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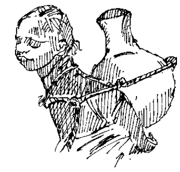
INTEGRATED DEVELOPMENT FOR WATER SUPPLY AND SANITATION



Hydrogeochemistry of waters in Lake Ziway area

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MOST OF THE water supply in the studied area is from groundwater sources; however, there is a quality problem. This is due to high TDS and fluoride concentrations.
Water samples and lithologic data of wells in the area were collected, analyzed and used, to identify the source of major constituents of surface and ground waters and to examine the suitability of the waters for different purposes.

Geochemical characteristics

Almost all the groundwater in the lowlands of the area is sodium bicarbonate type. The ground waters in the Eastern Highlands are calcium sodium bicarbonate type. When we consider surface water Ketar river is calcium bicarbonate type, Meki river is calcium sodium bicarbonate type and Bulbula river and Ziway lake are sodium bicarbonate type.

Silica (SiO_2)

In the studied area high silica concentration is mainly derived from dissolution of feldspars within weathered ignimbrites. Relatively low silica of Lake Ziway is due to low temperature and extraction of silica by organisms for shells and skeletons.

Sodium and potassium

In the ground water of the area sodium is the dominant cation. This is due to high rock - water interaction, which is confirmed by higher values in wells within lacustrine sediments and lower in welded ignimbrites and basalts. In rivers of the area Na^+ is low since the main source of sodium in water is dissolution of sodium containing minerals and river water have no long time interaction with rocks.

In the studied area the concentration of potassium follows the same trend as sodium (higher in ground water and low in surface water) but it is always less than sodium. This is due to two reasons: first potassium containing minerals (i.e. sanidine) are more resistant for weathering than sodium containing minerals (e.g. plagiolcase); second potassium is less abundant than sodium in the acidic peralkaline rocks.

Calcium and magnesium

Calcium (Ca^{2+}) ranges between 0 and 91 mg/l in waters of the studied area. The maximum value is at Gerbi well, which is located southwest shore of the lake within an irrigated area. This high value is due to the fact that recharge of the well is composed of irrigation drainage water. It contains higher proportion of calcium than sodium, since the exchange of sodium by calcium is common in waters drained from irrigated areas. The other higher Ca^{2+} wells are found nearby the rivers in the area, which indicate that these wells probably get higher amount of recharge from the rivers.

Magnesium mostly follows the same trend as calcium, but it is always less abundant than calcium. This is probably due to the fact that magnesium is present in a much lower concentration than calcium in most igneous rocks in the area. The highest value in the area is at Chefe Jila (14 mg/l), probably resulted from the surrounding recent basalts that contain high amount of ferro - magnesian minerals.

Bicarbonate (HCO_3^-)

In the studied area bicarbonate varies between 79 and 1179 mg/l. Because bicarbonate ion is not believed to be the main component of any of the minerals in the host rocks of the studied area, the high concentration of bicarbonate is derived from atmospheric and magmatic CO_2, according to the reaction

Na, K - Silicates + H_2O + CO_2 = Na^+, K^+ + HCO_3^- + H - silicates (see also fig 1.)

The contribution of magmatic CO_2 for high bicarbonate ion could be considerable since magmatism is active in the area.

Chloride (Cl^-) and fluoride (F^-)

The great variation of chloride ion concentration is observed in the ground waters of the area which indicates that the main source of chloride in the area is leaching of chlorine from acidic igneous rocks. This is also confirmed by high concentration of chloride ion in the wells within sediments dominantly composed of materials derived from volcanic rocks.

The main sources of fluoride (F^-) in natural waters are: chemical weathering of fluorine containing minerals, volcanic or fumarolic gases and atmospheric dust. The main chemical reactions control solubility of fluoride in natural waters are: ion exchange reactions, dissolution reactions and precipitation reactions.

By using Arnorsson et. al. (1982) equation to calculate the percentage of magmatic fluid contribution for the total amount of F^- based on the temperature of the system, Berhanu G. (1996) calculated that about 23 per cent of the fluoride in waters of the lakes district was contributed by deeper magmatic fluid. In general the high concentration of fluoride in the studied area and in the Main Ethiopian Rift (MER) may be due to magmatic contribution since the area is characterized by active volcanism. This can be supported by low concentration of F^- in the ground waters around the eastern escarpment of the MER. Specifically in the area high concentrations of fluoride ion are related with dissolution reactions and precipitation reactions.

The contribution of dissolution reactions is supported by high concentrations of fluoride, which are found in aquifers within volcanic ash and volcanic ash interbeded with other volcanogenic sediments, which are the main source of fluoride by dissolution reactions. On the other hand, aquifers which are composed of mainly pumice and tuff are relatively low concentration of fluoride.

The contribution of low calcium concentration is supported by high concentration of F^- in waters characterized by low Ca^{2+} (see fig.2, which shows a correlation of Ca^{2+} and F^- in waters of the area). The contribution of ion exchange reactions is negligible, since pH is not showing a great variation in the area.

Generally the main sources of high fluoride in the area are magmatic fluids (23 per cent), dissolution of volcanic rocks (mainly volcanic ash and volcano - sedimentary rocks) and low calcium concentration.

Sulfate (SO_4^{2-})

In the studied area the existence of sulfate is generally associated with volcanic activity in the area but the anomalous concentration of 338 mg/l in Semoye Chelemo well is due to locally highly oxidizing conditions, probably by human activity, which oxidize the reduced forms of sulfur.

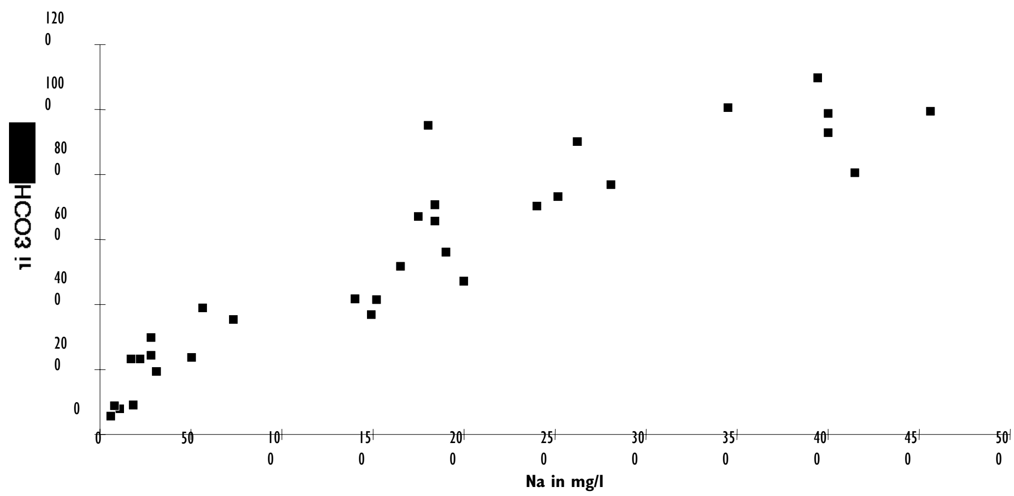

Figure 1. A plot showing the relationship between Na and HCO3 in waters of the area

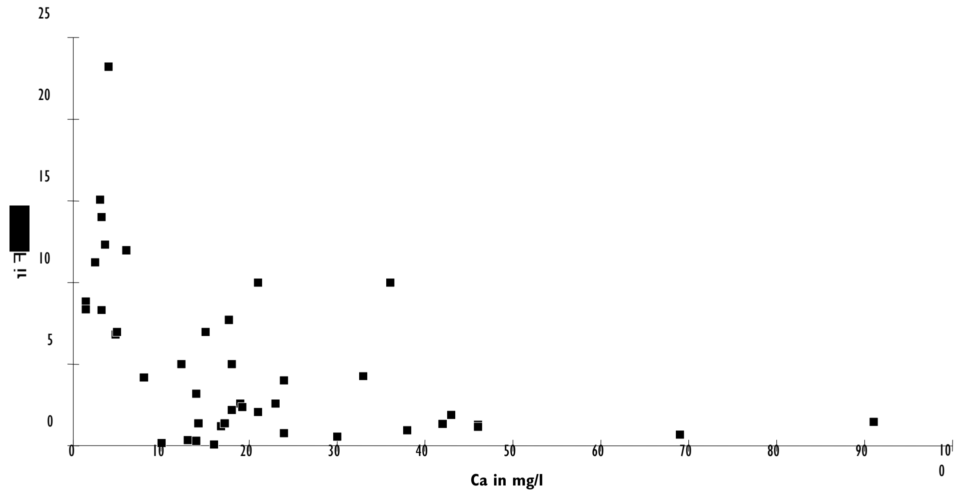

Figure 2. A plot showing Calcium and Fluoride relationships in waters f the area

Table 1. Chemical analyses results of waters in the studied area

Name of Well	EC in µs/cm	pH	SiO_2	Na	K	Ca	Mg	Cl	F	HCO_3	SO_4	TDS
Bore Wells												
Meki L.V.I.A.	627	7.8	-	25	3	42	8	10.5	1.4	-	-	-
Meki Municipality	-	7.8	75	73	4	46	6	14.0	1.3	355	3	579
Ate Fnuri	-	7.3	88	152	8	5	2	13.0	7.0	415	neg	690
Laluna Dero	673	7.9	100	56	10	24	3	3.0	4.0	390	neg	590
Choroke	1459	8	89	175	13	neg	1	50.3	6.5	672	55.3	1062
Gura Germegi	1601	8.5	96	180	15	2.5	1.4	21.0	11.2	951	neg	1278
Abonno 1	-	8	88	394	18	6	6	25	12.0	1098	neg	1647
Bada Gosa	2592	8.2	-	294	21	3.2	2	125	8.3	-	-	-
Mago	2794	8.1	-	314	20	neg	0.3	137	7.0	-	-	-
Ziway Bekele Molla *	-	8	82	200	15	14	9	18	3.2	473	5	934
Semoye Chelemo	2563	8.7	100	262	13	3.6	0	137	12.3	902	338	1769
Elkana Metromofa	2111	7.5	-	196	18	neg	2.09	21.0	9.4	-	-	-
Gubiba	1210	8.8	109	149	13	neg	neg	40.5	10.9	370	84.7	778
Galo Fechasa	1550	8.9	45	414.8	11	3.2	2	53.9	14	805.2	77	1430
Ziway Prison	1786	7.6	-	118	13	12.3	4.48	19.27	5	-	-	-
Koshe *	-	7.9	113	140	16	19	5	16	2.6	418	6	736
Ziway Town	-	7.5	90	252	20	19.2	3.9	21.3	2.4	732	neg	1154
Gush Gulla	-	8	85	281	17	8	3.4	20	4.2	768.6	neg	1188
Worga Garbi	2366	8.3	-	212	22	3	3.67	85	15.1	-	-	-
Boromo	1526	8.6	100	184	12	4	0	71.4	23.3	707	16.5	1118
Shisho Tabo	1278	8.2	-	119	10	neg	1.1	27.3	6.8	-	-	-
Adami Tulu	1151	8.4	-	151	9	neg	1.82	20.1	6.1	-	-	-
Garbi	-	7.4	64	190	10	91	6	119	1.5	561	88	1132
Waji *	-	7.6	38	18	2	13	2	7	0.4	92	0	172
Eleas *	-	7.4	99	11	2	16	2	7	0.1	79	0	216
South of Kulumsa *	-	7.7	121	22	6	46	9	7	1.2	232	0	443
Hand Dug Wells												
North of Meki *	-	-	75	400	20	21	9	140	10	930	10	1617
Chefe *	-	8	68	165	20	43	8	16	1.9	519	23	867
Abonno	1923	8.3	110	184	16	1.4	1.11	20.1	8.4	658	87.7	1087
Wolimbula	2218	7.7	-	212	18	neg	neg	54.9	10.3	-	-	-
Abosa *	-	8	98	456	20	21	8	129	2.1	996	74	1806
Chefe Jila *	-	8	43	345	33	36	14	48	10	1007	33	1571
Abura	406	-	-	21	8	18	4.18	8.8	2.2	-	-	-
North of Abura *	-	7	77	50	6	23	4	4	2.6	237	3	407
Surface Waters												
Bulbula River	498	8.3**	39 **	31	12	14.2	5.41	15.5	1.4	195 **	<10 **	318
Ketar River	203	-	-	5	4	30	3.67	4.6	0.6	-	-	-
Meki River	438	8.5**	30 **	17	8	38	6.6	15.5	1.0	232 **	<10 **	353
Ziway Lake	463	-	-	28	12	17	5.71	13.6	1.4	-	-	-

Springs

Name of Spring	T(⁰c)	Flow(l/s)	pH	CO_2	HCO_3	K	Na	Ca	Mg	F	Cl	SO_4	SiO_2	TDS
Gonde *	-	30	-	3	56	3	6	10	3.5	0.2	10	5	39	140
Burkitu *	-	10.5	-	3	89	3	8	14	5	0.3	3	6	49	185
Tulu Gudo Island **	60	0.1	7.6	208	704	25	240	15	8	7	31	< 10	159	1404
Tulu Gudo Island **	78	Small	8.2	58	988	38	400	8	5	5	95	31	176	1804

Unit is mg/l unless otherwise stated, * - Data taken from Tesfaye C. (1982), ** - Data taken from UN 1973

Water quality

In the studied area the main problem of water for drinking is fluoride ion which is almost in all of the ground water above the maximum allowable value 1.5 mg/l except ground waters in the eastern escarpment and in Meki town north of Meki river. It is known that prolonged intake of water with a concentration of fluoride of 2 mg/l and above can cause mottled enamel and skeletal fluorisis. This effect is observed in the people of the area particularly in the western part of Ziway town.

All the water in the area met the standard limit for livestock consumption in respect to TDS but in respect to fluoride almost all the ground water in the area, except the ground waters in the eastern escarpment have more than the maximum allowable limit for livestock.

Based on Sodium Adsorption Ratio (SAR), percent sodium and electrical conductivity the quality classification of water for irrigation is conducted and it can be concluded that most of the ground waters in the western part of the area are unsuitable for irrigation. The wells in the eastern escarpment have excellent quality for irrigation. When we consider surface waters: Ketar and Meki rivers has good quality and Bulbula river and Ziway lake have poor qualities for irrigation.

In general most of the ground water in the area have poor quality for industries like food and beverage processing, chemical pulp and paper, wood chemicals and hydraulic cement manufacture due to their high fluoride, TDS, silica and bicarbonate concentrations. Water of the rivers (Meki, Ketar and Bulbula) and Ziway lake meet most quality requirements.

Conclusions

From hydrochemical point of view the common properties of both surface and ground waters throughout the studied area are high bicarbonate, high sodium and high silica concentrations. However the TDS and some ions like fluoride show a wide range within the waters of the area. Most of the waters are sodium bicarbonate type except the ground water in the eastern escarpment and Meki river which are calcium sodium bicarbonate type. Ketar river is calcium bicarbonate type.

Water of rivers and Ziway lake have low TDS and fluoride concentrations which have good chemical qualities for drinking. However most ground waters in the lowlands of the area have high TDS and fluoride concentrations.

The major problem for drinking water quality in the waters of the area is its fluoride content, in most cases above the recommended limit (1.5 mg/l). The source of this high fluoride concentration in the area is related with three causes: addition of fluoride by active volcanic and fumarolic activities, high water - rock interaction (particularly interaction of water with volcanic ash) and low calcium concentration, which restricts the precipitation of fluoride as fluorite (CaF_2).

When we consider the quality of water for agricultural and industrial purposes all ground waters in the Eastern high lands and all surface waters have generally good qualities. However, most ground waters in the lowlands have poor qualities.

Recommendations

1. In the towns and villages near to perennial rivers and Ziway lake, exploitation of these water resources is very recommendable since they have relatively good chemical qualities and great potentials for different purposes.
2. In places where very high total dissolved solids and high fluoride contents of groundwater, construction of reservoirs and ponds to collect rainwater and overland flow during rainy seasons would be helpful.
3. Detail chemical and isotopic investigations of waters and reservoir rocks would be necessary in order to understand the contribution of each sources for high fluoride contents and to conduct chemical water balance of the area.

References

AMERICAN PUBLIC HEALTH ASSOCIATION, American Water Works Association and Water Pollution Control Federation (1976), Standard Methods for the Examination of water and Wastewater, Fourteenth Edition, Washington DC, 1193P.

CHERNET T. (1982), Hydrogeology of The Lakes Region, Ethiopia (Lakes Ziway, Langanno, Abijata, Shalla and Awassa), Ethiopian Institute of Geological Surveys, Addis Ababa, Ethiopia, 97P.

CHERNET T. and TRAVI Y. (1993), Preliminary Observations Concerning the Genesis of High Fluoride Contents in The Ethiopian Rift, Geoscientific research in Northeast Africa, Balkema, Rotterdam, PP651-655.

DARLING W.G, BERHANU G. and ARUSE M.K (1996), Lake - Ground Water Relationships and Fluid - Rock Interaction in The East African Rift Valley, Isotopic Evidence Journal of African Earth Sciences 22, PP 423 - 431.

GIZAW B. (1996), The Origin of High Bicarbonate and Fluoride Concentrations in Waters of The Main Ethiopian Rift Valley, East African Rift System, Journal of African Earth Sciences 22, PP 391 - 402.

HAILE G. (1998), Hydrogeology and Hydrochemistry of Lake Ziway Area and the Surrounding, M. Sc. Thesis, Addis Ababa University, Addis Ababa, 124 p.

HEM I.D (1992), Study and Interpretation of The Chemical Characteristics of Natural Water, Third edition, US Geological Survey Water Supply Paper 2254, Washington DC, 266P.

UNDP (1973), Geology, Geochemistry and Hydrology of Hot Springs of The East African Rift System Within Ethiopia, Investigation of Geothermal Resources For Power Development, New York, 275P.

WHO (1984), Guideline For Drinking Water Quality, water supply projects of Lay Volunteers International Association (LVIA).

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