Available Online at

http://www.ijcpa.in

April-June 2017

International Journal of
CHEMICAL AND PHARMACEUTICAL
ANALYSIS

eISSN: 2348-0726 ; pISSN : 2395-2466

DOI : http://dx.doi.org/10.21276/ijcpa

Research Article | Volume-4 | Issue-3 | Article ID: 1130

# ASSESSSMENT OF GROUNDWATER QUALITY FOR DRINKING PURPOSE USING GIS TECHNOLOGY AND WATER QUALITY INDEX (WQI) IN ADIGRAT AREA, TIGRAY, NORTHERN ETHIOPIA

**Grmay Kassa**

Department of Earth Science, College of Natural and Computational Sciences, Adigrat University, Adigrat, Ethiopia

**Corresponding Author: Email: grmaykassa@yahoo.com*

Received: 17 September 2016 / Revised: 30 May 2017 / Accepted: 25 June 2017 / Available online : 29 June 2017

**ABSTRACT**

*This paper assesses the groundwater quality and evaluates its quality for drinking purpose using GIS technology and Water Quality Index (WQI) approach and compare with WHO and Ethiopia water quality standards in Adigrat area (38.94 km$^2$) in Tigray, northern Ethiopia. Chemical composition of the groundwater in the area varies widely depending up on the human activities. A total of 22 (13, 4, 4 and 1 from Bore hole, shallow wells, 4 handug well and reservoirs respectively), Depth integrated groundwater samples were collected by purpose sampling technique. These samples were analyzed for their Physico- chemical components. 26 physical and chemical parameters were assessed to evaluate the groundwater quality for drinking use and the $Na^+$, $Ca^{+2}$ and $Mg^{+2}$ from cation and $Cl^-$, $HCO3^-$ and $SO4^{-2}$ from anions are the major ions. The groundwater is suitable for drinking purpose with respect to pH, EC, TDS and hardness as $CaCO_3$ as well as physical parameters but, with parameters of Alkalinity and total hardness, iron, calcium, magnesium and chromium concentration, the groundwater needs some water treatment for quality adjustment. It is also suitable for drinking purpose taking in to account all anionic concentrations ($SO_4^{-2}$, $PO_4^{-2}$, $NO_3^{-2}$, $NO_2^-$, $Cl^-$ , $F^-$ and $HCO_3^-$). The ionic concentration and the chemical parameters, generally is high around the town and the old waste disposal sites and in the highly cultivated agricultural fields where point and non sources of domestic, factories as well as feltrizer beside the nature sources. 95.45% of the water quality index is classified under excellent but, 4.55% indicated the water quality index poor and unsuitable class and the groundwater is suitable generally with some restrictions. The objectionable groundwater is restricted around the town with main of contaminants domestic and factories wastes. The hydro chemical data reveal that the groundwater of the study region consists of six hydro chemical facies, Including Ca-Mg-HCO3-SO4, Ca-SO4-HCO3, Mg-Ca-SO4-HCo3, Ca-Mg-SO4-HCO3, Mg- Ca -HCO3-SO4and Ca-HCO3-SO4.*

*Keywords – Groundwater; Drinking; GIS; Quality; Adigrat; WQI*

## 1. INTRODUCTION

Water is the most common substance within the earth. Water plays a central role in any secteral activities such drinking, irrigation, industry, domestic etc. Surface and sub-surface waters are the main sources of water supply for different activities. Groundwater is widely distributed resources as well as an important source of water supply throughout the world. Science groundwater is directly linked with the well being of the society, the quality of water is a vital concern for mankind. In Adigrat area, the population is fully dependent on groundwater as the only source of drinking water supply.

Distribution of fresh water resources is uneven throughout the world and the fresh water availability is becoming scarce day by day owing to population growth and diverse human activities. In the absence of fresh surface water resources, groundwater is exploited to meet the demand exerted by various sectors (H. Annapoorna etal, 2015)[1].

The quality of water is as important as its available quantity. Once precipitation reaches the ground, it reacts with soil, rock, and organic debris, dissolving still more chemicals naturally aside from any pollution generated by human activities. The type and concentration of salts in water depend on the processes that have affected the water since it fell as rain. Chemical weathering of the rocks, open sanitation and agricultural return flow have contributed greatly for the major elements of groundwater (H. Annapoorna etal, 2015).

Groundwater is not pure water because it usually contains dissolved mineral ions. The type and concentration of these dissolved minerals can affect the usefulness of groundwater for various purposes. The quality required of a groundwater supply depends on its purpose; thus, needs for drinking water, industrial water, and irrigation water varies widely. Therefore, the quality of water determines if the groundwater is suitable for the purpose for which it is abstracted. Particularly, the standards for domestic use are sever, because people's health is at stake. Water quality thus must be a consideration when evaluating water supplies.

A wide variety of materials have been identified as contaminants found in groundwater which include synthetic organic chemicals, hydrocarbons, inorganic cations, inorganic anions, pathogens, and radionuclides (Fetter, 1999)[2]. The importance of water quality in human health has recently attracted a great deal of interest. In developing countries like Ethiopia around 80% of all diseases are directly related to poor drinking water quality and unhygienic conditions (Olajire and Imeokparia, 2001)[3].

The best groundwater quality zone can be assessing from spatial distribution map of certain parameters prepared from the hydro chemical data in GIS environment and Mapping the spatial distributions of major elements and their interpolation have contributed for the better understanding of the chemical processes of water and the methods of their acquisition (H. Annapoorna etal, 2015).

So far many researchers in the world (Babiker et al., 2007; Vennila et al., 2008; Shomar et al., 2010 and Magesh et al., 2013) have carried out studies with spatial technologies and interpreted the quality of groundwater for different purposes[4-7].

GIS is a powerful tool to assess the water quality parameter, determining water availability of water, preventing flooding, understanding the natural environment, and managing water resources on a local regional scale (Collet, 1996)[8]. GIS techniques facilitate integrate and conjunctive analysis of large volumes of multidisciplinary data both Spatial and non – spatial within the same geo-reference (Saraf and Choudhury, 1998)[9]. Spatial analysis extension of GIS allows interpolation of the water quality parameter at unknown location from know values to create a continuous surface which will help us to understand the scenarios of water quality parameter of the study area

Water quality index improves understanding of water quality issues by integrating complex data and generating a score that describes water quality status and evaluates water quality trends (Boyacioglu, 2007)[10].

House and Newsome, 1989, stated that the Water Quality Index (WQI) allows 'good' and 'bad' water quality to be quantified by reducing a large quantity of data on a range of physic-chemical variables to be a single number in a simple and objective manner (Liou sm et al., 2004)[11,12].

**1.1 Location**

The study area, Adigrat town is located in Tigray Regional State. It is located towards Northern part of Ethiopia (Figure 1.1). Geographically it bounded between 547165 to 553246m latitude and 1574517 to 1583969m longitude. It covers all the well fields which are serving both the community of the town as well as University with a total areal coverage about 38.94km$^2$.

## 2. MATERIALS AND METHODS

### 2.1 Material and equipments used

The following material and equipments were used during the research work:

- GPS, Plastic bottle, Ice box, Plaster( scotch), Permanent marker
- EC, pH and TDS meter
- ASS, UV and Titrometric materials and chemicals

### 2.2 Methodology

#### 2.2.1 Sample Collection

For chemical constituents and physical parameter of groundwater analysis, field surveying was conducted and purpose sampling technique was applied to collect 22 samples with one litter amount from different water points and transported to the laboratory (Mekelle university) and conducting the analysis with a week from the date of data collection to avoid possible contamination. For this purpose five, four, twelve, and one sample from handug, shallow, deep well and collecting chamber respectively were taken by applying depth integrated groundwater sampling.

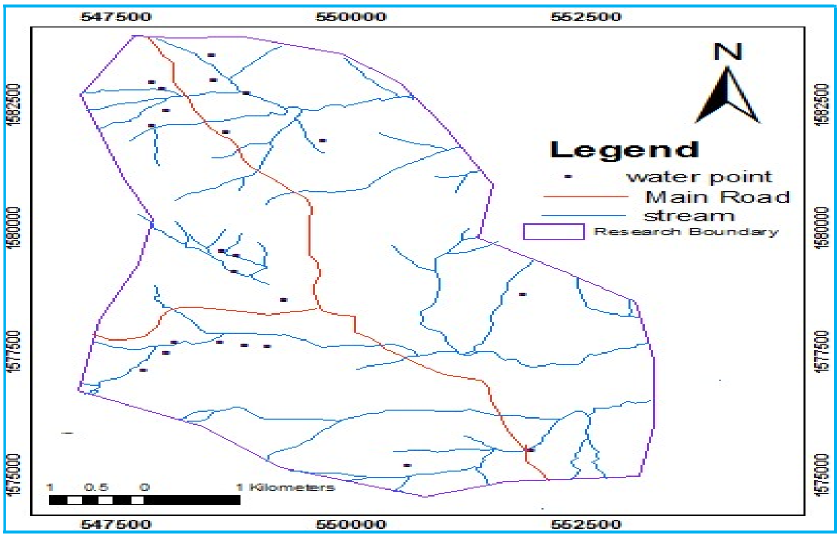


**Figure 2: Location of Groundwater point**

#### 2.2.3 Sample analysis

Analysis of 22 groundwater samples for the major and minor ions ( $Na^{+}$, $K^{+}$, $Ca^{2+}$, $Mg^{2+}$, Fe, Mn, Cr, Cu, and NH3 ) and anions (F, Cl, NO3, NO2, , HCO3, $SO_4^{2-}$ and PO4 and other chemical parameters (total hardness, hardness as calcium carbonate, Alkalinity pH, EC, TDS) as well as Physical parameters (Turbidity, True color, order and taste) were done.

#### 2.2.4 Water Quality Index

Calculating of water quality index is to turn complex water quality data into information that is understandable and useable by the public. Therefore, water Quality Index (WQI) is a very useful and efficient method which can provide a simple indicator of water quality and it is based on some very important parameters.

In current study, Water Quality Index (WQI) was calculated by using the Weighted Arithmetic Index method (Cude, C. 2001)[13]. In this model, different water quality components are multiplied by a weighting factor and are then aggregated using simple arithmetic mean.

For assessing the quality index of water in this study, firstly, the quality rating scale (qn) for each parameter was calculated by using the following equation;

$$qn = \{[(V_{actual} – V_{ideal}) / (V_{standard} – V_{ideal})] * 100\} \text{ ----------(1)}$$

Where,

qn = Quality rating of ith parameter for a total of n water quality parameters

Vactual = Actual value of the water quality parameter obtained from laboratory analysis

Videal = Ideal value of that water quality parameter can be obtained from the standard Tables

Vstandard = Recommended Ethiopian and WHO standard of the water quality parameter.

Once the quality rating scale (qn) was calculating, the weightage factor (Wn) was calculated using the following expression;

**Wn = K/ Sn------(2)** where Wn is weightage factor

Sn is national or WHO standards of the ith parameter and K are proposal constant derived from:

**K=[1/$\sum_{i=1}^{n} 1/Sn$]** ----------------------(3) where Sn is national or WHO standards of the ith parameter

Final the Water quality index (WQI) is calculated for each sample as follows:

**WQI=$\sum qn * Wn/\sum Wn$------------ (4)**

Where WQI is water quality index of each sample

qn is quality rating of ith parameter and Wn is weghtage factor of the ith parameter

Further, the analytical results were taken in to GIS environment to generate the numerical spatial distribution of the parameter and IDW (Inverse Distance weight) technique adopted to create the spatial distribution maps of water quality parameters and WQI and further manipulation the analysis results were done using the Aquachem 2014.2 to determine the groundwater type.

The individual groundwater quality parameters were compared and evaluate using Ethiopian national Water Quality Standards and WHO standards to evaluate its suitability for drinking purpose. Beside this, the suitability of the groundwater for drinking was evaluated based on the water quality index as parameter comparing with status of water quality index (Chaterejee and Raziuddin, 2002)[14].

The accuracy of the analysis results were checked by two option methods which are duplicated method and The Electro Neutrality analysis methods. The duplicated run method was applied during the analysis period at a random check points and the difference between the two run was with insignificant value.

The Electro Neutrality analysis methods was done using the equation (Matthess, 1982)[15], which is the balance between cations and anions to check how accurate the chemical analysis results were beside the two duplicated method.

$$\text{Error balance (e)} = \frac{\text{Sum cations} - \text{Sum anions}}{\text{Sum cations} + \text{Sum anions}} \times 100$$

Where e is the ion balance error and in general the value of e should be less than 5% and certainly less than 10% (Singhal, 1999)[16], but it has observed that most of the samples revealed ion balance error value less than 5 % and only four samples show greater than 5 % this could be due to the fact that as the analysis were conducted with per objective of the present work, there may be one or more ionic species most probably anions with a significant amount that has not been analyzed abundant. The water samples in the study area have negative value of error balance and indicate that anions are more abundant than cation.

## 3. RESULTS AND DISCUSSION

### 3.1 Physical parameter

The common parameters that had analyzed include odor, taste, turbidity and color. All of the groundwater samples are characterized by odorless and tasteless (Appendix 1.1 ) which indicates as the groundwater in the area is suitable for drinking purpose.The true color of the groundwater in the area ranges from 3.05TCU in $HDW_4$ to 5.86TCU in $DW_2$ (Appendix 1.1). Since all the groundwater samples in the area indicate a color very far below the permissible limit as stated by WHO standards, the groundwater is suitable as far as color is concerned where it can be used for drinking use without restriction.

The turbidity in the groundwater of the area varies from 1.01NUT in $SW_3$ to 2.17NUT in $HDW_4$ (Appendix 1.1). According to the water quality standard set by WHO for turbidity, the groundwater in the area is not hazardous for drinking purpose and can be used without any restriction.

**3.2 Chemical parameter**

**3.2.1 pH**

The pH of the groundwater in the area is within the recommended tolerance interval (pH = 6.5 – 8.5) and is ranging from 6.8 in DW3 to 7.76 in $WD_7$ (Appendix1.2). Hence, the groundwater is suitable for drinking purpose. The higher value recorded in the southern and south eastern where as lower generally in the western and north western part of the area (Figure 3 A). This is due to the liquid waste discharged from the surrounding factories

**3.2.2 EC and TDS**

In the area, the electrical conductivity of the groundwater is below the maximum tolerance as compared to the national water quality standards. It is ranging from 142$\mu$S/cm in $DW_7$ to 836 $\mu$S/cm in $HDW_6$ (appendix1.2)

The groundwater is suitable for drinking purpose from Electrical point of view. From the above diagram, the higher is indicated recorded in the western, north western as well as eastern but, it is lower in the southern and central part of the area in generally

The range of electrical conductivity of the area shows that, there is an increasing both its value and variability as one goes from southern to northern in general (figure 3 B) In the western part, this is due to wastes materials due non point source dumped by the track and the chemicals leaching elements from the waste disposal site and introduce to the groundwater but, in the eastern part it could be due to the liquid and solid wastes discharge from the town and the APF that are responsible for the electrical conductivity of the water to be increase. Beside this, the Carbone containing sandstone as aquifer has also higher contribution for the variation of the EC

The TDS values of the groundwater of the basin range from 144 mg/l in $DW_7$ to 596.17 mg/l in $HDW_6$ (Appendix1.2). The concentration revealed a general increasing nature as one goes from southern to northern part of the area with a high variation in concentration around the town (Figure 3 D) It depicts high concentration in some specific spots place could be due to waste materials and chemicals that discharge from these cities and the industries around in addition to the effect of the aquifer materials. It is not surprising that the variation of TDS has the same trend as that of the EC because they are related directly to each other

The groundwater quality status based on TDS is evaluated to be good to excellent classes. Out of the analyzed twenty two, 31.8% of them indicate excellent and where as the remaining 68.2% reflect good class. Hence, the groundwater is recommended for drinking purpose without any restriction. From the diagram below, the TDS value is high at some spot places western and eastern but, low in some spot in generally in the southern.

**3.2.3 Alkanity and Hardness**

The alkalinity of water is a measurement how the water is capable to neutralize acids and this is due to the presence of bicarbonates. From the groundwater sample analysis, its concentration ranges between 45mg/l in $SW_3$ to 330mg/l in $DW_6$ (Appendix1.2). The spatial variability of alkalinity increase from south eastern and eastern to word the western in general (figure 3 E). This variation is more appreciable around the spot sites where tracks dumping the wastes from the town which is a good evidence for the contribution of the waste materials and chemicals that disturb the groundwater chemistry in the area. Out of the analyzed twenty two, 68.2 % of them indicate alkalinity value under the maximum permissible limit set by national water quality where as the remaining 31.8% of them indicate alkalinity value above the maximum permissible limit set by national water quality. Hence, the groundwater is recommended for drinking purpose with some quality adjustment.

**3.2.4 Total Hardness**

Total hardness of Water is caused primarily by the presence of the cation such as calcium and magnesium and anions such as carbonate bicarbonate etc in water. This measurement takes into account both Ca2+ and Mg2+ ions. Hard water is not suitable for drinking purpose. The total hardness in the area is ranging from 154.17mg/l in $DW_2$ to 360 mg/l in $DW_{10}$ (Appendix 1.2). The hardness value in the area shows high at some spot in the eastern and western part of the area (figure 3 C) like the other parameters as it proportional to the concentration of calcium and magnesium which show high variable in the eastern and western part of the area. Except six groundwater samples that show a hardness value greater than the maximum limit as stated in the Ethiopia water quality standards and more than 72% of the samples reflect that the groundwater is recommended for drinking purpose. Therefore, the groundwater is recommended for drinking purpose with some water quality treatment.

**3.2.5 Hardness as Calcium Carbonate**

This hardness of Water is caused primarily by the presence of the calcium carbonate. Hard water is not suitable for drinking purpose.

The hardness in the area is ranging from 0.005mg/l $SW_2$ to 0.584 mg/l in $HDW_6$ (Appendix 1.2). The hardness value in the area shows high in the eastern part of the area (Figure 3 F) proportional to the concentration of calcium which show high variable in the eastern part of the area. All groundwater samples that show hardness value far below the maximum limit as stated in the Ethiopia water quality standards that the groundwater is recommended for drinking purpose without any restriction.

**3.2.6 Calcium Concentration**

Calcium is the most abundant cation in the area as per concentration in milligram per litter. Calcium ranges between 55mg/l in $SW_3$ to 144mg/l in $DW_8$ and $DW_7$ and he concentration of this cation revealed highly variable in western, eastern and central parts of the area (Appendix 1.3). The variability and the concentration also increase in the direction of the general surface water flow path in the area (Figure 4 A). The increments of this cation along the flow path of groundwater could be from the meta dolomite that observed in the log. The depth at which the Meta dolomite layer encountered decreases as one goes from western to eastern part of the area. However, in the western part the concentration is relatively low which could be due to the ion exchange between sodium and calcium as well as the less solubility nature of the dolerite. As far as the drinking purpose is concerned, the groundwater in the area is not suitable since greater than 59% is beyond the maximum limit based on the Ethiopian national standards which needs treatment and adjustments.

**3.2.7 Magnesium Concentration**

Magnesium is the abundant element in the form of magnesium ions. It has high concentration next to calcium in the area. Magnesium concentration in groundwater is highly variable in different groundwater points between 5 mg/l in $HDW_4$ to 87.4mg/l in $DW_8$ (Appendix 1.3). The high concentration of magnesium was recorded in the western and central as well as in some spot in the northern part of the area which could be caused by the dolerite intrusions dyke (Figure 4 B). The magnesium concentration in the area is characterized by increase from almost from all part toward the town (Figure 4 B). This is due to anthropogenic sources. As the evident geological observations, the dolomite is dominant as we go from the eastern to western as well as from the southern to the northern part and this is the cause for the variability of the magnesium in the area. In addition to this, other magnesium containing geological materials also plays a greater role in changing the concentration from both eastern to western part of the area in general. From Drinking purpose point of view, except five groundwater samples about 77.3% of the sample indicates that the groundwater of the area is suitable for drinking purpose.

**3.2.8 Sodium concentration**

Sodium is an abundant element next to magnesium in the area and ranges from 1mg/l in $RV_1$ to 29 mg/l in $DW_6$ (Appendix 1.3). From the spatial distribution map of sodium (Figure 4 C), the maximum concentration observed in the western, south and northwestern part of the area. This is due to clay material disintegrated from the volcanic rocks. Additional anthropogenic source for the sodium concentration beside the natural sources, effect of the wastes and chemicals discharged from the town and the industries in the town itself and in the nearby area also contributed to the increase mental of sodium concentration. The water analysis result indicates that, the groundwater in the area is suitable for drinking use as the sodium concentration is far below the maximum limit stated in the Ethiopian water quality standards.

**3.2.9 Potassium concentration**

Potassium concentration in the area ranges between 0.92mg/l in $DW_{12}$ to 0.13mg/l in $HDW_4$ (Appendix 1.3). The concentration of this cation is not highly variable and from the spatial distribution map, high concentration of potassium is observed in the southeastern and southwestern part of the area (Figure4.D) This high concentration of potassium related to chemical wastes, clay materials and some feltrizers in the agricultural fields. But, it is low particularly in the northern part due to the carbonate rocks observed in the geological logs in which the potassium constituent is very low. This cation shows relatively low variation of concentration in the eastern and central and.

The water analysis result indicates that, the groundwater in the area is suitable for drinking use as the potassium concentration is far below the maximum limit stated in the Ethiopian water quality standards.

**3.2.10 Chromium Concentration**

The chromium concentration observed in the groundwater ranged from 0 in most of the samples to a maximum of 0.13mg/l in $DW_9$ (Appendix1.3). From the spatial distribution map of Chromium, one can realized that a high chromium anomies in the southeastern part of the area special in the town (Figure 4 E) which indicates anthropological source of chromium which could be the contaminant as solid and liquid wastes discharge from the factory, old waste disposal site as well as from the town itself

Except $DW_9$, all the analyzed samples showed values of chromium below the national water quality limit; the groundwater is general suitable and can be used for drinking purpose with some restriction.

**3.2.11 Copper Concentration**

Copper is a trace element in groundwater in the area which varies 0.008mg/l in $DW_8$ to 0.56gm/l in $DW_{12}$ (appendix 1.3). High concentration is observed in the eastern and northern part of the area (Figure 4 F). This concentration is due to the waste discharged in the eastern and from the old disposal site in the northern. As the all the samples reflected a copper concentration below the maximum allowable limit based the national standards, the groundwater in the area is recommended for drinking use without any restriction.

**3.2.12 Ammonia Concentration**

The values measured for ammonia concentration in the groundwater ranged from 0.001 in RV to 0.015 mg/l in $SW_4$ (Appedix1.3). As such, all the analyzed samples showed values below the national water quality limit; the groundwater is suitable for drinking purpose. There is high concentration generally in the northern and south as well as at some incident points in the central part of the area (Figure 4 H ) This is all due to the waste material discharged from the town, factory as well as from the animal wastes and feltrizer.

There is no hazardous and the groundwater in the area is suitable for drinking use as far as the ammonia concentration is within the maximum limit stated on the national water quality standards.

**3.2.13 Manganese**

The manganese concentration values measured in the groundwater ranged from 0 in most of the samples to a maximum of 0.12mg/l in $DW_9$ and $DW_7$ (Appendix1.3). As such, all the analyzed samples showed values below the national water quality limit; the groundwater is suitable and can be used for drinking purpose without any restriction.

**3.2.14 Iron**

The values measured for Iron concentration in the groundwater of the ranges from 0.04 in $DW_3$ to 0.82 mg/l in $DW_{10}$ (Appedix1.3). More than 59.1% of all the analyzed samples showed Iron concentration value beyond the permissible limit based on the national water quality standards. This Iron concentration makes the groundwater to be unpleasant in the area for drinking purpose. The Iron concentration can be caused due to oxidation of steel components in the well like pipes in addition to the natural sources. Accordingly, the groundwater in the area is not suitable for drinking purpose which needs some management to reduce the Iron concentration and improve the groundwater quality in the area.

**3.2.15 Sulphate Concentration**

The concentration ranges from 89.6 mg/l in $SW_5$ to 227.61 mg/l in $DW_5$ (Appendix1.4).The high concentration of sulphate is recorded in generally in the eastern with some spot in the northern and western part of the area (Figure 5A). It is not surprising for the high concentration of sulphate in the eastern part around the Addis pharmaceutical factory because chemicals such as sulpheric acid and waste solid materials containing iron sulphide are discharge and thrown to the environment without proper control system to surrounding that can disturbed the groundwater chemistry by leaching of sulphate ions. But, rain water has also its contribution of sulphate concentration that might play a role in fluctuating its concentration in the area. From the drinking purpose point of view, the groundwater is suitable taking sulphate as parameters as it is below the permissible limit of the Ethiopian standards.

**3.2.16 Phosphate concentration ($PO4^{2-}$)**

The phosphate is low abundant anion in the area that ranges from 0.051mg/l in $HDW_1$ to 0.001 mg/l in $HDW_4$ (Figure 5B and Appendix 1.4). The high concentration of phosphate is recorded in the southern, northern and some spot in the central part of the area (Figure 5B). This peak value is most probably due to the agricultural practice (feltrizer). Like others; the concentration of this constituent is highly variable and is increasing on the general low elevated and discharge zone part of the area. The solid and liquid waste disposal is also contributed in the increasing of the concentration particularly northern part of the area. But, the effects of the constituents that are leached from the wastes and uncontrolled sewerages and the fertilizers that the people used for their agricultural practice have greater contribution in variation of this ionic concentration. The relatively high agricultural practice in southern and northern part supports that, feltrizer is the main source for the variation of this ionic concentrations. From the drinking purpose point of view, the groundwater is suitable taking phosphate as parameters as it is below the permissible limit of the WHO standards.

**3.2.17 Nitrate Concentration ($NO3^{-2}$)**

The groundwater sample from area show the concentration of nitrate ion range between 9. 68 mg/l in $WD_6$ to 1.5 mg/l in $WD_{10}$ (Appendix1.4). The concentration of this constituent has a variability nature different from other constituents in such a way that its concentration is high both in eastern, southern as well as northern part of the area (Figure 5C) round the concentrated rural areas. Having relative concentration in the recharge area could be due to natural nitrogen mixed with rain water in the air and from human and animal wastes with some contribution from fertilizers (mainly urea). Beside this contribution from the solid wastes and chemicals from the sewerage and the industries might be other source for the nitrate concentration in the area.

All the sample depict that the concentration of nitrate in the groundwater in the area is under the maximum limit as stated in the Ethiopia water quality standards which indicate that the groundwater is suitable As far as drinking purpose is concerned.

**3.2.18 Chloride**

Chloride is abundant anion next to sulphate anions in the area. The concentration varies from 2.13 mg/l in $SW_3$ to 26.12 mg/l in $SW_5$ (Appendix 1.4). From the spatial distribution map of the Chloride (Figure 5D) one can understand that there is high concentration in the western as well as at some spot in the south and northwestern part of the area. But, high concentration is relatively significant in the town and its surrounding including the pharmaceutical factory. This could be also due to the pollution effect caused by leaching of the constituents from sewerages and chemicals as well as the industries around and the leached components introduced to the groundwater thereby change the chloride concentration in the groundwater chemistry.

Since, the chloride concentration in the area is far below the permissible limit as National water quality standards, the groundwater is suitable for drinking purpose taking Chloride as parameters.

**3.2.19 Fluoride Concentration**

Groundwater usually contains fluoride dissolved by geological formation. Fluoride concentration is also a minor constituent of the in groundwater in the area. The Fluoride content of the groundwater varied from 0.001 mg/l to .00.282 mg/l in RV and $DW_7$ respectively (Appendix1.4). From the spatial distribution of fluoride map (Figure 5G), one can understand that, there is a high fluoride anomaly in the central part of the area especially in the town. The main source of fluoride attributed to leaching from fluoride rich rocks and easier accessibility of rain water to weathered rock.

With fluoride as parameter the groundwater in the area is suitable for drinking purpose as far as the fluoride concentration is below the maximum limit of the Ethiopia water quality standards.

**3.2.20 Bicarbonate**

Bicarbonate is the most dominant anion in the area that ranges from 54.81 mg/l in $SW_3$ to 420.3mg/l in $DW_{21}$ (Appendix 1.4). The maximum concentration is observed in the central and in some spot in the northern part of the area (Figure 5E). It particularly shows high variation around the Adigrat town. This may be due to the effect of the constituents that are leached from the sewerage and from the old waste disposal sites and the small factories that introduced in the groundwater.

**3.2.21 Nitrite Concentration ($NO2^-$)**

The groundwater sample from area show the concentration of nitrite ion range between 0.013 mg/l in $WD_3$ to 0.61 mg/l in $HWD_1$ (Appendix1.4). The concentration of this constituent has a variability nature in such a way that its concentration is high both in eastern and northern part of the area (Figure 5F) especially round the concentrated town. Having relative concentration in the town could be due to wastes discharged from the town, factory as well as from the old disposal waste site. Beside, this both the modern and human and animal wastes which can be applied as fertilizers in agricultural practice. In addition to this contribution from the solid wastes and chemicals from the sewerage and the industries might be other source for the nitrate concentration in the area.

All the sample depict that the concentration of nitrate in the groundwater in the area is under the maximum limit as stated in the Ethiopia water quality standards which indicate that the groundwater is suitable As far as drinking purpose is concerned.

**3.3 Water Quality Index**

The WQI concept is based on the comparison of the water quality parameter with respective regulatory standards (Khan F, et al., 2003)[17] and provides a single number that express overall water quality at certain location based on several water quality parameters (Yogendra and Puttaiah, 2008)[18]. In present study the WQI has been calculated by using standards of drinking water quality recommended by the Ethiopian National Water Quality Standards and WHO and weighted index method developed by Tiwari and Mishra 1985; Asadiet al., 2007 to determine the suitability of groundwater for drinking purposes. In the present study 22 water quality parameters were considered for computing water quality index[19].

The WQI in the study area varying from 1.38 in $SW_4$ to 180.76 in $DW_9$ (Appendix 1.6). From the spatial distribution map of WQI (Figure 6). High value of WQI has been observe in the eastern part of the area particularly around the town which indicates the groundwater quality is affected due to the solid wastes discharged from the town, old disposal site as well as from the pharmaceutical factory. This confirmed by the individual parameters where most of them reflect high around the town. More than 90% of the sample indicates a water quality index classified under excellent where as each 4.55% indicated the water quality index poor and unsuitable class. From this, the groundwater in the area is suitable generally with some restrictions.

**3.4 Groundwater Type**

Once the chemical analysis results of the groundwater samples further analyzed by the Aquachem 2014.2 software, the groundwater type of the area can be obtained as output and the predominant composition of the groundwater in the area were grouped. The Piper-Hill diagram (Piper, 1953)[20] is used to infer hydro-geochemical facies. Chemical data of representative samples from the area presented by plotting them on a Piper-tri-linear diagram. Water types are designed according to the domain ions in which they occur on the diagram segments. Accordingly, there are six groundwater types in the area with dominant groundwater type of Ca- Mg-HCO3-SO4 with some extent of Ca- SO4-HCO3 (Appendix 1.4). It is not surprising for the groundwater of the area to be dominated by Ca- Mg-HCO3-SO4 as long as the ions indicating in this type are the dominant concentration in the groundwater in the area. The groundwater type in the area is illustrated by following diagrams using the dominant mineral composition of these carbonate rocks.

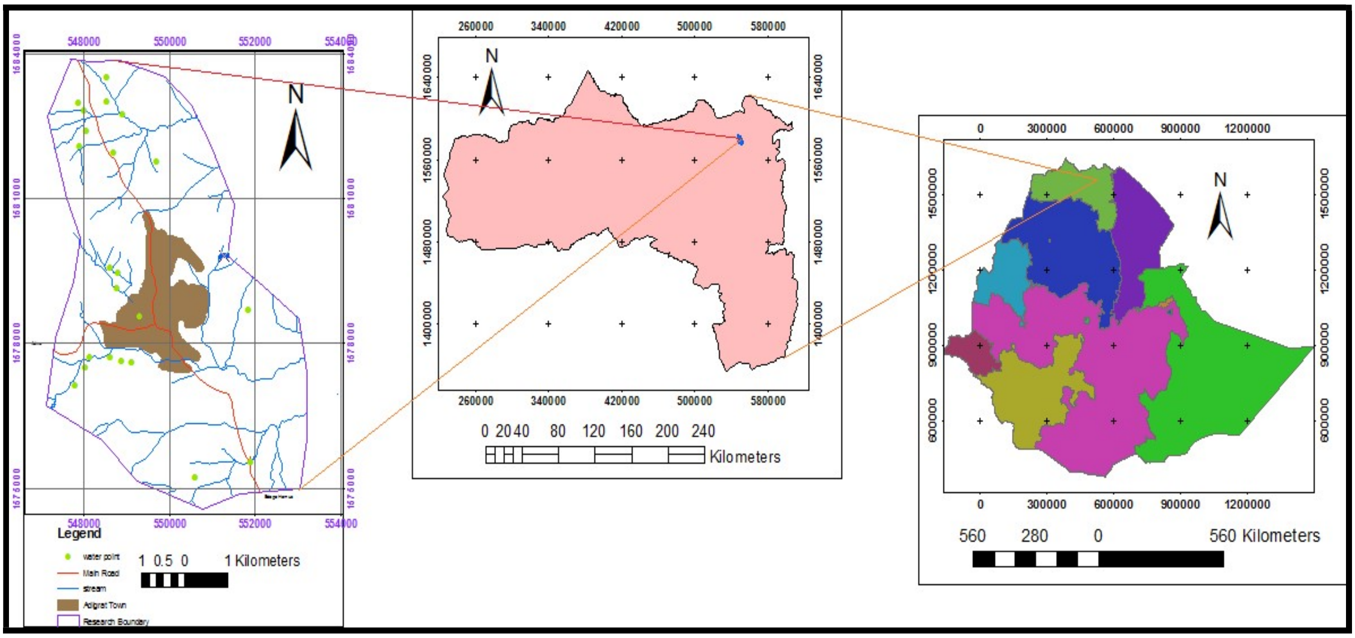


**Figure 1: Location map the area**

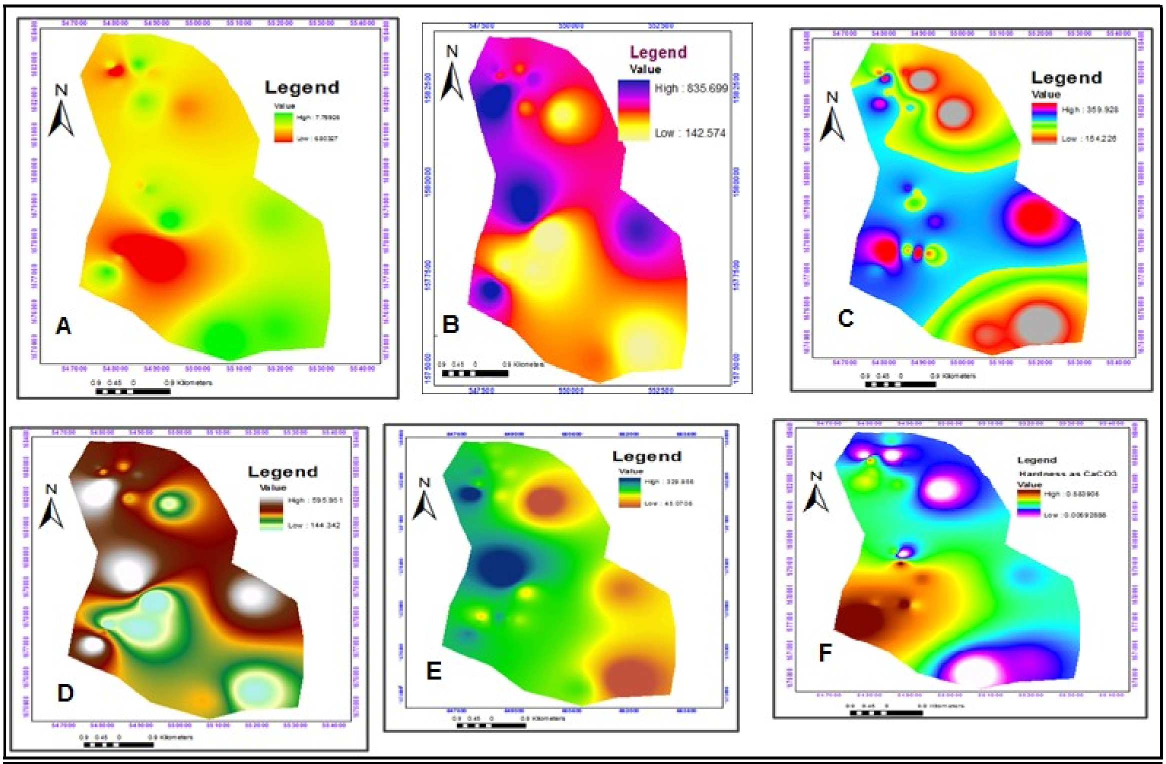


**Figure 3: Spatial distribution map A) pH, B) EC C) Total Hardness D) TDS E) Alkalinity F) Hardness as $CaCO_3$**

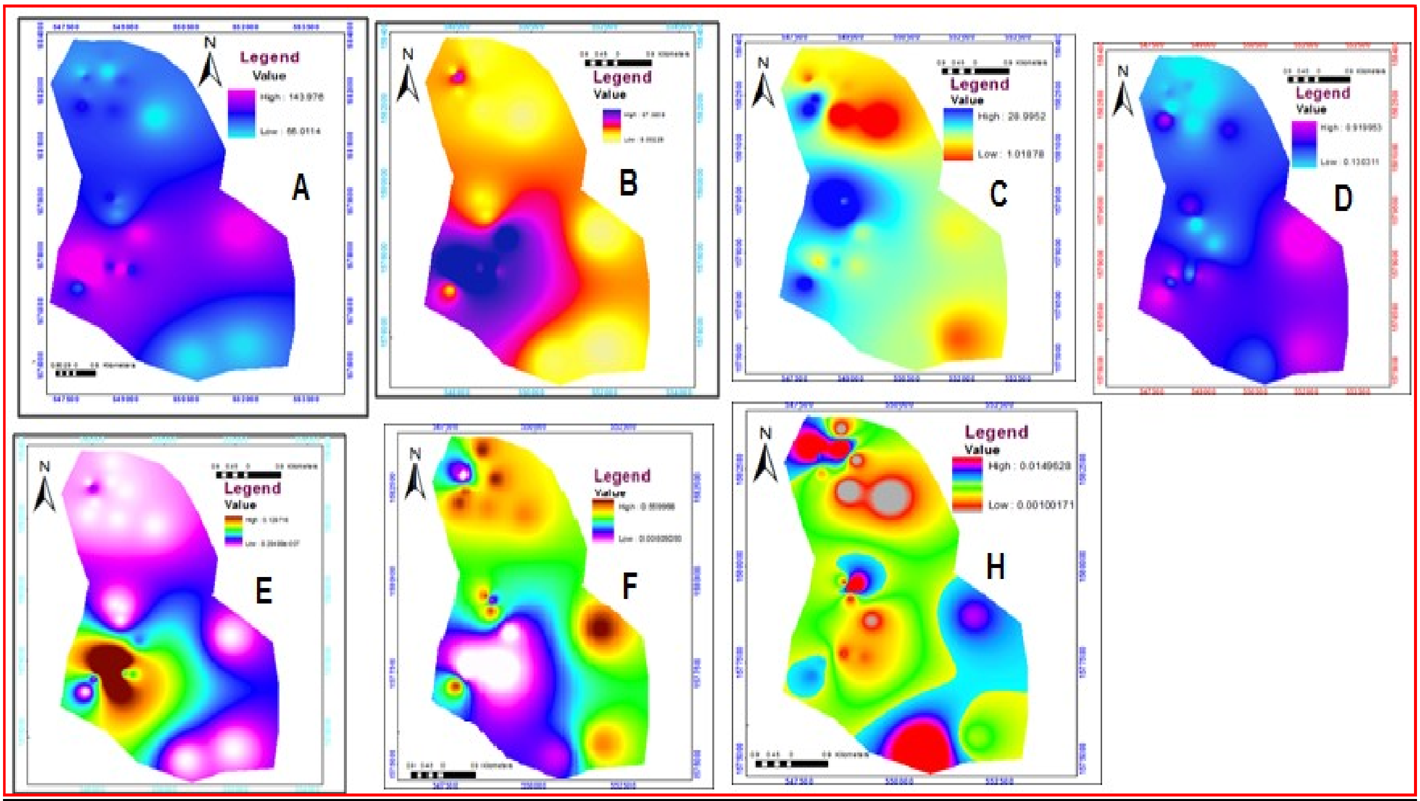


**Figure 4 Spatial distribution map Cations A) Calcium B) Magnesium C) Sodium D) Potassium E) Chromium F) Copper H) Ammonia**

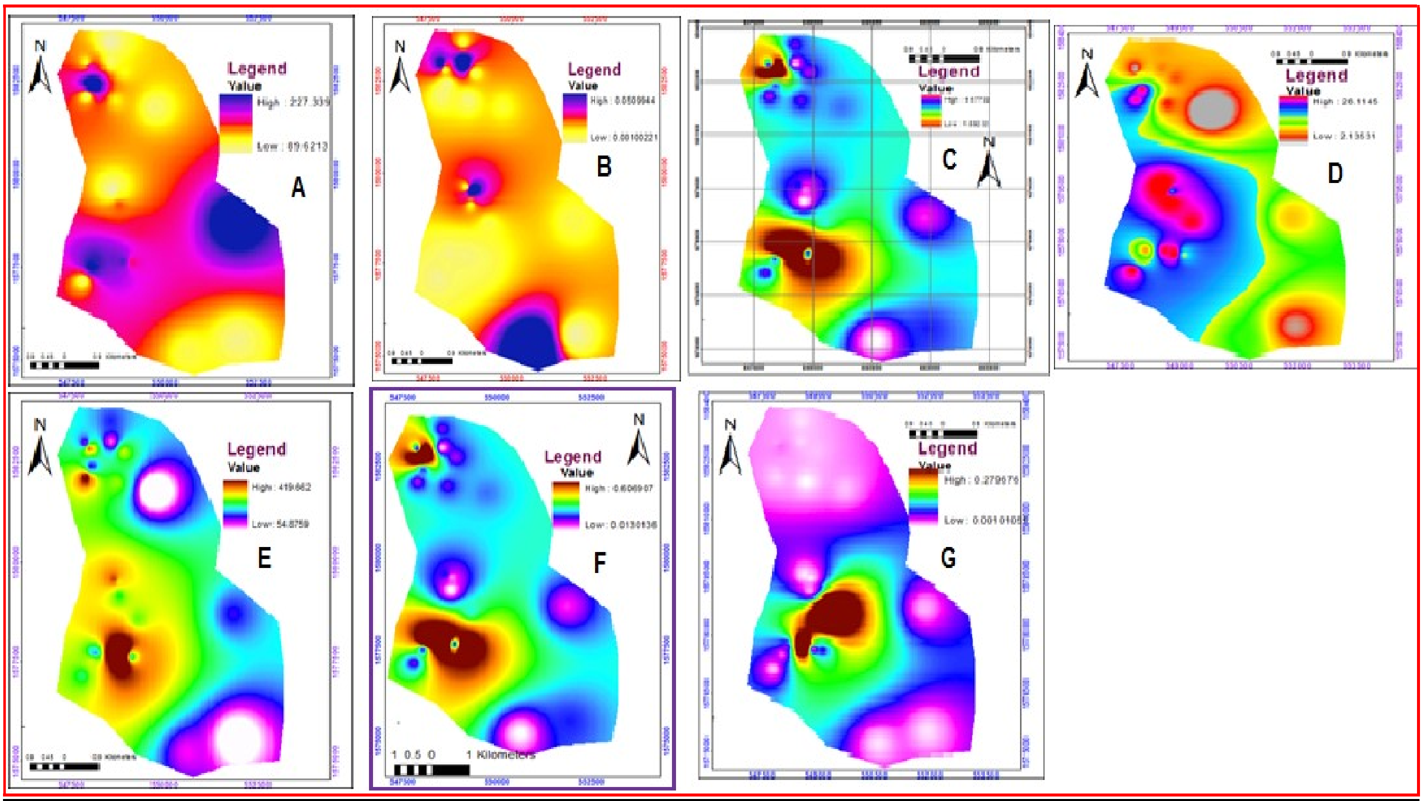


**Figure 5: Spatial Distribution map of anions A) Sulphate B) Phosphate C) Nitrate D) Chloride E) Bicarbonate F) Nitrite G) Fluoride**

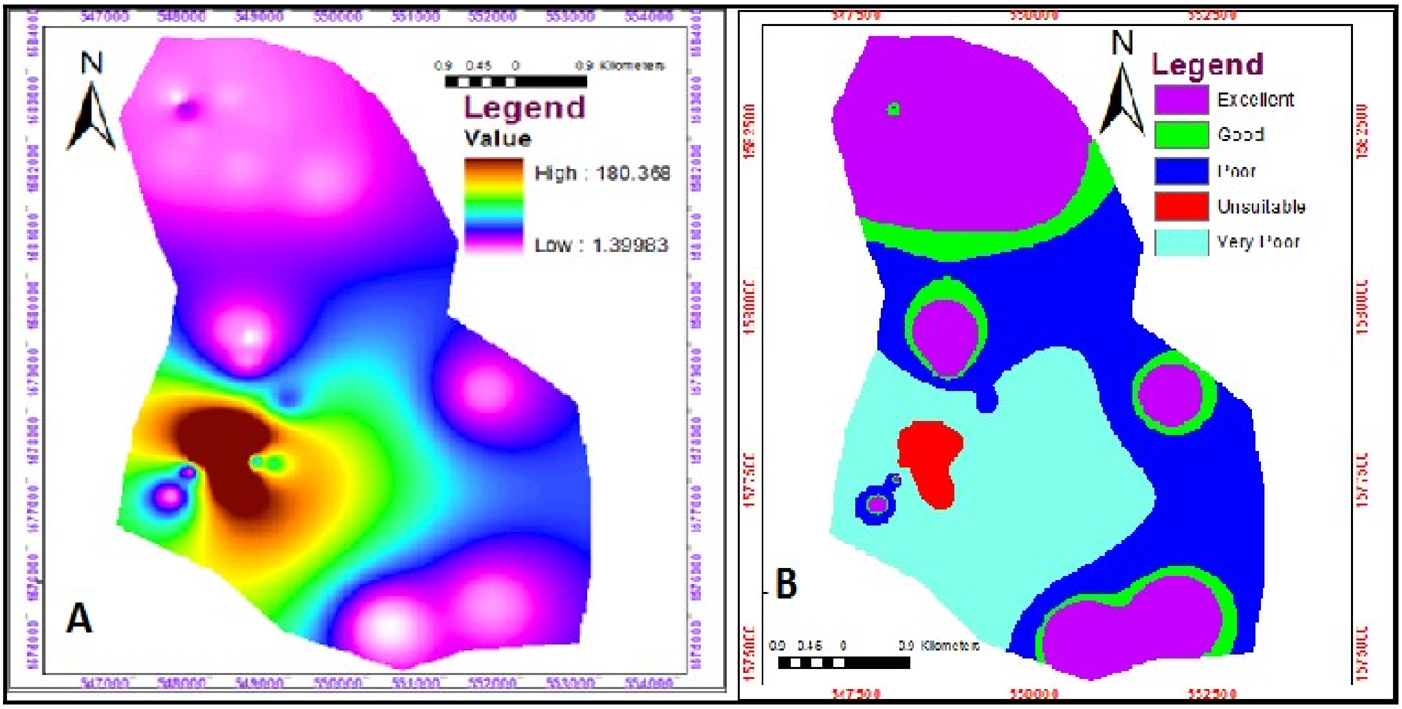


**Figure 6: Spatial Distribution map: A) Water Quality Index, B) potable index map**

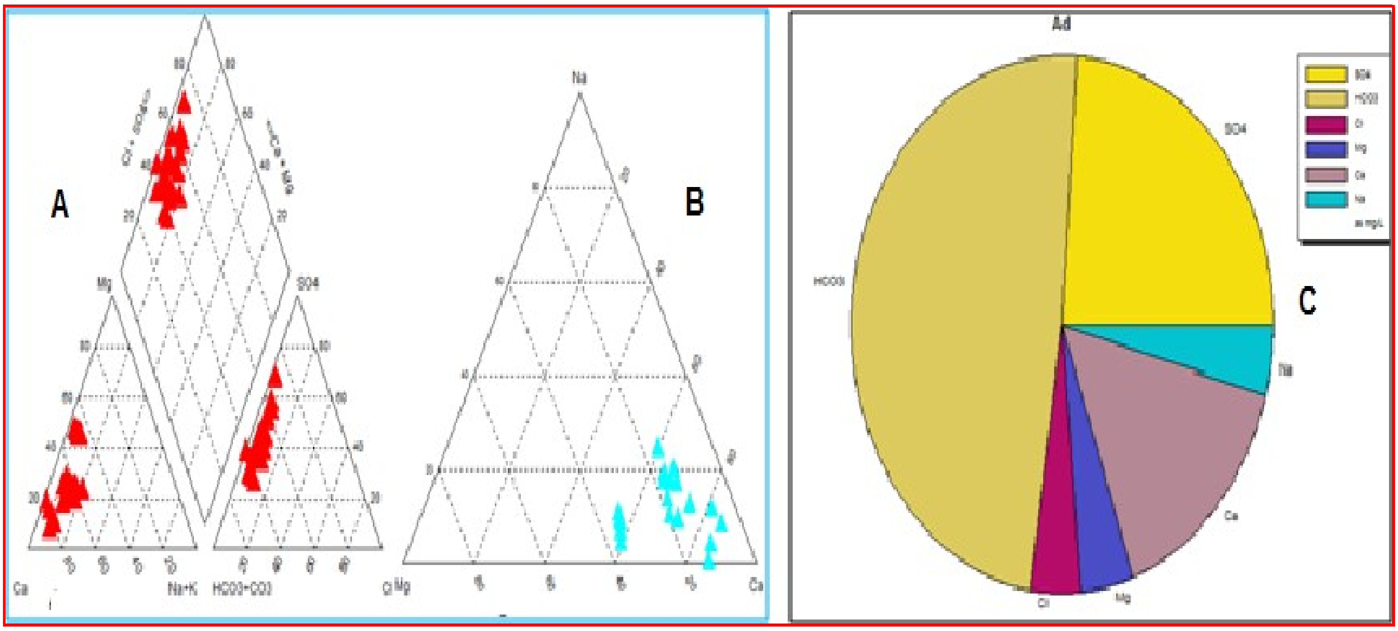


**Figure 7: Groundwater type of the area. A) Piper plot B) Ternary plot C) pie plot of major ions in the Groundwater**

Appendix 1.1 Physical parameter of groundwater

| No | Sample Code | True color | odor | Taste | Turbidity |
|---|---|---|---|---|---|
| 1 | HDW1 | 4.356TCU | No odor | Not Unpleasant | 1.03NTU |
| 2 | HDW4 | 3.05TCU | No odor | Not pleasant | 2.17NTU |
| 3 | DW3 | 4.13TCU | No odor | Not pleasant | 1.18NTU |
| 4 | HDW5 | 4.26TCU | No odor | Not pleasant | 1.03NTU |
| 5 | SW2 | 4.156TCU | No odor | Not pleasant | 1.02NTU |
| 6 | DW4 | 4.32TCU | No odor | Not unpleasant | 1.02NTU |
| 7 | DW5 | 4.851TCU | No odor | Not pleasant | 1.08NTU |
| 8 | DW2 | 5.86TCU | No odor | Not pleasant | 1.74NTU |
| 9 | SW3 | 3.11TCU | No odor | Not pleasant | 1.01NTU |
| 10 | SW4 | 4.235TCU | No odor | Not pleasant | 1.04NTU |
| 11 | SW5 | 5.27TCU | No odor | Not pleasant | 2.13NTU |
| 12 | DW6 | 5.12TCU | No odor | Not unpleasant | 1.23NTU |
| 13 | DW7 | 3.32TCU | No odor | Not unpleasant | 1.32NTU |
| 14 | HDW6 | 5.13TCU | No odor | Not unpleasant | 1.06 NTU |
| 15 | DW9 | 4.76TCU | No odor | Not unpleasant | 1.41NTU |
| 16 | DW10 | 4.48TCU | No odor | Not unpleasant | 1.24NTU |
| 17 | DW11 | 5.21TCU | No odor | Not pleasant | 1.34NTU |
| 18 | DW12 | 3.22TCU | No odor | Not pleasant | 1.03NTU |
| 19 | DW8 | 6.23TCU | No odor | Not pleasant | 1.04NTU |
| 20 | RV1 | 6.12TCU | No odor | Not pleasant | 1.51NTU |
| 21 | DW3 | 3.87TCU | No odor | Not pleasant | 1.52NTU |
| 22 | DW7 | 4.98TCU | No odor | Not pleasant | 1.63NTU |

Appendix1.2Chemical parameters of groundwater quality

| No | ID | Total Hardness | TDS | EC | PH | CaCO3 | Alkalinity |
|---|---|---|---|---|---|---|---|
| 1 | **HDW1** | 197.5 | 364.4 | 511 | 7.7 | 0.009 | 195 |
| 2 | **HDW4** | 170.8 | 240.32 | 337 | 7.6 | 0.167 | 70 |
| 3 | **DW3** | 260 | 581.89 | 816 | 7.3 | 0.35 | 195 |
| 4 | **HDW5** | 312.5 | 594.02 | 833 | 7.3 | 0.37 | 310 |
| 5 | **SW2** | 211.67 | 454.25 | 637 | 7.4 | 0.005 | 220 |
| 6 | **DW4** | 232.5 | 399.34 | 560 | 7.4 | 0.29 | 190 |
| 7 | **DW5** | 202.5 | 361.5 | 507 | 7.6 | 0.007 | 190 |
| 8 | **DW2** | 154.17 | 455.68 | 639 | 7.3 | 0.21 | 180 |
| 9 | **SW3** | 166.7 | 272.41 | 382 | 7.2 | 0.04 | 45 |
| 10 | **SW4** | 259.17 | 521.99 | 732 | 7.5 | 0.008 | 270 |
| 11 | **SW5** | 300 | 550.52 | 772 | 7.3 | 0.35 | 295 |
| 12 | **DW6** | 247.5 | 590.45 | 828 | 7.4 | 0.49 | 330 |
| 13 | **DW7** | 300 | 144 | 142 | 7.76 | 0.45 | 168 |
| 14 | **HDW6** | 278.3 | 596.16 | 836 | 7.6 | 0.584 | 245 |
| 15 | **DW9** | 220 | 250 | 402 | 6.85 | 0.46 | 232 |
| 16 | **DW10** | 360 | 220 | 347 | 6.83 | 0.52 | 196 |
| 17 | **DW11** | 210 | 240 | 374 | 6.88 | 0.38 | 184 |
| 18 | **DW12** | 338.3 | 528.58 | 701 | 7.5 | 0.246 | 130 |
| 19 | **DW8** | 360 | 220 | 345 | 6.91 | 0.44 | 164 |
| 20 | **RV1** | 266.7 | 352.28 | 494 | 7.5 | 0.33 | 175 |
| 21 | **DW3** | 332 | 350 | 520 | 6.8 | 0.43 | 240 |
| 22 | **DW7** | 325 | 380 | 480 | 7.3 | 0.51 | 200 |

Appendix1.3 Cation concentration of groundwater quality

| No | ID | NH4-Con | Na+ | k+ | Ca+2 | Mg+2 | Fe-Con | Mn -Con | Cri | Cu-Con |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **HDW1** | 0.012 | 15 | 0.42 | 59 | 12 | 0.13 | 0 | 0 | 0.16 |
| 2 | **HDW4** | 0.005 | 9 | 0.76 | 60 | 5 | 0.32 | 0 | 0 | 0.48 |
| 3 | **DW3** | 0.004 | 23 | 0.13 | 74 | 18 | 0.38 | 0 | 0 | 0.52 |
| 4 | **HDW5** | 0.005 | 24 | 0.72 | 90 | 21 | 0.42 | 0 | 0 | 0.53 |
| 5 | **SW2** | 0.014 | 9 | 0.26 | 58 | 16 | 0.36 | 0 | 0 | 0.18 |
| 6 | **DW4** | 0.002 | 13 | 0.13 | 73 | 12 | 0.52 | 0 | 0 | 0.54 |
| 7 | **DW5** | 0.013 | 12 | 0.31 | 56 | 15 | 0.52 | 0 | 0 | 0.42 |
| 8 | **DW2** | 0.002 | 11 | 0.14 | 80 | 19 | 0.17 | 0 | 0 | 0.54 |
| 9 | **SW3** | 0.001 | 3 | 0.54 | 55 | 7 | 0.43 | 0 | 0 | 0.48 |
| 10 | **SW4** | 0.015 | 20 | 0.53 | 72 | 19 | 0.41 | 0 | 0 | 0.15 |
| 11 | **SW5** | 0.003 | 28 | 0.61 | 90 | 18 | 0.48 | 0 | 0 | 0.52 |
| 12 | **DW6** | 0.003 | 29 | 0.15 | 69 | 18 | 0.43 | 0 | 0 | 0.51 |
| 13 | **DW7** | 0.0025 | 15 | 0.25 | 120 | 72.4 | 0.04 | 0.12 | 0.01 | 0.04 |
| 14 | **HDW6** | 0.007 | 24 | 0.86 | 78 | 20 | 0.21 | 0 | 0 | 0.52 |
| 15 | **DW9** | 0.003 | 18 | 0.3 | 88 | 53.4 | 0.18 | 0.12 | 0.13 | 0.048 |
| 16 | **DW10** | 0.004 | 16 | 0.7 | 128 | 77.6 | 0.82 | 0.08 | 0.011 | 0.008 |
| 17 | **DW11** | 0.0035 | 14 | 0.65 | 84 | 50 | 0.24 | 0.09 | 0.016 | 0.016 |
| 18 | **DW12** | 0.008 | 13 | 0.92 | 122 | 8 | 0.41 | 0 | 0 | 0.56 |
| 19 | **DW8** | 0.006 | 12 | 0.8 | 144 | 87.4 | 0.18 | 0.04 | 0.036 | 0.008 |
| 20 | **RV1** | 0.001 | 1 | 0.21 | 85 | 13 | 0.42 | 0 | 0 | 0.48 |
| 21 | **NDW3** | 0.007 | 14 | 0.35 | 80 | 48.5 | 0.04 | 0.08 | 0.007 | 0.012 |
| 22 | **NDW7** | 0.0065 | 17 | 0.4 | 144 | 87 | 0.14 | 0.08 | 0.004 | 0.024 |

Appendix1.4 Anion concentration of groundwater quality

| No | ID | F- | Cl- | No3- | No2 | Hco3 | SO4 | Po4 |
|---|---|---|---|---|---|---|---|---|
| 1 | **HDW1** | 0.003 | 14.56 | 2.56 | 0.013 | 137.9 | 107.3 | 0.051 |
| 2 | **HDW4** | 0.003 | 8.71 | 4.13 | 0.07 | 85.06 | 99.3 | 0.001 |
| 3 | **DW3** | 0.007 | 22.15 | 4.13 | 0.073 | 159.89 | 227.61 | 0.002 |
| 4 | **HDW5** | 0.004 | 21.52 | 6.13 | 0.05 | 277.4 | 102.71 | 0.003 |
| 5 | **SW2** | 0.007 | 8.12 | 3.58 | 0.043 | 148.39 | 108.5 | 0.031 |
| 6 | **DW4** | 0.003 | 11.52 | 8.76 | 0.06 | 161.21 | 90.21 | 0.005 |
| 7 | **DW5** | 0.004 | 11.13 | 3.12 | 0.021 | 131.8 | 103.2 | 0.042 |
| 8 | **DW2** | 0.005 | 10.53 | 6.12 | 0.053 | 219.6 | 112.52 | 0.004 |
| 9 | **SW3** | 0.005 | 2.13 | 5.12 | 0.08 | 54.81 | 102.13 | 0.006 |
| 10 | **SW4** | 0.002 | 18.26 | 4.15 | 0.031 | 229.39 | 112.3 | 0.041 |
| 11 | **SW5** | 0.002 | 26.12 | 7.56 | 0.07 | 259.18 | 89.6 | 0.004 |
| 12 | **DW6** | 0.006 | 23.53 | 9.68 | 0.013 | 202.59 | 128.33 | 0.006 |
| 13 | **DW7** | 0.28 | 22.4 | 4.24 | 0.099 | 210.3 | 132.5 | 0.0052 |
| 14 | **HDW6** | 0.005 | 22.53 | 6.52 | 0.06 | 197.7 | 103.5 | 0.002 |
| 15 | **DW9** | 0.21 | 22.2 | 2 | 0.43 | 320.4 | 158.77 | 0.003 |
| 16 | **DW10** | 0.01 | 23 | 1.59 | 0.06 | 420.3 | 161.77 | 0.0032 |
| 17 | **DW11** | 0.025 | 15.8 | 1.7 | 0.32 | 190.7 | 135.06 | 0.0043 |
| 18 | **DW12** | 0.006 | 12.15 | 7.61 | 0.04 | 158.09 | 201.2 | 0.005 |
| 19 | **DW8** | 0.02 | 11.5 | 2.48 | 0.33 | 172.5 | 165.3 | 0.0024 |
| 20 | **RV1** | 0.001 | 9.88 | 7.51 | 0.061 | 213.49 | 113.49 | 0.003 |
| 21 | **DW3** | 0.01 | 13.5 | 1.95 | 0.61 | 252.2 | 143.5 | 0.0031 |
| 22 | **DW7** | 0.01 | 15 | 1.9 | 0.07 | 221.4 | 177.2 | 0.0042 |

Appendix1.5 Groundwater Type of the area

| No | Station ID | Sample ID | Water Type | Remark |
|---|---|---|---|---|
| 1 | AD | $HDW_1$ | Ca-Mg-HCO3-SO4 | |
| 2 | AD | $HDW_4$ | Ca-SO4-HCO3 | |
| 3 | AD | $DW_3$ | Ca-Mg-HCO3-SO4 | |
| 4 | AD | $HDW_5$ | Ca-Mg-HCO3-SO4 | |
| 5 | AD | $SW_2$ | Ca-Mg-HCO3-SO4 | |
| 6 | AD | $DW_4$ | Ca-HCO3-SO4 | |
| 7 | AD | $DW_5$ | Ca-Mg-SO4-HCO3 | |
| 8 | AD | $DW_2$ | Ca-Mg-HCO3-SO4 | |
| 9 | AD | $SW_3$ | Ca-SO4-HCO3 | |
| 10 | AD | $SW_4$ | Ca-Mg-HCO3-SO4 | |
| 11 | AD | $SW_5$ | Ca-Mg-HCO3-SO4 | |
| 12 | AD | $DW_6$ | Ca-Mg-HCO3-SO4 | |
| 13 | AD | $DW_7$ | Ca-Mg-HCO3-SO4 | |
| 14 | AD | $HDW_6$ | Ca-Mg-HCO3-SO4 | |
| 15 | AD | $DW_9$ | Mg - Ca -HCO3-SO4 | |
| 16 | AD | $DW_{10}$ | Ca-Mg-HCO3-SO4 | |
| 17 | AD | $DW_{11}$ | Ca-Mg-HCO3-SO4 | |
| 18 | AD | $DW_{12}$ | Ca-SO4-HCO3 | |
| 19 | AD | $DW_8$ | Mg-Ca-SO4-HCo3 | |
| 20 | AD | RV1 | Ca-HCO3-SO4 | |
| 21 | AD | $DW_{13}$ | Ca-Mg-HCO3-SO4 | |
| 22 | AD | $DW_{14}$ | Ca-Mg-HCO3-SO4 | |

Appendix 1.6 Water quality index of the Groundwater Samples

| No | Sample Code | WQI |
|---|---|---|
| 1 | HDW1 | 1.462127088 |
| 2 | HDW4 | 4.202890415 |
| 3 | DW3 | 4.570060944 |
| 4 | HDW5 | 4.65442534 |
| 5 | SW2 | 1.632857618 |
| 6 | DW4 | 4.738624133 |
| 7 | DW5 | 3.709196474 |
| 8 | DW2 | 4.731717932 |
| 9 | SW3 | 4.210060403 |
| 10 | SW4 | 1.382959761 |
| 11 | SW5 | 4.5765897 |
| 12 | DW6 | 4.477758014 |
| 13 | DW7 | 14.27541213 |
| 14 | HDW6 | 4.565835204 |
| 15 | DW9 | 180.7616893 |
| 16 | DW10 | 15.36766145 |
| 17 | DW11 | 22.46385178 |
| 18 | DW12 | 4.903563832 |
| 19 | DW8 | 50.11216606 |
| 20 | RV1 | 4.21579351 |
| 21 | DW13 | 10.07376534 |
| 22 | DW14 | 5.812030788 |

## 4. CONCLUSION

The research has been conducting in Adigrat area, northern Ethiopia which s about 38.94km$^2$. Groundwater is the only resource for water supply in the area. So far, the community of the town and the university were used for their water supply from 19 and 3 deep wells respectively. In the area, groundwater drawn from 21 bore wells and one resrviorros were analyzed for their Physico- chemical components. 26 physical and chemical parameters were assessed to evaluate the groundwater quality for drinking use in the area. The analytical results of physical and chemical parameters of groundwater were compared with the standard guideline values recommended by the World Health Organization (WHO, 2011) and Ethiopian national water quality standards for drinking purpose. $Na^+$, $Ca^{+2}$ and $Mg^{+2}$ from cation and $Cl^-$, $HCO3^-$ and $SO4^{-2}$ from anions are the major ions in the area.

Based on the evaluation of physical parameters, the groundwater in the area is suitable for drinking purpose. The groundwater in the area is recommended for drinking purpose with respect to pH, EC, TDS and hardness as $CaCO_3$ from but, with parameters of Alkalinity and total hardness, the groundwater in the area needs some water treatment for quality adjustment. The groundwater in the area needs treatment from iron and calcium concentration point view and can be used for drinking use as far as sodium, potassium, copper, manganese and ammonia area concerned but, can be also used with simple treatment of magnesium and chromium.

The groundwater is also suitable for drinking purpose taking in to account all ionic concentrations ($SO_4^{-2}$, $PO_4^{-2}$, $NO_3^{-2}$, $NO_2^-$, $Cl^-$ , $F^-$ and $HCO_3^-$).From spatial distribution of the ionic concentration and the chemical parameters, generally it is high around the town and the old waste disposal sites and in the highly cultivated agricultural fields.

The ionic and chemical parameter of the groundwater in the area includes point and non sources of domestic, factories as well as feltrizer beside the nature sources.

The best groundwater quality zone in the area was assessing from spatial distribution map of certain parameters prepared from the hydro chemical data in GIS environment.

More than 90% of the sample indicates a water quality index classified under excellent where as each 4.55% indicated the water quality index poor and unsuitable class. From this, it is conclude that the groundwater in the area is suitable generally with some restrictions. The objectionable (poor and unsuitable class) groundwater is restricted generally around the town which indicates the main sources of the contaminants are from the domestic and factories wastes.

The hydro chemical data reveal that the groundwater of the study region consists of six hydro chemical facies, Including Ca-Mg-HCO3-SO4, Ca-SO4-HCO3, Mg-Ca-SO4-HCo3, Ca-Mg-SO4-HCO3, Mg- Ca -HCO3-SO4and Ca-HCO3-SO4.

## 5. CONFLICT OF INTERESTS

The author declare that there is no conflict of interests regarding the publication of this paper.

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