

THE LINKAGE BETWEEN GEOLOGICAL SETTING AND HUMAN HEALTH IN ETHIOPIA: A PRELIMINARY GEO-ENVIRONMENTAL-HEALTH MODEL

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ABSTRACT: Tropical environments are known for their prevalence of a number of geo-chemical diseases. This is related to the very nature of their geo-environments. Little research is conducted in geo-sciences in Ethiopia to investigate the linkage between geo-environments and associated health risks. Fluoride and related diseases are the most widely studied from geological perspectives. Ethiopia is characterized by complex but regionally homogeneous geo-environment. Climate is under the influence of monsoon from two oceans and continental sources. Locally orography modifies the redistribution of rainfall in the lee and wind ward directions. This leads to any combination of warm to cold and wet to dry climate. Prominent geologic features are rifting, volcanism and uplifting. Combination of geology, climate, and topography results in a complex pattern of geo-environment which in turn results in belts of availability or scarcity of certain geo-chemical elements. This work shows the presence of linkage between geo-environmental setting and prevalence of geo-chemical diseases such as goiter, elephantiasis, flourisis, and trace element related health problems. South-western Ethiopia, which is under the influence of Indian Ocean monsoon and underlain by volcanic rocks shows the highest incidence of Iodine Deficiency Disorder (IDD). Regions of Ethiopia under the influence of Atlantic Ocean monsoon or areas underlain by sediments and sedimentary rocks show the lowest IDD. Elephantiasis prevalence is linked to laterite soils derived from chemical weathering of basalts, a typical process commonly taking place in humid plateau of south-western Ethiopia between altitudes of 1000 and 2000 masl. Fluoride related diseases are common features in area where water supply for domestic water use depend on aquifers in acid volcanic rocks, commonly in the rift setting. Regardless of the prevalence of geo-chemical diseases, Ethiopia is also endowed with natural geo-chemical materials of significant health benefits (*e.g.*, Mineral waters and mud volcanoes). The work proposes a preliminary geo-environmental health model for Ethiopia.

Key words: Geochemical diseases, geo-environmental setting, Ethiopia, health belts

INTRODUCTION

At least 20 million people are affected or are at risk from toxic fluoride; at least two percent of populations in some sectors of Ethiopia are affected by elephantiasis and 20 million inhabited areas with risk of elephantiasis contraction. In affected areas prevalence rate may reach up to five percent of the general population. According to ministry of health and UNICEF report in 1993, 42 million people (78%) of the total population of Ethiopia are exposed to iodine deficiency, 35 million (62%) are iodine deficient, 14 million (26%) have goiter and at least one in 1000 people is cretin; with about 50,000 prenatal deaths. All these non communicable diseases are affecting the physical, mental, socio cultural and economic status of the individuals and the country.

Except for fluoride whose spatial distribution is well documented and whose geological origin is well investigated from the earth sciences and medical disciplines in Ethiopia (Kilham and

Hecky, 1973; Ashley and Bruley, 1994; Gezahegn Yirgu *et al.*, 1999; Tesfaye Cherenet *et al.*, 2001; Reimann *et al.*, 2003); the relation between the other two diseases and geological or geo-chemical processes is not well investigated.

Ethiopia is characterized by unique condition which leads to the prevalence of most of the geo-chemistry related tropical diseases. For examples the geology of Ethiopia is characterized by rifting, uplifting and volcanism. There is marked seasonality in rainfall (clear wet season and followed by clear dry season). The topography is very complex with mountain peaks intervening with deep gorges. Complex rainfall regime with monsoon dominated rainfall in some sectors, orographic rainfall in others and rain shadow effects in lowlands.

This unique nature of the geology, topography, and climate should lead to a marked variation belts in abundance and or deficiency of certain geo-chemical elements in the environment. For examples fluoride, arsenic, uranium and other

mobile trace elements are the most abundant in rift setting. Iron, Manganese, and immobile trace elements dominate soils in the areas dominated by monsoon precipitation.

This preliminary work is the first attempt to investigate the relation between geo-chemistry related diseases and the geo-chemical, geological and climatic processes in Ethiopia at a regional spatial scale. In doing so the paper attempts to predict vulnerable areas for the prevalence of the diseases. Five principal geo-chemistry related health issues will be addressed. These are goiter; elephantiasis; fluorosis; mineral waters; and emerging health risks associated with arsenic and uranium.

GEO-ENVIRONMENTAL AND GEO-CLIMATIC SETTING

Ethiopia is marked by its remarkable variations in geology (rifting, massive outpouring of volcanic rocks, uplifting to several thousand meters above sea level), topography (narrow constricted valleys intervening with mountain peaks); climate (deserts, humid tropical climate) and rainfall derivation (monsoon and orography interacting rainfall derivation). All these remarkable variability in geo-environmental conditions should result in geographic variation in geo-chemical elements.

South-western Ethiopia is under the influence of the monsoon climate whose moisture is derived from the Congo vegetation and the Atlantic Ocean (Tato Kebede, 1964; Daniel Gemechu, 1977). This is also supported by stable isotope studies in meteoric waters across Africa and Ethiopia (Rozanski *et al.*, 1996; Seifu Kebede, 2004). South-eastern Ethiopia is under the influence of the Indian Ocean moisture rainfall which represents the first condensate from ocean derived vapor. Rainfall amount decreases northward as one moves from the south-western lowlands.

Around two third of Ethiopia is covered by volcanic rocks (basalts and rhyolites). By geo-chemical classification the volcanic rocks from Ethiopia are dominantly transitional and tholeiitic (Pik *et al.*, 1998; Dereje Ayalew *et al.*, 1999). Basalts and rhyolites of northern and southern part of the north-western plateau show some compositional difference as measured by their titanium oxide abundance. In the southern part the volcanic rocks contain relatively higher titanium oxide (Pik *et al.*, 1998; Dereje Ayalew *et al.*, 1999). Furthermore in south-western low-

lands and mid altitude areas, the volcanic rocks directly overly the Precambrian metamorphic basement.

The remaining part of the country is underlain by metamorphic and sedimentary rocks. Sedimentary rocks crop out in the Blue Nile gorge, in the Tigray plateau and in the south-eastern part of the country. In the rift, which divides Ethiopia into two, lacustrine sediments cover the volcanic rocks. Compared to the highlands, the rift is also known for abundance of evolved volcanic materials such as ignimbrites and rhyolites which contain abundant trace elements.

Highly leached iron, aluminum and silica-rich red soils dominate the south-western and north-western lowlands of Ethiopia. In the northern part of the north-western plateau (*e.g.*, Shoa, Gojam and Gondar plateaus) black cotton soils dominate.

METHODS AND DATA

Spatial plotting of the geo-chemical diseases has been conducted in order to investigate if there is linkage between regional geo-environmental setting and the diseases.

Data on goiter prevalence in Ethiopia have been obtained from the World Health Organization (WHO) database <http://www.who.int/vmnis/iodine/data/database> accessed on 05 May 2009. The goiter prevalence data do not have geographic coordinate so efforts have been used to find the real locations of the sites using other available maps. GIS maps of towns of Ethiopia, Woreda maps of Ethiopia, and topographic maps at the scale of 1:250000 have been used for the purpose. In doing so the exact geographic coordinates for more than 95 percent of the locality names indicated in the WHO data base have been retrieved. In cases where more than one geographic location is possible for a locality name, the data have not been used.

In investigating the elephantiasis prevalence simple field observation by the author has been used. Previous observation on prevalence of elephantiasis (Price, 1974; 1976) has also been used.

For arsenic and uranium variation distribution maps in Ethiopia 18 ground water samples have been collected from central Ethiopia between Addis Ababa and Metahara. Table 1 shows the concentration of trace elements in the groundwaters along the Addis Ababa-Lake Beseka transect.

Table 1. Trace element concentration of groundwaters from wells distributed between Addis Ababa and Lake Beseka, concentration in ppb.

Location	Temperature (°C)	EC	pH	F	Li	B	Mo	As	U	Sr	Mn
Sebeta	18.6	233	6.97	0.40	5.34	9.70	0.73	0.39	0.31	132.80	1.16
Filwuha	59.0	4270	7.32	24.34	281.00	323.00	21.27	50.09	0.01	123.50	3.39
Akaki EP7	23.0	575	7.60	0.38	1.48	29.66	2.58	0.50	2.54	419.80	0.54
Dukem	26.7	620	7.26	0.31	6.27	22.93	1.001	0.48	2.48	475.70	1.91
Debrezeit	24.2	532	7.29	0.49	3.33	23.38	2.19	0.77	2.30	353.70	0.53
Jimjima	24.0	565	7.24	0.91	13.51	43.65	4.27	1.90	4.55	314.80	0.06
Tede	26.8	423	8.09	1.03	20.27	45.45	4.13	1.01	5.15	134.30	0.42
Chemer Jaw	28.9	476	7.66	1.56	26.65	49.54	4.86	1.82	6.00	210.90	1.23
Abu Diab	27.5	500	7.24	1.31	22.53	52.27	3.70	1.72	10.10	172.70	0.86
Nazareth	34.0	570	7.52	1.32	28.36	65.40	12.06	2.04	3.23	79.57	0.53
Wolenchit	33.0	620	7.62	2.25	23.27	162.10	18.49	4.83	3.11	171.90	0.03
Borcheta	36.7	1300	8.32	5.70	18.62	346.90	56.10	22.49	7.80	44.95	2.27
Ebilty Besek	33.9	1775	8.41	4.96	27.29	887.80	89.74	15.11	8.81	121.30	0.15
Keseme ket	50.1	2010	7.96	5.52	67.38	1088.00	81.30	26.39	5.80	60.65	0.05
Keseme ket	37.0	1927	8.23	3.75	62.97	1069.00	79.70	25.67	6.20	47.97	2.72
Gefersa sew	21.1	242	6.60	0.20	7.34	8.44	0.30	0.38	0.02	130.10	1.19
Meki	27.0	658	8.16	6.12	15.67	63.05	14.29	16.62	3.91	39.75	0.41

EC, .electrical conductivity

Furthermore iodine concentration in ground waters has been measured across the shoulder of the rift (Seifu Kebede, 1999; Table 2). The repeated analyses have been done in 1999 at the University of Wales, Department of Geography using ICPMS. In addition, extensive data set including trace element concentration in

Ethiopian rift groundwaters collected and analyzed by Reimann *et al.* (2003) has been used in this work.

Geothermal waters, soda springs and mud volcanoes which are believed to have therapeutic values and direct health consequences has been mapped from field evidences.

Table 2. Bromide and iodine concentration in goundwaters from the Western shoulder of the Ethiopian Rift (Debrezeit), concentration in ppb.

Sample code	Location	Br	I
28	CIM BW	27.7	9.2
33	Hora BW	63.4	10.1
35	West/north cheleleka, north, shore	5.4	50.8
37	Hora Tannary, BW	54.2	23.7
38	Kalehiwot Church Eastern BW	40.0	59.4
39	Almaz Doro Bw	71.7	102.8
44	Kalehiwot Church Southern BW	769.5	1659.6
45	Almaz Doro, Bw	22.6	58.9
46	East Cheleleka	4.3	108.7
47	Hora Tannary BW	76.7	20.8
57	Elfora BW	27.8	16.8
58	Hora Tannary BW	140.0	22.9
59	AdaPasta&mac. BW	70.5	44.5
60	Agri Res.Center East BW	125.5	38.8
61	N.FrancoBW	711.4	700.8
62	Agri Res Inst. BW	122.1	579.5
63	Management inst BW	131.0	27.3
64	Defence Eng. BW2	38.3	45.5
65	Defence Eng BW	548.4	1232.9
66	Dragados BW	34.9	5.9
67	BlueNilePF BW	55.4	27.4
68	HoraAgroInd.BW	74.9	143.9
69	AlmazDoro BW	88.6	30.7
70	Slaught House BW	324.4	28.7
71	Kalehiwot Church tap	146.6	12.7
72	Kalehiwot East BW	144.4	140.0
73	Ato Gizaw HDW	1626.8	1271.9
20	CIM-mission BW	83.7	10.7
21	Almaz Doro BW	12.1	34.8
22	Debrezeit	2.6	5.6

RESULTS AND DISCUSSION

Iodine vs. iodine deficiency disorder

Geo-environmental sources of iodine

Sea water with a mean concentration of 58 ppb of iodine is the most important reservoir for terrestrial iodine and this markedly influences the distribution of iodine in the secondary environment (Fuge and Johnson, 1986). Marine carbonate and sedimentary rocks contain iodine ranging from 2.5 to 30 ppm (Dissanayake and Chandrajith, 1999). Ground and surface waters are among the most important media that act as a bridge between rock, rainwater and soil

geochemistry and human physiology (Dissanayake and Chandrajith, 1999). In Ethiopian groundwaters iodine concentration is lower than the marine values.

Iodine deficiency disorder

Lack of adequate iodine in food and drinking water could lead to Iodine Deficiency Disorder (IDD). This causes goiter, cretinism, poor pregnancy, still birth, mental retardation and infant mortality (MOH-UNICEF, 1995). Iodine deficiency is the world's most common cause of mental retardation and brain damage and goiter incidence (Dissanayake and Chandrajith, 1999).

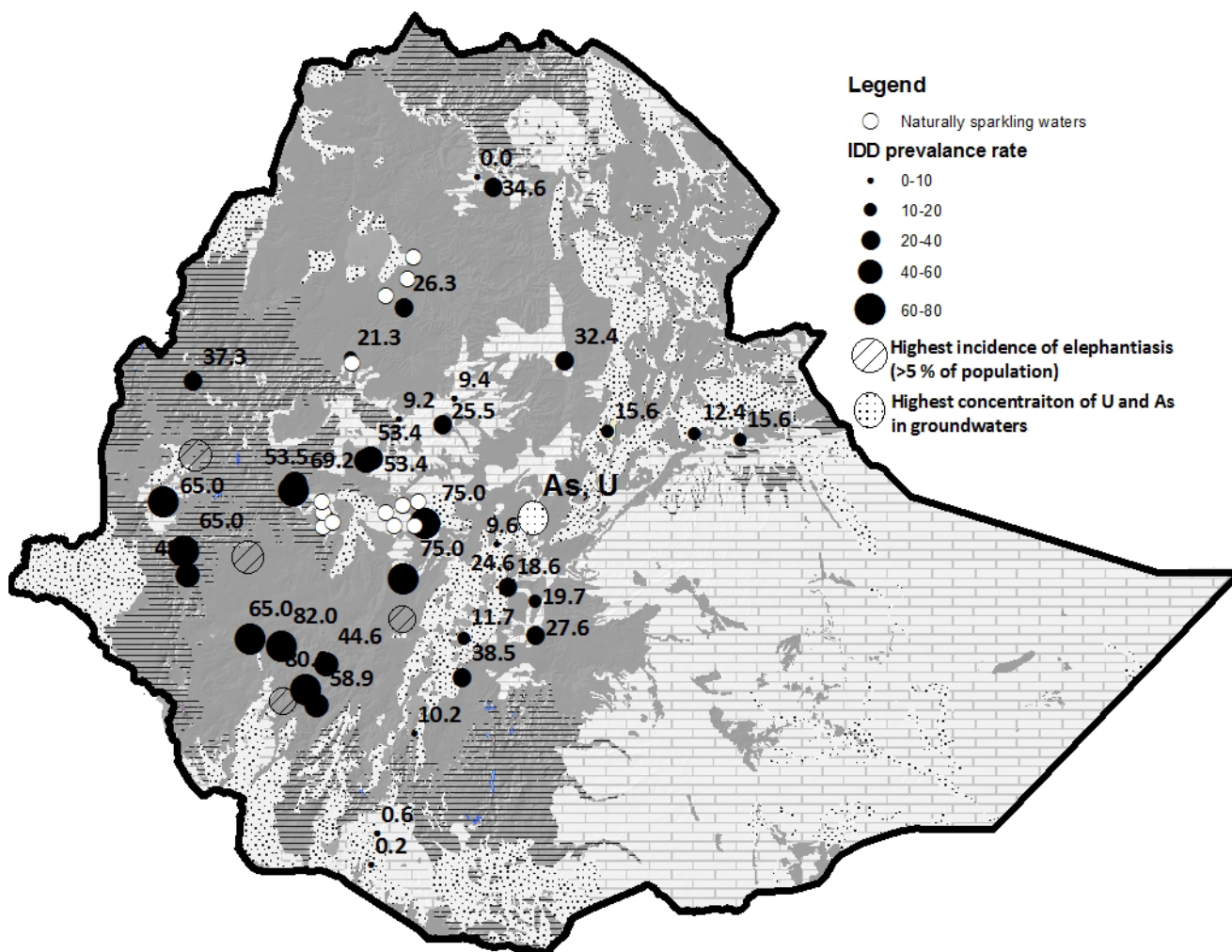


Fig. 1. Map showing observed incidence of goiter and elephantiasis in Ethiopia.

(Numbers near black circles indicate goiter prevalence rate, note that the size of the circle corresponds to prevalence rate. Data on goiter prevalence from WHO database accessed at: <http://www.who.int/vmnis/iodine/data/database>.)

Causal mechanism of Iodine deficiency vs. geo-environmental setting

Figure 1 shows spatial pattern of goiter prevalence rate in Ethiopia. The following information can be drawn from the spatial correlation. Medical sciences research in Ethiopia have previously recognized that risks of IDD is associated with: a) living in high altitudes; b) cassava and millet consumption; and c) leaching of iodine from top soil by erosion and flooding (MOH-UNICEF, 1995). However none of these works show the underlying mechanism of iodine enrichment and depletion with the geo-environmental setting. Two regions of Ethiopia with similar altitude (*i.e.*, the north-western plateau and south-eastern plateau) show different degrees of prevalence in goiter (Fig. 1). Therefore, altitude alone can not be the underlying mechanism of high incidence of goiter. The correlation between goiter prevalence and geo-environmental setting at regional scale leads to drawing up of the following hypothesis for the casual mechanism of iodine deficiency.

Comparison between the iodine concentrations of groundwaters from the two data sets shows (Table 2 vs. Fig. 3 in Reimann *et al.*, 2003) that high concentration of iodine is observed in the rift center than in the adjacent plateaus or escarpments. The highest iodine content are specifically observed in groundwaters from deepest wells, in wells from Borena lowlands, the central part of the rift around Nazareth and in the Afar depression. Except in deep groundwaters and groundwaters associated with lacustrine sediments. Iodine concentration in groundwaters of the western plateau is lower than that of sea water. This suggests the modification of ocean moisture by iodine deficient continental vapor input from Congo vegetation as already suggested by Rozanski *et al.* (1996) playing role in diluting the iodine content of moisture directly coming from the Atlantic Ocean.

- Goiter prevalence is significantly lower in the lowlands of Borena and the rift valley, both regions known for their high salt content in the groundwaters owing to evaporative enrichment of groundwaters prior to recharge and salt dissolution from lacustrine sediments. Iodine concentration in groundwaters of the rift is also higher than global average and than

the marine concentration owing to diffusion of trace gases from the mantle through rift faults.

- The highest goiter prevalence is observed in south-western Ethiopia which is under the influence of the south-westerly monsoon driving its moisture from the Atlantic Ocean and the advective moisture engulfed from the Congo vegetated basin. The dilution of the marine moisture by advected moisture from the Congo vegetation should be responsible for depletion of iodine in the monsoon rains. Furthermore the high rainfall intensity and associated strong leaching of the rocks could lead to elimination of iodine from availability (as groundwaters or biologically).
- In south-eastern Ethiopia goiter prevalence is lower. The region is under the influence of the Indian Ocean moisture which because of short moisture trajectory could contain higher amount of marine iodine. The survey by Reimann *et al.* (2003) also shows high concentration of iodine in groundwaters from the Harar and Arsi plateau bordering the rift. The marine sediments dominating the south-eastern Ethiopian region contribute also to lower prevalence of goiter.
- On the north-western Ethiopian plateau, goiter prevalence generally decreases from south to north. Rainwater collected from these sectors of Ethiopia show a northward increase in salinity (Seifu Kebede, 2004) owing probably to admixture of dust and aerosols derived from the Sahel and Arabian continent. The decrease in goiter prevalence could be related to increase in salinity of rainfall. Furthermore the northern part of the north-western plateau covered by Mesozoic marine sequences (Fig. 1) becomes important. This could directly or indirectly contribute to the natural availability of iodine in the environment.
- Variation in goiter prevalence in a single geo-climatic zone generally increases with increase in altitude. For example, data from altitudinal transect in Wag Hmrah shows that goiter prevalence is higher in highlands than in lowlands (Fig. 1). This being related to increase in salinity of groundwaters owing to higher evaporation in the lowlands and absence of such a process of salt enrichment in highland.

The highland of the Wag Hmrah is underlain by basaltic rocks while the lowlands are underlain by Mesozoic sediments. The variation in geology and salinity of groundwater across the altitude transect is the main controlling mechanism of goiter prevalence in this region of Ethiopia.

Immobile trace elements, red soils and elephantiasis

Agent of elephantiasis

Widely mentioned (*e.g.*, Price, 1974) and possible cause of elephantiasis in Ethiopia is related to the red soil on which certain barefooted populations live. It is believed that small chemical particles (aluminium, silicon, titanium and iron oxides) found in the soil may enter the skin through the bare feet. These particles then lodge in the lymphatic tissues and produce irritating effects. The traumatized tissue is then vulnerable to streptococcal infection.

Non filarial elephantiasis

Non filarial elephantiasis is non infectious swelling of the feet (Price, 1974).

Elephantiasis prevalence in Ethiopia

Elephantiasis is common disease in all sectors of Ethiopia. However previous reports (Price, 1974; 1976) and field observation by the author shows that the hot spots are located in Wolaita area, Dimbidolo, Wolegga, Upper Ghibe valley, and the south-western midland extending from southern Ethiopia to Metema in the north. Elephantiasis is common in red soil covered areas of Woinadega climate and the incidence drops significantly as one moves out of the red soil covered areas (Fasil Tekola, 2005).

Causal mechanism of elephantiasis in Ethiopia

Apparently little research in earth sciences discipline is conducted as to investigate the correlation between volcanic rock geo-chemistry and elephantiasis prevalence. Despite this at the scale of African continent, correlation has been noted to exist between alkali basalt provinces and elephantiasis prevalence (Harvey *et al.*, 1996). It is widely mentioned extensive weathering of alkaline basalts yield particles of size less than 5 micrometer. These particles are responsible for blockage of lymph. Microanalyses of particles

from elephantiasis affected tissue show that particles are composed of Si, Al, Ti and Fe (Price, 1974).

Regardless of the extensive research in geo-chemistry of volcanic rocks in Ethiopia the detailed investigation of the correlation between basalt geo-chemical variation in Ethiopia and elephantiasis prevalence remains unclear. However the preliminary elephantiasis prevalence map in Ethiopia (Fig. 1) shows no apparent correlation between regional variations in volcanic rock geo-chemistry. In contrast to the suggestion made by Harvey *et al.* (1996) that elephantiasis prevalence correlation with alkaline basalt domains, basalts in elephantiasis prevalent area of Ethiopia are transitional or tholeitic in their mineralogy (Pik *et al.*, 1998; Dereje Ayalew *et al.*, 1999). This may suggest basalt geo-chemistry alone may not be responsible but degree of weathering should be responsible. However there is a clear correlation between temperature, rainfall amount, altitude, rock type and soil type and elephantiasis prevalence. The most prevalent areas correspond to intensive monsoon rain, highly leached laterite soils, high temperature, altitude varying between 1000 and 2000 meters and volcanic rock cover. All this combination leads to the formation of thick red brown kaolinitic soil rich in Fe, Ti, Si and Al. The typical geo-chemical reaction which may lead to higher Fe, Ti, Si and Al in soils is shown in Fig. 2.

Arsenic, uranium and other mobile trace elements an emerging health issue

Hazards from excess arsenic, uranium and other mobile trace elements

Excess arsenic in the environment particularly in groundwaters is becoming a global health concern. Excess arsenic intake is commonly associated with skin and internal cancer, melanosis, keratosis, and death. The maximum allowable limit of arsenic in drinking water is set at 10 micrograms/per milliliter by World Health Organisation (WHO, 2006). Surveys by Seifu Kebede (1999) in groundwaters of Debrezeit, by Reimann *et al.* (2005) in the entire rift valley of Ethiopia, and by Seifu Kebede *et al.* (2010) in central Ethiopia show significant number of water points in Ethiopian rift return excess As and enriched trace element composition compared to the WHO (2006) standard. Table 1 shows mobile trace element data from the central

Ethiopia rift. Around thirty percent of drinking water sources from groundwater samples across the central Ethiopia show excess As, twenty percent show excess Mo (*exceeding 70 microgram/milliliter of WHO, 2006*) or B (*exceeding 500 micrograms/milliliter of WHO, 2006*).

Causal mechanisms of excess trace elements

Excess trace element composition in groundwaters of the rift valley above the global average value is related mostly to leaching of geothermal systems of the rift (Reimann *et al.*, 2003; Seifu Kebede *et al.*, 2010). The highest concentration of As and U is observed in the central part of the rift where deeper regional

groundwater flow paths are recognized. An investigation by Seifu Kebede *et al.* (2010) shows that the enrichment of the trace elements is related to the nature of geo-chemical environment of the rift. In the rift because of rarity of organic matter in the rocks the subsurface groundwater environment is mostly in oxidizing conditions. This favors enrichment of heavy trace elements such as uranium in waters. The fact that there is a clear correlation between mobile trace elements and fluoride (Fig. 3) suggest that the elements have similar mode of enrichment and that integrated approach is needed in managing the health risk.

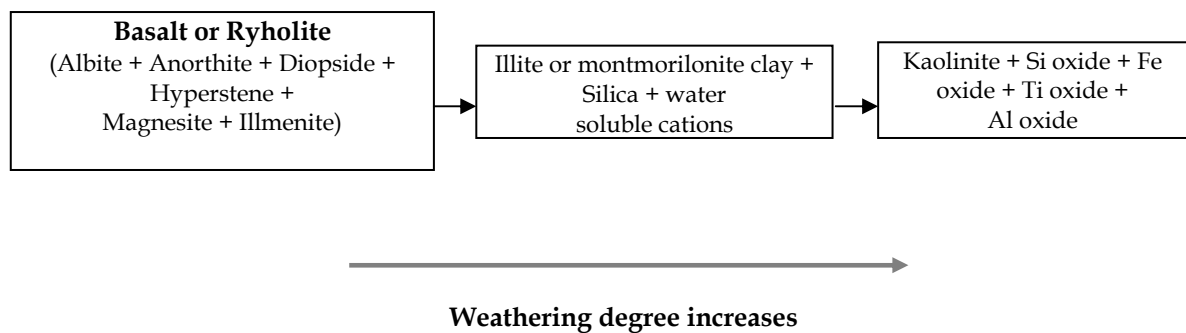


Fig. 2. Geochemical reaction model for the enrichment of elephantiasis causing agents in volcanic terrains of Ethiopia. (Note that any volcanic rock with initial alkaline or tholeitic composition may produce similar weathering end members.)

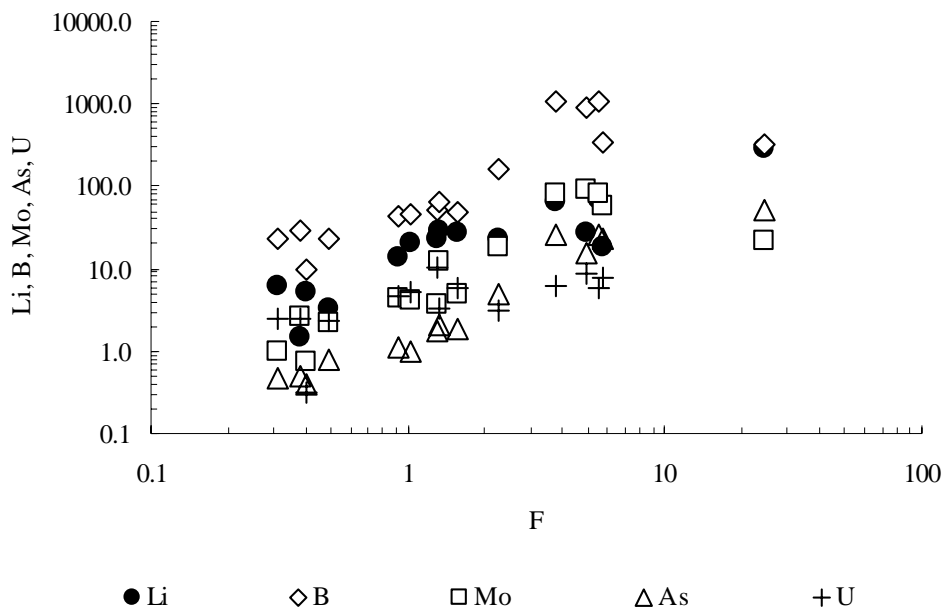


Fig. 3. Correlation between F and other mobile trace element concentration in groundwaters of the central part of Ethiopian rift.

Impact on health of arsenic and other trace elements

Regardless of the excess arsenic, boron and molybdenum in some drinking water points the effect on health of the general public in Ethiopia is not known.

Fluoride and fluorosis

Dental and skeletal fluorosis is a common health problem in the rift valley environment. The cause of fluorosis is excess fluoride. Excess fluoride comes from leaching of acid volcanic rocks containing alkaline minerals. Evaporative recycling of F in the environment also contributes towards enrichment of F in groundwaters. Unlike other geo-chemical health threats, detailed research has been conducted on sources of fluoride in the rift (Kilham and Hecky, 1973; Von Damm and Edmund, 1984; Ashley and Bruley, 1994; Birhanu Gizaw, 1996; Darling *et al.*, 1996; Gezahegn Yirgu *et al.*, 1999; Seifu Kebede, 1999; Tesfaye Chernet *et al.*, 2001). A number of researches have been conducted on defluoridation techniques as well.

Mineral waters and health

Myth and reality about mineral waters

There is no standard definition of mineral water. The World Health Organization does not have a separate standard for mineral waters. Often, groundwaters which are naturally carbonated, sparkling, warm at point of emergence, contain balanced constituents of mineral species, and contain appreciable amount of trace elements are considered as mineral waters. Generally, mineral waters contain higher total dissolved solids. Unlike ordinary groundwaters naturally sparkling mineral waters contain most of the dissolved constituents at balanced and similar proportions. This is the result of CO₂

joining the waters and keeping the mineral constituents in dissolved forms. Table 3 shows the chemical composition of an ordinary groundwater and a naturally sparkling mineral water. It can be seen that regardless of their similarity in overall total dissolved solids the sparkling water contain balanced composition of all major elements.

Mineral waters and health

Mineral waters by definition should provide balanced and rich elements for health. In normal waters, because of thermodynamic processes and separation of geo-chemical facies along groundwater flow paths, conditions are unfavorable to have similar abundance of each chemical element and rich mineral content. Ordinary groundwaters are rich in certain types of elements but not in others (*e.g.*, higher in Na and K but negligible content of Ca and Mg). The presence of rich and diverse chemical elements in mineral waters makes them suitable for human metabolic functions and health.

Occurrence of naturally sparkling groundwater in Ethiopia

Naturally sparkling groundwaters are rare world wide. A rare combination of geological and geo-chemical processes is responsible for the occurrence of mineral waters. This requires natural source of carbon dioxide from deeper sources, cold and shallow groundwaters circulating at shallow depths, heat from deeper geologic sources, *etc.* In Ethiopia such a combination occurs in regions surrounding the Wonchi volcano, and in the Lake Tana graben (Fig. 1). Some naturally sparkling groundwaters are also noted in the Didessa valley.

Table 3. Comparison of chemical composition of ordinary groundwater (ow) and naturally sparkling groundwaters (MW).

Locality	PH	TDS	K	Mg	Na	Ca	HCO ₃	SO ₄	Cl	F	NO ₃	Type
Ambo	6.7	1651.9	27.5	39.4	314.0	52.9	1159.0	13.0	42.5	0.5	2.6	MW
Keseme kebena	8.2	1445.3	34.2	0.4	335.7	2.1	786.0	69.8	108.8	3.8	1.5	OW

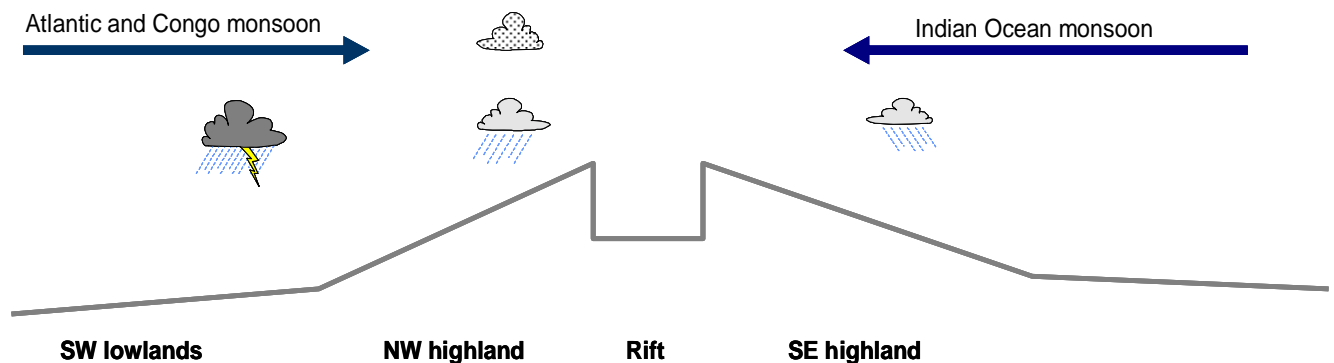
Both (OW and MW) contain similar amount of total dissolved solids but the mineral waters show more balanced distribution of chemical constituents. Data from Seifu Kebede *et al.* (2005) and Seifu Kebede *et al.* (2010).

While the high and balanced mineral content could be beneficial to health, the exact relation between public health and consumption of mineral waters is not clear in Ethiopia. However the public believes that such waters have healing effect from diseases.

Geo-environmental model of geo-chemical diseases in Ethiopia

Figure 4 depicts the relation between geological processes and geo-chemical diseases in Ethiopia. Figure 5 shows risk maps of geo-chemical diseases in Ethiopia. The maps have been constructed based on the observed disease prevalence, data and knowledge that exist on geo-chemistry, geology, climate, altitude and soil types of Ethiopia. By comparing the prevalence of geo-chemical diseases and the geo-environmental settings shown in Figure 4 geo-chemical health risk belts have been constructed (Fig. 5).

As a result of the unique nature of the Ethiopian geological settings both elephantiasis and higher goiter belts are found in common association in SW lowlands and mid-altitude regions. In other tropical settings, heavy monsoon rains generally contain higher iodine content leading to lower prevalence of goiter (Dissanayake and Chandrajith, 1999). The heavy monsoon rain in south-western lowlands and mid-altitude regions of Ethiopia derives part of its moisture from continental setting such as the Congo vegetation. Entrapment of marine iodine by the vegetation probably leads to depletion in the element in the monsoon rains of south-western Ethiopia. Despite the suggestion that highlands are characterized by higher goiter prevalence, in SE Ethiopia, goiter prevalence is lower (Fig. 1). The characteristic pattern in the prevalence of geo-chemical diseases in Ethiopia is produced by a complex interaction of geology, soil formation processes, evaporation degree, rifting and topography.



Warm; intensive chemical weathering, altitude 1000-2000 masl	Cold; orographic rain; lower degree of chemical weathering; rain total dissolved solids is higher	Warm and dry, high degree of Evaporation	Cold and wet, rain water dissolved solids is higher because of proximity to the ocean source	Temperature
Heavy monsoon, moisture from Atlantic & Congo vegetation, Low Iodine	Influx of dust particles from Sahel and Arabian continent, rain with relatively higher I	Low intensity rainfall, rain shadow effect	Monsoon moisture from Indian Ocean, higher Iodine owing to proximity to moisture source; rainfall amount lower than the NW plateau	Rainfall derivation
Highly leached, Fe, Al, Si reach regoliths and red brown soils dominate	Black cotton soil dominate the landscape, soils are thin on higher grounds	Salt reach, regosols and alluvio lacustrine soils	Black cotton soils dominate the landscape	Soil
Basalts and Metamorphic	Basalts with marine sediments in places	Acid volcanic rocks, basalts and lacustrine sediment, mantle fluid influx	Basalts and marine sediments in some places	Geology
Prevalent Elephantiasis Prevalent Goiter	Less prevalent goiter in intervening valleys and in sediment covered areas, less prevalent elephantiasis	Less prevalent goiter and elephantiasis, prevalent flourisis	Less prevalent Goiter, lower prevalent elephantiasis	Geochemical disease

Fig. 4. Schematic model of geochemical disease prevalence and geo-environmental setting in Ethiopia.

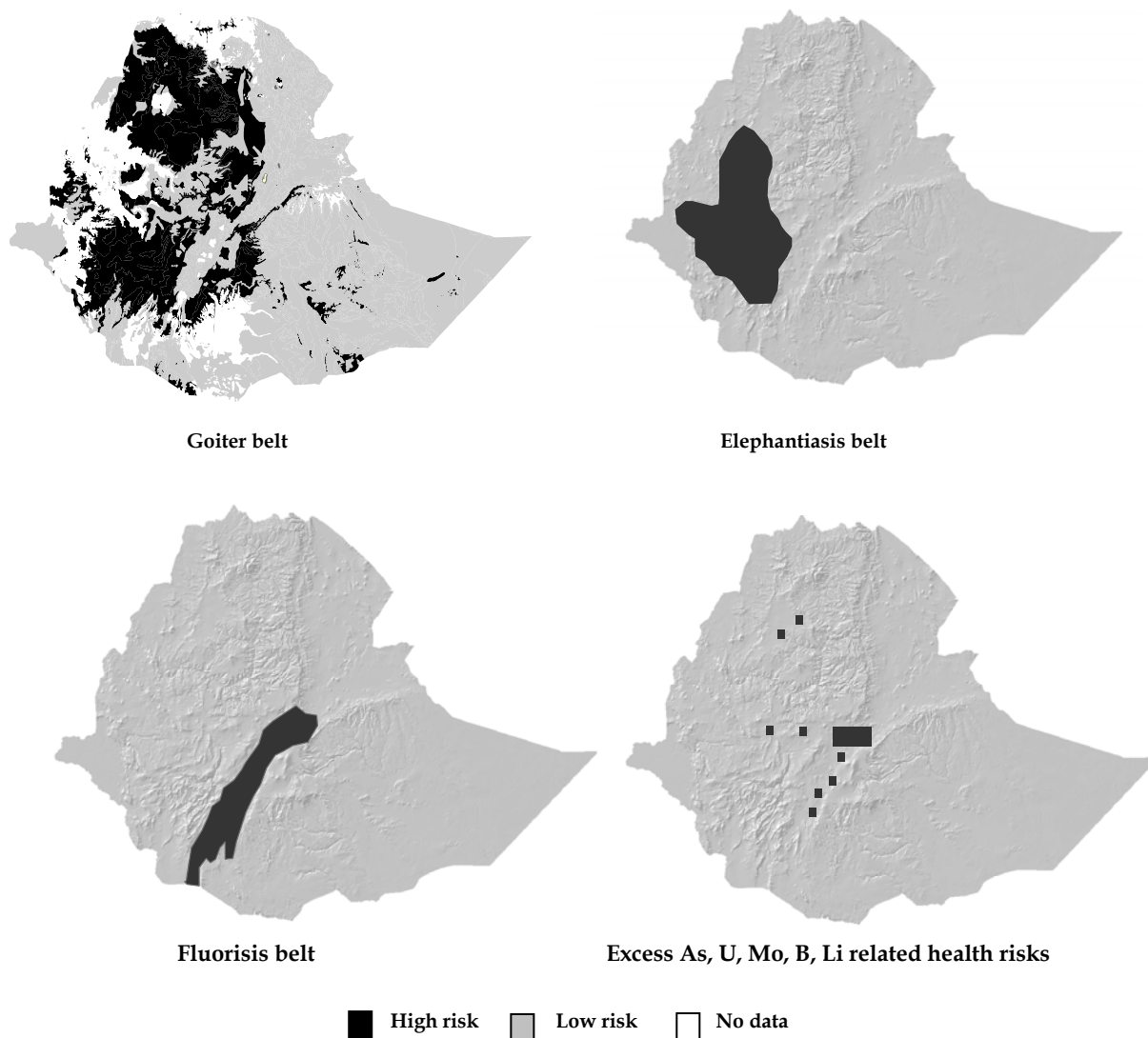


Fig. 5. Projected geochemical health risk belts in Ethiopia.

GENERAL REMARKS AND CONCLUSIONS

This preliminary work shows that the spatial variation in geo-chemical diseases in Ethiopia correlates well with regional variation in geo-environmental setting. The geo-environmental disease model has been constructed based on limited data set particularly on groundwater trace element geo-chemistry, soil geo-chemistry, and rainwater geo-chemistry. A detailed research initiative may be needed to come up with a complete picture of the linkage between geo-chemical diseases and geo-environmental setting.

On the other hand further investigation is needed regarding the threats posed from high arsenic and uranium in central Ethiopia. A

number of questions arise from this preliminary investigation such as:

1. What is does the iodine geo-chemical cycling within the Ethiopian terrain look like?
2. What is the effect of geo environmental setting on animal health?

To fully benefit from research at the interface between earth sciences and medical sciences in Ethiopia, prevalence of geo-chemical diseases needs to be documented according to geo-environmental setting in place of administrative region based documentations. A better geo-environmental health model and further research in the discipline would help health intervention

initiatives such as the national iodization programs.

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