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Ground Water Quality Determination of former Lake Haramaya, Haramaya District, Eastern Haranghe Zone, Oroma Regional State, Ethiopia

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ABSTRACT: Assessment of the potential of available groundwater in a certain area is indispensable for further development of human being in every sector. This study assessed the current groundwater quality determination to check suitability of ground water for domestic purpose. Both primary and secondary data were collected to achieve the objective of the research. In order to determine the basic hydrologic parameters, meteorological data was collected from Haramaya meteorological station. The ground water quality analyses were conducted in Dire-Dawa Water Bureau laboratory and Haramaya University laboratory. Physical, chemical and biological analysis was carried out for seven triplicate samples from the former lake area and from its catchment. Based on TDS and hardness the samples were classified as fresh and very hard water. 33.3 percent of Fluoride (mg/l) and 66.67 percent of Nitrate (mg/l) results were higher than WHO recommended value with mean of 0.88 ± 0.18 and 17.6 ± 4.4 respectively. 66.7 percent of the turbidity was found to be above the WHO limit and 83.3 percent of the samples have total colifoms above the guideline value and it reveal the necessity of treatment before use. @JASEM

Lake Haramaya had been decade's source of water for the town of Harar, Aweday and its surrounding community. Besides its Local fishing and recreation the lake gave great view for the surrounding and kept the ecology of the land. To mention the Haramaya University, one of the leading university in the country, was established before five decades in between Lake Haramaya and Gara Muleta taking in to consideration the beautiful view. The 440ha University uses the lake as a teaching learning demonstration and uses the water for drinking and various activities.

The previous Lake Haramaya was formulated from rainfall precipitation and drains along the catchments. In its hay days Lake Haramaya boasted a depth of 10-12m, before a decade the depth was 12 cm and currently no water at all (Figure 1). Lake Haramaya provided freshwater for drinking, irrigation, fishing (Oreochromis niloticus and Clariasgariepinus), animal watering, general municipal uses and recreation to over 120,000 people of the region (Brook, 2003 and 1994).

The Haramaya Lake which is enormously used for domestic water supplies of Harar, Haramaya and Aweday towns, and for irrigation by the local farmers decreases tremendously and cause shortage for the towns supply of water. To alleviate this water shortage problem, other supplementary groundwater sources were found in Dire-Dawa (Aseliso).

Groundwater is generally a preferred source for water supplies because its constant and good natural quality and relatively low capital cost of water supply system development. Due to the extinction of the Lake, Harar town, Aweday towns and the neighboring region of the lake faces severe shortage of water. To alleviate the problem Harari National Regional State together with the Oromiya National Regional State developed the groundwater well field in the vicinity of the lake. These wells supply domestic water for towns of Harar, Aweday and Haramaya.

Beside these wells, Haramaya University and the surrounding community as well explore the ground water in the area.

The current ground water balance of the area is not deeply studied and it is very hard to predict the withdrawal amount beside the current exploration in the surrounding is not done in a scientific manner. Hence, this study aims to assess the ground water quality, study its trend and recommends based on the output.

MATERIAL AND METHODS

Methodology of the Study: The methods applied in this study are to review previous studies, conduct water point inventory and to perform laboratory analysis for physical, chemical and biological parameters.

Description of the Study Area: The former Lake Haramaya is situated in the Eastern Ethiopia highlands found in Haramaya District, Eastern Hararghe Zone, Oromia Regional State. It lies $9^0 22' 03''$-$9^0 30'$ north Latitude and $41^0 58' 14''$- $42^0 06'$ east Longitude (Figure 2).

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Fig 1.Aerial photograph of lake Haramaya (1996)

The catchment is situated on the main road from Addis Ababa to Harar town at a distance of 505 km form Addis Ababa and 20 km north - west of Harar town. The total area of the catchment is 5,030ha of which the area of Lake Haramaya was 228 hectares. The catchment also covers part of Haramaya town, the Haramaya University, Bate town, three peasant associations (Damota, Ifa-Bate, and Tuji-Gebissa) fully, and another two (Ifa-Oromia (90%) and Guba-Selama (10%)) partially.

Fig 2: Lake Haramaya in its hay days

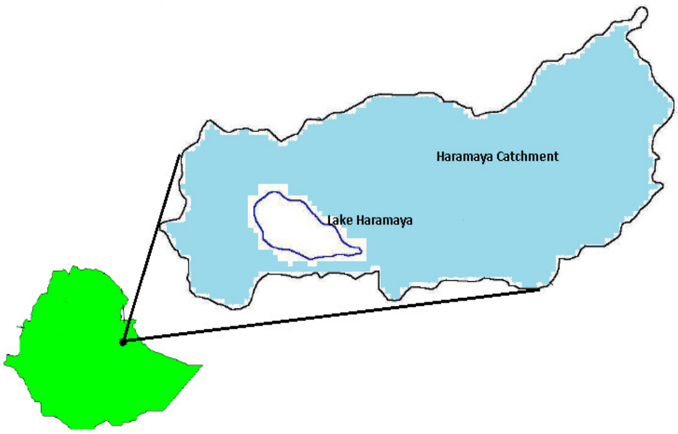

Fig 2: Location map of Lake Haramaya Basin, Eastern Ethiopia

Lake Haramaya was formed due to marine transgression in the region from Late Triassic to Early Cretaceous time ~225-100 million years ago. Lake Haramaya basin comprises undifferentiated Lower Complex basement rocks overlain by shallow marine sediments of Triassic and Jurassic age. Many of the river valleys have substantial Quaternary, lacustrine and alluvial fan deposits. The major portions of the agricultural soils in the catchment are very shallow and most soils of the steeper slopes are unproductive truncates exposed to the sub soils (Behar, 2002; Boselline, 2001; Brook, 1994). Locating of water points, collection of water samples, and measurement of discharge of wells were checked. Also data of pumping test, water table fluctuation and lake history data were obtained from Harer Town Water Supply and Sewerage Authority.

Ground water wells were carefully selected in the vicinity former lake. From the wells that are inside the University samples were taken in duplicate from 3 wells (S2, M1 and A8), two wells from the former Haramaya lake area and two additional samples were taken from Harar Water supply wells. The selected physical parameters for the study were temperature (T_o), electric conductivity (EC), pH, turbidity and total dissolved solids (TDS). The physical parameters were measured on site for all identified wells using ELE international Conductivity meter 4071 U.K, ELE international PH/mV meter U.K, HANNA instruments HI 9635 microprocessor conductivity/TDS meter, and HANNA instruments HI 93703 microprocessor turbidity meter using the standard procedures (Tortora et al., 2003; APHA, 1998).

Samples for chemical and biological analysis were taken carefully to avoid accidental contamination during sampling. The ice box used to carry samples were cleaned and disinfected after each use to avoid contaminating the surfaces of bottles and the sampler's hands. Sterile gloves were used during sampling to avoid external contamination. In addition, sample collection bottles were removed from their container and the rest will not be contaminated by immediately closing the container. Samples were clearly labeled with the site, date and other relevant information and transported from the study area to Haramaya University laboratory and Dire Dawa Water Bureau for analysis within 24 hours. Water samples were kept at +4˚C so that changes that may occur in the bacterial content of water on storage can be reduced to a minimum by ensuring that samples were not exposed to light and are kept cool. Examination began as soon as possible after sampling and certainly within 48 hours (Tortora et al., 2003; WHO, 2003; APHA, 1998).

For chemical analysis, water samples were collected using half liter plastic bottles from the wells. Triplicate samples were collected from each well for replication (accuracy) purpose. A total of 21 samples were collected from domestic water wells and user home samples. Separate analysis for the three samples was conducted and average values were taken. Chemical analysis of samples was conducted for anion and cation determination including concentrations of nitrate (NO_3^-) and hardness following a standard laboratory procedure.

Nitrate (NO_3^-) was identified using UV Spectrophotometric Screening Method (APHA, 1998).where, matched silica cell of 1 cm (UV - Visible spectrophotometer) was used for use at 220 nm and 275 nm. Both the sample and standard were treated by 1M HCl. A wavelength of 220 nm was used to obtain NO_3^- reading and a wavelength of 275 nm to determine interference due to dissolved organic matter. Both for sample and standards, two times the absorbance reading at 275 nm was subtracted from the reading at 220 nm to obtain absorbance due to NO_3^-.

Hardness, which reads the concentration of calcium and magnesium ions, was determined as indicated in the literature (APHA, 1998). Accordingly, 100 ml sample was transferred to conical flask. 2 ml buffer solution was added followed by about 0.4 g of solid indicator. Samples were titrated immediately but slowly with continuous stirring until the last reddish tinge disappears and blue color was observed. Reagent blank used for comparison was titrated in a similar way as for the sample. Finally**,** Ethylenediaminetetraacetic acid (EDTA) titrant was standardized against Calcium standard.

For mibrobiology samples were analyzed according to a standard procedure by membrane filtration method followed by incubation of the membrane to give direct count of colonies after 24 hours for total coliforms (Tortora et al., 2003; WHO, 2003; APHA, 1998). For the study topographic map, aerial photographs, satellite imagery, administrative base map of Haramaya area, measuring tape, scientific calculator, compass, water tank, glass bottles of 100 ml, 250ml and 10.52 L, measuring cylinders and stopwatch were also used.

RESULT AND DISCUSSION

Source Inventory in Haramaya University and inside the area of the former lake: Groundwater water inventory had been done in Haramaya University with the objective of determining the location of the water points with coordinate and the water level and also to investigate the status of the water points. In Haramaya University 14 boreholes has been constructed since 1952. Of these wells, 4 are under operation (Table 1 and Figure 3). The first well "A1" is constructed in 1952 and it had a water depth of 5m however currently the depth ranges from 20-25m with additional 10m drawdown. From this it is clearly indicated 40-70 cm average depth of ground water depletion per annum which is very high comparing to one millimeter replenishment rate of the catchment.

Table 1: Existed wells in Haramaya University

No.	Description (Well No.)	Supply	Connected to	Yield
1	M1**	C	Pumped to main reservoir in the University	3.5L/s
2	M2	C	Pumped to main reservoir in the University	3.5L/s
3	S1	C	Pumped to main reservoir in the University	4L/s
4	S2	C	Pumped to main reservoir in the University	5L/s
5	A1**	C	Pumped to main reservoir in the University	2.5-3l/s
6	Arab well (AW)	C	Pumped to main reservoir in the University	3.5L/s
7	A2**	I	Directly pumped to Farming unit	<1L/s
8	A3	I	Water Truck, provide water to contractors	<1L/s
9	A4*	-	No connection, but pump test is done and it is ok	2L/s
10	A5	-	Filled with debris and has a chance of rehabilitation	2.5L/s
11	A6	-	Filled with debris and has no chance of rehabilitation	<1L/s
12	A7*	C	From surface reservoir pumped to dormitories	1.8 L/s
13	A8	C	From surface reservoir pumped to dormitories	<1L/s
14	A9*	-	Abandoned	-

C= continuous, I= intermittent, *Constructed in 2008, M1, A1, A2 were rehabilitated in 2008

Well number "A9" had a good yield but collapse during construction and currently it is abandoned. In the future the University intends to construct 2 wells in the compound. Until now the history of static and dynamic head fluctuations are not well known for all the wells which are found in the University. Hence, it is recommended to conduct head analysis and perform ground water exploration using scientific data.

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According to the information from the University, detail data of the wells is not kept recorded. From the scattered records available in the University, the depth of the wells range between 20 – 72 mts and the Static water level, dynamic water level and the yield ranges from 17 – 20 mts, 15 - 45 mts, 1 – 5 l/sec respectively for continues discharge.

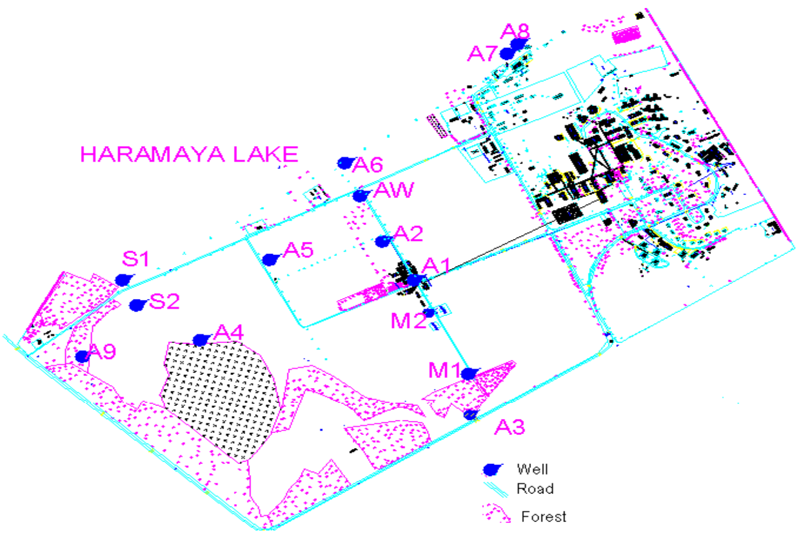

Fig 3: Location of Well fields in Haramaya University, Ethiopia

The exploration conducted for "A9" by Ethio-Drilling in 2008 and find static water level at 32m b.g.l. The point of drilling is located at the intersection of the slope and the fringe area of the lake co-ordinate. The investigation continues up to 72m, and the exploration shows the possibility of confined aquifer beyond 72m and it is recommended to conduct exploration program using geophysical method of sub surface exploration, seismic as well as electrical methods, since the lithology shows the existence of under lying formation in general. The exploration conducted for "A4 and A7" also done by Ethio-Drilling and Water Engineering in 2008. The drilling was conducted by mud drilling method and 90% of the aquifer zones were covered with slotted steel casing for both wells. The data of the two wells are summarized below and every water level data was taken from the top of the well head, which is 0.75m from natural ground level. Where, the wells have multiaquifer formation and main water bearing zones are weathered and fractured granite and sand.

Table 2: Summary of borehole, A4 and A7, data conducted by Ethio-Drilling and Water Engineering in 2008

No.	Description	Borehole one (A7)	Borehole two (A4)
1	Duration of pump test (hrs)	24	24
2	Well yield (M^3/hr)	6.48 (1.8l/s)	7.2 (2l/s)
3	Pump position (m)	54	36
4	Static water level, SWL (m)	12.15	7.48
5	Maximum dynamic water level (m)	43.41	15.96
6	Drawdown (m)	31.26	8.48
7	Well recovery (%)*	95.8	89.74
8	Well specific capacity (M2/d)	4.98	20.4
9	Aquifer transmissivity (M2/d)	7.11	77.2
10	Hydraulic conductivity (m/d)	0.6	6.4
11	Recovery test duration (min)	60	20
12	Screen position (m)**	24-36 42-48	14-32

*residual drawdown after pump turned off, **provided on 90% of the aquifer zone

The source inventory outside the University also reveals the existence of eight wells in Lacustrine deposits. The wells range in depth from 13 – 53 meters b. g. l. with static level and yield ranging from 3 -19 meters b. g. l. and from 1.5 – 4.5 l/s respectively. Besides, it was counted that there are more than 50 farmers around the vicinity of the previous lake exploring the ground water for irrigation.

Analysis of Ground water quality: Samples were taken from six wells in Haramaya catchment for biological, chemical and physical tests.

Four samples were taken from Haramaya University compound and two samples were taken from Harar and ormia water wells which are found adjacent to the University. In the formere Lake Haramaya there exists a total of eight wells. Out of the eight wells two belongs to Oromia (well number 7 and 6) and six wells belong to Harar (well number 1, 2, 3, 4, 5 and 8). Well number 8 is new and it is not yet started and well number 3 is not working because of sand at the well and its unsuitability for the pump.

Table 3: Sampling point co-ordinates with result of physical parameters

No	Description	Northing	Easting	pH (T in °C)	Turbidity (NTU)	Remark
1	A3	09° 24' 47.9"	42° 02' 28.9"	6.86 (21.9)	7.76	48m well depth where water level is at 12m
2	M1	09° 24' 49.1"	42° 02' 22.9"	7.39 (21.5)	14.37	58m well depth where water level is at 14m
3	S2	09° 24' 16.4"	42° 01' 53.7"	7.34 (22.1)	0.76	72 m well depth where water level is at 18m
4	A8	09° 25' 18.9"	42° 01' 42.8"	7.55 (22.6)	0.16	-
5	H3	09° 25' 15.6"	42° 02' 16.2"	-	-	Tap water sample, far house from reservoir
6	H1	09° 23' 58.9"	42° 01' 42.5"	7.52 (23.8)	0.20	-
7	H2	09° 24' 08.3"	42° 01' 33.2"	7.65 (22.0)	0.00	-

Table 4: Chemical Analysis results for Six water points in the study area and WHO standards (1981 and 1984)

No	Description	Average	Ave. dev	WHO	
				Recommended	maximum
1	TDS (ppm)	488	± 35	500	1500
2	EC (μS/Cm)	971	± 75	-	-
3	T. Hardness (mg/l $CaCO_3$)	488.7	±32.3	-	500
4	Alkalinity (mg/l $CaCO_3$)	384	± 11	-	-
5	Fluoride (mg/l F^-)	0.88	± 0.18	0.7	1.5
6	Iron Fe	0.01	± 0.01	0.1	1.0
7	Manganese Mn	0.004	± 0.004	0.02	0.5
8	Nitrate (mg/l NO_3)	17.6	± 4.4	25	45
9	TC (CFU/100 ml)	-	-		0/100 ml

Physical Analysis: All the physical analyses of the groundwater samples of the basin have been compared with standard values set by WHO (1981 and 1984). The comparison of WHO standard with maximum measured value of different chemical concentration in different part of the watershed is given in Table 3 and 4 and the results are discussed as follows.

The mean value of pH and Turbidity of the measured samples were found to be 7.26 ± 0.40 and 3.88 ± 3.88 respectively as shown in Table 3. The pH is within the WHO standard however for turbidity 33.3 percent of the sample is above the WHO guideline. The high turbidity for well number "A3, M1 and S2" could be directly related to the marshy land that was observed during the study that was due to leakage of water source.

TDS was also measured in the laboratory. The result (Table 4) indicates that, almost all water samples have TDS less than 550 mg/l. The small TDS value and lesser major ionic constituents reveals that the area has only local flow systems whereby water reaches the discharge areas without undergoing substantial flow paths. This means that, the recharge area and discharge areas are very near to each other so that the residence time of groundwater within rocks or aquifers is very short unlike the regional flow systems (Enger and Smith, 1995). Such type of flow system has an immediate response to the rain water and the quantity of groundwater discharge is the direct consequence of rainwater. In general, the groundwater of the study area is classified as fresh water (TDS less than 1000 mg/l). The electric conductivity in the study area is found to be in the range of 0.5 to 0.55 of the TDS value.

Chemical Analysis: For hydro-chemical investigation of the study area, a total of six (four wells in Haramaya University compound and two samples from wells inside the former Haramaya Lake) water samples were collected for laboratory analyses. The basic parameters for chemical analysis were computed as follow. The total Hardness concentration in mg/l of CaCO3 in the watershed is found to be 488.7 ± 32.3 ranging from 329.4 to 521 mg/l. Where the entire sample is below WHO maximum value except one which is found at the center of the previous lake and it is classified as very hard water. The concentrations of Mg^{2+} and Ca^{2+} in the groundwater are below the upper limit of WHO standard which are 150 and 200 mg/l respectively.

The Hard water causes a serious treat for Public health by reduced uptake of heavy metals (Pb, Cu, Zn) from water pipe material. Not only are heavy metals taken by human but also present in the waste water. As per WHO guideline hardness of 200 mg/l is indicated for scaling and excessive soap consumption and contributing high detergent and phosphate concentration in waste water and from domestic softeners brine water is produced. The high hardness results in economical problem by increasing detergent use and destruction of closes, and causing scaling and corrosion of domestic devices leading to high energy consumption. And the energy and time wasted by the women in preparation of food and drinks due to scaling effect and energy wasted during washing to form foam is considerably significant. Beside hardness also causes a harsh effect on human skin and hair.

On the other hand tuberculation is a serious problem caused in the distribution network. Tuberculation refers to the accumulation of scaling materials to the inside of the pipe mainly at the areas of pitting corrosion (localized non uniform corrosion hardly detected before a hole appears). Tuberculation rarely affect the water quality unless some of the tubercles are broken, however it can decrease the cross sectional area of CI pipe from 47- 76 percent and also leads to a drastic increase of pipe roughness (Trifunovic, 2006).

Alkalinity of the groundwater is 384 ± 11 ranging from 290 mg/l CaCO3 to 405 mg/l CaCO3 where, all over the watershed Ca^{++} is the dominant cation with reasonable amount of Na^{+}.

The fluoride (F^{-}) concentrations in the watershed is 0.88 ± 0.18 ranging from 0.65 mg/l to 1.05 mg/l where 50 percent of the sample is above WHO recommended value. The most common composition of fluoride in water bodies is 1 mg/L for seawater and for typical rivers / lakes the value is mostly less than 0.5 mg/L. however, in the study area the possible rise of fluoride might be due to the presence of fluoride-bearing minerals like apatite, fluorite and biotite in the rocks. Fluoride is also an element that is sometimes deficient, but in the provision of rural water supplies from groundwater, excess is more likely to be a problem. The range of desirable concentrations of fluoride in drinking water is relatively small. At concentrations below about 0.5 mg/l, dental caries may result, and fluoride is added to many tooth-pastes and some water supplies to promote dental health. Concentrations above the guideline in drinking water can begin to cause dental flurosis.

Iron and The manganese (Mn^{2+}) concentration in the study area are found to be 0.01 ± 0.01 and 0.004 ± 0.004 respectively. Besides to the sources, concentrations of Iron and Manganese are low due to constraints imposed by solubility of minerals and adsorption on clay minerals or organic matter. Regarding the concentrations of Sodium, Sulfate and chloride ions in the groundwater of the study area, all values are in the recommended interval.

The most abundant nutrient in water from all samples is nitrogen in the form of nitrate. The measured nitrate concentration in the study area is 17.6 ± 4.4 ranging from 13.2 to 26.4 mg/l where 33.3 percent of the sample is above WHO recommended value. Unlike most other elements in groundwater, nitrate is not derived primarily from the minerals in rocks that make up the groundwater reservoir. Nitrate in groundwater generally originates from nitrate sources on the land surface, in the soil zone, or in shallow subsoil zones where nitrogen-rich wastes are buried. Here the high value of nitrate is mostly due to the open area defecation as there is no proper sanitation system in the area and also from fertilizer.

Phosphate (PO_4^{3-}) is found in a concentrations ranging from 0.58 to 1.50mg/l. The phosphate is may be due to the presence of slightly soluble phosphorus-bearing minerals. In general phosphate concentration of groundwater in the watershed is low, due to the presence of high concentration of calcium and the combination is solid and insoluble in water.

Generally, the analyses result of the physic-chemical concentration of the study area show that the groundwater of the Lake Haramaya watershed is suitable for drinking purpose.

Microbiological Analysis: According to WHO guideline, the guideline value of coliform organisms in drinking water is 0 CFU/ml. Groundwater is generally a preferred source for water supplies because its constant and good natural quality, however based on the TDS result which reveals local flow is predominate and the high turbidity and nitrate also shows the possibility of short detention time of the water in the soil puts a suspicion to conduct microbiological analysis. For all the six samples the microbiology were analyzed for total colifoms according to a standard procedure by membrane and the result of the analysis is summarized in Table 4 and 5.

Table 5: Distribution of tested samples for TC (CFU/100 ml) according to their level of contamination and treatment procedure required.

Range of TC	Degree of Contamination [a]	Number of tested sample and (%)	Treatment procedure
0-3	0	1 (16.7%)	No treatment required
4-50	1	3 (50.0%)	Chlorination only
51-50,0000	2	2 (33.3%)	Flocculation, sedimentation then chlorination
>50,000	3	0	Very high contamination, need specific treatment

[a](Al-Khatib and Orabi, 2004).

Since, treatment is necessary for 83.3 percent of the sample due to bacteriological test. The high bacteriological load in “A3 and M1” is due to its shallow ground water coupled by the waste water flow from adjacent upstream area of Ifa-Bate and also supported by the high turbidity of the samples. Hence, it is mandatory to clean the area surrounding the well or better to avoid these well due to the necessity of complex treatment unit, Flocculation, sedimentation then chlorination.

In general, WHO recommends for proper disinfection of the samples residual chlorine shall be at least 0.5mg/l after a contact time of 30 min for pH and turbidity less than 8 and 5 NTU respectively. However, the high turbidity in the study area leads to shielding effect during chlorination, whereby the chlorine and organisms do not come in contact which leads to more chlorine consumption. Hence, excess disinfectant, primarily chlorine, is needed to be added to impact the microorganisms. However, this has its own negative effect since excess chlorination in the presence of organic matter forms Disinfection Byproducts (DBPs) like THMs which are carcinogenic, mutagenic and with the potential to cause central nervous system damage will be formed hence precaution is better to be considered for source protection in order to maintain the health of the community (Tebeje, 2011 and 2010; Spencer and Winkowska, 1991).

If the area persists to be the water supply source then the catchment should be zoned at least in to three different stages, the Lake vicinity free from agriculture and grazing land, certain radius free from farmers who uses pesticide, herbicides and fertilizers and free farming area with pesticide also it is mandatory to put observation wells for quantity and quality control.

Conclusion: Mostly ground water is preferred as a source for drinking water over surface water due to its safety to drink, from microbiological and toxicological point of view. However the process of weathering and leaching introduces different inorganic constituents to the ground water. The small TDS value and lesser major ionic constituents reveals that the area has only local flow systems whereby water reaches the discharge areas without undergoing substantial flow paths. Beside, the high concentration of t nutrient nitrogen in the form of nitrate reveals the existence of short detention time for the water to reach the wells. Due to the above facts and the bacteriological results is a must to treat the water before use. Beside, due to the high fluoride (F^-) concentrations in the watershed it is recommended not to give this water to infants before treatment. At last it is recommended to conduct up to-date ground water balance and maximum yield before further exploration of the ground water in the catchment coupled by proper treatment.

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