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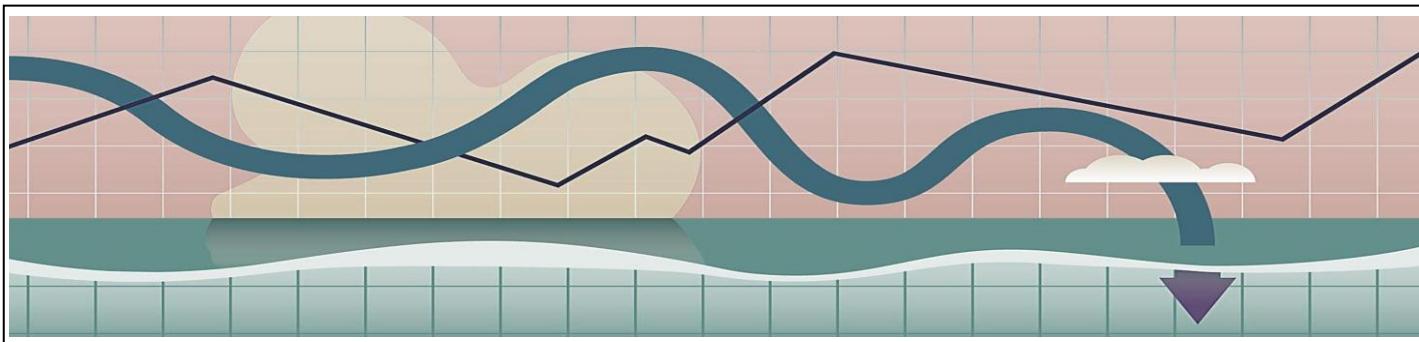
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# A potential approach for evaluation of groundwater quality and its suitability for drinking, domestic, and agricultural uses in Wama Catchments, East Wollega Zone of Oromia region, Western Ethiopia

## ORIGINAL RESEARCH ARTICLE

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## ABSTRACT

Wama is a small catchment and located in southern parts of Abay river basin, Upper part of Didessa sub basin, and bounded between 8°24'0"N-9°0'0"N latitude and 36°24'0"E- 37°24'0"E longitude. It is characterized by highly rugged topography, dendritic drainage pattern, and tropical to sub-tropical climate condition. The area receives high amount of rainfall that reaches 2100mm annually. Much of this influx infiltrates into the thick accumulation of in-situ residua. The thick weathered profile generally serves as a huge reservoir that intercepts vast portion of rainfall and releases it at slower pace to the underlying discontinuous bedrock. Water samples from these boreholes were analyzed to investigate the chemical composition and physical parameters to check if it meets the national and international guidelines for potable water. It was found that pH and TDS vary over narrow ranges of 6.9 to 7.5 and 156 to 196 mg/l, respectively. The mean cationic concentration follows the order  $\text{Ca}^{2+}>\text{Na}^{+}>\text{Mg}^{2+}>\text{K}^{+}$  while anions follow  $\text{HCO}_3^{-}>\text{NO}_3^{-}>\text{Cl}^{-}>\text{SO}_4^{2-}$  order indicating that  $\text{Ca}^{2+}$  and  $\text{HCO}_3^{-}$  are dominant ionic species in the catchment. Our findings revealed that none of the physical and chemical parameters exceeded the maximum limit suggested by national and international guidelines for potable water. The hydro geochemical analysis result shows that Ca and  $\text{HCO}_3^{-}$  are dominant cation and anion, respectively. Based on graphical plots, the major water type found in the area is Mg-Ca-HCO<sub>3</sub> and Ca-Mg-HCO<sub>3</sub>. The suitability of groundwater for drinking and agricultural purposes was evaluated by comparing with WHO water quality standard and different irrigation water quality indices (Na%, and SAR), respectively. Accordingly, water can serve for both domestic and irrigation without posing much risk.

**KEYWORDS:** Assessment, domestic, Geochemical, Groundwater, Surface water

## CITATION OF THE ARTICLE



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## I. INTRODUCTION

Hydrochemistry is an outstanding scientific approach in field of hydro geological study to provide information both in space and time related to origin, quality and history of natural water. It plays crucial role in interpreting the general occurrence of various constituents in waters, controlling factors and the relation of these constituents to water use. Ground Water is important natural resource for living things to exist on the earth and it is a backbone of civilization. The resource is used for irrigation, industries, and domestic purpose. It is also one of major source, which contributed a lot to the world water demand. Nowadays, the development of groundwater in urban centers is anticipated to dramatically increase to improve water supply coverage in response to fast growth rate of urban population. One of the leading impacts of urbanization is its role in groundwater quality. In most cases, groundwater from urban areas is susceptible to pollution because of urbanization and industrialization. The quality of groundwater also depends on various chemical constituents and their concentration, which is mostly derived from the geological formations of the particular region (Hem, 1985; Appelo and Postema, 1993; Drever, 1997; Hitchon et al, 1999; Langmuir, 1997). At the present one fifth of all water used in world is obtained from the ground resource (Fetter, 2001).Ground water plays important role in Ethiopia as a major source of water for domestic uses, industrial and Agricultural uses. Lack of professional and public awareness about the sustainable use of ground water resource made gaps in ground water management.

The atmospheric chemical composition of rain water, the composition and chemical conditions of the soil and geological formation determine the composition of groundwater in the basin. Such that hydro geochemical analysis of water composition may provide information about the environment through which the water has circulated. Thus to determine the usefulness of the basin's water for various purposes, chemical analysis is very important for the recommendation of water quality. In this chapter it was attempted to provide the hydro geochemical characteristics of the catchment's groundwater from the point of view of spatial natural compositional variation along with quality analysis for domestic and agricultural uses. There is rising of population number in and around the catchment which in turn requires adequate quantity and quality of water. Currently, in addition to large scale irrigation of sugar cane plantation for Wama, there is newly irrigation scheme of earth dam now on construction progress nearby Wama river confluence. Despite water requirement is increasing very rapidly with the growth of human population and irrigation in the area, there is no significant research conducted to know the

groundwater resources. On the basis of this concept, this study is proposed to give some detail picture on groundwater characteristics by hydro geochemical methods to come up with reasonable result with respect to the potentialities of the resource. GSE (2014) produced hydro geological and geological map of Arjo area at scale of 1:250,000. This study confirmed the presence of different rock unit (metamorphic, sedimentary, volcanic and recent deposit) in the area. The annual rainfall was estimated using arithmetic method and obtained value is 1848 mm. The geology of Nekemte area (NC 37- 9) is compiled by Solomon Gera and Mulugeta Hailemariam, 2000 (Geological Survey of Ethiopia). Detailed geologic description is forwarded by this work. The geological map of Nekemte area is presented by (GSE, 2003) at 1:250,000 scale.

## II. LOCATION OF STUDY AREA

### 2.1 Location and Accessibility

The study area, Wama Catchement, which is the major tributary of Upper Didessa, is bounded between  $36^{\circ} 24' 0''\text{E}$  to  $37^{\circ} 24' 0''\text{E}$  longitudes and  $8^{\circ} 24' 0''\text{N}$  to  $9^{\circ} 0' 0''\text{N}$  latitude, and is located in the East Wollega zone of Oromia region, Western Ethiopia. It is situated at about 281km west of Addis Ababa and it includes major parts of Nekemte town which is the capital city of East Wollega Zone. The area which has a total area of  $3385.5\text{ km}^2$  is accessible through Addis Ababa → Ambo → Nekemte asphalt road. Weather and seasonal gravel roads which connects different town of woreda are also available in the catchment.

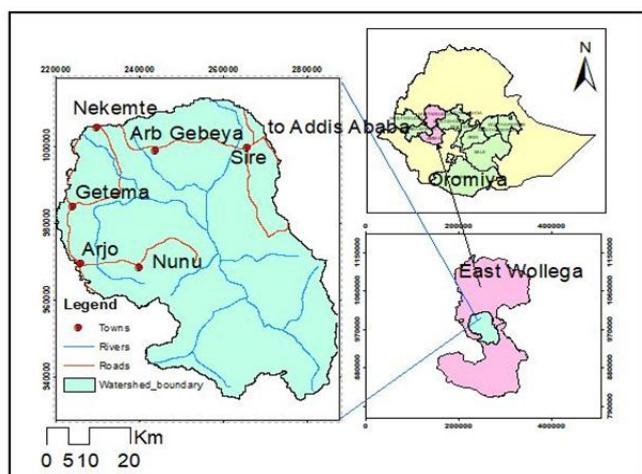


Figure 0.1 Location map of the study area

### 2.2 Physiographic setup

Surface elevation in the catchment varies from 1923 to 2180m (a.s.l). Higher areas are generally in the northern periphery of the catchment that gradually slopes southward forming plain at southern extreme (fig.1). The establishment of base elevation in the south

has instigated a drainage system that in the north-south direction with dendritic drainage pattern.

### 2.3 Climate

Climate of Nekemte area is tropical highland monsoon. Rainfall distribution and pattern over the country is generally controlled by the movement of Inter Tropical Converge Zone (ITCZ) with respect to equator (Lacaux et al., 1992). The Western region receives summer rainfall when ITCZ moves northward. Elevated rainfall amount is usually received during the months of June, July and August while dry condition persists during the rest of the year.

## III. GEOLOGY OF THE STUDY AREA

The area is situated in the Western Ethiopian plateau and underlain mainly by Eocene-Pleistocene (Solomon, 2000) volcanic rocks and small portion of Mesozoic sedimentary and metamorphic basement rocks. It is contained in the Abay basin, Upper Didessa Sub-basin, particularly the Wama river catchment. Geology of Western Ethiopia has complex tectonic history starting from Precambrian and Phanerozoic sedimentation to tertiary volcanic activity resulted in exposure of metamorphic, sedimentary and volcanic rocks. The Western basement terrain is considered to contain lithological components common to both the Arabian-Nubian shield (ANS) and Mozambique Belt (MB) (Kazmin et al., 1978, 1979). Recent studies have divide tectonic evolution of the Western Ethiopian shield into Gore-Gambella area which comprise Birbir, Baro and Geba domains (Ayalew, 1997) as well as Tulu Dimtu belt that comprises five domains from East to West; Didessa, Kemashi, Dengi, Sirkole and Daka domains (Allen and Tadesse, 2003).

The Didessa domain extends from approximately 5km East of Didessa River in Wollega area covering about 70km to 25km west of Gimbi town. Didessa domain is characterized by moderate grade gneiss, intruded by Neoproterozoic intrusive rocks like poly deformed gabbroic and granitoids bodies and post-kinematic mafic and felsic plutons (Allen and Tadesse, 2003). The western Precambrian basement is overlain either by Paleozoic-Mesozoic sandstone or tertiary volcanic product. Sandstone is supposed to be southwestern extension of central Ethiopian (Abbey) sedimentary succession (Geological Survey of Ethiopia, 2000). The tertiary volcanics covering western Ethiopia is commonly trap series which constitute majority of the Ethiopian plateaus. The Ethiopian volcanic plateau is divided into west and southeast plateau. However, the regional and wide E-W oriented rift transversal structure called Addis AbabaNekemte tectonic line (Abbate et al., 2015) or Yerer-Tulu Wollel Volcano Tectonic Lineament (YTVL) (Abebe et al., 1998) has divided the western

plateau volcanics into Northwestern and Southwestern Plateau. The southwestern plateau, of which the study area is part, is characterized by thicker volcanic rock.

The succession of this volcanic begins with a hundred meters of mildly alkaline basalts (Omo Basalts), capped by a thick unit, up to 1,000 m, of rhyolites, acidic tuffs, and subordinate Jimma volcanic comprises trachyte basalts and rhyolites which covers most part of the southwestern Ethiopian plateau. The sedimentary rocks of the catchment area are the southwestern extension of the West central Ethiopian sedimentary succession. These rocks are exposed around Beda Sire, Fungan Sire localities and Finca'a valley (Nekemte map sheet) (Solomon Gera and Mulugeta, 2000). It consists of thick lower sandstone succession that is overlain by thin remnants of transitional beds.

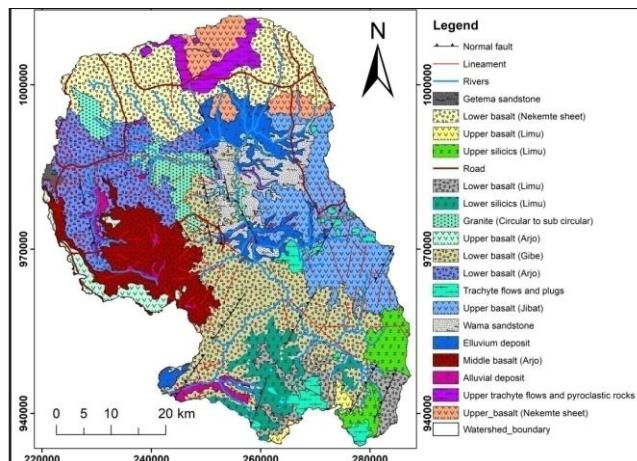
The late Paleozoic and Mesozoic sediments are uncomfortably overlain by thick massive flood lavas, mainly of basalt; which is classified as Trap series by (Mohr, 1962). These rocks cover the northwestern plateau. The volcanic rocks in the catchment area are the Southern extension of these rocks. These volcanic rocks are generally post - Oligocene- Quaternary (Berhe,et al., 1987; Conticelli et.al, 1999) which have stratified nature, built up of various succession of flood basalts. Quaternary volcanic activities with the formation of lava flow, trachyte plugs and scorea cones are also recorded (Mengesha, et al., 1996). The geology of the Wama catchment is constituted by the rocks ranging in age from Precambrian to recent time (GSE, 2014). They include metamorphic, sedimentary, igneous and recent deposit (Figure 3.1) and are described below. Even though it includes a variety of rocks, volcanic rocks are the most extensive lithology in the study area.

Basic regional geology and field checking have indicated the occurrence of three major types of rocks in the catchment area.These are Precambrian crystalline basement rocks, Mesozoic sedimentary rocks, Tertiary volcanic rocks and associated plugs and Quaternary soils. These rock assemblages are thought to be the northern extension of Mozambique Belt. The juxtaposition of the ANS (Arabian-Nubian Shield) and MB(Mozambique Belt) makes the western region of the country to be geologically remarkable. Elsewhere, in this region, clastic sedimentary rocks ranging in age from Paleozoic to Mesozoic are found sparsely distributed (GSE, 2000). Volcanic rocks (mostly basalt) of Tertiary age (GSE, 2000; EIGS, 1996) underlie the vast portion of the western region in general. Variably weathered basalt underlay study area.

The study catchment. Recent (Quaternary) phonolite plugs found sporadically distributed in the northern part of the study area marking surface water

divide. The study catchment in particular is underlain by basalt, which was emplaced by Tertiary volcanism (EIGS, 1996) in (fig.3). The stratigraphic relationship with the regional geology of the western region reveals that the basalt in the catchment is the result of old volcanic episode, hence termed lower basalt (EIGS, 1996;GSE, 2000).It unconformable overlays either the Precambrian basement rocks or sandstone of Paleozoic age.

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**Figure: 3.1** Geological map of the study area

## IV. METHODS & MATERIALS

### 4.1 Methods

**Desk study :** Prior to field work published and unpublished materials were collected and reviewed in order to get the detailed awareness on geology and hydrochemistry of the area. This includes water resources study reports, water points completion reports (borehole, hand dug wells, springs, pump test data, geophysical reports or any other literature regarding the catchment area and its' surrounding). It also includes the collection of hydro meteorological data, regional geologic map, digital elevation models (DEM), scanned topographic maps of the area with appropriate scale.

**During field work :** At this stage, water samples for chemical analysis were collected. In doing this, systematic sampling of representative water samples of different water sources (deep wells, shallow wells,

hand dug wells, and springs) in the study area have been collected. During sampling, the sample bottles were carefully cleaned with distilled water and have been washed in the field by the water to be sampled. Sampling from some wells was carried out right on borehole using leakage but for others it is just near the well head before entering the reservoir.

Under this stage, Insitu measurements of Temperature, pH and EC is conducted for all water samples using pH and EC meters; field photographs are captured for documentation and interpretation.

### 4.2 Materials

During field and throughout the phases of the research work, different relevant software and material were used including instrumentation used in the laboratory analysis. Materials used during field work are topographic map of the area, Global Positioning System(GPS) and Compass, bottles for collecting water samples for laboratory analysis, (pH, Temperature, and Electrical Conductivity (EC) ) meter.

The analytical method and instrumentation used in physico-chemical analyses of the collected water samples are listed below in (Table 4.1)

**Table 4.1** Analytical method and instrumentation used.

Parameter	Analytical method and instrumentation used
pH, TDS, and T	Potentiometric, pH meter (model 107),TDS and Temperature meter
Electrical conductivity (EC)	Potentiometric method
Calcium ( $\text{Ca}^{2+}$ )	Titration/volumetric method using EDTA solution (0.01M), sodium hydroxide (IN) and murexide indicator.
Magnesium ( $\text{Mg}^{2+}$ )	Calculation method using the volume of EDTA used in Determination of calcium and total hardness.
Bicarbonate( $\text{HCO}_3^-$ )	Titration method using hydrochloric acid (0.1N), methyl orange indicator, phenolphthalein indicator and sodium Carbonate (0.1N).
Chloride ( $\text{Cl}^-$ )	Titration method/volumetric method using silver nitrate (0.02N) and potassium chromate (5%)
Sulphate ( $\text{SO}_4^{2-}$ )	DR 5000 spectrophotometer method using (APHA 1992) Standard procedure.
Sodium ( $\text{Na}^+$ ) and Potassium ( $\text{K}^+$ )	Atomic absorption spectrophotometer (AAS) method, model 210 VGP using (APHA 1992) standard procedure, Sodium at 589nm and potassium at 766.5nm.

## V. HYDROGEOCHEMISTRY OF STUDY AREA

### 5.1 Field measured parameters

Some of physical parameters have to be measured Institution in order to avoid contamination of the sensitive parameter. These include temperature, electrical conductivity and hydrogen ion activity.

**Table 5.1 Statistical description of field measured parameters**

Parameter	Minimum	Maximum	Mean	Standard deviation
T (°C)	21.3	28	24.65	0.4
EC ( $\mu\text{S}/\text{cm}$ )	62.7	452	257.25	145
TDS (mg/l)	29	1930	298	92.8
pH	3.04	8.5	5.77	0.5

### 5.2.1 Electrical Conductivity (EC)

Electric conductivity is the ability of water to conduct an electric current relating to amount of dissolved solid in the water. As groundwater circulate through geological media, it enriched by different constituents through reaction and leaching property of water such that EC become high. The presence of charged ionic species in solution makes the solution conductive. As amount of ionic concentrations increase, conductance of the solution increases. Therefore, the conductance measurement provides an indication of ion concentration in the given water. The overall EC value of study area varies from  $62.7\mu\text{S}/\text{cm}$  to  $452\mu\text{S}/\text{cm}$ ;  $62.7\mu\text{S}/\text{cm}$  is the lowest EC among borehole's EC value and is recorded for BH-6. This may related to shallow water circulation as it is shallow well or/and because it is a recharge area which get replenished by fresh water that had short time water rock interaction.

The high EC ( $452\mu\text{S}/\text{cm}$ ) is recorded for Mote deep well (200m), related to high temperature around depressed area (at elevation of 1509m). High temperature raises solubility and dissolution of many minerals and provides more ionic charge (solute) that elevates electrolytic property of water. As a result, water at deep may incorporates high mineral constituents through rock dissolution triggered by high temperature coming from depth. The EC value of the area has no systematic trend in its distribution. This is attributed to rugged nature of the catchment which favors many local recharges and discharge so that groundwater replenished and exposed in any form of discharge without moving far from source area and resulted in low EC.

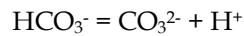
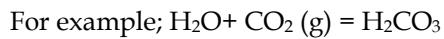
However, there is general increase from area of recharge to discharge as the highland of active recharge area has low EC. On the other hand the upper north eastern side of the catchment around Wama and LimuSeka shows highest EC in the

catchment. Knowingly, there is low rainfall and high temperature in the vicinity of these areas. Therefore, this high EC may be due to high evapotranspiration which leaves behind more salt as well as low rainfall that cannot provide dilution.

### 5.2.2 pH (Hydrogen ion activity)

pH is a measure of water's acidity or alkalinity that has scale range from 0 (high concentration of hydrogen ions and acidic) to 14 (high concentration of hydroxide ions and strong base). In pure water, the concentration of hydrogen ions is in equilibrium with the concentration of hydroxide ions so that pH measures exactly 7. However, since pure water is hardly found in nature the PH value of natural water usually deviates from equilibrium value. This is also true for study area whose pH value range from 3.04 to 8.5. Potable water should have pH value between 6.5 and 8.5 according to WHO (2006) and Ethiopian drinking water quality standard. Any water with PH less than 6.5 is regarded as acidic and above 8.5 is basic. Most water sample fall in this range but 5 samples is below the lower limit of World Health Organization standard. Among these, two are deep well, two are hand pump well and one is spring.

pH is controlled by types of geologic formation and hydrogeochemical reactions that produce or consume hydrogen ions.



Since,  $\text{pH} = -\log [\text{H}^+]$ , the process that contribute hydrogen ion concentration to a reaction lowers the PH of a solution. Therefore, these observed low PH may be a result of chemical and biochemical decomposition of vegetative residues and from activity of micro-organisms that release more carbon dioxide into subsurface. The above listed samples are below pH level of WHO, and are relatively shallow and most necessarily affected by near surface, biological and biochemical process that generate  $\text{CO}_2$ . Otherwise, the natural water in the area has generally a good quality in terms of pH value.

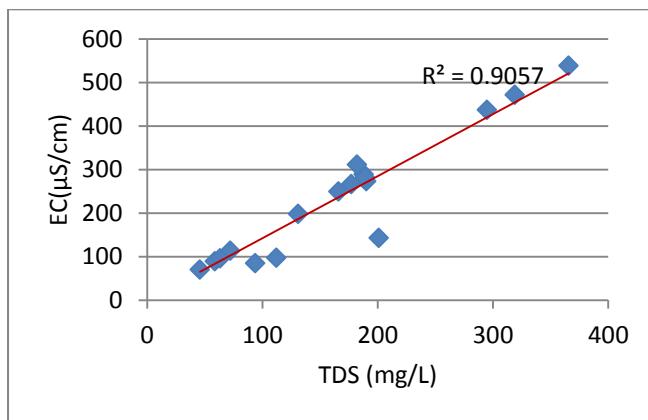
### 5.2.3 Total Dissolved Solid (TDS)

Total dissolved solids include all the solid material in solution and is determined from the weight of dry residue remaining after a sample of water has evaporated at a temperature of  $105^\circ\text{C}$ . As water flows through a geologic formation it dissolves rock of different composition it encounter on the flow path. The amount of dissolved materials in natural water is one of the basic measures of the water quality. It is better to see the well water and spring water in study area separately. The TDS value varies from minimum

value of relatively fresh groundwater of 45.8mg/l, for Gombo spring located at Gute (X- 0238784, Y-997496N and Z-1882m) to 365.7mg/l, for a deep well having 200m deep, which is located at Mote (X-0271200 ,Y-0972400 and elevation of 1509m). The lowest (45.8 mg/l) TDS value is recorded for SP-1, which is also expected value for recharge area. Even if this spring is part of discharge area, which could have high TDS value, this much value may indicate another source because dissolved solid can also added to groundwater by anthropogenic impact. On the other hand, the highest TDS (365.7mg/l) observed for BH2 (Mote), indicates that TDS value of groundwater is strongly controlled by the time of water-rock interaction along the flow path. Generally, high land has low TDS as compared to low lands because of low water rock interaction than low land. This means, as long as the water moves from the source area through porous spaces for a long time to a long distance, the TDS became higher. There is a direct relationship between TDS and EC value. The more total dissolved solids (TDS) in water the more it will conduct electricity. As observed from (Fig. 6.1) they are correlated with best fit of regression ( $R^2= 0.905$ ). On the basis of USGS classification of TDS, the water of study area falls under fresh water.

**Table 5.2 Water class on TDS.**

TDS(Mg/l)	Water class
0-1000	Fresh
1000-10000	Brackish
10000-100000	Saline
>100000	Brine



**Figure 5.1 TDS-EC relationships**

### 5.3 Major ion chemistry

More than 90% of solute in water is dominated by eight ions comprised of;  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{HCO}_3^-$ ,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$  and  $\text{CO}_3^{2-}$  (Fetter, 1994). They are usually present in water at concentration greater than 1mg/l and water chemistry is highly controlled by this species. These solutes are naturally very variable in surface and groundwater due to local geological, climatic, and geographic conditions.

Calcium is present in all waters as  $\text{Ca}^{2+}$  and is readily dissolved from rocks rich in Calcium minerals. This cation is abundant in surface and groundwater. Acidic rain water can increase the leaching of calcium from soils and rock. From the water sample analysis results of study area, Calcium is the most dominant cation. It's concentration in groundwater sources shows variability and generally range from 15.2 mg/l to 69.6 mg/l for borehole. Surface springs have calcium concentration from 31 mg/l to 68.7mg/l. This high calcium is derived from probably the ca-rich weathering products of plagioclase feldspar and pyroxene rich basaltic rock.

Sodium is the second dominant cation next to calcium in study area. The concentration of sodium in analyzed sample is within the range of 6.72 mg/l (BH-4) to 68.5 (BH-6) for deep well and for spring water, it is from 6.4mg/l (SP-1) to 46.3 mg/l (SP-2). The high concentration of Na is in deep well. This is insisted by deep circulation of water through subsurface fracture encountered high temperature.

Magnesium is another major cation with low concentration in the study area, relative to calcium and Sodium. This may be because of its less mobility. The  $\text{Mg}^{2+}$  value ranges from 1.1mg/l to 28.4 mg/l. The concentration shows variation between highland and lowland but more dominant than  $\text{K}^+$ . The minimum  $\text{K}^+$  concentration is 1.1mg/l for (BH-4) and the maximum is 14.8mg/l for spring (SP4). Potassium is hardly liberated from silicate minerals but rather exhibits a strong tendency to be reincorporated into solid weathering products and is thus found in water with low amounts.

In study area  $\text{HCO}_3^-$  is the most dominant major anion followed by  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  respectively. The maximum value is (689.4 mg/l) for deep well (BH6) and the minimum is (29.28 mg/l) for (BH-1). The higher concentration of bicarbonates is due to the reaction between water and dissolved carbon dioxide that emitted from underlying heat reservoir.

Chloride is the dominant anion following bicarbonate. The maximum chloride concentration of study area is 59.6 mg/l for spring and the minimum is 2.06mg/l for boreholes. High chloride (59.6 mg/l) is from spring water and it is due to anthropogenic effect mainly from Nunu Kumba town, but in the case of BH (22.3mg/l), it could be the result of deep water circulation.

Sulfate is another anion found in very low concentration next to chloride. Majority of analyzed sample has very insignificant amount of sulfate. It varies from 1.5 to 16.5mg/l in study area. The maximum concentration for borehole is 11.8mg/l (BH-5). The variability of the chemical ion in solution expressed by variation (standard deviation) is very

important as majority of the analyzed parameter has difference in their quantity from site to site. The average and standard deviation are close to each other indicating little variation from sample to sample.

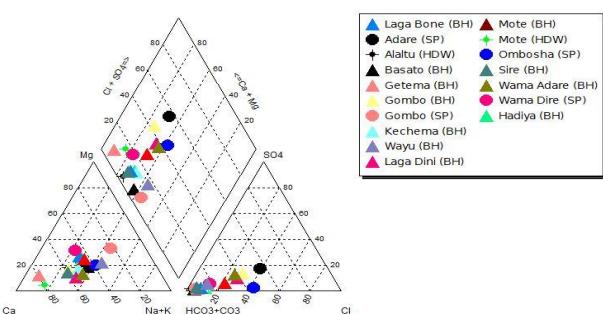
**Table 5.3 Statistical description of the major ions**

Parameter (mg/l)	Minimum	Maximum	Average	Standard Deviation
Ca <sup>2+</sup>	15.2	69.6	42.4	17
Mg <sup>2+</sup>	1.1	28.4	14.75	7.6
Na <sup>+</sup>	6.41	68.4	37.4	17.7
K <sup>+</sup>	1.1	14.8	7.95	4.1
HCO <sub>3</sub> <sup>-</sup>	29.28	689.4	359.34	186
Cl <sup>-</sup>	2.06	59.6	30.83	12.7
SO <sub>4</sub> <sup>2-</sup>	1.5	16.5	9	4.8

All water samples collected from the study area have a tds value of less than 1000mg/l.

Among the important task in hydrogeochemical investigation is the presentation of the chemical data in a proper manner for interpretation. There exists different methods for hydrogeochemical data presentation but, it is believed that the graphical methods based on major cations (Ca<sup>2+</sup>, Mg<sup>2+</sup>and Na<sup>+</sup> + K<sup>+</sup>) and major anions (HCO<sub>3</sub><sup>-</sup>, Cl<sup>-</sup> and SO<sub>4</sub><sup>2-</sup>) are thought to be best for visual observation. The classification uses a percentage of mill equivalents per liter of the anions and cations to denote amount of ions on graph. For this purpose piper plot is used to present the analysis as given below. Piper tri-linear diagram is the most widely used method for interpretation and classification of water. This is due to the capacity of method in showing mixing effects between different water in addition to showing much sample at once. Here, water type is classified based on the plotting position of cations and anions.

As observed from (Fig 6.3) there are Ca-HCO<sub>3</sub>, Ca-Na-HCO<sub>3</sub>, Ca-Na/Na-Ca-HCO<sub>3</sub>, and Ca-Na-Mg-HCO<sub>3</sub>water types. But, two water samples (one spring (Ombosha) and one borehole (Kechema)) show distinct water type, which is Ca-Na-Mg-HCO<sub>3</sub>-Cl type. This type of water type may relate to agricultural activity like fertilizer and animal manure, or the result of anthropogenic activity. As described above in the major anion in the study area, Ombosha spring which is represented by blue color in piper plot is a water supply situated nearby town at the down side of the ridge and probably affected by domestic wastes and faeces from Nunu town.



**Figure 5.2** Piper plots of the water samples

#### 5.4 Classification of water type

Accordingly, the groundwater is classified into three major water types and these groups are explained here under. However, there is also another water type like Ca-Na-Mg-HCO<sub>3</sub>-Cl. As observed from the piper plot, Ca-HCO<sub>3</sub>, Ca-Mg/Ca-Na-HCO<sub>3</sub> and Na-Ca/Na-Mg-HCO<sub>3</sub> are the three types of water in area. It can be observed from the piper plot, that the cations plot mainly clustering around the Ca<sup>2+</sup> showing the dominant cation is Ca<sup>2+</sup> with some samples aligned towards the Na<sup>+</sup> apex showing progressively increasing sodium enrichment. This depicts that the dominant controlling factor is rock-water interaction than mixing of distinct water types(Ca-Type, Ca-Mg type to Na-type). On the other hand, the anion plot exclusively clustered around the (HCO<sub>3</sub><sup>-</sup>) manifesting all the water samples are bicarbonate- type.

##### Ca-Mg-HCO<sub>3</sub> water

This water type is commonly a typical characteristic of recharge area. It seems like that the water is fresh and not subjected to more water-rock interaction. In the general groundwater chemical evolution, Ca-Mg-HCO<sub>3</sub> types waters are often regarded as recharge area waters which are at their early stage of geochemical evolution (Bartolino et al., 2003). Hence the Ca-Mg-HCO<sub>3</sub> type of water which is found in the recharge areas of the northern and southern highlands area dynamically circulating and evolving groundwater. The average TDS of this type water is 150mg/l which verify the water is fresh and hasn't undergone pronounced geochemical reaction.

##### Ca-Na/Na-Ca-HCO<sub>3</sub> water

Majority of the analyzed water sample belong to this water type. Such water is noticed in almost all of eastern and south eastern part of the catchment. This area is known by different lithology like Jimma volcanic (basalt, rhyolite, and pyroclastic unit) and recent volcanic of trachyte to phonolite origin as well as sandstone unit. Hence, it is likely that such water type is attributed to dissolution of the above mentioned feldspar bearing rock that release Ca<sup>2+</sup> and Na<sup>+</sup> into water. On the other hand, this area can be slightly taken as recharge area on south eastern margin of the catchment.

But some area much look like a discharge zone since majority of the recharge is provided from boundary ridge like Koma and Mote. Thus, this zone also partly acts as local discharge area and has Ca-Na-HCO<sub>3</sub>/Na-Ca-HCO<sub>3</sub> water which is a characteristic type of transitional zone.

##### Na-HCO<sub>3</sub> water

This water type is enriched by Na<sup>+</sup> and HCO<sub>3</sub><sup>-</sup> ions. The TDS value of this water type is high in

average with about 916mg/l as compared to the other groundwater samples of the area. The active discharge area of the catchment mostly the middle part belongs to this group.

The  $\text{Ca}^{+2}$  ion dominance from the northern, southern, south western and south eastern part of the catchment area decreases down along the flow direction and finally replaced by  $\text{Na}^+$  ion evolving into this water type. There are 17 samples and the type of water for each sample is as follows.

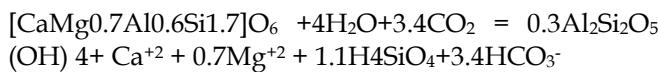
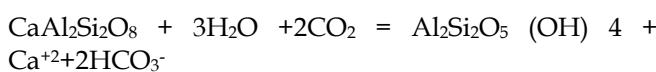
**Table 5.4 Types of water in the catchment**

Nº	Water type	Number of samples
1	$\text{Ca}-\text{HCO}_3$	4
2	$\text{Ca}-\text{Mg}-\text{HCO}_3$	2
3	$\text{Ca}-\text{Na}-\text{Mg}-\text{HCO}_3$	3
4	$\text{Ca}-\text{Na}-\text{Mg}-\text{HCO}_3-\text{Cl}$	2
5	$\text{Na}-\text{Ca}-\text{HCO}_3$	4
6	$\text{Na}-\text{Ca}/\text{Mg}-\text{HCO}_3$	2

## 5.5 Hydrochemical evolution and major process controlling the chemistry of groundwater

### 5.5.1 Major cation

Knowingly, most waters of the basic and acidic volcanic province are dominated by  $\text{Ca}-\text{Mg}$  and  $\text{Na}$  ions respectively. But their amount in water is a function of many geochemical processes. Calcium which is a principal constituent of many rocks might be derived from mineral silicates of pyroxene, amphibole and the feldspar as well as carbonate rock. But, in study area carbonate dissolution is unlikely to be a case for calcium as no reported carbonate rock though it may be present as a partial filling particle between interstice of sandstone and other detrital rocks. Therefore, being a part of Ethiopian plateau the main source of  $\text{Ca}^{+2}/\text{Mg}^{+2}$  in the study area could be hydrolysis of silicate that compose the basic volcanic. Some silicate minerals undergo dissolution through a reaction to form cation and anion with solid clay mineral (Herczeg, 2001).



These silicate hydrolysis can also represent the geochemical reaction that generate both cation ( $\text{Ca}^{+2}$ ,  $\text{Mg}^{+2}$ ) and anion ( $\text{HCO}_3^-$ ). In general, calcic plagioclase, calcium rich pyroxene and amphibole hydrolysis suggested being main source of calcium, magnesium and bicarbonate ions in study area.

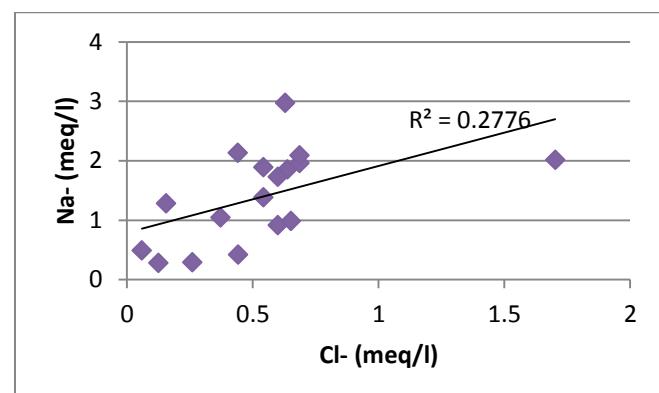
The other dominant cation is sodium. Many geochemical processes are responsible for addition of sodium ion in natural water. The common are dissolution of silicate and Halite, evaporation and

cation exchange. The Halite dissolution is not likely to be a source for sodium here. If halite is the case, a linear relationship should be observed by a line with approximate slope equal to one (1:1) when concentration of  $\text{Na}^+$  is plotted against  $\text{Cl}^-$  because both ions enter into solution in equal quantity during halite dissolution. However, if points are below or above the line the most common source for  $\text{Na}^+$  is silicate or ionic exchange. But as observed from (Fig 6.4) there is no 1:1 relationships between them indicating  $\text{Na}^+$  is not from halite.

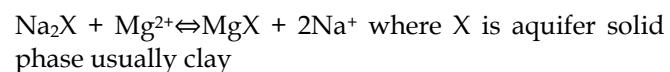
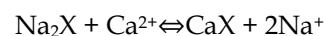
Thus, source of sodium in the study area could be hydrolysis of feldspar which makes up volcanic rock and sandstone. This silicate hydrolysis put  $\text{Na}^+$  into solution but also produces a new solid phase, clay minerals. These reactions are incongruent in that there is a new solid phase produced by the reaction.



Another source of sodium may be from cation exchange of magnesium and calcium for sodium retained by adsorption on mineral surface deposits having high cation exchange capacities such as clay.



**Figure 5.3**  $\text{Na}^+$  vs.  $\text{Cl}^-$  relationship.

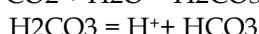


This reaction can be verified from lithologic log. For instance, from the secondary data collected, borehole located in Bilo, Bidaru, is  $\text{Na}-\text{HCO}_3$  type water and it has a maximum concentration of sodium. It has a thick clay soil as observed from lithologic log.

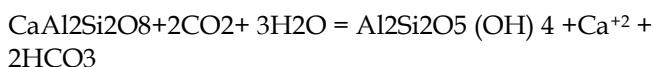
### 5.5.2 Major anion

The major anion of interest in study area is bicarbonate. Bicarbonate ion is derived from the atmospheric and soil  $\text{CO}_2$  as well as dissolution of carbonates rocks such as calcium carbonate. Bicarbonate usually the primary anion in groundwater is derived from  $\text{CO}_2$  released by organic

decomposition in the soil (Todd, 2005). Similarly, the major source of  $\text{HCO}_3^-$  in study area is supposed to be from biological process in the soil. The decayed organic matter in soil produce dissolved carbon dioxide which react with  $\text{H}_2\text{O}$  to form carbonic acid in the soil zone that later dissociate to form  $\text{HCO}_3^-$  as represented below.



And the other source of  $\text{HCO}_3^-$  is silicate hydrolysis



These two reactions are the primary source of  $\text{HCO}_3^-$  concentration in study area. The other anion ( $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ) are minimum in concentration. Chloride enters surface waters with the atmospheric deposition, dissociation of some sedimentary rocks, evaporation, industrial and sewage effluents, and agricultural practices. Minerals in which chloride is an essential component are not very common, and chloride is more likely to be present as an impurity (Hem, 1985). Chloride is frequently associated with sewage and often incorporated into assessments as an indication of possible faeces contamination. Likewise, evaporation and anthropogenic activity is expected to be a source for chloride in study area as so. Sulfate may come from leaching of sulfur containing mineral in contact with aerated water, polluted rainfall and anthropogenic source. It also emanated from subsurface heat zone as a volcanic gas.

## 5.6 Water quality

The primary purpose of water analysis is to determine the suitability of water for intended use. Therefore, in the assessment of water quality, it needs to identify the purpose for which the quality is referred to. Such that determination of quality of natural water for certain use is according to certain standards set by different organization (e.g. World Health Organization (WHO) for specific water uses (drinking, agricultural, Industrial).

Since groundwater often occurs in association with geological materials containing soluble minerals, higher concentrations of dissolved salts are normally expected in groundwater relative to surface water. The type and concentration of salts depends on the geological environment and the source and movement of the water. Two principal features of ground water bodies distinguish them from surface water bodies. Firstly, the relatively slow movement of water through the ground means that the residence times in ground waters are generally longer than for the surface water, therefore, once polluted; a ground water body could remain so for decades or even more (UNESCO guide, 1992).

Secondly, there is a considerable degree of physico-chemical and chemical interdependence between the water and the aquifer. And there is considerable scope of water quality modification by the interaction of the two. For comparison purpose the World Health Organization, WHO guidelines for drinking water and the ranges of concentration of major ions are supplied in the following table.

### 5.6.1 Groundwater quality for domestic purpose

Groundwater forms an important source of water for drinking and other domestic purposes. Groundwater is safe for use than surface water especially from point of view of bacterial pollution and its enrichment in important mineral. The prescribed standards for drinking-water vary from country to country, depending upon climate condition, food habits and geographic location and etc. Ethiopia has its own standard guideline values, but recognizes the WHO standards as a target for drinking water. For this work, the chemical analysis results from the water samples in the study area have been evaluated and compared with WHO guideline values for water quality standard. As seen from water quality data, almost all of the sampled water fall within the range of WHO standard.

**Table 5.5 Comparison of water samples with WHO (2011) drinking water quality standard.**

Parameter	WHO (2011) standard	% Samples exceeding WHO (2011) standard
PH	6.5-8.5	23
TDS (mg/l)	1000	0
Na (mg/l)	200	0
Ca (mg/l)	200	0
Mg (mg/l)	150	0
Cl (mg/l)	250	0
SO <sub>4</sub> (mg/l)	400	0

The overall abundance of sulfate and chloride is very low. This indicates that deterioration of groundwater due to human impact is not a serious problem in study area.

### 5.6.2 Water quality for irrigation purpose

Water quality along with soil type and cropping practice play a vital role in successful agricultural activity. Water of good quality permits maximum yield consistent with proper soil and water management. However, suitability of water varies spatially and temporarily depending on the geologic environment, climatic condition and source of groundwater. The quality of water for irrigation can be measured using electrical conductivity (EC), Sodium adsorption ratio (SAR), Sodium percentage (Na %), Residual sodium carbonate (RSC) and others.

#### Electrical conductivity (Salinity hazard)

The most influential water quality guideline on crop productivity is the water salinity hazard as

measured by electrical conductivity. The primary effect of high EC water on crop productivity is the inability of the plant to compete with ions in the soil solution for water. When the EC is higher, less water is available to plants even though the soil may appear wet because plants can only transpire pure water. This means, usable plant water in the soil solution decreases with increasing EC amount. Thus, salinity of the water governs its suitability. Evapotranspiration tends to concentrate salinity in soil water and usually used as good assessment technique in arid environment.

**Table 5.6 Irrigation water quality compared with EC.**

Parameter	Sample (n=27)			Range	Water class	% Sample
	Min	Max	Mean			
62.2	452	288.2	2	≤250	Excellent	
				250-750	Good	
				750-2000	Medium	
				2000-3000	Bad	
				≥3000	Very bad	

Based on above salinity hazard criteria, about 44.5 % of the water samples are in the range of excellent class and the rest one 55.5% are in fall in the range of good class. This depicts that catchment is suitable in general and no quality objection is rise in terms of salinity (EC). Figure 6.5 also shows less salinity hazard.

#### Sodium Adsorption Ratio (SAR)

The sodium hazard expressed as the sodium adsorption ratio (SAR) has great effect on soil physical properties. It is a ratio of sodium to calcium and magnesium in water. Sodium reduces permeability and hardens the soil. This happens when  $\text{Na}^+$  in soil water replaced for  $\text{Ca}^{+2}$  and  $\text{Mg}^{+2}$ .

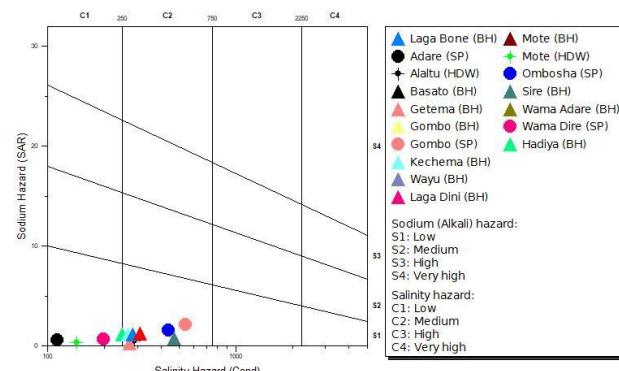
The United States Salinity Laboratory (1954) as cited in Hem (1985), proposed that the Sodium Adsorption Ratio (SAR) using the following relation could calculate the sodium effect.

$$\text{SAR} = \frac{\text{Na}}{\sqrt{\frac{\text{Ca} + \text{Mg}}{2}}}$$

**Table 5.7 Water quality for irrigation based on Sodium Adsorption Ratio (SAR).**

SAR	Water class	% Sample	Remark
<10	Low	100	Use of sodium sensitive crop should be cautioned
10-18	Medium	0	Good for coarse-grain permeable soil.
			Unsuitable for clay soil. Amendment such as gypsum and leaching needed
18-26	High	0	Generally unsuitable for continuous use and needs more addition of organic matter and high drainage
>26	Very high	0	Generally unsuitable

In the catchment the SAR value for analyzed water point ranges from 0.87mg/l to 9.4 mg/l with an average value of 4.34 mg/l. As observed above and from (Figure 5.4) water has little amount of SAR, indicating that the area has good quality for irrigational purpose.



**Figure 5.4 Wilcox Salinity and SAR hazard**

#### Sodium percentage (Na %)

The relative proportion of sodium to other cations in irrigation water usually has been expressed simply as the percentage of sodium among the principal cations. Accordingly, it is also possible to classify water for irrigation considering sodium hazard using.

$$\% \text{Na} = [(\text{Na} + \text{K}) / (\text{Ca} + \text{Mg} + \text{Na} + \text{K})] \times 100$$

**Table 5.8 Irrigation water quality based on Na% criteria.**

Na%	Water class	% Sample
<20	Excellent	12
20-40	Good	70
40-60	Permissible	18
60-80	Doubtful	0
>80	Unsuitable	0

From this table, we can understand that the percentage of sodium (%Na) is low relative to the other cations, which indicates the suitability of water for irrigation.

## VI. CONCLUSION

In this project we have analyzed the groundwater samples from boreholes for major cations, anions and physical properties. It is found that the ionic concentrations of cations and anions follow the order of  $\text{Ca}^{+2} > \text{Na}^+ > \text{Mg}^{+2} > \text{K}^+$  and  $\text{HCO}_3^- > \text{NO}_3^- > \text{Cl}^- > \text{SO}_4^{2-}$  respectively. This indicates that  $\text{Ca}^{+2}$  and  $\text{HCO}_3^-$  are dominant ionic species in the catchment and hence the water is alkaline in nature. Hydro chemical data has been used in order to understand the hydro chemical variability of the region. Topography and hydro chemical trends are found to be good indicators of recharge and discharge areas. Chemical analysis of

water shows that the catchment has a characteristic chemistry of fresh water. This is attributed to short residence time of infiltrated rain water to reach discharge area due to undulated topographic nature of the watershed. The predominant water type in the study area is a bicarbonate type. Ca-Mg-HCO<sub>3</sub> and Ca-Na/Na-Ca-HCO<sub>3</sub> water type dominates the area. As indication of anthropogenic impact, chloride and sulfate are low in concentration as there is no huge industry that can pollute ground water in the catchment so far except few contaminations from feces and agricultural activities.

With regard to groundwater quality, none of the parameters exceeds the maximum limits given in WHO and MWR guidelines for potable water. Though we have not analyzed for other essential elements like iron and manganese, we believe that the rust-red abundant soil in the region suggests the presence of appreciably large quantity of iron. Therefore, further investigation may shed lights on the availability of such metals in these samples.

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