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Hydro-Geochemical Characterization and ground water quality of Basalt Aquifer of Tinfa Catchment, Nekemte, Ethiopia

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NAME OF THE AUTHOR'S

[1]Dr. Shayaq Ali*
[2]Gaddissa Deyassa

[1]Professor, Department of Earth Sciences, Wollega University, P.O Box 395, Nekemte, Ethiopia

[2]Assistant Professor, Department of Earth Sciences, Wollega University, P.O Box 395, Nekemte, Ethiopia

ABSTRACT

Tinfa is a small catchment situated South of Nekemte town in Western part of Ethiopia. Variably thick weathered mantle cover basalt bedrock in the area. Well-developed columnar joints that are affected by sub-horizontal sets of discontinuities are abundant on the basalt bedrock. 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. There are three boreholes (yields vary from 6 to 27l/s) tapping this aquifer which supply water to Nekemte town. 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 to7.5 and 156 to 196 mg/l, respectively. The analytical results revealed that concentration of cations such as Ca2+ range from 21.4 to 32.9mg/l, Mg2+ from 13.5 to 17.3 mg/l, K+ from 2.1 to 2.8mg/l and Na+ from 12.5to19.5mg/l. Anion concentrations vary over a narrow ranges: HCO3- from 163.4 to 190.6mg/l, Cl- from 1 to 2mg/l, NO3- from 3.25 to 7.5mg/l and SO42- from 1.1 to 2mg/l. The mean cationic concentration follows the order Ca2+>Na+>Mg2+>K+ while anions follow HCO3->NO3->Cl->SO42- order indicating that Ca2+ and HCO3- 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.

KEYWORDS: Tinfa, catchment, basalt bedrock, aquifer , potable water.

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** Corresponding Author*

I. INTRODUCTION

Groundwater is the preferred source of water supply worldwide. Especially in many urban areas across Sub-Saharan Africa, it is vital source for piped water supplies (Adelana et al., 2008; Foster et al. 1999). In Ethiopia, many urban centers including the capital city of Addis Ababa (Tamiru, 2008) has groundwater as its water supply source. 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 urbanisation 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). Thus, the provision of drinking water should not only aim at its quantity but also should focus on its quality. For Nekemte Township, three boreholes were drilled as emergency relief following the drying up of a previously constructed dam due to huge quantity of silt filling the dam. The wells drilled south of the town in a small catchment called *Tinfa* where fractured basalt overlain by weathered mantle constituent the major aquifer. The wells tap dominantly fractured aquifer and the yield varies from 6 to 27l/s. Because the wells are located in close proximity to the town and in downstream side, it is anticipated that groundwater can be affected by pollutants from industrial sources. Therefore, groundwater samples were collected from the wells and analyzed for chemical constitutes to assess groundwater quality for drinking.

1.1 Location

Nekemte town is found in the Oromia regional State, Western part of Ethiopia, (fig.1).The specific site for this study, Tinfa catchment, with area of 28sq.km, is situated South of Nekemte town, It is located between longitude $36^{0}32'$E, $36^{0}35'$E and latitude $9^{0}1'$N, $9^{0}6'$N (fig.1). There are three drilled boreholes found in the southern periphery of the catchment and supplying groundwater for the township (fig.1).

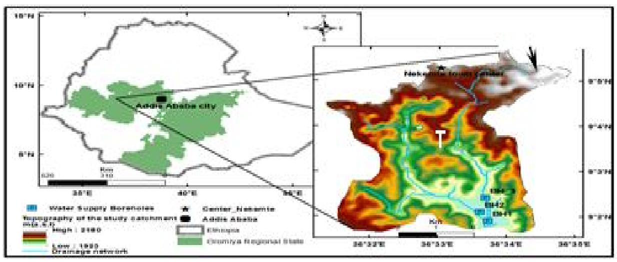

Figure 1: Location map and physiographic feature of the study area

1.2 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.

1.3 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.

Defines on -modal type rainfall pattern in the western region of the country. As part of the region, Nekemte area and the study catchment rainfall pattern is mono-modal. The average annual rainfall recorded at Nekemte station is nearly 2100mm.

Temperature in the area is as high as 27^{0}C in the months of February, March and April and as low as 11^{0}C in the months of September and October. Mean monthly temperature is about 18^{0}C with minor elevations to about 20^{0}C in the months of March and April.

II. GEOLOGY OF THE STUDY AREA

Many regional geological studies in the western part of the country (e.g. Alemu and Abebe, 2007; Kebede and Koeberl, 2003; EIGS, 1996; Asrat et al., 2001; Geological Surveys of Ethiopia, 2000) revealed that the terrain comprises of rocks ranging in age from Precambrian to Quaternary. The oldest rock in the region is of Precambrian age that includes low-grade meta-volcano-sedimentary assemblages and associated intrusive which collectively form the southern extension of the Arabian-Nubian-Shield (Kebede and Koeberl, 2003; Asrat et al., 2001). While, high-grade metamorphic rocks comprised of gneisses and migmatites with associated intrusive dominate the eastern part of the western region (GSE, 2000; Alemu and Abebe, 2007).

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 Nekemte area and 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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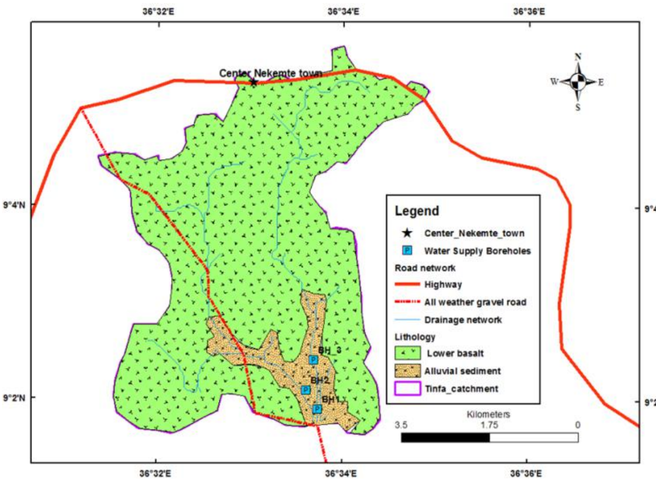

Figure 2: Geological map of the study catchment with locations of boreholes

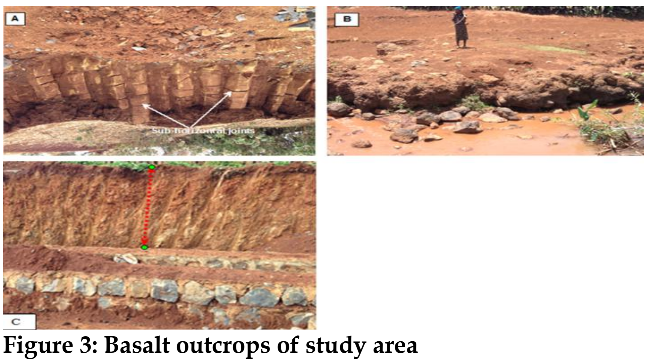

Figure 3: Basalt outcrops of study area

4 A) well-developed columnar joints cut by younger sub-horizontal joints (fractures)

4. B) Weathered basalt bedrock exposed in a stream cut; the bedrock is vesiculated

4. C) Residue of in-situ weathered mantle developed on basalt bedrock (in interfluves areas)

Thickness of the lava flow decreases southwards, from the volcanic centers of Komto hill (fig.1) where elevation goes up as high as 2482 m a.s.l. Outcrops of this rock are observed in stream cut and quarry sites (fig.3). The fresh rock has a dark gray to gray color, and weathers to gray and reddish brown color depending on the degree of weathering. Well-developed faces of columnar joints are observed at quarry sites (fig.3A). Columnar joints are commonly oriented vertically and are intersected by other horizontal sets of joints (fig.3A). Elsewhere, vesiculated basalt rocks are also noticed (fig.3B).Mineralogical compositions of the basalts are spatially variable but all the basalt in western region dominantly contain plagioclase laths; olivine and pyroxene are also common (GSE, 2000). Bedrocks in the interfluves areas are frequently covered by variably thick residua of weathering mantle commonly capped by lateritic cover (fig.3C). Development of such thick weathering profile could be attributed to deep weathering (Dosseto, 2012). Superficial alluvial deposits occurring in the catchment are restricted to places of topographic lows, particularly along the banks and within the courses of streams (fig.2). These sediments are dominantly composed of silt clays when occurring on river banks and also include pebbles and even boulders when occurring in the river courses. Boulders and coarse gravels are also common along stream channels. The colour of soil is reddish except in few topographic low areas where water accumulates and gets darker.

III. HYDROGEOLOGY

The catchment receives rainfall as high as 2100mm annually. Much of the influx infiltrates in to thick accumulation of in-situ residua owing to the low relief of the weathered surface. In western region, much of the rainfall is transmitted through weathered profile to be added to groundwater reserve (as groundwater recharge) (Deyassa et al., 2014).Groundwater recharge in the western region reaches as high as 400mm (EIGS, 1988). In interfluves areas, because of thick weathering mantle, water moves in subsurface via different horizons of weathering profiles mainly saprolite and saprock (Wright, 1992). In the course of the movement its chemistry is subjected to continuous change because of ionic exchange resulted from water-soil/rock interaction (Appelo and Postema, 1993; Drever, 1997).These geochemical reactions along groundwater flow paths can lead to variations in chemicals that changes the quality of water (Plummer and Glynn, 2005).

Columnar joints (fig.3A) which are ubiquitous on basalt rocks generally facilitate downward movement of water. Sub-horizontal sets of discontinuities (joints) on other hand enhance lateral movement thereby maximizing groundwater flow into wells and spring discharges. The thick weathered profile generally serves as a huge reservoir that intercept vast portion of rainfall and release it at slower rate to the underlying discontinuous bedrock. Thus, the complete succession of weathered mantle and the fractured and jointed basalt bedrock constitute the hydro geological system of the catchment area. It follows that direct recharge takes place by movement of water through vadosezone (weathered profile) to be added in to the saturated zone. Consequently, the northern part of the catchment constitutes mainly recharge area while the southern periphery is generally the discharge zone indicating groundwater flow direction dominantly in N-S direction. Thus, the three wells are sited in the discharge zone (fig.1; fig.2). All the three wells with depth 160-161m, tap fractured basalt aquifer and the yield from the well varies from 6l/s to 27l/sand supply Nekemte Township.

IV. MATERIALS AND METHODS

The aim of the sampling is to collect a portion of material small enough in volume to be transported conveniently and handled in the laboratory while still accurately representing the material to be sampled, (APHA, 1992) and (W.H.O., 2006, 2008) guidelines. Groundwater samples a pair from each borehole, were collected from the three boreholes (fig.3) using 1-litre pre-washed polyethylene bottles. The bottles were rinsed 3times by the same water to avoid contamination. They were filled completely and capped tightly and further sealed with plastic scotch to avoid any escape of gasses. Samples for cation analysis were acidified to pH 2 by dropping diluted nitric acid (HNO_3) in to the bottles.

In order to avoid any impurity, the wells were duly pumped so that the stagnant water is completely removed from site within well assembly. After labeling, samples were transported to laboratory the same day and kept cool until they were analyzed. After filtering with 0.45µm membrane, concentrations of major anions (Cl^-, SO_4^{2-}, NO_3^-) were measured using ion chromatography, while major cations (Ca^{2+}, Na^+, K^+, Mg^{2+})were analyzed using ICP-MS in the central laboratory of Water Works Design and Supervision Enterprise Water Quality Section. Electric Conductivity (EC), Total Dissolved Solids (TDS), and pH were measured in the field using portable field kit.

4.1 Analytical techniques of water samples

The physico- chemical characteristic of water samples have been determined according to the standard methods of (APHA, 1992) and (W.H.O., 2006, 2008).The concentration of calcium, magnesium, bicarbonate, chloride and total hardness determined by titri-metric method. Calcium and magnesium determined by EDTA titration, for HCO3, Hcl titration to a methyl orange point. Chloride also determined by titration with AgNo3 solution. Flame emission photometry used for the determination of sodium and potassium. In this method water sample of the light emitted by a particular spectral line measured with the help of photoelectric cell and a galvanometer. Sulphate analyzed by gravimetric method. The concentration of nitrate and fluoride determine with the help of double beam U.V. spectrophotometer.

V. RESULT AND DISCUSSION

5.1 Physical property of water

Results of the analysis of physical parameters (table 1) of the samples have shown that temperature of groundwater varies over narrow range of 19.7 to 20.3^{0}C. This is nearly the same as atmospheric temperature which may be indicative of local groundwater flow regime. Likewise, pH from the samples of the three wells also vary narrow range of 6.9 to 7.5 (table-1) representing slightly alkaline water.

Table 1: Physical parameters of groundwater samples from the study area

Borehole	Sample Location		T(^{0}C)	PH	EC	TDS
	North	South			(µS/cm)	(mg/l)
BH1	232006	999156	14.7	7.5	135	196
BH2	231781	999520	15.3	7.5	115	166
BH3	231936	1000096	15.5	6.9	108	156
Mean			**15.2**	**7.3**	**119**	**173**

Total Dissolved Solid (TDS) of the samples varies from 156 to 196mg/l (table 1, Correspondingly, Electric Conductivity (EC), also varies from 108 to 135µS/cm. Commonly, such very low TDS is usually indicative of short evolution distance and time, which implies local groundwater flow regime. Groundwater that involves local flow regime is generally classified as fresh water (Freeze and Cherry, 1979; HEM, 1985).

Table 2: Chemical concentration of major cations and anions in mg/l

Borehole	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	Cl^-	NO_3^-	SO_4^2	F^-
BH1	32.9	17.3	12.5	2.8	190.6	2.0	7.5	1.1	-
BH2	21.4	13.5	19.5	2.6	165.7	2.0	7.3	2.0	-
BH3	26.7	13.5	14.0	2.1	163.4	1.0	3.25	2.0	-
Mean	**27.15**	**15.4**	**16.0**	**2.7**	**178.15**	**2.0**	**7.4**	**1.55**	

The results of chemical analysis reveal that cations variably range: Ca2+from 21.4 to 32.9mg/l, Mg2+ from 13.5 to 17.3 mg/l,K+ from 2.1 to 2.8mg/l and Na+ from 12.5 to 19.5mg/l (table-2). The highest values are for water sample of BH1 and the lowest values are for BH3 (table-2) for Ca2+, Mg2+ and K+ respectively. However, sample of BH2 has maximum concentration of Na+ (table-2). Similarly, anion concentrations vary over arrow ranges (table2): HCO3- from 163.4 to 190.6mg/l, Cl- from 1 to 2mg/l, NO3- from 3.25 to 7.5mg/l and SO42- from 1.1 to 2mg/l.

The mean ionic concentration follows the order of Ca2+>Na+>Mg2+>K+ for cations and HCO3->NO3->Cl->SO42- for anions indicating that Ca2+ and HCO3- are dominant ionic species in the catchment (table-2).Higher concentration of Mg2+ can be attributed to the dissolution of ferromagnesian species (olivine). For example, attack on ferromagnesian species may be represented by the decomposition of for sterite to release magnesium ions as dictated in HEM, (1985). The relative abundance of Ca2+ and Na+ ions can also attributed to decomposition of feldspar(anorthite) respectively(Hem,1985).

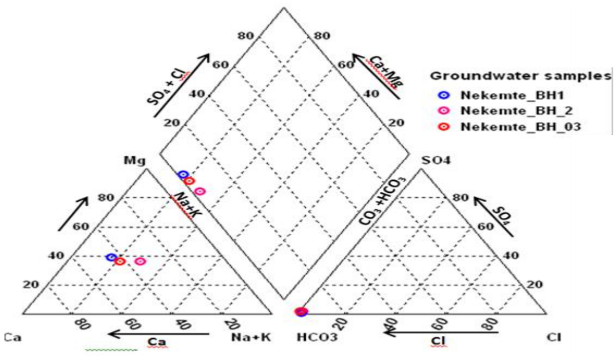

Figure 4: Water type classification using piper plot diagram

In most cases, in such igneous rock, the major cationsin groundwater are mostly derived from the dissolution of plagioclase feldspar by the attack of carbonic acid-rich water. The bicarbonate is then the major anion balancing the cations as indicated by the pioneering work of Garrets (1967) and Mackenzie (1967).This is the plausible explanation as basalt is a kind of rock impoverished in quartz but contains small amount of anorthite. Classification of groundwater from the wells using Piper plot (Piper, 1944) (fig.4) based on classification scheme suggested by Back, (1961) and Hanshaw, (1965), revealed that the water in the study is bi-carbonate type water (fig.4). .

VI. WATER QUALITY

The suitability of groundwater in the catchment for drinking and domestic use has been analyzed by check in the physical and chemical parameters against the values recommended by World Health Organization guideline (WHO, 2006; WHO, 2008) and Ministry of Water Resources of Ethiopia (MWR, 2002) as tabulated in table3.

Table 3: Evaluation of physico-chemical parameters of water from the study area

Water quality parameter	WHO(2006) and WHO,2008 Guidelines		Water sample from the study catchment		MWR (2002) guideline Ethiopian
	Desirable limit	Permissible limit	Range	Mean	
Temp(⁰C)	Variable	Variable	14.7-15.5	15.2	
Ph	7.0-8.5	6.5-9.2	6.9-7.5	7.3	6.5-8.5
EC(µS/cm)	<250	<1500	108-135	119	
TDS(mg/L)	<500	<1000	156-196	173	1776
Ca^{2+}(mg/L)	<75	<200	21.4-32.9	27.15	-
Mg^{2+}(mg/L)	<50	<150	13.5-17.3	15.4	-
Na^{+}(mg/L)	<120	<400	12.5-19.5	16	358
K^{+}(mg/L)	<100*	<200*	2.1-2.8	2.7	
HCO_3^-(mg/L)	<200*	<600	163.4-190.6	178.2	
Cl^-(mg/L)	<250	<500	1-2	2	533
F^-(mg/L)	<1.5	1.5	0.4	0.4	3
SO_4^{2-}(mg/L)	<200	<400	1.1-2	1.55	483
NO_3^-(mg/L)		50	3.25-7.5	7.4	50

For drinking use with respect to WHO guidelines (WHO, 2006; WHO, 2008) and Ministry of Water Resources, Ethiopia (MWR, 2002). Groundwater quality assessment was made using physical parameters (T, pH, EC,TDS) and chemical analysis of ions(Ca^{2+},Mg^{2+},Na^+,K^+,HCO_3^-,Cl^-,F^-,SO_4^{2-} andNO_3^-). It was found that the pH of groundwater in the catchment varies from 6.9 to 7.5 to acceptably fit the range indicated in guidelines of WHO and MWR (table-3). In general, none of the parameters exceeds the maximum limits indicated in WHO and MWR guidelines for potable water.

VII. 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 $Ca^{2+}>Na^{+}>Mg^{2+}>K^{+}$ and $HCO_3^->NO_3^->Cl^->SO_4^{2-}$ respectively. This indicates that Ca^{2+} and HCO_3^- are dominant ionic species in the catchment and hence the water is alkaline in nature. The plausible explanation for the source of major cations is the dissolution of plagioclase by the attack of carbonic acid-rich water. Bicarbonate is the major anionic species balancing the cations. 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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