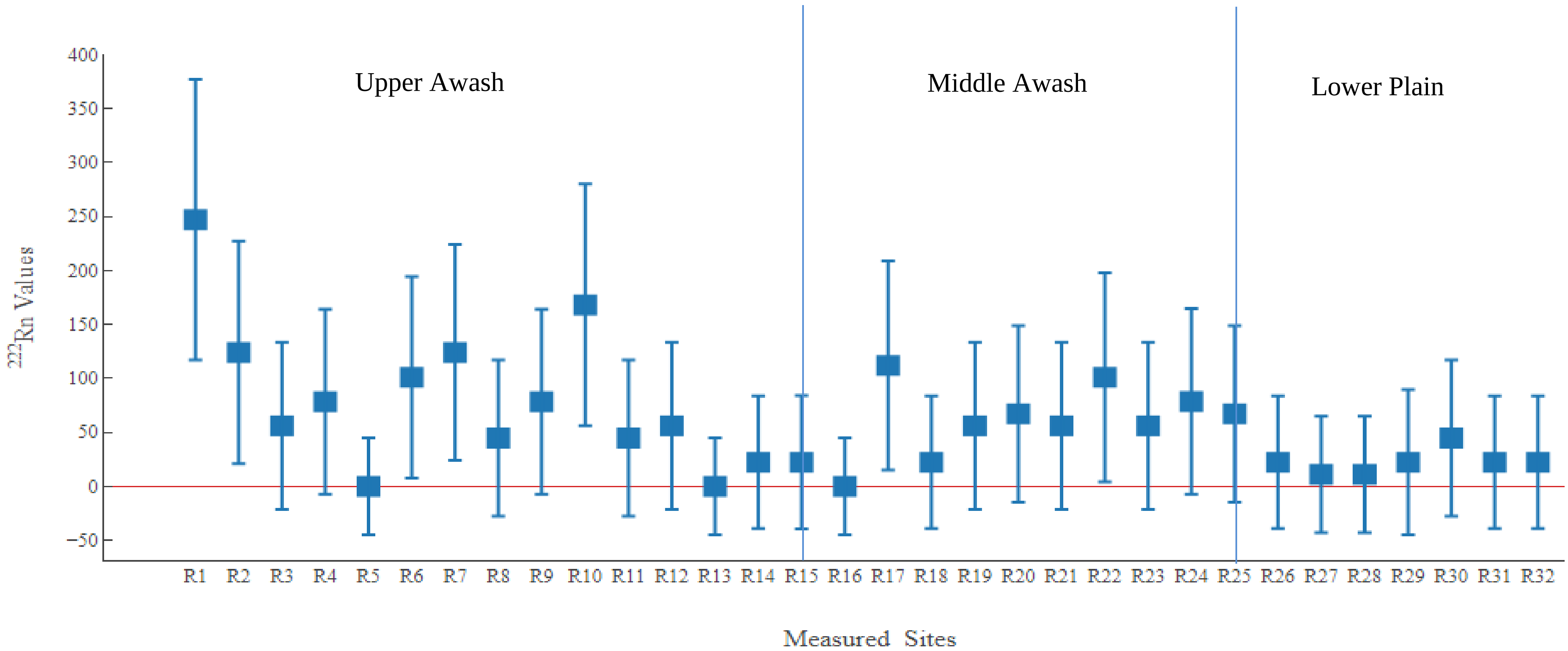


Figure 4.3 Error bar representation of ^{222}Rn level during wet season

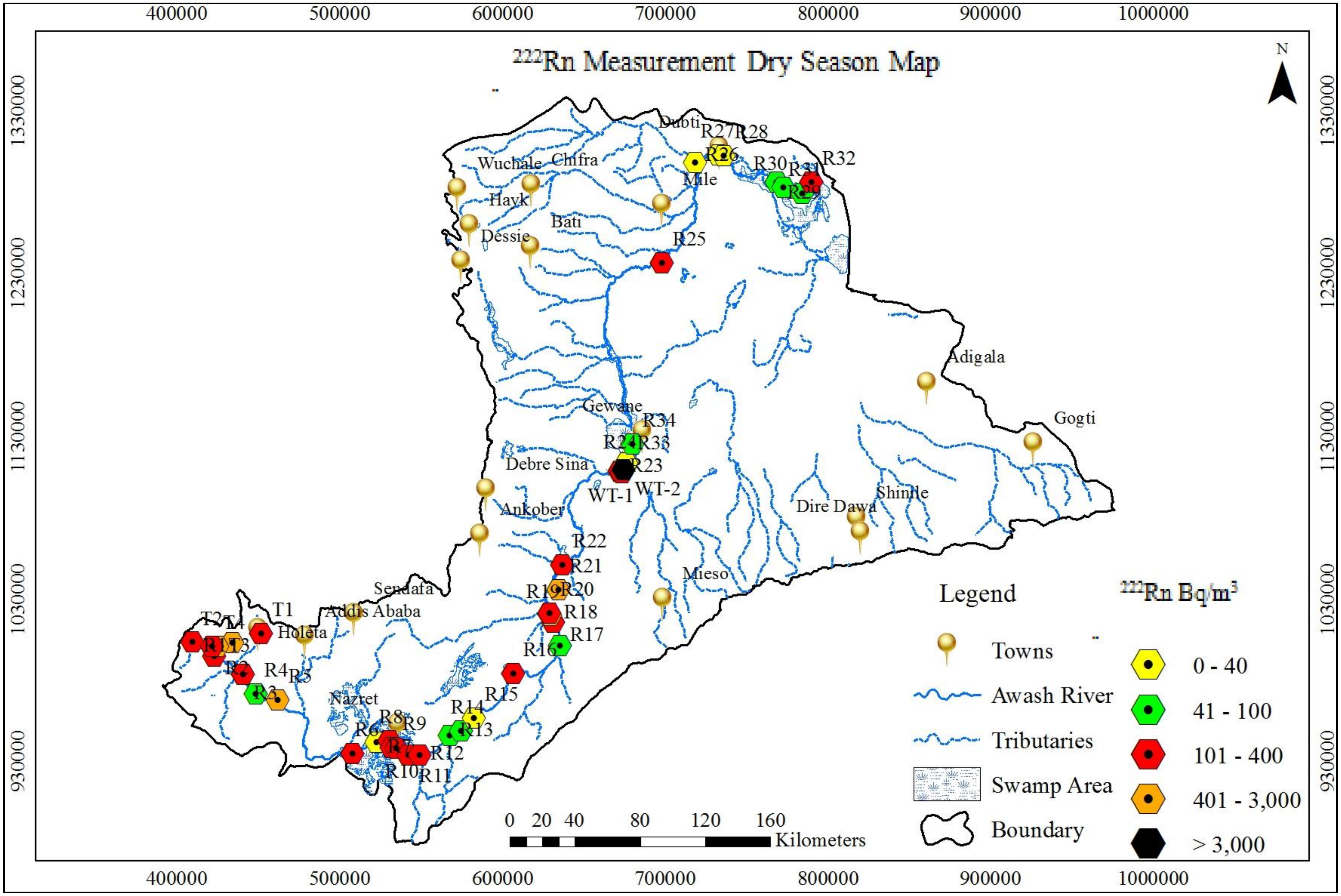


Figure 4.4 ^{222}Rn values during Dry season

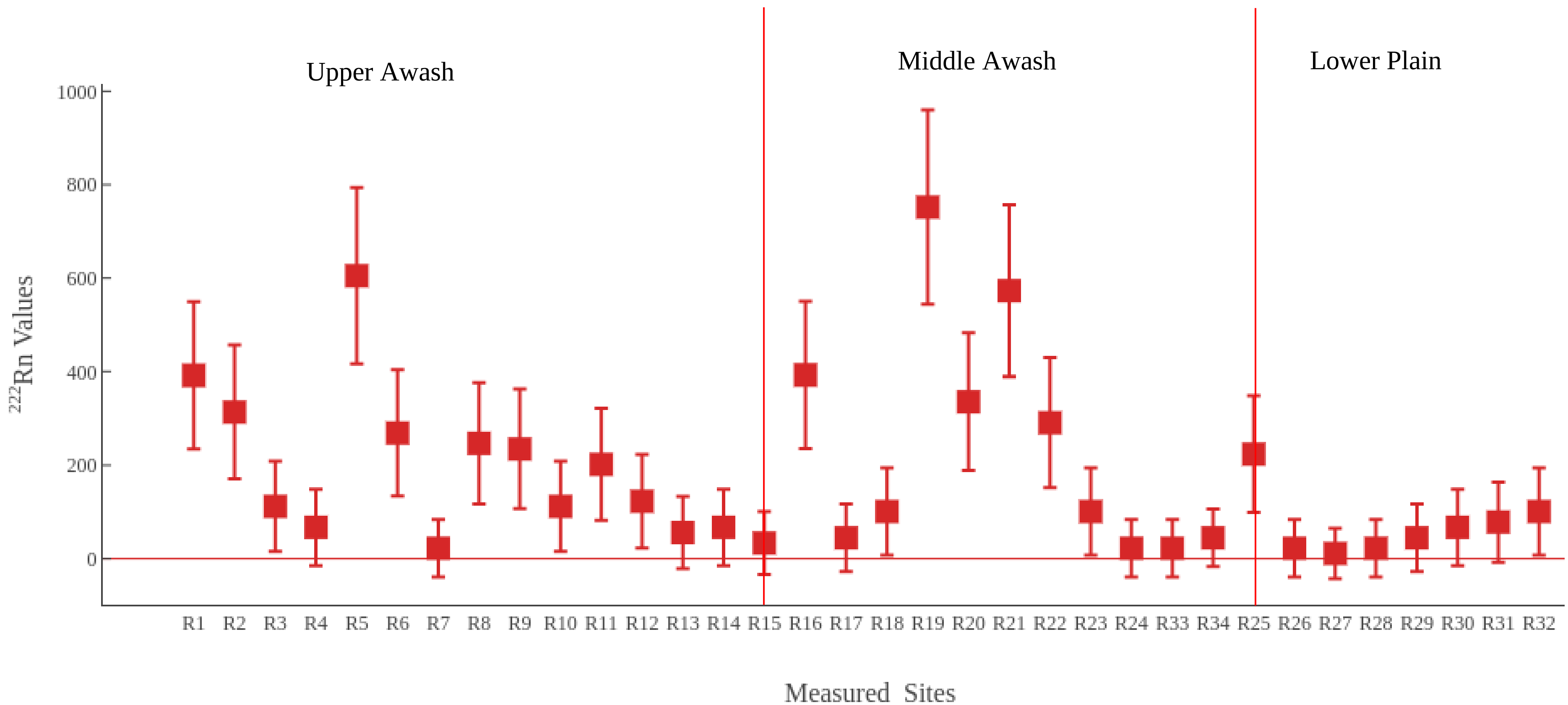


Figure 4.5 Error bar representation of ^{222}Rn level During Dry season

4.2 Deuterium and Oxygen-18

Ratios of stable isotopes δD and $\delta^{18}O$ are used for several geohydrological investigations based on fractionation, depending on the factors such as altitude, distance from ocean and evaporation. By large, stable isotopes of oxygen-18 and Deuterium are helpful in assisting for the identification of potential flow path of groundwater, mixing of water between different aquifers or source of water (Woocay and Walton, 2008).

Several researches have been carried out on identifying the groundwater movements and sources of recharge by using stable isotopes of δD and $\delta^{18}O$. These previous studies proved that it is possible to identify the source of groundwater and flow direction through these stable isotopes. The importance of these stable isotope techniques in water resource investigation is from the perspective that, δD and $\delta^{18}O$ are different for different water origins (K.S. Muir and Tyler B., 1983). In addition various climate zones have different δD and $\delta^{18}O$ that is between geographically separated surface water as well as groundwater.

Awash River, starting from the head water passes through reservoirs (Koka), wetlands (Meteka area) and makes a long journey on various sizes of open channels. This long flow path exposes the river water to undergo evaporation, as it flows along the course down to the lower plain.

On both occasions of the field work a total of 101 water samples were collected for stable isotope analysis. Out of the 101 water samples, 71 of them are from groundwater wells, 15 are from springs and the rest of 15 samples are from upper Awash River segments.

The main purpose of carrying out seasonal sampling is that, isotopic composition of groundwater varies as a result of temperature variability and also as a result of seasonal rain intensity variations. In order to observe such natural changes, sampling is carried out twice the course of the research work. After following a proper sampling and sealing procedures, the water samples are sent for stable isotope analysis. Isotopes of oxygen and hydrogen analysis were performed at laboratory of CNESTEN in the laboratory of Morocco. The analysis was held with a Picarro L2130i laser spectroscope. Significant variations in isotopic composition were observed in the river water samples, spring waters and also samples from groundwater wells of various depths. The results are reported in per mil (‰) relative to VSMOW (Vienna Standard Mean Ocean Water) with a standard deviation of ±0.2‰ for $\delta^{18}O$ and ±1‰ $\delta^{2}H$.

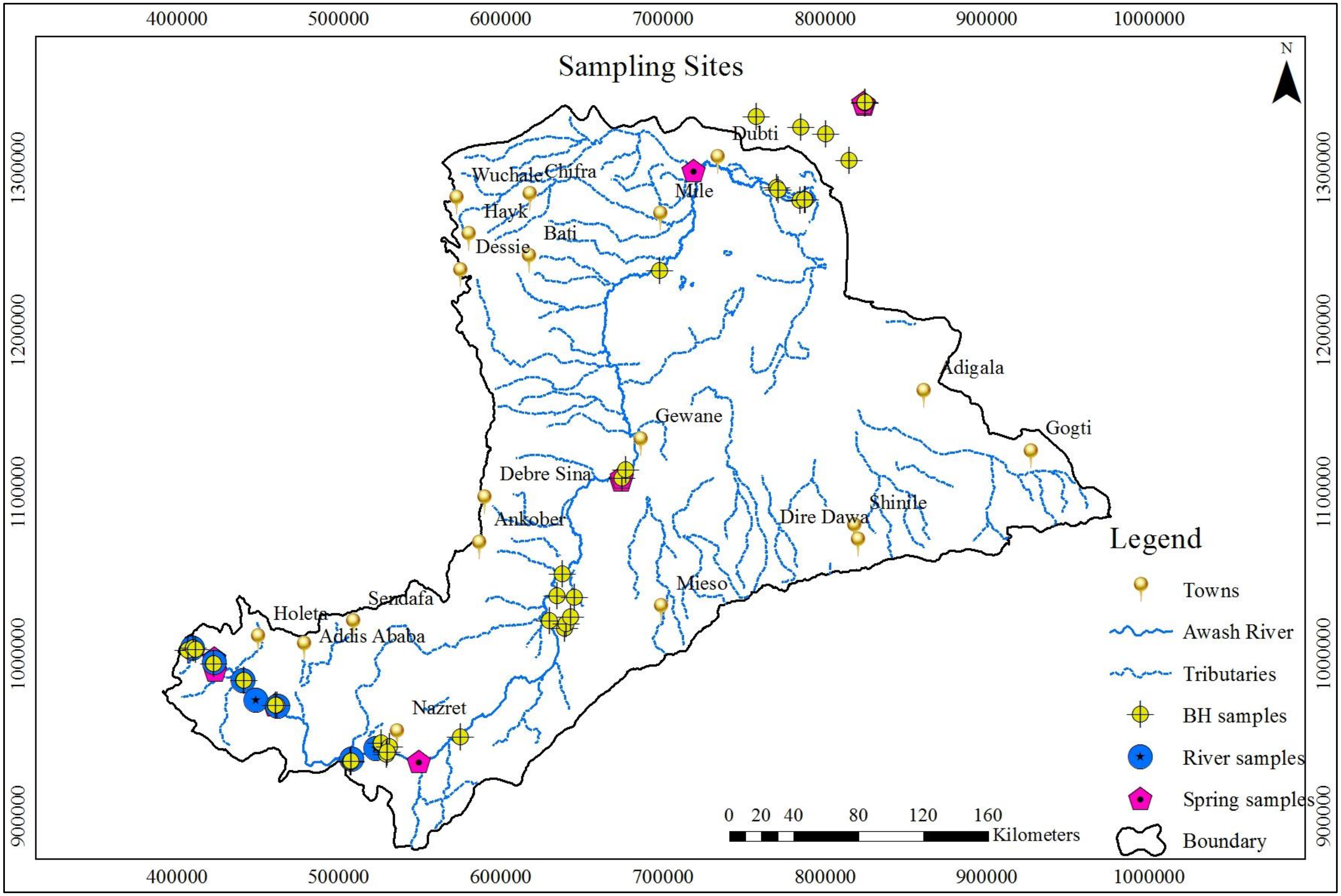


Figure 4.6 Sampling sites for δ^2H and $\delta^{18}O$

4.2.1 δ^2H and $\delta^{18}O$ in Awash River

River water samples were collected from upper Awash River segments. Results were reported in per mil (‰) relative to VSMOW (Vienna Standard Mean Ocean Water) with a standard deviation of ±0.2‰ for $\delta^{18}O$ and ±1‰ δ^2H.

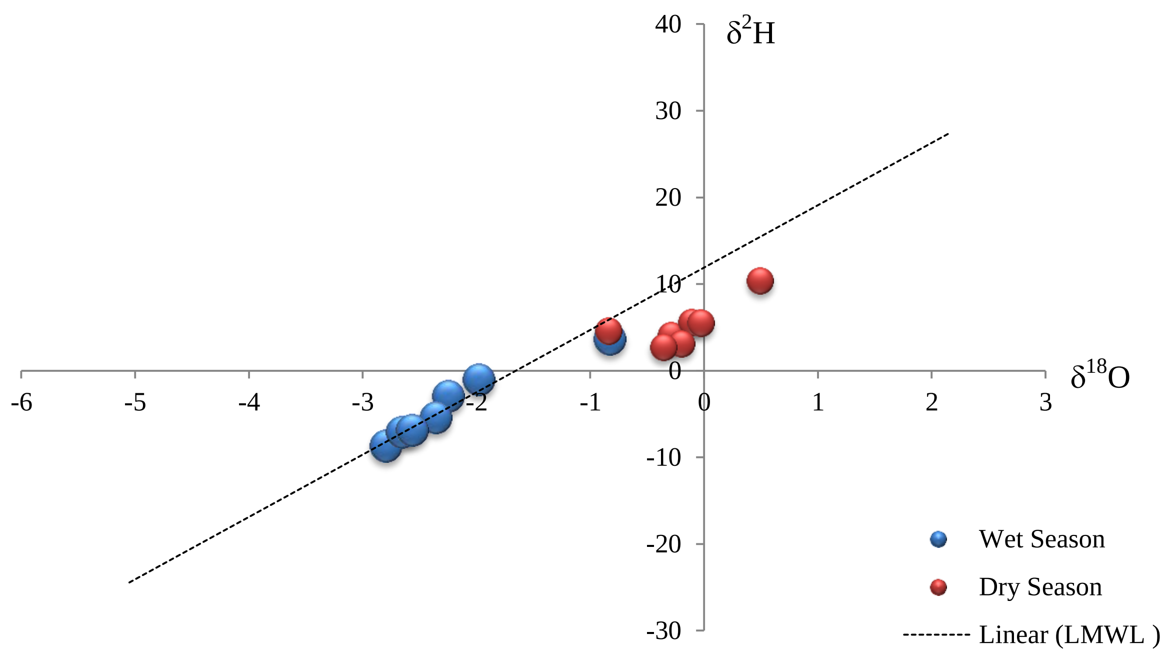
Wet season analysis results of $\delta^{18}O$-δ^2H of Awash River indicate that, there is an observable depletion in isotopic composition of the river waters. This is as a result of the dilution of the river water by the seasonal precipitation, at the time of sampling.

On the dry season survey the same river water samples were collected from upper Awash River segments. These river water samples exhibited a progressive enrichment in $\delta^{18}O$-δ^2H composition, compared to the wet season isotopic values. This can be as a result of evaporative water loss during the dry season.

From the graph below all most all the river water samples fall on the LMWL of Addis Ababa, indicating these river water samples form a similar slope with the LMWL of Addis Ababa. The isotopic compositions of these water samples signify that the river segments are getting recharge direct from seasonal rainfall.

One sample from the lower plain is also analyzed for isotopic composition of $\delta^{18}O$-δ^2H. R_8 (Lake Afambo) where Awash River terminates indicate that the water is highly enriched depicting that the lake is highly affected by evaporation ($\delta^{18}O$ 6.29‰ and δ^2H 40.8‰).

Generally, isotopic composition of $\delta^{18}O$-δ^2H of Awash River showed a sign of enrichment, moving from the upper plateau to the rift valley. This denotes that, the river is affected by evaporation as it flows to the low land of the arid region.



ID	Locality	Wet Season	
		^2H	^{18}O
Rh-1	Ginchi	-0.99	-1.98
Rh-2	Cheleka Bobya	-2.89	-2.25
Rh-3	Awash Belo	-8.66	-2.5
Rh-4	Darimo Kelecha	-7.07	-2.66
Rh-5	Awash Lemon	-5.4	-2.36
Rh-6	Upper Koka	-6.84	-2.57
Rh-7	Koka Dam	3.65	0.83

ID	Locality	Dry Season	
		^2H	^{18}O
Rh-1	Ginchi	4.6	-0.84
Rh-2	Cheleka Bobya	4.1	-0.29
Rh-3	Awash Belo	5.6	-0.11
Rh-4	Darimo Kelecha	5.5	-0.03
Rh-5	Awash Lemon	3.1	-0.2
Rh-6	Upper Koka	2.7	-0.36
Rh-7	Koka Dam	10.4	0.49
Rh-8	Lake Afambo	40.8	6.29

Figure 4.7 Scatter plots of Awash River wet season and Dry season

4.2.2 δ^2H and δ^{18}O of springs

δ^2H and δ^{18}O data from hot and cold spring assists in determining the source of recharge, altitude of recharge, mixing of cold water, thermal diffusion and flow pattern (Gupta, 2010). Spring water samples were also incorporated for this research to determine the groundwater flow pattern as well as to define the source of groundwater recharge along the course of Awash River. Likewise, the results of δ^2H and δ^{18}O were reported in per mil (‰) relative to VSMOW (Vienna Standard Mean Ocean Water) with a standard deviation of ±0.2‰ for δ^{18}O and ±1‰ δ^2H.

The isotopic composition of springs, collected on both events of sampling gives out similar isotopic compositions of δ^{18}O-δ^2H, without a notable variation. From the collected springs, found in Upper Awash, the composition of δ^{18}O-δ^2H depict that the springs are discharging from the deep aquifer system. In addition these isotopic compositions of springs indicate that the springs have similar isotopic composition with the modern day rainfall, suggesting that the aquifer gets its recharge directly from the percolation of seasonal precipitation. Locally recharged aquifer systems like spring Sp_2 get dry on seasonal basis. Whereas spring (Sp_3) demonstrates that the groundwater is discharging from pristine aquifer, suggesting the local groundwater is supplying minable water resource.

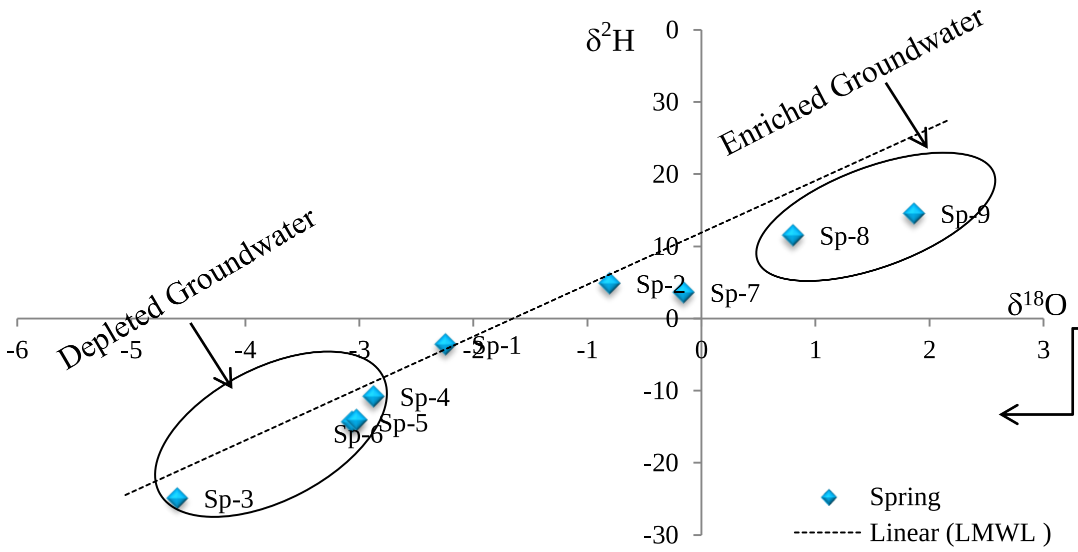
Moving out from the upper plateau, the highly discharging spring Sodera (Sp_4) exhibited some degree of depletion in isotopic composition of δ^{18}O-δ^2H. The isotopic composition of this spring has similar concentration with present day rainfall. The contribution of upper plateau regional groundwater flow down to the rift escarpment is also observed on the isotopic composition of Sp_4.

On section 3.6.3 it has been stated that the middle valley has numerous springs, found one next to each other like a door step. The density of fault, the degree and number of fracturing increases as one goes down to Awash Basin. Most springs found in Meteka area like Sp_5 and Sp_6 are discharging through these observed faults and fractures. The isotopic compositions of δ^{18}O-δ^2H of middle valley springs infer that the springs are discharging from deep aquifer system. Regional groundwater flow down from the upper plateau and minor mixing of Awash River sum up to contribute for the presence and existence of these springs.

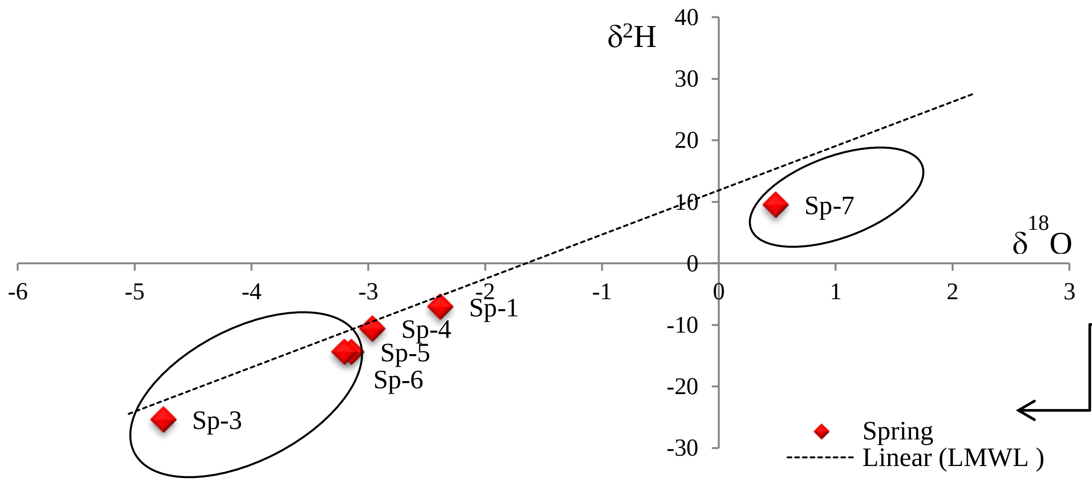
Spring samples were also collected from outside Awash Basin, in order to determine if Awash River is draining outside its basin. These samples are collected from and around Elidar on both occasions of sampling.

The wet season isotopic composition of $\delta^{18}O$-$\delta^{2}H$ of these samples reflects the aquifer system was recharged by the local flood water. On the next phase of sampling i.e. during dry season, these springs went dry, signifying the spring water was recharged from locally percolated and accumulated rain water.

By using the concepts of d-excess value, the values define the isotopic signatures of spring waters and the interconnection of the aquifer system with Awash River. Thus the d-excess value of most of the springs demonstrated that the springs do not have interconnection with Awash River, except springs found in the middle valley (Sp_5, Sp_6 and Sp_7). The isotopic composition of these springs suggests that Awash River water has undergone evaporation prior to recharging the aquifer system of the region.



ID	Locality	Wet Season		
		^2H	^{18}o	D-Excess
Sp-1	Cheleka Boba-2	-3.51	-2.25	14.49
Sp-2	Cheleka Boba-3	4.93	-0.81	11.41
Sp-3	Jimjima Gerba	-24.83	-4.6	11.97
Sp-4	Sodera	-10.73	-2.88	12.31
Sp-5	Arca Spring	-14.28	-3.07	10.28
Sp-6	Meteka	-13.96	-3.03	10.28
Sp-7	Logiya	3.69	-0.16	4.97
Sp-8	Elidar-1	11.6	0.8	5.2
Sp-9	Elidar-3	14.62	1.86	-0.26



ID	Locality	Dry Season		
		^2H	^{18}o	D-Excess
Sp-1	Cheleka Boba-2	-7	-2.39	12.12
Sp-2	Cheleka Boba-3	Seasonal (Dry)		
Sp-3	Jimjima Gerba	-25.3	-4.76	12.78
Sp-4	Sodera	-10.5	-2.97	13.26
Sp-5	Arca Spring	-14.3	-3.15	10.9
Sp-6	Meteka	-14.3	-3.21	11.38
Sp-7	Logiya	9.6	0.48	5.76
Sp-8	Elidar-1	Seasonal (Dry)		
Sp-9	Elidar-3	Seasonal (Dry)		

Figure 4.8 Scatter plots of spring (a) wet season, (b) Dry season

4.2.3 δ^2H and $\delta^{18}O$ in Groundwater wells

Several researches proved that, interconnection between aquifers, discharge process and groundwater flow mechanisms can be best deal with the analysis of stable isotopes of groundwater. Thus analyzing groundwater samples best suited for this research from the perspective that groundwater surface water interaction can be well investigated through stable isotopes.

During the wet season sampling event, 30 groundwater wells were sampled for sable isotope analysis. In addition, 41 groundwater samples were collected on the course of dry season, including boreholes that have been sampled on the previous event of sampling. The additional boreholes samples are incorporated in order to investigate further groundwater and surface water studies.

Groundwater samples, which are collected from upper Awash during the wet season sampling, are isotopically depleted. Almost all the results obtained are below 0‰ ranging between -0.02‰ to -4.8‰. Whereas the dry season analysis exhibited that, the groundwater samples are enriched with respect to heavy isotopes. Some groundwater samples do not demonstrate significant change in isotopic composition, on both occasions of analysis results.

The isotopic composition of $\delta^{18}O$-δ^2H of the groundwater samples collected from Upper Awash depict that these groundwaters have similar isotopic concentration with that of the present day rainfall. The similarity of the isotopic concentration of the modern day rainfall and the groundwater's indicate that, the aquifer system of the region is recharged with fresh rain water from upper highlands during cold climate conditions. Boreholes sampled from upper Awash on both occasions of sampling postulate that there is no signature of mixing of Awash River with the groundwater system.

Groundwaters that are found after the town of Awash Belo (BH-8 to BH-14) notify that, the groundwater wells are supplying from old aquifer system (pristine aquifer). This indicates that a minable water resource is being pumped out without any replenishment.

In between these boreholes, groundwater wells found around Koka (BH-11 and BH-12), even if these boreholes are discharging from deep aquifer system the isotopic composition of $\delta^{18}O$-$\delta^{2}H$ of the groundwater wells signify that, there exists a minor interconnection of Awash River with the deep Aquifer system.

Moving to the rift escarpment, the isotopic composition of the groundwater wells point out that, the groundwater has similar isotopic composition to that of the modern day rainfall. This suggests that the aquifer system get recharged from deep percolation of seasonal precipitation that occurred on the upper plateau. By using the concept of d-excess value boreholes of Wonji area BH-15 to BH-18 the compositions of $\delta^{18}O$-$\delta^{2}H$, postulates that the deuterium intercept is <10. From this it can be inferred that, in addition to the deep percolation of rain fall recharge, the local aquifer system of the area is highly connected with Awash River. The interconnection of these boreholes with Awash River proves that, the river is contributing, for sustainable supply of the boreholes.

Various modes of groundwater recharge and discharge conditions are well observed from groundwater samples collected from Middle Awash. Generally groundwaters sample of Middle Awash region are slightly depleted in isotopic composition of $\delta^{18}O$-$\delta^{2}H$. Boreholes of this section include BH-19 to BH-23 and deep wells of Alidegie plain (BH-31 to BH-34). Some of groundwaters in section have similar isotopic composition of $\delta^{18}O$-$\delta^{2}H$ with the present day rainfall and some of groundwater samples notify that the groundwaters are from old aquifer system.

Alidegie plain deep wells that go to 480m are assumed to represent the deeper aquifer system of the region. Groundwaters of this plain (BH-31 to BH-34) signify that, the deep aquifer system get recharged form the percolation of the present day rainfall. On the top of the modern day rainfall recharge source, the plain is assumed to receive much of its water from eastern highland or regional groundwater flow from Upper Awash. The concept of the d-excess value define that, the aquifer system of Alidegie plain has no connection with the flowing Awash River.

The isotopic composition of, BH-19 and BH-20 showed, the deep aquifer is supplying from pristine aquifer system. This signifies that there no interconnection with Awash River or with any other regional groundwater flow.

The other groundwaters found in Middle Awash signify the presence of clear interconnection Awash River with the deep aquifer system. BH-21, BH-22, BH-23 and BH-40 have a similar isotopic composition with the modern day rainfall. In addition the isotopic composition of $\delta^{18}O$-$\delta^{2}H$ of these wells, exhibited the blending of the groundwater with Awash River.

By being exceptional groundwater well found in Tendaho (BH-24) point out that the water is discharging from deep pristine aquifer. This aquifer has no connection with Awash River or with other regional flow, indicating the groundwater is mining is taking place around this region.

Reaching to the termination point of Awash River, groundwaters of Afambo and its environs contains isotopic signature of Awash River that has been evaporated prior to recharging the aquifer system of the region.

Groundwater samples in lower plain and even further to the Danakil depression have been utilized for this research in order to observe if Awash River flow out of its basin. On both events of sampling, isotopic enrichment is observed on boreholes found in the lower plain reflecting that an evaporated Awash River has leaked to the deep aquifer.

Moving out of Awash Basin, groundwater samples from Danakil depression (Elidar, Dobi, Afedera and Serdo) and on the way to Djibouti road (Diceheto and Galafi) have also been sampled. Groundwaters of Danakil depression exhibited an isotopic enrichment of $\delta^{18}O$-$\delta^{2}H$. BH-42 gives a signature of an evaporated Awash River to the aquifer system, by having $\delta^{18}O$ 3.1‰ and $\delta^{2}H$ 19.2‰. This reflects the blending of the shallow aquifer system with the evaporated Awash River. BH-30, BH-37, BH-38 and BH-39 point out that the isotopic signature of the groundwaters takes back after the local flood water.

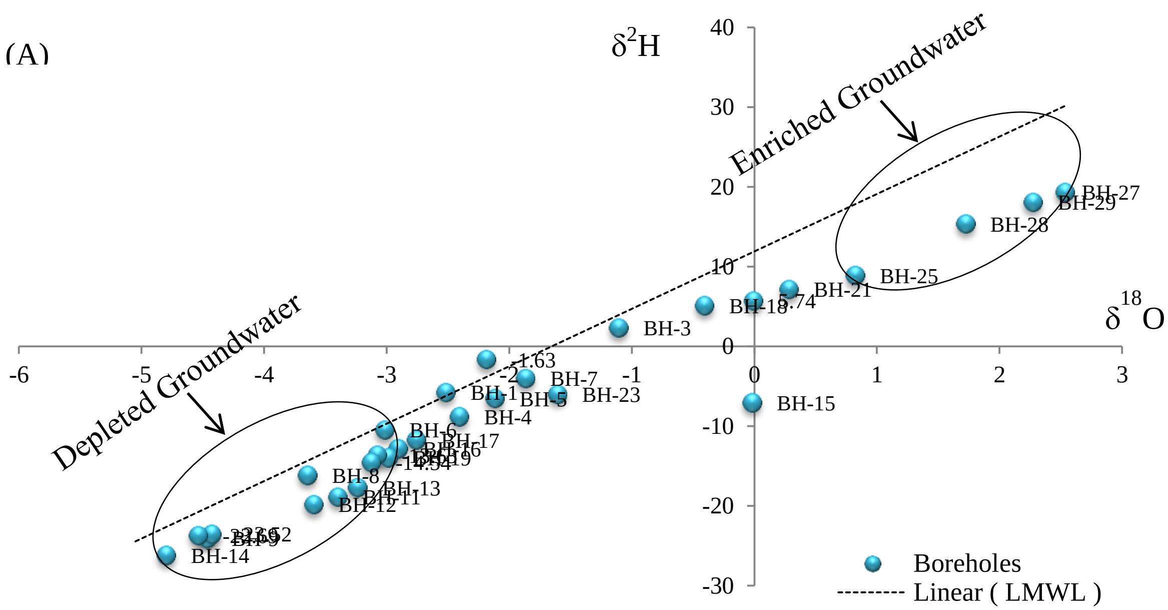


Figure 4.9 Borehole samples collected during wet season

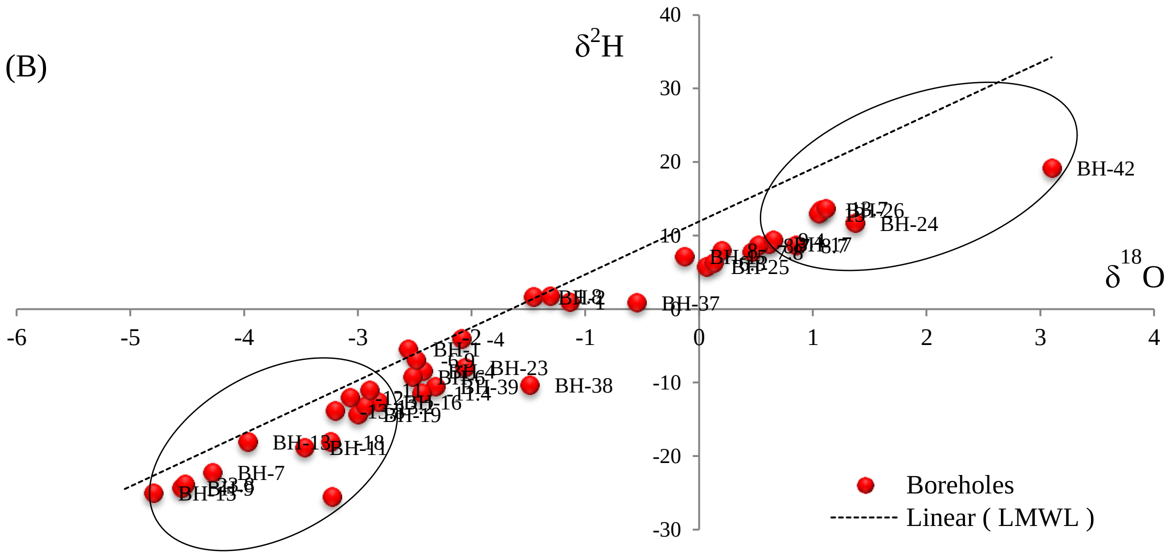


Figure 4.10 Borehole samples collected during dry season

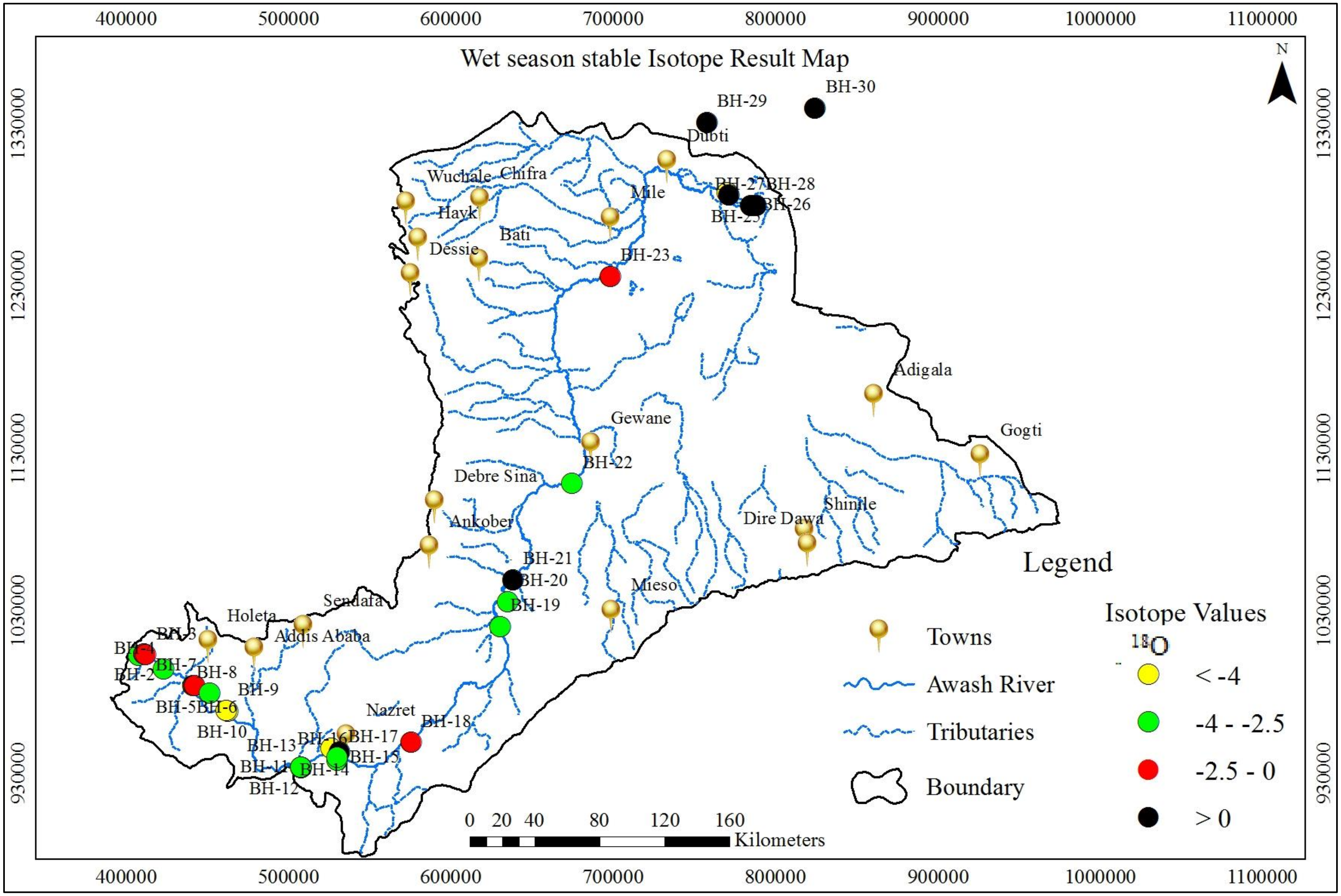


Figure 4.11 Distribution of Stable Isotopes of wet season

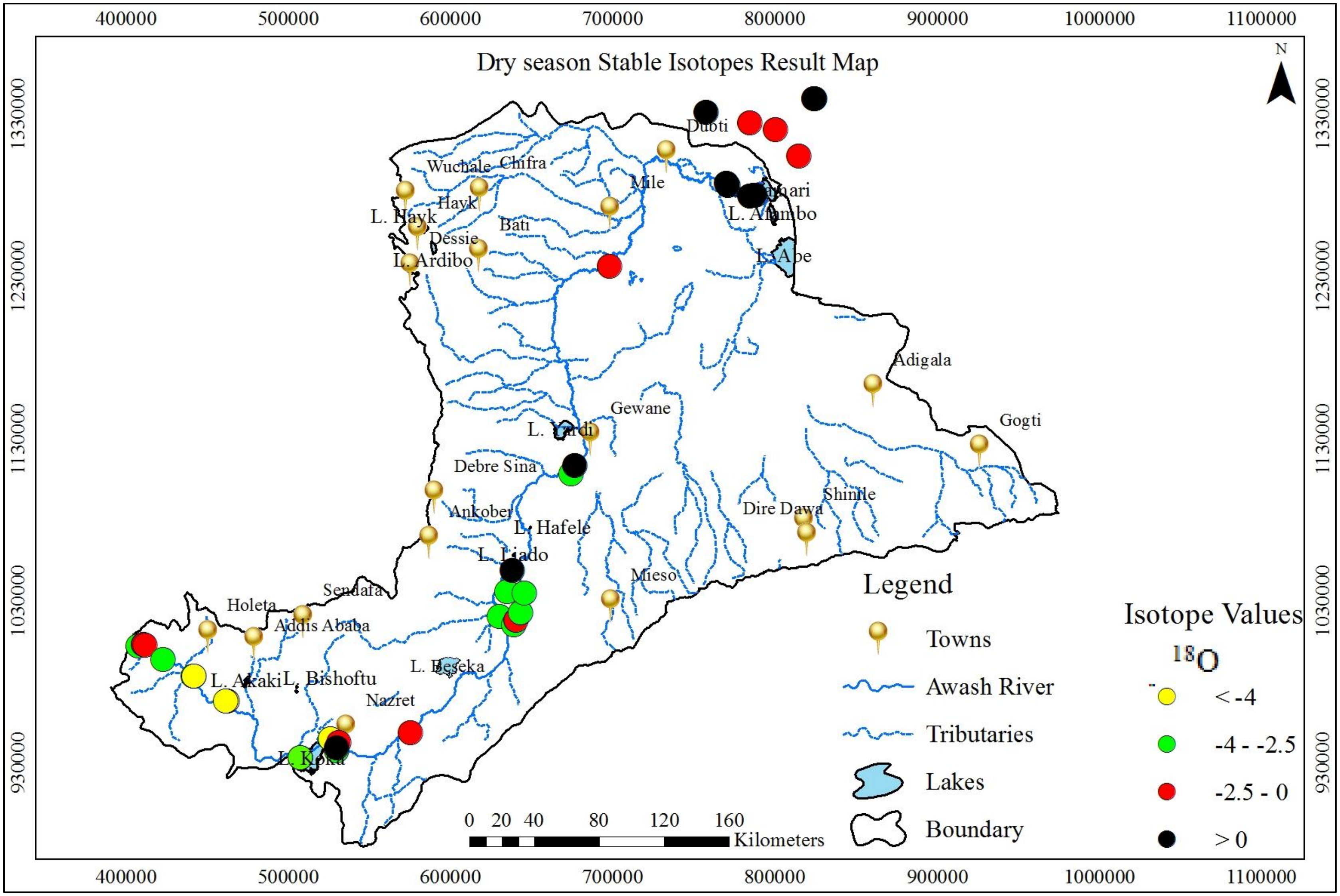


Figure 4.12 Distribution of Stable Isotopes of Dry season

4.3 Piezometeric head distribution and groundwater flow direction

The importance of piezometeric evidences has been mentioned on section 2.3, in addition to the stated significance, the main objective of incorporating piezometeric data for this research is to support the other two methodologies carried out, by using radioactive isotope and stable isotopes.

Integrating the isotopes analyses with piezometeric evidences will contribute to have a better insight and understanding for the groundwater flow conditions. For this section of the research special emphasis is placed on groundwater flow conditions to determine areas where groundwater surface water interaction is taking place along the stretch of Awash River.

A depth to water table maps (isobaths map) are generally the projections of equipotential groundwater heads, which can by and large represent any aquifer systems. Isobaths maps can show a spatial distribution of the depth of a water table (Gundogdu et.al, 1983). Water level data's are used to construct isobaths maps, which can show spatial variation of groundwater elevations (USGS, 1999). Groundwater elevation variation at any geographic setting can assist, to determine groundwater flow conditions and the degree of groundwater surface water interaction. Thus, producing a water table map is very important approach to incorporate in any groundwater investigations (Gundogdu et.al, 1983).

As a result of large topography variations and various irrigational schemes sites, it is required to define Awash Basin in to some sections or sub-basins. Classifying Awash Basin to selected sections or sub basins is carried out based on similar environmental conditions and topographic settings. It is then subdivided in to 6 segments, the sectioned areas include, upper Awash, Wonji irrigation area, Metahara section, Middle Awash section, Middle valley and the lower plain of Awash Basin. This approach contributes to clearly identify which river segments of Awash River are losing and gaining, on the top of that, it will also support to indicate the groundwater flow direction.

Piezometeric data are typically scares in Awash Basin, thus additional data sources are used in order to fill the data gap formed as a result of limitation of Piezometeric evidences. Groundwater levels of test wells and production wells found in the basin are used as an additional input to generate a water table map.

Piezometeric well information is collected from MOWIE. Groundwater levels and additional information's of test wells and production wells are compiled from WWDSE.

Hydraulic head observations of water wells having a penetration depth of 100m and above are mostly utilized for this research, by assuming that these wells could represent the regional aquifer system. Besides using the static water levels of these wells the associated lithostratigraphy layers have been also used to determine the flow geometry of the groundwater in the basin.

There are so many deep and shallow boreholes in Awash Basin that are drilled for various purposes, but there are only 470 boreholes with a full information and suitable for producing water level maps for this research.

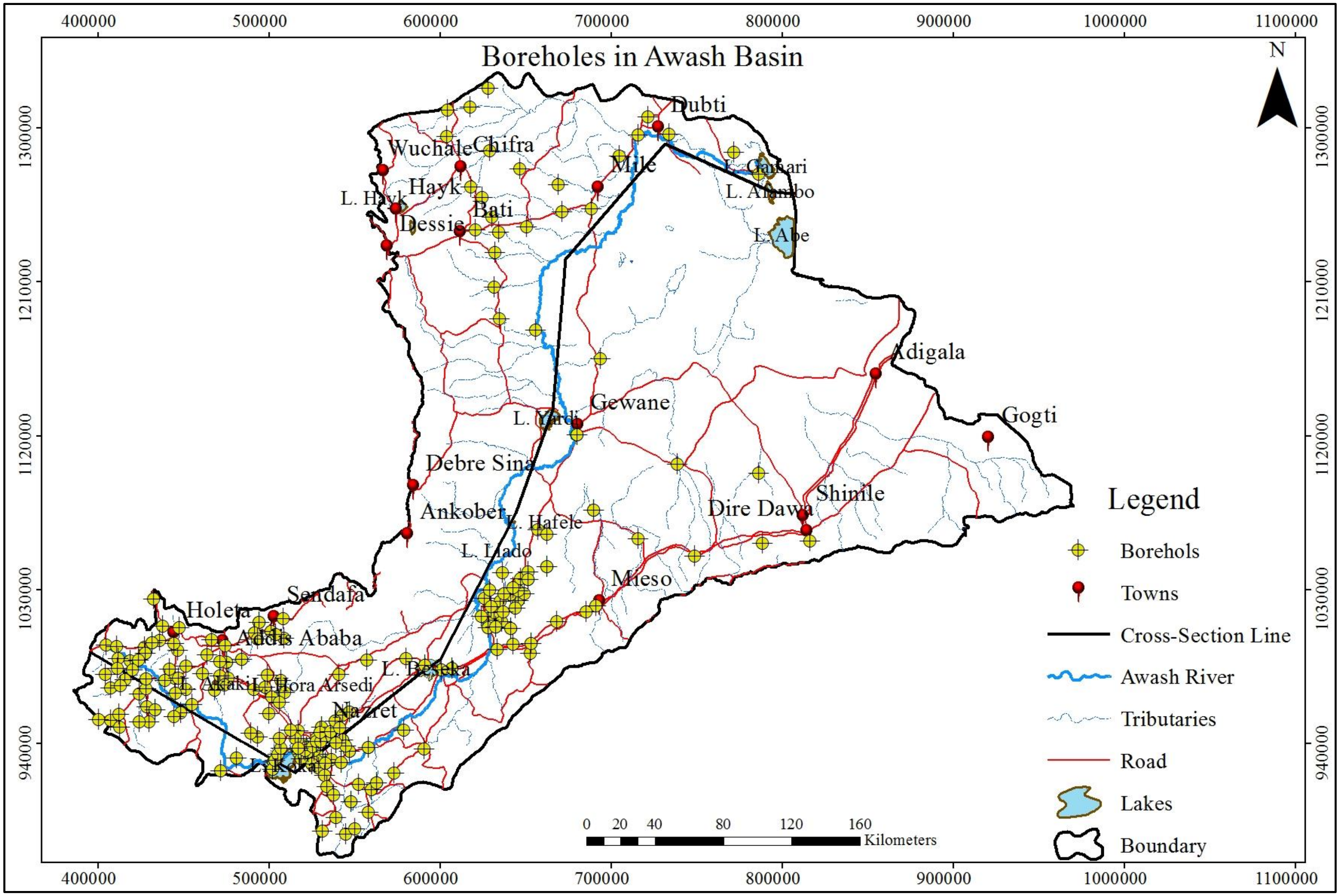


Figure 4.13 Boreholes used for Contour Maps

The first section of the water table map is the Upper Awash section. This section starts from the head water i.e. from Ginchi (R_1) down to Lake Koka (R_7), which is considered to have similar physiographic setup and similar environmental conditions throughout the section (Figure 4.14).

Isobaths map of this section is produced by using groundwater levels of 92 deep boreholes which are drilled for various purposes. The contour lines are generated with a contour interval of 50m. These equipotential groundwater head-lines of Upper Awash converges towards upstream of Awash River, indicating that groundwater slopes towards the river. Presentation

On the Geology section of this research (Section 3.5) it has been stated that Upper Awash is dominantly covered with a layered Ashangi group. These groups mainly composed of volcanic Rocks such as Basalts, Ignimbrites, Trachytes and Rhyolites. These fractured volcanic rocks are the most favorable formations for highland recharge in Upper Awash (Tenalem Ayenew, et.al, 2007). The layering of this Ashangi group in this section results in restricting the vertical permeability of the groundwater that result in the contribution of surface water system (Halcrow, 1987). By integrating these geological setting of Upper Awash with the trend of the contour lines, it can be inferred that that the groundwater is seeping towards Awash River through these volcanic aquifers. Besides geological settings, geological structures are also primary controlling factor in groundwater flow conditions. Naturally faults and fractures can act either as a barrier or channels for groundwater flow. In this section of the basin the fault get dense around R_5, thus the groundwater flow seems to be guided by geological structures that generally trends SE-NW direction.

The groundwater flow lines are tend to be more vertical at the northern part of this section indicating that the aquifer system of the area is less permeable. On the top of this the contour lines are closely spaced depicting that the area has steep slope with low conductivity. Whereas going down to the lower part of this section around Debrezeyt and upper Koka area (R_6), the aquifer system becomes highly permeable. The horizontal orientation of the flow lines and the evenly spaced contour lines indicate the permeability of the aquifer system.

In general, the contour lines that cross Awash River from R_1-R_7 follow gentle slope pointing upstream of the river. These lines indicate that, there is a hydraulic gradient from the groundwater towards the river segments, depicting that Awash River is gaining river. Owing to the topography and the highly conductive nature of aquifer system of Upper Awash, groundwater Contribution to Awash River is high.

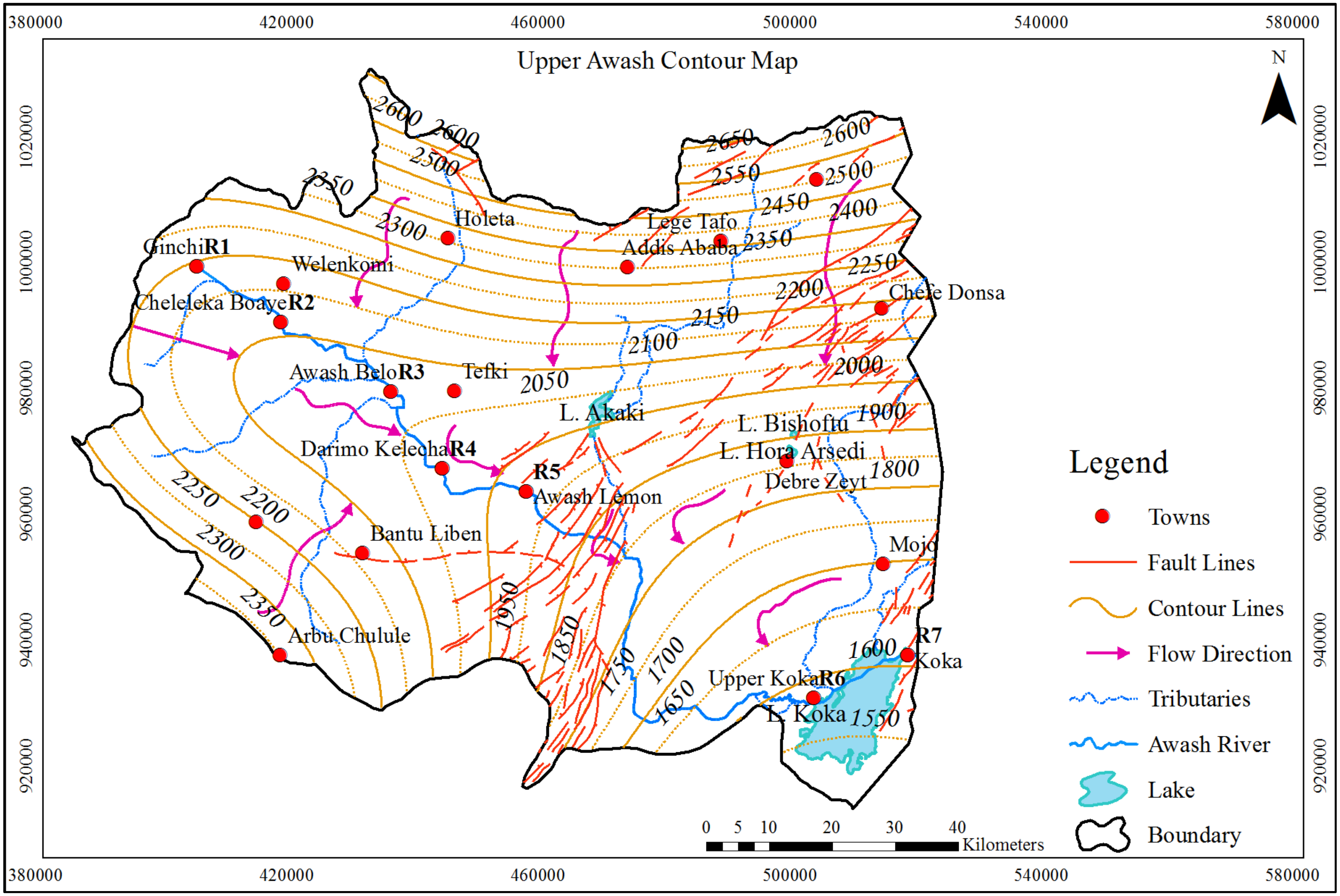


Figure 4.14 Contour Map of Upper Awash

The next section is wonji area, where one of the largest Sugar Estate in Awash Basin. Wonji sugarcane farm and the town have a very gentle and regular slope, which is a favorable topographic setting for farming activities. The main source of water supply for this farm is Awash River, where water is pumped from the river through a pumping station to the sugarcane plantation.

This section contains areas starting from Wonji (R_8) down to Doni river segment (R_{13}). The water table map of this section is produced by utilizing groundwater levels of 100 boreholes with a 50m contour interval. The resulting contour lines from the equipotential groundwater head of these boreholes form various patterns.

The contour lines produced along Awash River segments spread-out by forming a wide space among each other. The wide space formed between the lines indicates that the area has a gentle slope with an aquifer system of high hydraulic conductivity. Whereas the contour lines formed at the southern part of the section are very closely spaced signifying, the steepness of the area as well as the low conductivity of the section.

The conductive nature of the northern section aquifer system can also be inferred from the groundwater flow lines. The groundwater flow lines tend to be more horizontal on the northern section, indicating that the aquifer system composed of highly permeable geological formations. As Kazmin and Seifemichael (1978) noted aquifers of the rift starting from Nazreth and further north east to Welenchit town is characterized by interlayering of the alluvial sediments, Ignimbrites and fractured Basalts associated with a highly faulted terrain. These volcanic aquifers creates and form a good water bearing zones with the dominate SE-NW fault configurations. Abera Taye (2007) classified this region as one of groundwater discharging zone with a high groundwater potential. The SE-NW trends of these faults generally control groundwater flow system of the area, by channeling the water down to the rift floor.

The collected water level data’s of Wonji town and its environs, witnessed that the groundwater table of the boreholes is at shallow depths. Thus main recharge for this shallow aquifer system could be seepage from Awash River and Lake Koka. The deep aquifer is assumed to receive much of its recharge from highland of Upper Awash that is mainly controlled by topographic setting and degree of fracture of the rift volcanics. Generally Awash River is gaining in this section where groundwater contribution is very high depending on seasonal variations of groundwater level and Awash River water level rise.

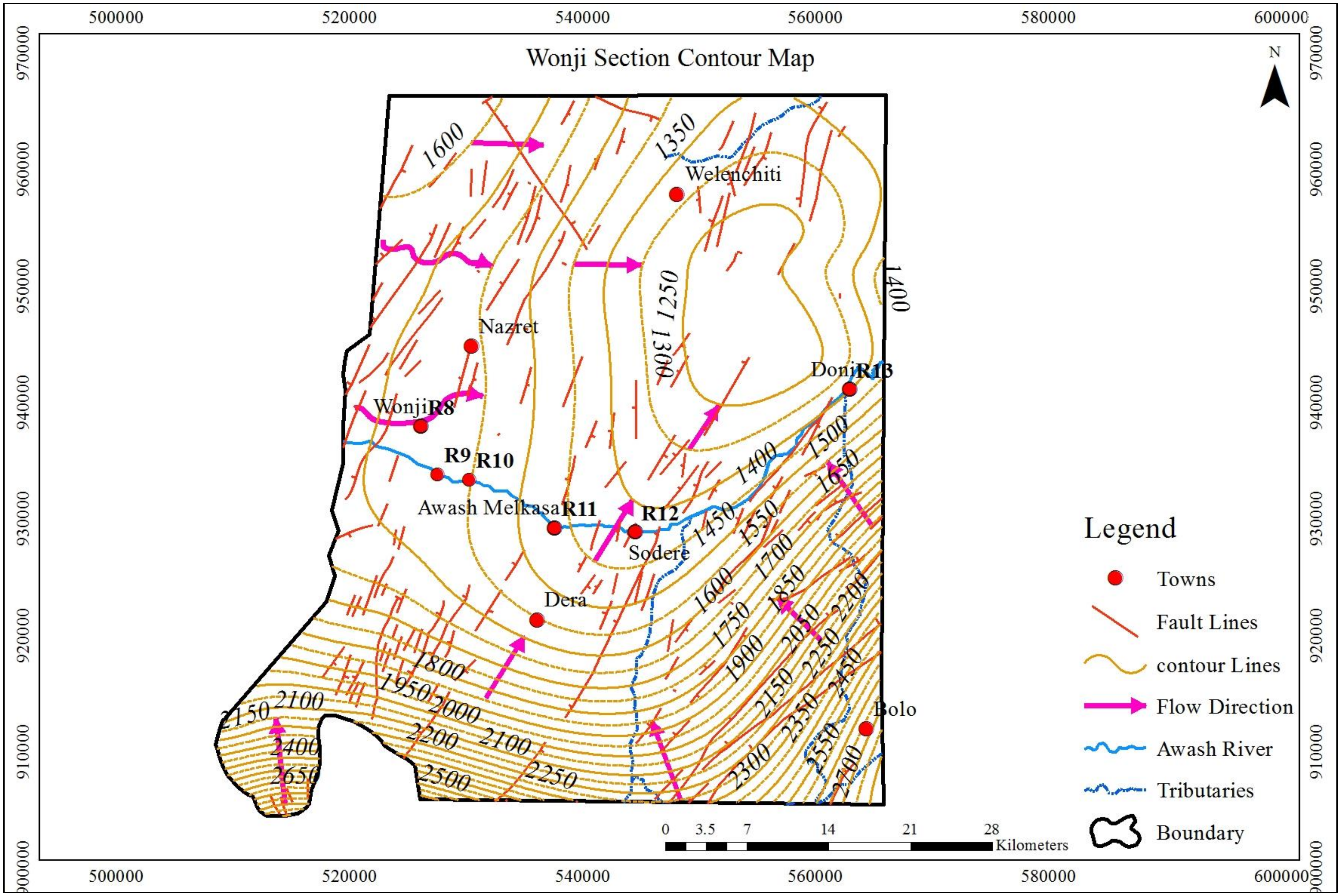


Figure 4.15 Contour Map of Wonji Section

The other section comprises Awash River segments, which start from upstream of Koka down to Metahara (Figure 4.16) including the earlier discussed Wonji section. Incorporating the pervious section here assists to have a better insight on the losing and gaining segments of the upper valley of the Basin. The isobaths map of the upper valley is produced by utilizing groundwater levels of 150 deep and shallow boreholes with a contour interval of 50m.

The geological formation of upstream of Lake Koka is dominantly lacustrine deposits, which creates a hydraulic linkage with the aquifer system by contributing water for Awash River. Going down to the lake at R_7 this linkage become less but the river becomes the source of recharge for the aquifer system, Awash River is a losing segment at this section. This can also be witnessed from groundwater levels of boreholes found around this area which exhibited a water level lower than Awash River. In addition from the contour lines around Koka dam, (R_7) the lines diverges from upstream of Awash River, indicating that the Lake water is discharging towards the groundwater system.

Moving to the Wonji area, Nazreth and even further to Metahara the recent highly fractured Wonji group covers the rift and the escarpment (Tenalem Ayenew et.al, 2007). The degree of fracture with a dense fault configuration, favors the discharge of groundwater to Awash River, by making the section a gaining river segment. Contour lines from R_8-R_{16} converges towards upstream of Awash River, depicting Awash River is a gaining river segment. Reaching around Lake Beseka the contour lines form approximately a concentric closed contour with decreasing values towards the center. This indicates that the discharged groundwater is accumulating at Lake Beseka.

The lineament density of this section increases while going down to the middle valley. The dense orientation and the variously oriented fault systems with various size fault alignments serves as a conduit for the passage of groundwater. The flow of groundwater through highly fractured volcanic rocks, can adequately contribute groundwater for Awash River. The horizontally oriented flow lines formed along the Metahara section indicates that the aquifer system becomes highly permeable following the densely populated faults.

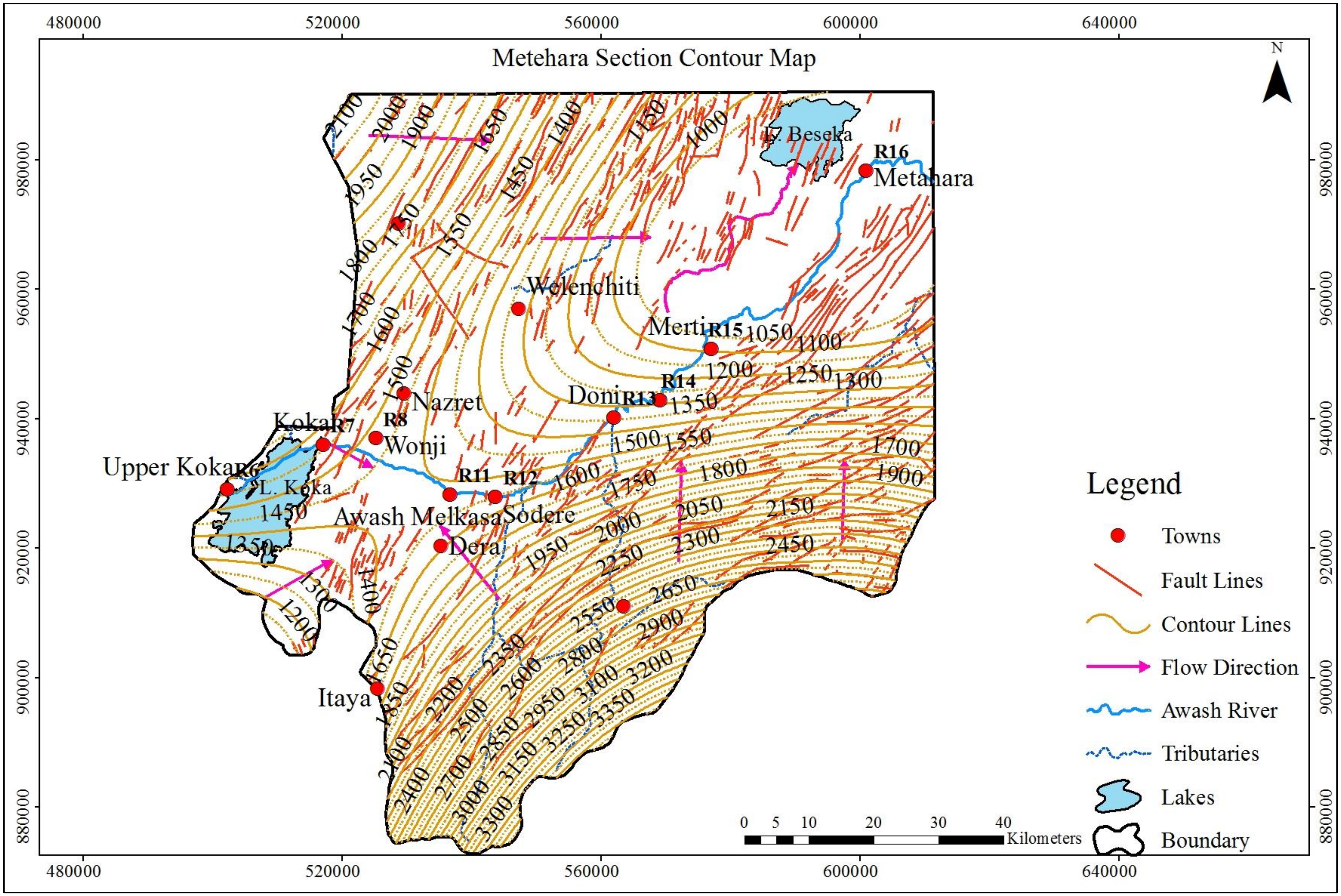


Figure 4.16 Metehara Section Contour Map

Following the flow of Awash River water table maps for middle Awash has also been produced. This section is meant to be analyzed alone from middle valley is as a result of the presence of irrigational activities that can affect the natural flow of groundwater. The water table map of this section is produced by incorporating 55 deep boreholes, groundwater level points with 50m contour interval.

The contour lines crossing Awash River around Awash Sebate points up stream of the river signifying the river segment is a gaining river. This contour lines that cross Awash Sebate, stretch and spread-out by pointing downstream of Awash River, suggesting the presence of a losing river segment.

Such orientation of contour lines once pointing upward and again pointing downward on the same trend depicts the presence of bidirectional movement of water. Moving even further to Melka Worer the same zigzag pattern is repeated reflecting the presence of two directional movements. The contour lines indicate that Awash River is a gaining river segment at Melka Sede and Melka Worer. Then the same contour lines lengthens towards Amibara area by pointing downstream of Awash River, suggesting Awash River is a losing river segment.

Owing to the natural gentle slope, the presence of fractured rift volcanics accompanied with a dense fault system play a primary role for the existence of this bidirectional flow of water. This section clearly indicates Awash River and the deep aquifer system are hydraulically connected to one another.

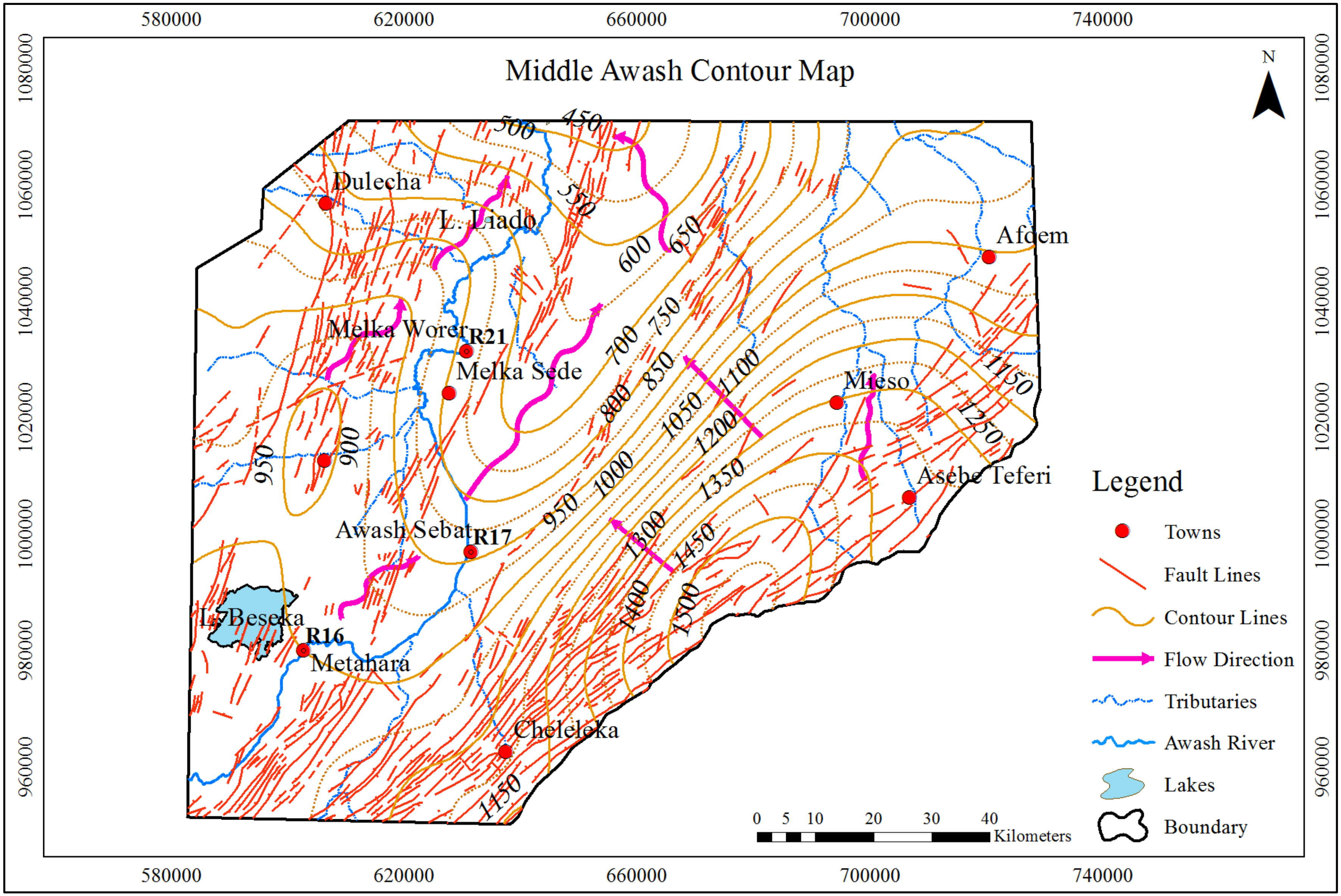


Figure 4.17 Middle Awash Contour Map

Based on physiographic setup Awash Basin has been classified to four sections, one of the sections is the middle valley. Middle valley stretches from Metahara up to Mile town. For this section the middle valley is cropped up to the town of Adayitu. Thus groundwater table map of the middle valley is generated by utilizing all the boreholes that has been used for Metahara and Middle Awash section. A total of 64 deep and shallow boreholes are incorporated to create an isobaths map for the middle valley with a contour interval of 75m.

On the previously discussed section of Middle Awash, both gaining and losing river segments and the bidirectional movement of water has been observed. The same contour pattern is also displayed here in a large scale of the middle valley.

Away from Melka Worer, the contour lines that cross Awash River at Lake Leado points upstream, suggesting Awash River is a gaining river segment. Moving away from Lake Leado, the contour lines that are created around Lake Hafele form a single concentric circle with a decreasing value, depicting the accumulation of the flowing water in the lake.

By projecting borehole data's located at the eastern and western side of the section the flow of groundwater has been identified. The contour lines formed at the eastern and western section infer groundwater is converging towards Awash River channeled by NE-SW trending faults through the alluvial and fractured rift volcanic aquifers. As a result of the limitation of borehole information's around Meteka and Gewane area the clear picture of the flow of groundwater cannot be displayed.

Generally, as a result of the good aquifer system in the valley of the basin and the dense fault system around Awash River creates a gaining river segments up to the town of Adayitu.

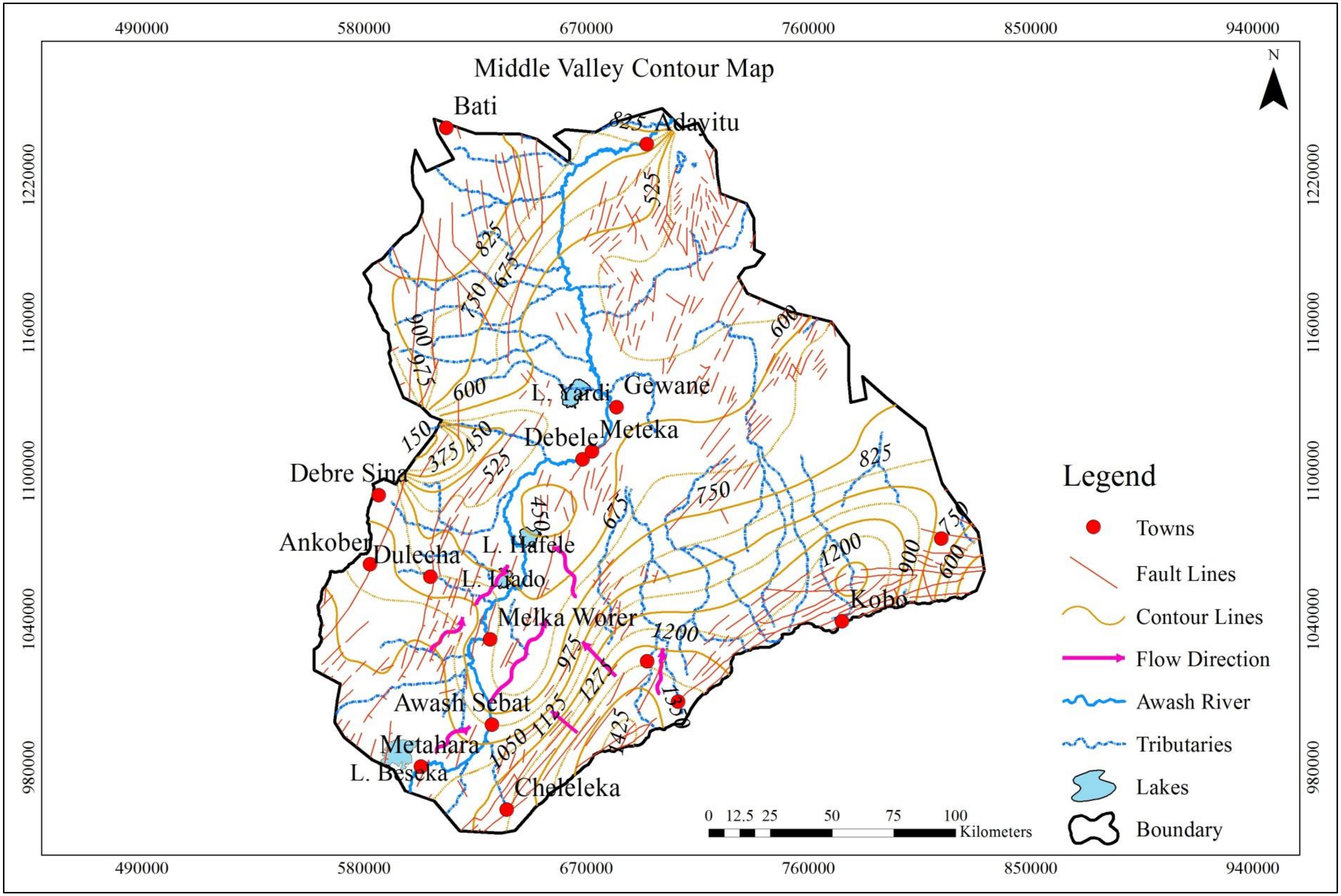


Figure 4.18 Contour Map of middle valley

For this section the lower plain is discussed from the town of Adayitu i.e. extending from the previous section (Middle Valley). The isobaths map of the lower plain is prepared by incorporating 53 borehole groundwater heads with a contour interval of 40m.

It has been mentioned on the geology and hydrogeology section that, the lower plain is dominantly covered by the geological formation of the Afar group. This group mainly composed of Rhyolites and Ignimbrite interbedded with alluvio-colluvial deposit with the dense fault system with various orientation and length.

In the lower plain case the contour lines diverge from the upstream by converging towards downstream, where Awash River terminates. This indicates that Awash River is a losing segment at the lower plain of Awash Basin.

Following the pattern of the contour lines starting from the western side of the section, the lines infer that groundwater is flowing down to the direction of the Lakes from steep slope. After then, at Werenso the contour lines start to get apart depicting the groundwater is flowing on gentle slope.

The general groundwater flow pattern of the lower plain is towards the lowest topographic part of the basin, where Awash River contributes to the aquifer system.

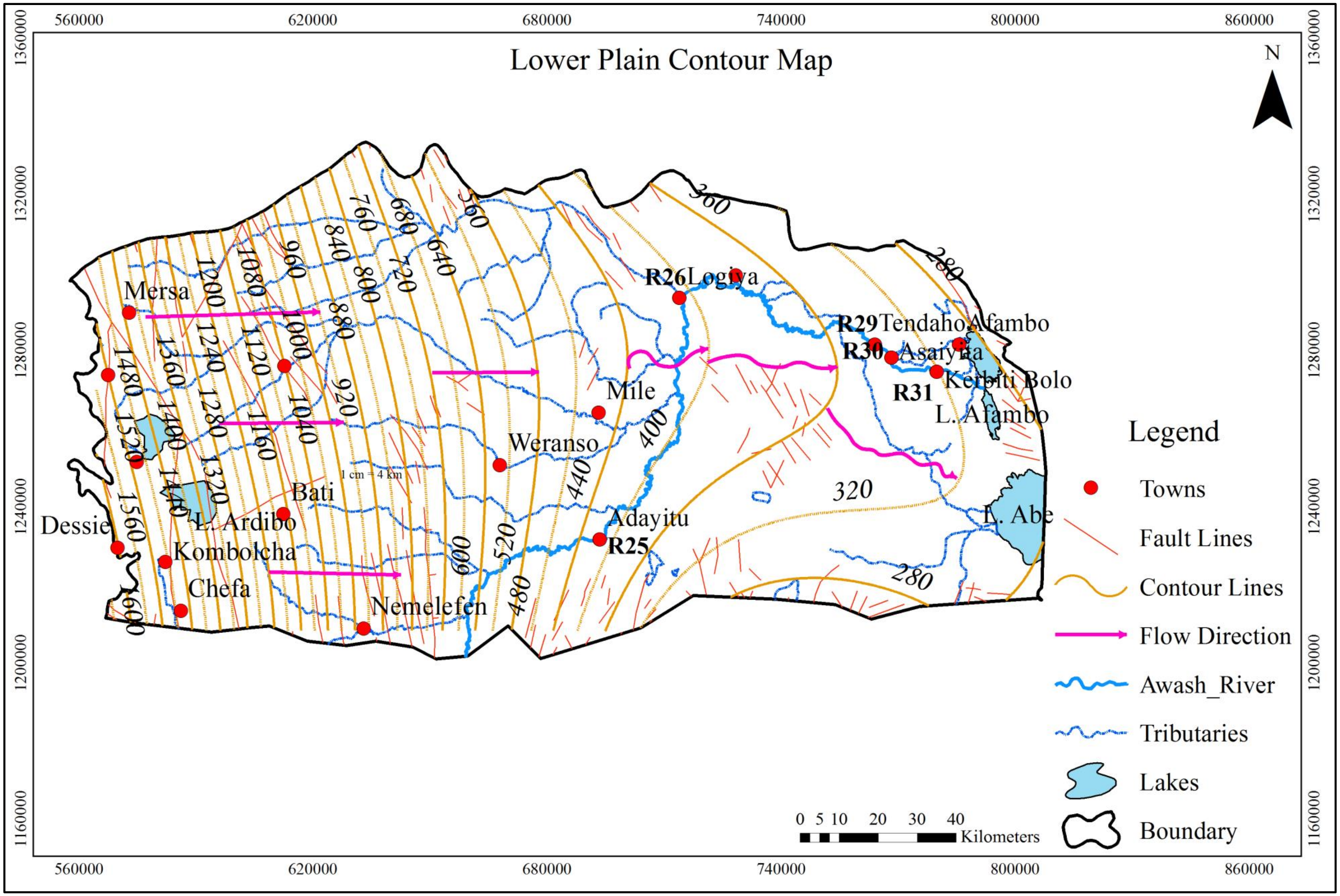


Figure 4.19 contour Map of Lower plain

Taking all the previous borehole information's Awash Basin water table map has also been produced. Several deep and shallow boreholes are incorporated to generate the isobaths map of Awash Basin with a contour interval of 100m.

On previously discussed Awash Basin Sections, the gaining and the losing river segments has been identified. The same pattern of contour lines is displayed in a large scale. From the water table map below (Figure 4.20) the contour lines starting from upper Awash up to the middle valley point upstream of the river. Suggesting the groundwater is been discharge to the river all the way down to the middle valley.

From the groundwater level head distribution map of Awash Basin on Figure 4.20, it can be clearly seen that, most of the groundwater loss that occur in the lower part of Awash, takes place between Amibara and Mile. This groundwater flows towards North Easterly direction and probably discharges into Lake Abe or into the sea or into other lower areas in Ethiopia. On the lower plain the contour lines generally indicate, Awash River is discharging in to the aquifer system, depicting that the river is a losing segment.

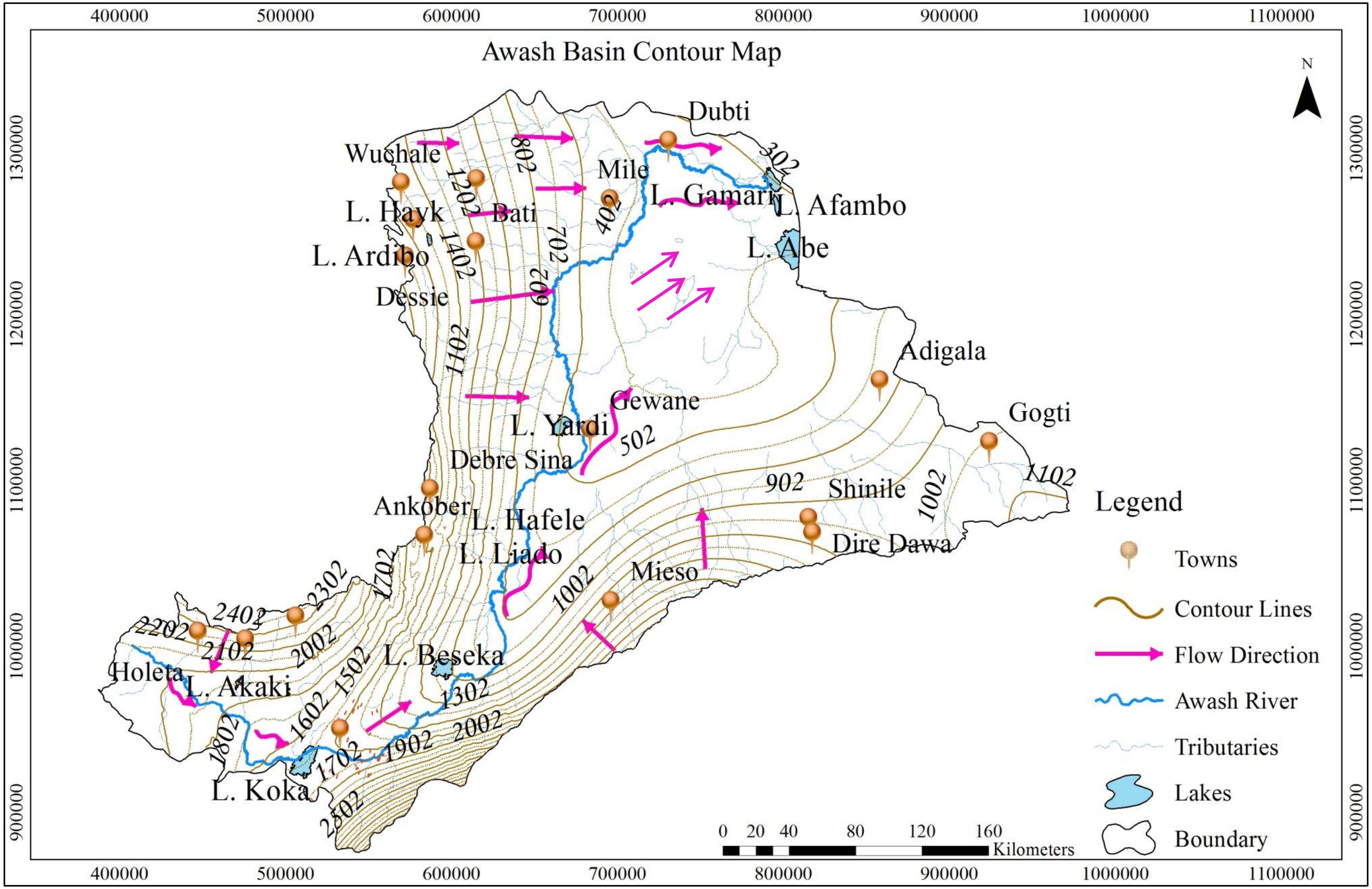


Figure 4.20 Contour Map of Awash Basin

4.4 Recharge sources and well fields in Awash Basin

Surface water or groundwater is not commonly available at locations and times where and when it is most needed. Consequently, various mechanisms are applied in order to distribute and utilize this resource from available zones to areas that is most needed.

Regardless of the scale of the water-supply system, proper development of either of the water resource i.e. groundwater or surface water can eventually balance the water demand and supply of any region. However, as a result of the continuously increasing population of the country, providing clean water is becoming a very great challenge for various sectors.

Awash River Basin is the most utilized river basin on both surface water and groundwater resources, with a number of various scale irrigation schemes; industries located along the river; urban and rural water supply schemes (Hague, 2013). In the Basin there are many well fields that are constructed either for urban water supply (domestic use) or for various irrigational developments. These well fields are distributed throughout the basin on different topographic settings with various scales.

The main well fields operating in Awash Basin are namely: Addis Ababa well fields, Ada and Becho well field, Wonji (Melkalida well field), Metahara Alidegie well field and well fields in the Lower Awash plain. Some of these well sites are operational and supply water for the intended purposes, and some of them are not functional as a result of various issues.

Compared to other well fields in Awash Basin groundwater potential of Addis Ababa region and its environs are well investigated. Aquifer systems have different categories based on a total penetration depth of a drilled borehole (AAWSA, 2013). These categories of aquifer include: (1) the very shallow aquifer (<30meter), (2) the shallow aquifer (30-100meter), (3) the deep aquifer (100-250meter) and (4) the very deep aquifer (>250meter).

According to AAWSA report (2013) these 4 classes of aquifers are being used in the water supply of Addis Ababa and its vicinities. Previously the most intensively used aquifer class was the shallow and deep aquifers that fall in the range of 30-100meter. In which the boreholes are supplying water that is being locally recharged or recently rejuvenated from direct precipitation.

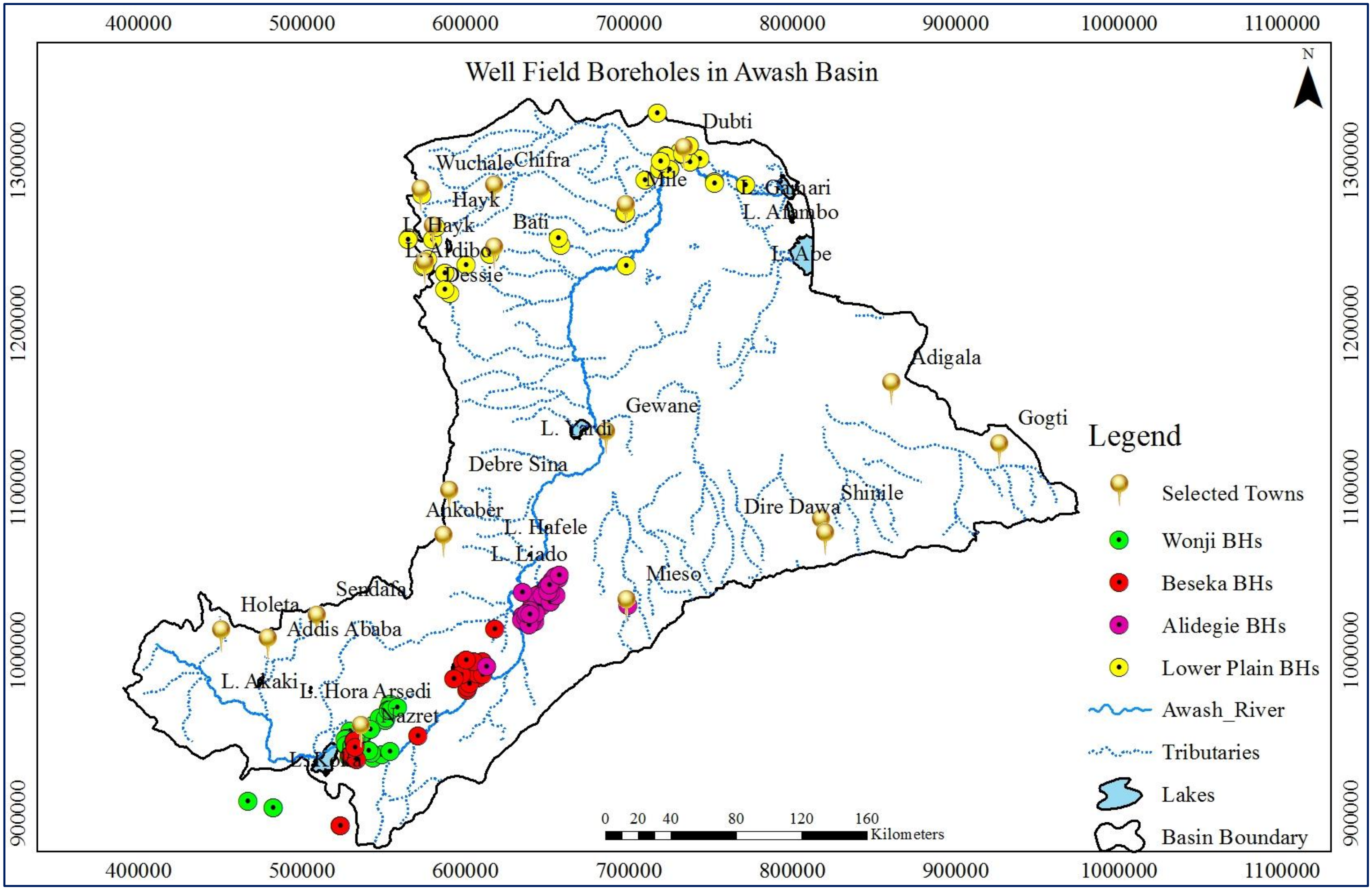


Figure 4.21 Well field boreholes in Awash Basin

In addition to this, now a day's very deep boreholes up to a depth of 500meters with high discharge rates are being drilled and completed for water supply of the city. Addis Ababa and the surrounding areas comprise well-known well fields namely: Legedadi-Legetafo, Ayat Fanta, Sebeta-Tefki, Melka Kuntire and south west Akaki well fields. These very deep well sites are purposely constructed to expand water coverage and to fulfill the clean water demand of the city.

The very deep boreholes class of the city and its surrounding are discharging water from deep fractured volcanic rocks. Signifying that, the wells are discharging old groundwater from the deep pristine aquifer.

The other well field found 35km away from the city is the Ada'a plain well field. This well field is constructed for a large scale irrigation activity. Like Addis Ababa and its surrounding wells, the boreholes are very deep that reach up to a depth of 500meters.

In addition to the upland regional groundwater flow recharge, the plain get recharges from three different direction such as; 1) inflows between mountains of Yerer and Guji, 2) inflows between Bede Gebaba and Ziquala and 3) inflows from Mojo, Wedecha and Belebela catchment, (WWDSE, 2009). Lithostratigraphy succession information's of boreholes of Ada'a plain suggest, the main source of recharge of this plain is made through the unconsolidated sediments overlying on the weathered and fractured volcanic rock.

Wonji sugarcane plantation is one of the largest sugarcane estate found on the rift escarpment. This sugarcane farm uses Awash River through pump stations as a main source of water supply. Apart from Awash River, the plantation uses groundwater wells of Wonji (Melkalida well field) and Welenchit for the sustaining the irrigational activity. According to the classifications of aquifers, these wells range from shallow to very shallow aquifers.

The scatter plot of Melkalida groundwater samples are shown on figure 4.22. The isotopic composition of $\delta^{18}O$-$\delta^{2}H$ of these shallow and very shallow groundwaters is similar to isotopic composition of the modern day rainfall. From this it can be inferred that the boreholes are recharged from direct percolation of summer rainfall.

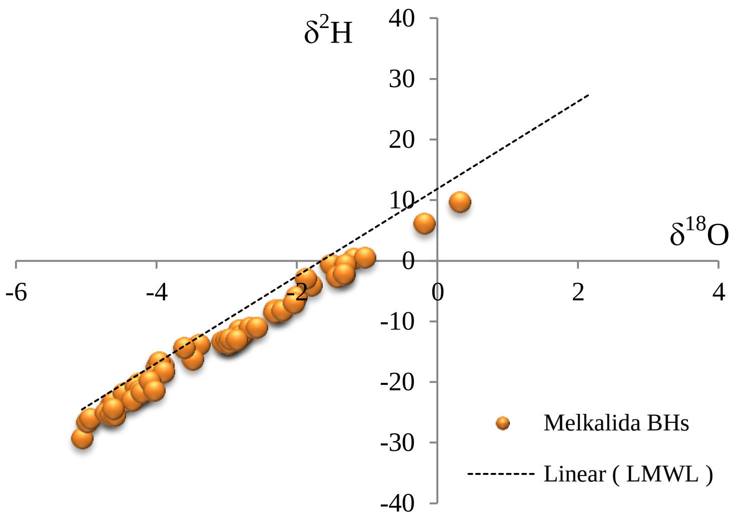


Figure 4.22 scatter plot for Melkalida Boreholes

Some boreholes at Melkalida exhibited enrichment in isotopic composition, indicating evaporative fractionation of the isotope of water. This resembles evaporated Awash River has recharged the aquifer of Melkalida well field.

There are quality concerns in shallow and very shallow aquifers, specifically in Melkalida well field. The well field is located near and around the irrigation area of the sugarcane plantation. These boreholes are very shallow having a penetration depth from 23-80meter with a groundwater depth of around 8meters. In areas where aquifers are unconfined and groundwater depth is very near, the risk of groundwater pollution is very high. Irrigation return water and several contaminated discharge waters from domestic and industrial sectors are the main sources of shallow aquifer pollutants. Consequently shallow boreholes of this area are highly vulnerable to external pollutants as result of anthropogenic effects and return water of the irrigational sites.

In order to have a sustainable usage of these groundwaters, attention has to be given to such highly susceptible areas by protecting the wells from external contaminants.

There are also several shallow boreholes around and within Metahara and Lake Beseka. Awash River is the main source of water supply for Metahara sugarcane factory. Groundwaters of Lake Beseka region have a high Ec values that range between 1600 and 3000µscm^{-1} (Seifu Kebede, 2013). Since Awash River has lower EC than the groundwater of the area, the river is the main water supply for both human and livestock's.

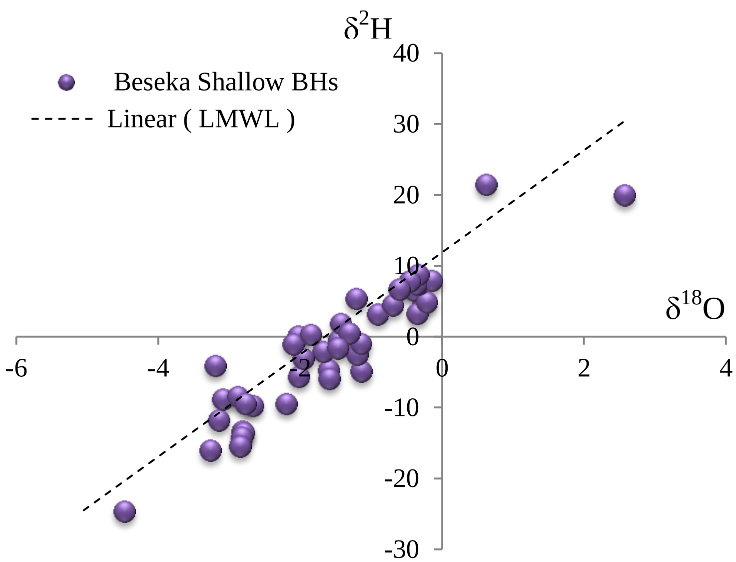


Figure 4.23 scatter plot for Beseka Boreholes

The isotopic composition of groundwaters found within and around lake Beseka signify both depleted and dominate enriched values falling to the right of the LMWL. The groundwaters exhibited both depletion and enrichments in the concentration of δ^{18}O-δ^{2}H. The depleted isotopic composition of these waters indicates that, the groundwaters are recharged from uplands regional deep groundwater flows, having similar signature with the present day rainfall.

Whereas groundwaters with enriched isotopic concentration values signify that, the groundwater has undergone mixing with an evaporated Awash River. Similar to Wonji area boreholes of this region fall to the range of shallow to very shallow aquifers. As it has been mentioned earlier, aquifers with shallow penetration depth and with a shallow groundwater levels are highly prone to natural and human induced pollutants. Thus care and attention has to be given to the wells found around the sugarcane factory.

On shallow well aquifers quality is the main concern, when it comes to deep and very deep wells quantity and sustainability becomes an issue. Some boreholes of Alidegie isotopic composition indicate that the wells are providing water from fractured rift volcanic of the pristine aquifer.

This aquifers contains old waters of the deep aquifer, since this aquifers are not connected to any recharging system, depletion of groundwater is probable to occur after some time of the working age of the boreholes. Thus, caution has to be made on the discharging rate of such groundwater wells found within and round Alidegie plain.

The lower plain consists of both shallow and very deep groundwaters. The shallow groundwaters comprise springs and shallow boreholes. These shallow boreholes are constructed for community water supply, whereas the very deep wells are aimed to construct for irrigation water purpose. From the compiled isotopic composition of groundwater wells, there are two groups of groundwater recharge systems. 1) Groundwaters that maintain the aquifer from evaporated Awash, 2) groundwaters that receive regional deep groundwater from the western highlands.

The shallow groundwaters take back the isotopic signature of evaporated Awash River, falling to the right of the LMWL, depicting that the groundwater is feed by the flowing Awash River. Most of these groundwaters, mostly the Alalobad Springs of the lower plain exhibits a positive $\delta^{18}O$ shift, signifying the lower plain rocks contain Silicon Oxide, that are rich in oxygen concentration. When these rocks interact with the groundwater the groundwater will show a positive $\delta^{18}O$ shift, Most of the Alalobad Spring exhibits a positive $\delta^{18}O$ shift.

Observing at the obtained isotopic concentration of the very deep aquifers, the composition of this groundwater suggests that the groundwater has undergone, slight mixing with Awash River.

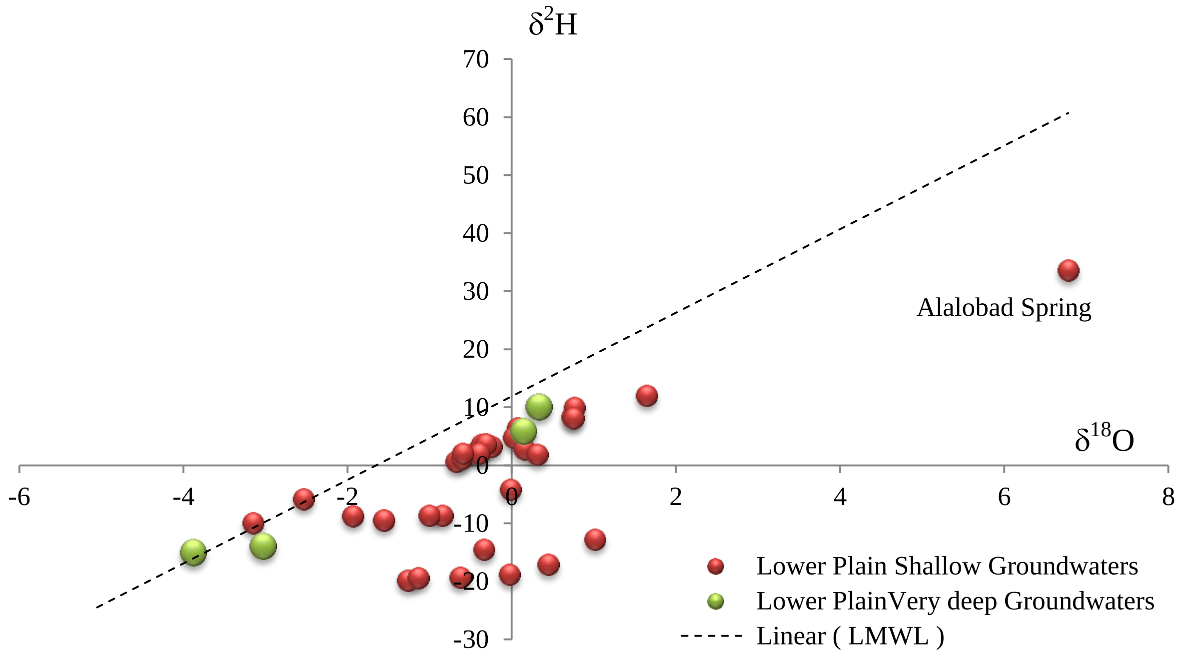


Figure 4.24 Scatter plot for Lower plain groundwater

The lower plain is known for the scarcity of water supply. A number of hand dug wells are kept on digging to fulfill the demand of the water supply. The very shallow wells have quality issues like the other upland boreholes. Since the groundwater levels of the boreholes are near to the surface, human induced pollution as well flood caused by rainfall events can readily pollute these groundwater wells.

Thus, attention has to be given to such susceptible groundwater wells in order protect the life span of the wells and safeguard community water supply, from contamination.

4.5 Physico-Chemical Parameters

4.5.1 Electrical Conductivity

Conductivity is the measure of the ability of water to pass an electrical current, and Electrical conductivity (EC) indicates the degree of salinization of water. In river and stream waters electrical conductivity is affected by the geological formations, human activities as well as climatic condition of the region. This conductive nature of water is generally affected by the presence and amount of inorganic dissolved solids in the water. Thus the values that are obtained while measuring electrical conductivity will give a relative indicator for the amount of dissolved salts.

For this research EC values were measured along the course of Awash River that is accessible for the survey i.e. from the head waters of Awash to Lake Afambo. EC was measured by a digital reader that incorporates both PH and temperature sensors. A total of 78 in situ electrical conductivity measurements are obtained on both occasions of the field work. 66 of the measurements are taken from main Awash River, the 8 measurements are from the tributaries of Awash River and the rest of the 4 measurements are taken from the wet lands of Meteka area (middle Awash).

There are several factors that raise the value of EC, such as urban area pollution, return water from irrigations and climatic variability of the region. These factors affect the degree of salinization of river water. As Emanuel Mazor (2004) noted the EC of a given water increases with increasing temperature. Open surface water bodies in high temperature regions lost most of their water through evaporation. Water loss by evaporation is another factor that elevates the EC of water. Such phenomena usually occurs in arid and semi-arid regions were most of the water is lost through evaporation.

From the graph below (Fig 4.25) during the wet season (August, 2017), from upper Awash River segments the maximum EC value that was measured is 300μscm^{-1}. This is considered to be low saline water. This value suggests, since the measurements are carried out during the rainy season it could be as a result of the dilution of the river by fresh precipitation.

While going down to the middle valley starting from R_{15}-R_{25} the value of EC slowly increases at some segments and then decreases again with low amplitude. In the lower plain of Awash basin an elevated EC values are obtained (600μscm^{-1}). As it has been stated earlier the values of EC concentration is directly proportional to the temperature of the region, where temperature plays a great role in determining the value of EC. The other postulate for the increment of EC in the middle valley is assumed to be, there are several tributary streams that join Awash River, since these tributary streams are highly exposed to evaporation for longer time, the streams have a potential to accumulate salt. When these streams join Awash River it elevates that salt concentration of the river.

The same activity was held during the dry season (March, 2018), the maximum value attained in upper Awash is 430μscm^{-1}. Areas found along the river segments of R_6, R_9 and R_{10} are irrigational areas, where higher EC values are expected to be obtained, rather these sites exhibits a moderate EC values (360μscm^{-1}). This could be as a result of groundwater discharge to the river that dilutes the salt concentration of the river.

The temperature of the basin changes as Awash River flow along its path and joins the middle Awash Valley. In the middle valley of the basin there are several irrigational areas, such as Metahara, Kesem and Melka Worer. These areas generally exhibit higher EC values 740μscm^{-1}, 1480μscm^{-1} and 1520μscm^{-1} respectively. This suggests that the high EC values are as a result of the return water from the irrigational activities. The irrigational activity integrated with the high temperature of the area elevates the EC values.

Lake Afambo is one of the saline lakes in Awash Basin the EC of the lake at the time of the measurement was 2100μscm^{-1}. Lake Afambo receives all the water of Awash River that was flowing all the way from the head water. Owing to the long journey it made through various geologic settings and climatic zones there is no fresh water that joins the Lake Afambo. As a result the salinity of the lake is very high.

All in all EC values of Awash River segments is relatively higher during the dry season compared to the wet season measurements. This suggests that high evaporation rate elevates the concentration of slat in water and during the rainy season inflow of fresh water from precipitation and surface runoff dilutes the salinity of the river.

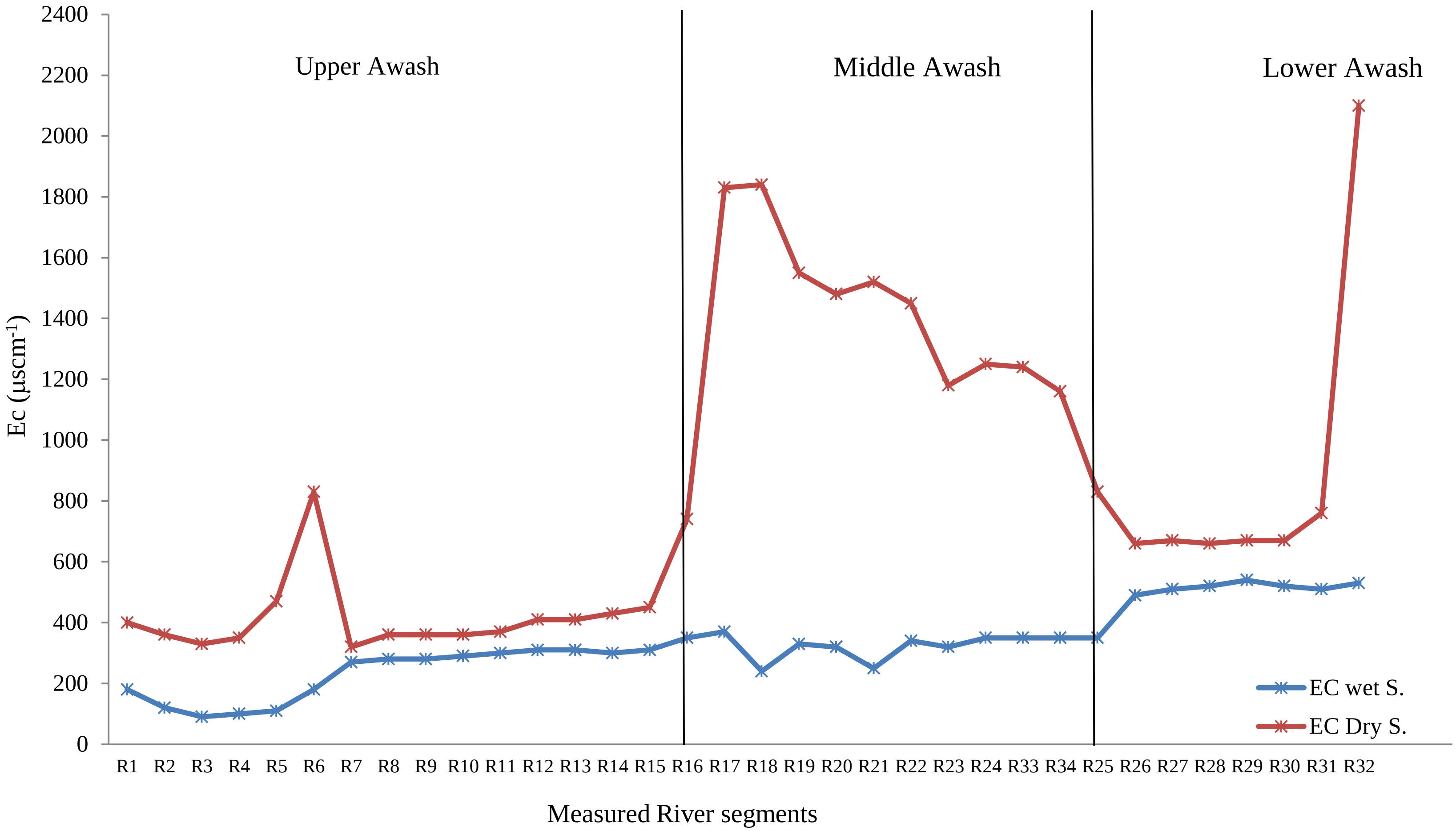


Figure 4.255 Ec of Awash River during wet and dry season

4.5.2 Temperature

Temperature data are important for identification of various water types and groups. Flowing river water may mix with different water types occasionally be detected by temperature measurements. Thus carrying out temperature measurements is very useful in detecting intermixing of river water with nearby water bodies; it especially gives out important information when temperature data’s are coupled with isotopic measurements. Temperature values can be affected by the seasonal variations and geographic settings.

Likewise the EC measurements 78 in situ Temperature measurements were took on both occasions of the field work. 66 of the measurements are taken from main Awash River, the 8 measurements are from the tributaries of Awash River and the rest of the 4 measurements are taken from the wet lands of Meteka area (middle Awash).

The digital reader is immersed in the flowing river water and temperature reading was taken when the reading is stabilized while keeping the reader in the water. The measured values showed that the temperature of Awash River increases as its goes to the lower plain of Awash.

During the wet season measurement it is observed that the temperature of the lower plain, Awash River segments is higher compare to the measurements taken during the dry season measurements. The wet season survey was carried out on the rainy season of the upper and Middle Awash while the season is not the same while going down to the lower plain.

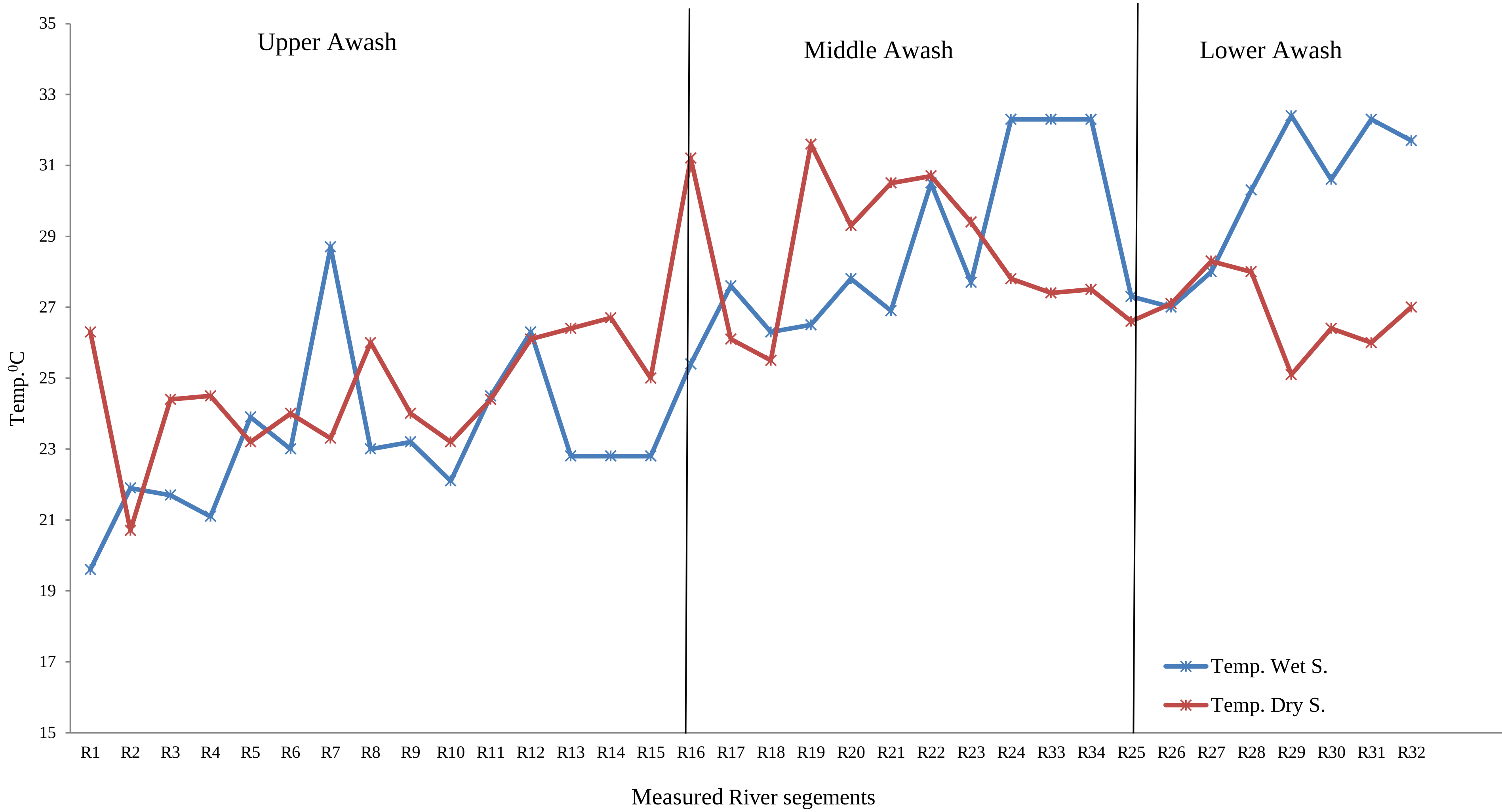


Figure 4.26 Temperature of Awash River segments during wet and dry season

4.5.3 PH

PH describes the acidity or alkalinity of water and represents the balance between hydrogen ions (H^+) and hydroxide ions (OH^-) in water. The value for pH is expressed on a scale ranging from 0 to 14. Solutions with more H^+ than OH^- ions have a pH value lower than 7 and are said to be acidic. Solutions with pH values higher than 7, have more OH- than H+ ions and are said to be basic, or alkaline. Water with a pH of less than 4.8 or greater than 9.2 can be harmful to aquatic life. (http://ga.water.usgs.gov/edu/characteristics.html)

As seen in the graph below, all the river segments of Awash River have similar trend, but with minor amplitudes on both event of the measurements. PH in the Awash River is relatively constant on during the wet season survey. The average PH value acquired was 8.26 which is the river water is considered to be slightly basic. During the dry season survey the PH value increases. In the course of the dry season survey there was a time rain fall happens at some segments of Awash River. This short lengthened rainfall dilutes the alkaline substances in the river water consequently making the river water to have higher PH values. The other factor that may increase the PH value of the river during the dry season survey might be the dissolution of atmospheric carbon dioxide (Sheikh Nisar and Yaregi, 2003).

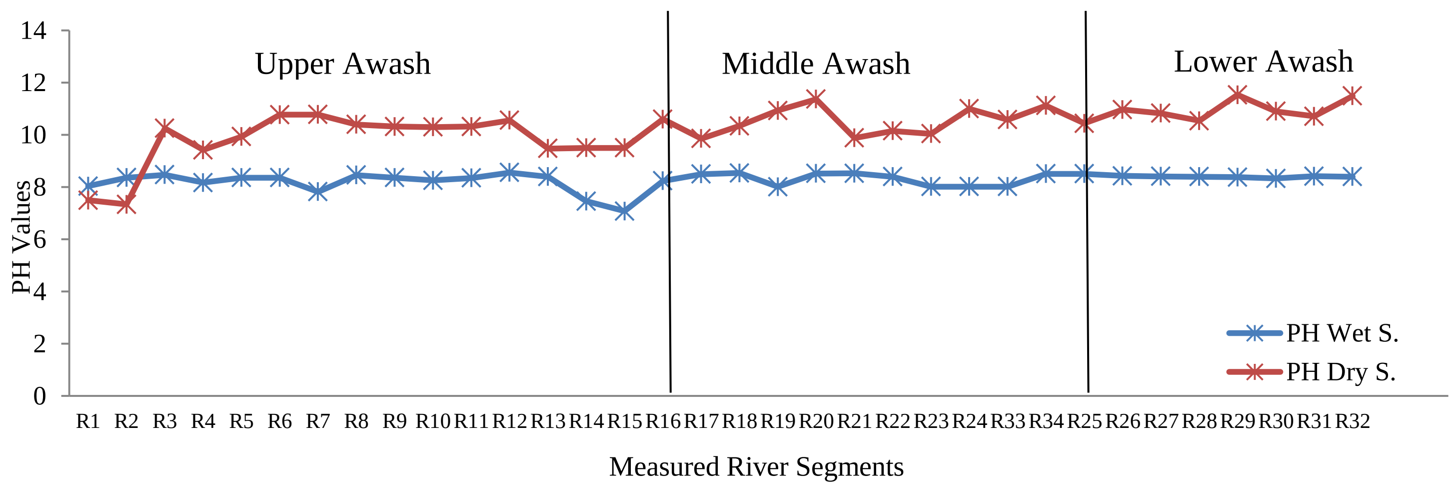


Figure 4.27 PH values of Awash River segments during wet and dry season

5. Discussion

The overall picture of groundwater surface water interaction along the course of Awash River has been determined using various approaches. Integrating the obtain results of radioactive isotopes (^{222}Rn) and stable isotopes ($\delta^{18}O$-$\delta^{2}H$) assist in defining areas where groundwater surface water interaction is taking place. In addition supporting these two methodologies with piezometeric evidences and using other additional hydrogeological considerations has a great deal in determining groundwater and surface water flow conditions.

Owing to the natural topography and poor accessibility to Awash River, at some places of the river segments, determining groundwater surface water interaction is difficult. Thus, such exceptional areas has been discussed based other additional hydrogeological considerations, such as geological formation and geological structures and also by benchmarking previous understanding and observations on other river segments.

On figure 4.28 and 4.29, the spatial variation of isotopic signature of upper Awash River water samples, groundwaters (Shallow and deep groundwaters) and spring waters are plotted. The isotopic composition of $\delta^{18}O$-$\delta^{2}H$ of the groundwaters and spring waters of the headwater of Awash (in the highlands), depict that the waters have similar isotopic composition to that of unevaporated rainfall but very depleted compare to the summer rain of Addis Ababa. The pronounced isotopic depletion observed on some of Upper Awash groundwater results indicate that the groundwaters are from pristine aquifer that emerge from deeper ground levels through faults and fractures. On the scatter plot the highland borehole and spring samples are not plotted far from the LMWL, indicating the groundwater samples have the same origin. Thus, groundwater of these boreholes is recharged through direct rainfall percolation. The general values of ^{222}Rn measurements of the river segments and tributary streams of upper Awash River are higher; signifying the presence of high groundwater discharge is taking place. From lithological logs of boreholes in Upper Awash, the main geologic units are fractured Basalts and Ignimbrites, where higher ^{222}Rn values are obtained. Naturally the discharge of groundwater favors fractures and week zones to reach surface water bodies.

As Tilahun Azagegn (2014) noted upper Awash River segments and the tributary streams that cross the old YTVL are more like to associate with the local groundwater flow.

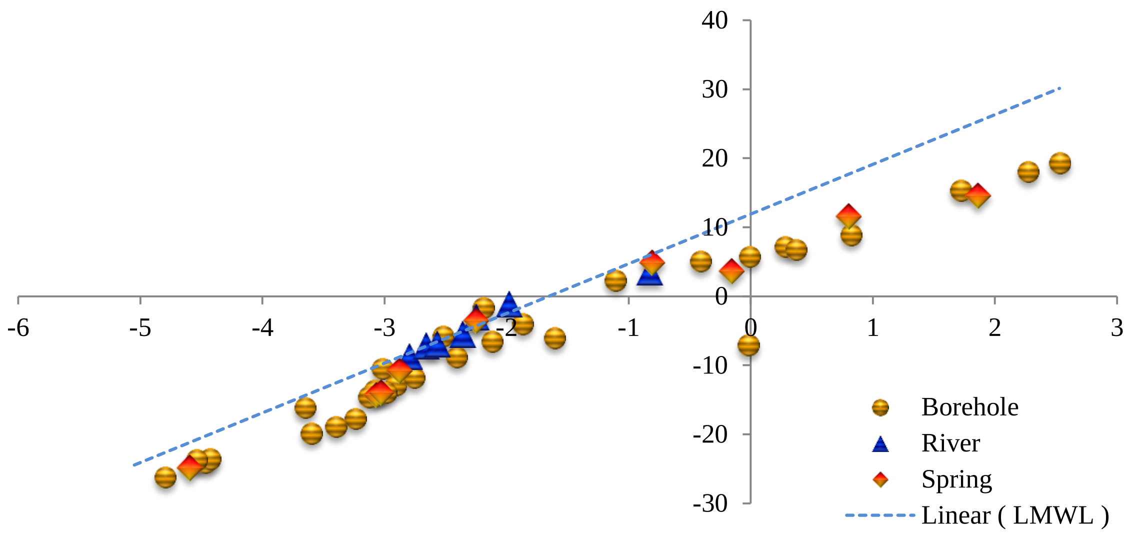


Figure 4. 268 Scatter plot of isotopic composition of different water samples (Wet season)

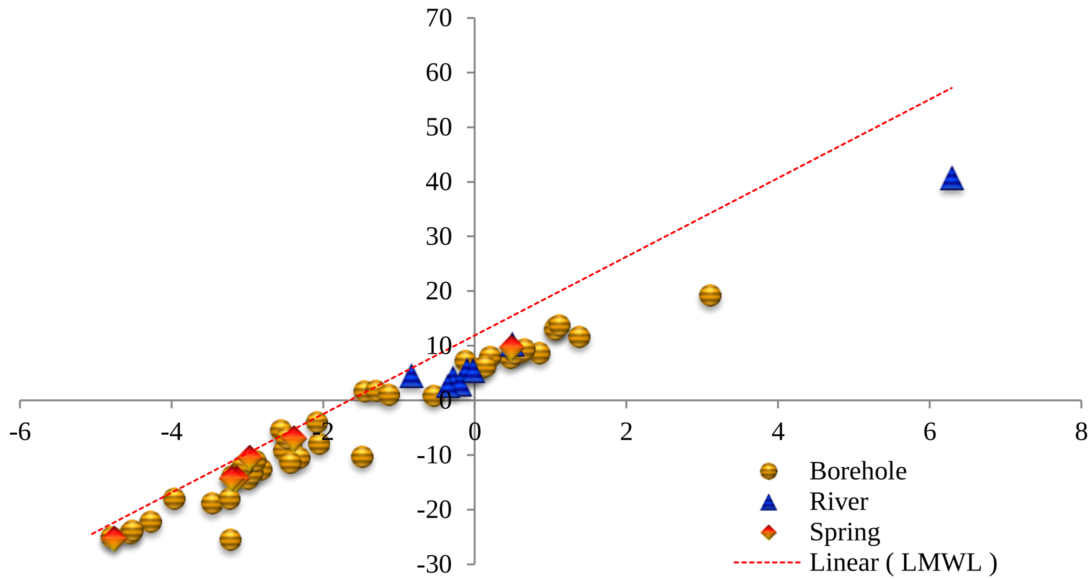


Figure 4.29 Scatter plot of isotopic composition of different water samples (Dry season)

During the seasonal field survey it is observed that Awash River generally flows through channels that are highly fractured basalts and ignimbrites. These geological formations allow the linkage of the river water with the local groundwater flow. Supporting the postulates of the radioactive isotopes and the stable isotopes, equipotential groundwater head-lines generated for Upper Awash section suggest groundwater slopes towards Awash River.

^{222}Rn values obtained around wonji and its subsequent river segments is high ranging 202-247Bq/m^3 suggesting, groundwater is being discharged in to the river segments. Groundwater isotopic compositions of this irrigational area generally signify that the deeper old groundwater and regional groundwater from upland is being utilized as a source of main water supply. This pristine aquifer waters joins the surface water through faults and fractured geological formation of the Wonji group. Results from the stable isotopes and radioactive isotopes depict that there exists a bidirectional movement of water. This movement of water i.e. the back and forth flow of water helps to maintain the ecological balance of the region.

Contour lines prepared for the section of Wonji illustrate that the area has a gentle slope in which, groundwater headlines generally converges upstream of the river. Combining all the aforementioned indicators of groundwater surface water interaction, the section of the rift escarpment and the middle valley i.e. up to Sodera groundwater contribution to the flow of Awash River is high.

Starting from the escarpment to the middle valley region of Awash Basin has various irrigational scheme sites. The presence of such developmental activities has a great impact on both groundwater and surface water bodies. Areas at R_{13}, R_{14}, R_{15} and R_{16} are irrigation areas where Awash River seepage has been remarked. The isotopic concentrations of $\delta^{18}O$-$\delta^{2}H$, of BH-18, indicate that slightly depleted Awash River water has percolated in to the groundwater system. Percolated irrigation water's in to the groundwater has a great effect on the water quality and type of groundwater. In situ EC measurements of river segments on both seasons signify that the salinity of this section is high and showed a pronounced increment at R_{15} and $R_{16,}$ which can also be as a result of inflow from Lake Beseka.

^{222}Rn value on R_{16} exhibited higher value (393± 157 Bq/m^3) on dry season measurement; implying groundwater contribution to the river segments is higher compared to the other river segment that comprises irrigational sites.

Even though the electrical conductivity of this section is extremely high, groundwater flow to this river segment dilutes the concentration of the salt that has been accumulated in the river. This groundwater surface water interaction has brought a great significance for the subsequent river segments by balancing the salinity of the river.

Middle Awash section comprises areas from Metahara up to Mile town. At the uplands of Awash Sebat (R_{17}) groundwater discharge to the river has been observed by using various approaches. In middle Awash, Awash River contribution to the groundwater is minimal; rather groundwater contribution to the river segments is clearly detected.

The discharge of groundwater to the river is made through the rift volcanics that dominantly contains fractured Basalt overlay with clay formation. The fractured rift volcanic rocks accompanied with the dense fault system channeled the groundwater to flow to the surface waters. The overall ^{222}Rn values of the middle Awash is generally high ranging from 752-101Bq/m^3, inferring high groundwater discharge is playing a great role in sustaining the flow of Awash River. With the parallel approach the isotopic composition of deep groundwaters from Alidegie plain and its environs, signify that Awash River has no contribution to the groundwater. Rather the very deep groundwater is being recharged from the present day rainfall and form deep percolation of regional groundwater flow from upper plateau and from Eastern highlands.

Irrigation areas in the middle Awash, around Melka Worer (R_{21}) and Awash Ambashe (R_{22}) exhibited high ^{222}Rn activities, depicting higher groundwater discharge is taking place within the river segments. On the top of this, the isotopic composition of $\delta^{18}O$-$\delta^{2}H$ of the groundwater of this region, illustrates that Awash River has leaked in to the groundwater. Likewise the irrigation areas found at uplands of Awash Sebat (R_{17}), the Middle Awash section, illustrates a bidirectional flow of water. In situ Ec measurement of this river segment at (R_{18}) notifies that the electrical conductivity of the river segment is high (1450μscm^{-1}), Suggesting saline water is infiltrating to the groundwater system.

From the point of groundwater quality the deep groundwater is being affected by the saline irrigation water that is being seep through fractured rift volcanic rocks. This contaminated leaked irrigation water will flow through the fractured formations and will affect the following middle valley and lower plain groundwaters.

Following the flow path of Awash River the measured ^{222}Rn in Gewane town justify that groundwater discharge to the river is very low, ranging 22.4 - 44.8Bq/m^3. Observing the isotopic composition of the groundwater of Gewane indicate that there is a high contribution of Awash River to the groundwater system. The infiltrated evaporated Awash Water in the groundwater is observed in BH-40.

Meteka town is a town of springs and wetlands, where so many springs emerge on the surface through the dense faults and fractures of the region. These springs and wetlands are perennial that do appear on both wet and dry seasons. Groundwater that has been regionally pressured starting from uplands will be exhaled as a spring through highly fractured and dense fault system of Meteka. ^{222}Rn measurement is made on the wetlands of Meteka and its surroundings. The readings obtained from the wetlands on both events of the field work indicate that the system is completely groundwater dependent, where the ^{222}Rn value exceeds up to 12,000Bq/m^3. Whereas in Awash River segments, groundwater discharge to Awash River is low on both occasions of the measurements. While observing the isotopic compositions of $\delta^{18}O$-$\delta^{2}H$ of the groundwater and spring samples of Meteka, the deep groundwater is recharged from regional groundwater flow from upper highlands, with minor signature of Awash River.

As a result of inaccessibility to Awash River there is an information gap between the town of Gewane and Adayitu. The expected results concerning groundwater surface water interaction can be explained by bench marking the previous observations made on Upper and middle Awash. Progressive decline in groundwater discharge has been observed from ^{222}Rn readings. As it has been discussed on the geology section 3.5.1, the dominant geological formation of this plain is the Afar Group that is interbedded with the alluvio-colluvial deposits. On the top of the type of geologic formation the structural map presented on section 3.5.3 testifies the region is located in a highly faulted terrain. Even though these geological formations and the dense faults can make a good aquifer, they are not expected to contribute groundwater to the surface water as a result of the topographic settings. Therefore from the observations of the natural setting, the river segment in this case is assumed to be a losing river, where Awash River water is expected to contribute much of its water for groundwater.

Before reaching the lower plain, ^{222}Rn measurement were taken near the town of Adayitu that gives out higher reading (224±125Bq/m^3). Observing the isotopic composition of the groundwater well found near the river signify that the groundwater has been mixed with Awash River. Higher result of ^{222}Rn and the presence of isotopic signature of Awash River in the groundwater justify the presence of a bidirectional flow of water.

Immediately after the town of Adayitu, part of the groundwater that came all the way down from uplands, escapes to North East direction this groundwater flow that outflows from the flow path of Awash River, probably discharge in to Lake Abe or in to the sea or into other lower parts of Ethiopia. Some part of groundwater flows that reach the lower plain is pressured from the upper sections. The isotopic composition of these groundwaters in the lower plain denotes that an evaporated Awash River and seasonal surface runoff has percolated through the fractures and lost in the lower plain. From groundwater wells information it has been observed that, the groundwater level of the lower plain region is approximately similar with the river water level. As Halcrow (1989) also noted lower plain is the region where the groundwater and river water level merge close to the lakes. Seasonal ^{222}Rn measurement is held on the lower plain in every accessible river segments. The result of the readings showed that groundwater contribution to the surface water is very low. Whereas the groundwater isotopic composition of $\delta^{18}O$-$\delta^{2}H$ signifies that, enriched Awash River water has fed the aquifer system of the plain. Groundwater head distribution map for the lower plain also showed that the river water diverges from upstream and converges downstream of the river. This generally indicates that Awash River is a losing segment on the lower plain.

6. Conclusion

Groundwater surface water interaction has been investigated in Awash River Basin trough all accessible ways, where Awash River can be physically examined. The combined results of, onsite ^{222}Rn and physico-chemical measurements, analysis results of $\delta^{18}O$-$\delta^{2}H$ and the supporting piezometeric evidences, bring about a converging evidence for mapping areas where groundwater surface water interaction is taking place.

Owing to the surface topography, geological setup and due to the channeling geological structures, Awash River changes from groundwater gaining stream in Upper Awash to a losing stream in the middle and lower plain of the basin. Upper Awash River segments and the tributary streams are generally associated with the local groundwater flow signifying the connection of the aquifer with the present day recharge.

Discharge of groundwater in Middle Awash and in the valley is observed at some specific spots such as, in irrigation areas of; Wonji, Metahara and Melka Worer. Since groundwater surface water interaction is clearly observed in the irrigation sites, percolation of irrigation return water has a great role in altering the quality of groundwater. An inflow from Lake Beseka towards the deep aquifer system is also another factor that can slowly increase salinity of Awash River and deteriorate the local water quality of the aquifer system.

Groundwater and surface water link was not observed in one of the major aquifers of Awash Basin; such as Alidegie plain. The aquifer system of Alidegie plain is disconnected from Awash River, the deep groundwater of this plain is supplying from pristine aquifer without having any new source to rejuvenation. Disconnection from present day recharge of the regional flow could mean local depletion of the aquifer system may occur.

Down to the middle valley groundwater discharge is noticed in the wetlands and in the thermal spring of Meteka. Besides the large scale discharge of groundwater, slight signature of Awash River water is detected from isotopic analysis of the groundwaters. Such insignificant interaction with a low surface water contribution to the groundwater and less groundwater involvement to the surface may categorize the region among those which have a separate water resources.

In the lower plain, increase in gradual as well as pulsed increase in salinity of the river is observed. This can be related to inflow from tributaries draining the lower part. Isotopic composition of $\delta^{18}O$-$\delta^{2}H$ the deep groundwaters from the lower plain have their origin from old recharge, signifying disconnection from present day recharge.

7. Recommendations

Since Upper Awash groundwater system is connected with the present day recharge developing groundwater in area does not have a significant impact on the groundwater potential of the aquifer. Whereas over abstraction of groundwaters found near surface water bodies can reduce the available surface water supply by taking the groundwater flow that otherwise would have discharged to surface water, this may lead to decrease in the sustainability of the river flow. One of the basic objectives of carrying out groundwater surface interaction studies is for balancing these water resources for maintaining the ecosystem. In order to protect the living organisms in the ecology attention has to be given in areas where aquifer hydraulic link is high.

Hydraulic link created between surface water and groundwater within irrigation areas will contribute pollution to the nearby river as well as to the subsequent river reaches. For instance Metahara area is a large scale irrigational scheme site, in which a distinctive spike of EC value is observed. Such a pronounced increment in Ec value could be as a result of withdrawal of water from shallow aquifers that are directly connected to surface water bodies. Abstracting shallow groundwaters can have a significant effect on the movement of water between these two water resources. Thus, these irrigation sites should utilize advanced technologies in order to reduce contamination within and downstream river segments.

The deep groundwater in the middle and Lower Awash is considered as separate water resources from the surface water. Specifically in Alidegie plain, since it has been confirmed that, the aquifer system of the area is disconnected from present day recharge, developing large scale groundwater either for irrigation purpose or for other usage would have an impact on the local aquifer of the plain. In areas where there is no connection between the aquifer and the surface water, the river is not affected by the abstraction rate and amount of the aquifer. Consequently, the river segment will be in the same sate through-out the working age of the boreholes. Thus, developing groundwater in such area does not have impact on the river flow and sustainability.

In such large basin like Awash Basin piezometeric wells are important to provide time series groundwater level data records. These time series data are essentially required to assess the groundwater level conditions. Groundwater is related with surface water bodies at some specific spots of the basin, the interrelation of the water resources is mainly based on seasonal variation. Thus, a well-organized monitoring system and database is very important to determine groundwater recharge and predict the probable rise and fall of groundwater as a result of natural process.

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Appendix

Table 1. Selected Metrological Stations Mean Annual Temperature

Station	Jan.	Feb.	Ma.	Ap.	Ma	Jun.	Jul.	Au.	Sp.	Oct.	Nov.	Dec.
Adama	19.2	20.5	21.8	22.5	22.4	22.3	18.4	20.6	21	20.1	18.6	18.2
Adayitu	23.4	24.4	26.1	27.6	29.2	31.3	29.7	28.5	28.8	27.1	24.8	23.5
Awash 7	23	24.3	25.9	27	28.1	29.1	27.1	26	27	25.9	23.4	22.3
Gewane	22.1	22.7	24.3	26	26.8	29.1	27.4	26.1	26.2	24.8	22.1	20.9
Holeta	15.4	16.4	17.6	17.7	17.3	16.3	15.2	15.1	15.5	15.2	14.2	14.5
Melka Worer	23.6	24.8	26.5	27.8	28.6	30.1	28.1	26.8	27.6	26.1	23.7	22.5
Metahara	22.5	23.7	25.4	26.3	26.9	28.4	26.5	25.6	26.2	24.6	22.2	21.4
Tendaho	24.4	25.3	26.9	28.4	30.4	32.5	31	30.1	30.3	28.2	25.9	24.7

Table 2. Selected Metrological Stations Mean Annual Rainfall

Station	Jan.	Feb.	Ma.	Ap.	Ma	Jun.	Jul.	Au.	Sp.	Oct.	Nov.	Dec.
Adama	11	22	45	58	43	74	200	210	102	24	13	6
Adayitu	9	18	35	32	19	10	63	91	28	7	7	3
Awash 7	21	44	51	53	47	30	99	129	52	21	13	7
Gewane	10	43	39	38	34	18	80	137	47	8	6	6
Holeta	15	35	61	81	83	129	259	266	156	31	9	9
Melka Worer	21	50	48	49	36	32	76	128	44	19	12	16
Metahara	18	38	41	42	39	30	115	134	47	18	11	4
Tendaho	7	7	29	20	11	5	43	54	16	5	6	2

Table 3 Isotope analysis results of boreholes

ID	Locality	Wet Season			Dry Season		
		^{2}H	^{18}O	D-Excess	^{2}H	^{18}O	D-Excess
BH-1	China Agriculture	-5.74	-2.52	14.42	-5.4	-2.56	15.08
BH-2	Gypsum Factory	-1.63	-2.19	15.89	1.7	-1.46	13.38
BH-3	Paper Factory	2.34	-1.11	11.22	1.8	-1.31	12.28
BH-4	Cheleka Bobya	-8.8	-2.41	10.48	-8.4	-2.43	11.04
BH-5	Awash Belo-1	-6.53	-2.12	10.43		Not Functional	
BH-6	Awash Belo-2	-10.45	-3.02	13.71	-9.2	-2.52	10.96
BH-7	Awash Belo-3	-3.97	-1.87	10.99	-22.2	-4.28	12.04
BH-8	Debele Yohanese	-16.14	-3.65	13.06		Not Functional	
BH-9	Jimjima	-24.08	-4.47	11.68	-24.3	-4.55	12.1
BH-10	Jimjima Erbata	-23.52	-4.43	11.92	-23.8	-4.52	12.36
BH-11	Beri-1	-18.88	-3.4	8.32	-18.8	-3.47	8.96
BH-12	Beri-2	-19.82	-3.6	8.98	-18	-3.24	7.92
BH-13	Beri-3	-17.69	-3.24	8.23	-18	-3.97	13.76
BH-14	Koka National Cement	-26.19	-4.8	12.21	-25	-4.8	13.4
BH-15	Wonji Awash	-7.04	-0.02	-6.88	7.2	-0.13	8.24
BH-16	Wonji High school	-12.81	-2.91	10.47	-12.6	-2.82	9.96
BH-17	Wonji Town	-11.75	-2.76	10.33	8.9	0.61	4.02
BH-18	Tedecha Bela	5.12	-0.41	8.4	1	-1.14	10.12
BH-19	Addis Rayie	-13.94	-2.99	9.98	-14.3	-3	9.7
BH-20	Melka Worer	-13.63	-3.08	11.01	-13.8	-3.2	11.8
BH-21	Awash Ambashe	7.18	0.28	4.94	7.8	0.46	4.12
BH-22	Meteka	-14.54	-3.13	10.5	-13.2	-2.94	10.32
BH-23	Adayitu	-6	-1.61	6.88	-7.9	-2.06	8.58
BH-24	Tendaho	-23.69	-4.54	12.63	11.7	1.37	0.74
BH-25	Asayita Finance	8.91	0.82	2.35	5.8	0.06	5.32
BH-26	Kerbit Bolo	6.8	0.37	3.84	13.5	1.07	4.94
BH-27	Afambo-1	19.35	2.53	-0.89	13	1.05	4.6

ID	Locality	Wet Season			Dry Season		
		^{2}H	^{18}O	D-Excess	^{2}H	^{18}O	D-Excess
BH-28	Afambo-2	15.36	1.72	1.6	13.7	1.11	4.82
BH-29	Sedro	18.11	2.27	-0.05	8	0.2	6.4
BH-30	Elidar-2	5.74	-0.01	5.82	8.7	0.52	4.54
BH-31	Alidegie plain - 1	-	-	-	-6.9	-2.49	13.02
BH-32	Alidegie plain - 2	-	-	-	-4	-2.09	12.72
BH-33	Alidegie Plain - 3	-	-	-	-11	-2.9	12.2
BH-34	Alidegie Plain -4	-	-	-	-12	-3.07	12.56
BH-35	Elidar - 3	-	-	-	8.7	0.58	4.06
BH-36	Elidar – 4	-	-	-	9.4	0.65	4.2
BH-37	Dobi	-	-	-	0.9	-0.55	5.3
BH-38	Galafi	-	-	-	-10.3	-1.49	1.62
BH-39	Diceheto	-	-	-	-10.5	-2.32	8.06
BH-40	Gewane	-	-	-	6.3	0.13	5.26
BH-41	Saba	-	-	-	-11.4	-2.44	8.12
BH-42	Afedera	-	-	-	19.2	3.1	-5.6
BH-43	Asayita	-	-	-	-25.5	-3.23	0.34

ID	Max. Outliner	^{222}Rn Wet season	Min. Outliner	Max. Outliner	^{222}Rn Dry season	Min. Outliner	Temp. Wet season	Temp. Dry season	PH Wet season	PH Dry season
R1	130	247	-130	157	392	-157	19.6	26.3	8.04	7.5
R2	103	124	-103	143	314	-143	21.9	20.7	8.36	7.34
R3	77.3	56	-77.3	96.8	112	-96.8	21.7	24.4	8.47	10.25
R4	85.8	78.4	-85.8	81.7	67.2	-81.7	21.1	24.5	8.17	9.42
R5	44.8	0	-44.8	189	605	-189	23.9	23.2	8.36	9.93
R6	93.3	101	-93.3	135	269	-135	23	24	8.36	10.77
R7	100	124	-100	61.2	22.4	-61.2	28.7	23.3	7.82	10.78
R8	72.5	44.8	-72.5	130	247	-130	23	26	8.46	10.4
R9	85.8	78.4	-85.8	128	235	-128	23.2	24	8.36	10.32
R10	112	168	-112	96.8	112	-96.8	22.1	23.2	8.26	10.3
R11	72.5	44.8	-72.5	120	202	-120	24.5	24.4	8.35	10.32
R12	77.3	56	-77.3	100	123	-100	26.3	26.1	8.56	10.56
R13	44.8	0	-44.8	77.3	56	-77.3	22.8	26.4	8.4	9.48
R14	61.2	22.4	-61.2	81.7	67.2	-81.7	22.8	26.7	7.46	9.5
R15	61.7	22.4	-61.7	67.3	33.6	-67.3	22.8	25	7.08	9.5
R16	44.8	0	-44.8	157	393	-157	25.4	31.2	8.24	10.6
R17	96.9	112	-96.9	72.5	44.8	-72.5	27.6	26.1	8.5	9.86
R18	61.2	22.4	-61.2	93.3	101	-93.3	26.3	25.5	8.54	10.34
R19	77.3	56	-77.3	208	752	-208	26.5	31.6	8.01	10.93
R20	81.7	67.2	-81.7	147	336	-147	27.8	29.3	8.52	11.37
R21	77.3	56	-77.3	184	573	-184	26.9	30.5	8.53	9.88
R22	96.8	101	-96.8	139	291	-139	30.5	30.7	8.4	10.15
R23	77.3	56	-77.3	93.3	101	-93.3	27.7	29.4	8.02	10.04
R24	86	78.6	-86	61.2	22.4	-61.2	32.3	27.8	8.02	11
R33	86	-	-86	61.2	22.4	-61.2	32.3	27.4	8.02	10.58
R34	81.7	-	-81.7	61.2	44.8	-61.2	32.3	27.5	8.51	11.12
R25	81.7	67.2	-81.7	125	224	-125	27.3	26.6	8.51	10.44
R26	61.2	22.4	-61.2	61.2	22.4	-61.2	27	27.1	8.43	10.97

ID	Max. Outliner	^{222}Rn Wet season	Min. Outliner	Max. Outliner	^{222}Rn Dry season	Min. Outliner	Temp. Wet season	Temp. Dry season	PH Wet season	PH Dry season
R27	54.1	11.2	-54.1	54	11.2	-54	28	28.3	8.41	10.83
R28	54.1	11.2	-54.1	61.2	22.4	-61.2	30.3	28	8.4	10.54
R29	67.2	22.4	-67.2	72.5	44.8	-72.5	32.4	25.1	8.38	11.53
R30	72.5	44.8	-72.5	81.7	67.2	-81.7	30.6	26.4	8.33	10.9
R31	61.2	22.4	-61.2	85.8	78.4	-85.8	32.3	26	8.42	10.71
R32	61.2	22.4	-61.2	93.3	101	-93.3	31.7	27	8.4	11.49
T1	177	506	-177	130	247	-130	18	17.5	8.4	10.53
T2	77.3	56	-77.3	189	606	-189	18.8	22.7	8.73	10.36
T3	146	326	-146	199	685	-199	17.5	23.5	8.15	9.87
T4	109	157	-109	135	269	-135	19.4	26.6	8.47	9.44
WT-1	89.7	89.7	-89.7	93.3	101	-93.3	28.2	89.7	8.56	9.18
WT-2	821	120009	-821	720	10000	-720	45.5	120009	8.03	10.2

Declaration for Originality

I declare that this thesis is my original work for the requirement of Master's degree accomplished under the supervision of Dr. Seifu Kebede, School of Earth sciences, Addis Ababa University, during the year 2017/18. My further declaration is that this work has not been presented and /or submitted to any other college, institution, or university for award of any degree or Diploma. All the secondary data, sources and material used in the thesis work have duly cited and acknowledged.

Tsedenya Aregu Tafesse (MSc. Candidate)

Signature ___________________________ Date ____________________________

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

Dr. Seifu Kebede (Advisor)

Signature ___________________________ Date ____________________________