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Distribution of Fluoride in Groundwater in Selected Villages in Northern Red Sea and Anseba Regions of Eritrea

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DISTRIBUTION OF FLUORIDE IN GROUNDWATER IN SELECTED VILLAGES IN NORTHERN RED SEA AND ANSEBA REGIONS OF ERITREA

by

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DEDICATION

I would like to dedicate this thesis to all of my family and friends back in Eritrea. I appreciate the love and support that you have given me.

Filmon Tsegay Fisseha

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DISTRIBUTION OF FLUORIDE IN GROUNDWATER IN SELECTED VILLAGES IN NORTHERN RED SEA AND ANSEBA REGIONS OF ERITREA

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The aim of the study is to describe the fluoride concentration of water samples primarily from sources used for household needs in selected villages of Eritrea, with emphasis on the most severely affected parts of the country. Water sample quality data were collected from The Water Resource Department of Eritrea and water quality reports indicated that high levels of fluoride content were found for some villages' groundwater sources. The highest concentration was found in Aquar, 7.7 mg/L; Northern Red Sea region, above the 1.5 mg/L Maximum concentration recommended by The World Health Organization.

Waters with high fluoride concentrations occur in extensive geographical belts associated with a) sediments of marine origin in mountainous areas, b) volcanic rocks, and c) granitic and gneissic rocks. Geological basis for high concentrations of high fluoride in Eritrea are presumed to be the pegmatite intrusion hosted by granitic batholiths and water interaction with volcanic rocks. Significant positive correlations were also observed between dental caries prevalence rate and high fluoride distribution in the study area.

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CHAPTER I

INTRODUCTION

Fluoride is naturally found in volcanic rocks and significant concentrations have also been found in Precambrian rocks. Fluorite (fluorspar, CF_2) is the most important fluoride-bearing mineral. The element is mainly stored in clay soils, groundwater and lakes in volcanic areas. Groundwater with calcium-poor aquifers which is located in areas where fluoride-bearing minerals are common is the most important source of fluoride. High fluoride concentrations may also increase in ground waters in which cation exchange of sodium for calcium occurs (Edmunds and Smedley, 1996). Secondary sources are related to pollution from industries (ceramic factories, coal burning) and agricultural activities, particularly the use of phosphate fertilizers. Recently it has been noticed that huge amounts of fluoride have been released into indoor environments in China through the combustion of coal, with the consequence of increased gaseous and aerosol fluoride pollution of food sources World Health Organization, 2006(WHO). This has resulted in serious complications of osteo-dental fluorosis (Ando et al., 2001). The magnitude of the problem in China is enormous, with more than 10 million people in Guizhou Province and surrounding areas reported to be suffering from dental and skeletal fluorosis (Finkelman et al., 1999).Similar fluoride problems are found in many parts of the world, although in many areas, the extent of the problems are unknown.

The great African Rift Valley extends from Syria and Jordan in the Middle East to Mozambique in Southeast Africa. This massive region is also associated with high fluoride levels in groundwater. The main sources for drinking water with high fluoride content in the semiarid areas of the Rift Valley regions are deep wells. There are significant variations in the fluoride levels of the deep wells within the Rift Valley and even within the same area. This is probably related to the local geophysical and geochemical characteristics of the areas, as well as the climatic conditions impacting various portions of the massive Rift Valley. Consumption of water from deep wells in the Rift Valley has led to endemic fluorosis in several Northeast and East African countries, notably Ethiopia(Tekle-Haimanot *et al.*, 1987),Sudan (Smith et al.,1953),Tanzania(Grech,1966;Latham and Grech,1967),Kenya (Ocherse,1953; Kahama,1997) and Uganda (Moller et al., 1970). The highest fluoride levels have been reported in the Kenya's Lakes Elementaita (1640 mg/L) and Nakuru (2800 mg/L) (Williamson, 1953).The widespread distribution of high fluoride in drinking water leads researchers to the conclusion that implementation of the United Nations millennium development goal of reducing by half the number of people without access to clean water by 2015(McDonald, 2005) will be difficult to apply to the Rift Valley region given that not enough attention is given to groundwater contamination.

Fluoride is one of the chemicals that have been shown to have significant health effects for the people using this water. Fluoride has beneficial effects on teeth at low concentrations in drinking-water, but excessive exposure to fluoride in drinking-water, or in combination with exposure to fluoride from other sources, can give rise to a number of adverse effects. These range from mild dental fluorosis to crippling skeletal fluorosis as the level and period of exposure increases. Crippling skeletal fluorosis is a significant cause of morbidity in a number of regions of the world. Fluoride is known to occur at elevated concentrations in a number of parts of the world and in such circumstances can have, and often had, a significant adverse impact on public health and well-being (Fluoride in Drinking-water, WHO 2006).

Problem Statement

Preliminary surveys carried out by The Water Resource Department of Eritrea National Water Wells Inventory Study in 2001 revealed that mean fluoride levels are 0.99 mg/L in the Maakel region, 0.16mg/L in the Gash-Barka region, 0.27 mg/L in the Southern Red Sea region, 2.10 mg/L in the Northern Red Sea regions, 0.16 mg/L in the Anseba and 0.56 mg/L in the Debub region (Fluoride in Drinking-water, WHO 2006). Except for The Northern Red Sea region, the levels of fluoride distribution in groundwater wells are within the acceptable level. According to the World Health Organization standard, a 1.5 mg/L fluoride distribution is acceptable level for human health and well being.

Endemic fluorosis, especially dental mottling and discoloration has been prevalent for a long time among the population in villages around Keren town, about 90 km west of Eritrea's capital city of Asmara situated along the River Anseba (Zerai, 1993).At the same time, the fluoride level of borehole wells for some villages in the Northern Red Sea region are exceptionally high even though there is no detailed assessment on the geochemistry and environmental health effect of excessive fluorine occurrence (WRD,2006). The sources of fluoride are diverse, including food stuffs (Cholab, 1959) and tea (Pires et al., 1996). The contribution of fluoride from local sources, however, also remains high including fluoride in water used for cooking from local water sources (Karthikeyan et al., 1996). Therefore, the local contributions of fluoride remain high throughout the year, with particularly high intake among those people engaged in hard manual labor (Krishnamachari, 1974).

In Eritrea, although different studies and assessments address the issues of fluoride contamination as regionally important concern, very few studies have been done to understand the fluoride distribution and its human health effects at the village level (Srikanth et al., 2002). This study is designed to address these issues for villages which were not explored by larger scale national studies.

Research Objective

The proposed study will

- Identify exposed villages and population.
- Find the connection between the concentration of fluoride and other hydrochemistry elements in ground water, as well as seek explanations related to the importance of the sourcing chemicals in ground water as the controller of the fluoride content.
- Determine the correlation between dental caries and fluoride concentration at sub region level.
- Suggest possible remedial measures for excessive fluoride removal from drinking water.

Hypothesis

One of the main purposes, of this thesis is to determine those independent variables that might explain/influence fluoride levels across villages in Anseba and the Northern Red Sea Region. The null hypothesis is that for each independent variable there is no relationship between it and fluoride levels. The alternative hypothesis is that well depth, climate, bicarbonate, pH, sulfate, electric conductivity, magnesium and sodium will affect the fluoride levels of ground water in the Anseba and the Northern Red Sea regions within Eritrea.

Purpose of the Study

The aim of the study is to map and analyze the spatial distribution of fluoride concentrations in groundwater samples taken primarily from sources used for household needs in regions of the Northern Red Sea and the Anseba of Eritrea and, as well, to investigate the importance of the hydro chemicals in ground water as the controller of the fluoride content. The findings will assist decision makers in their effort to improve the safety of drinking water by providing efficient and cost effective remedial measures for villages which are affected by excessive fluorine.

Significance of the Study

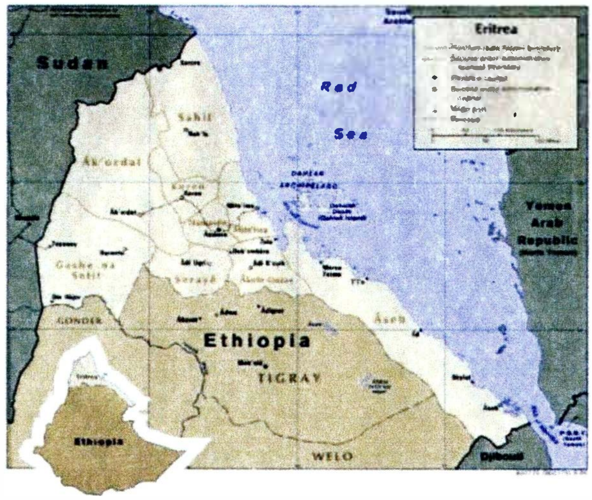
Recent water quality data for some village's borehole wells in the Northern Red Sea region and Anseba showed that the level of fluoride is high (WRD,2006).High fluoride concentrations for this area could be associated with a) sediments of marine origin in mountainous areas, b) volcanic rocks and c) granitic and gneissic rocks (WHO,2006).

A reconnaissance geological survey conducted in the area reveals that most of the villages are underlaid by granotoid intrusions of rich granites, biotite granite, and granodiorite. Mica schists and amphibole schists of medium grade and chlorite schists of low-grade metamorphism with pegmatite intrusions and aplitic dykes are the main lithological units recognized in the study area (WRD, 2002).

The final product will help for planning, early warning and environmental health protection programs by providing information on concentrations of fluoride in boreholes, while identifying possible health effects that are caused by exceeding fluoride level intake and by suggesting possible remedial measures to minimize the problem.

Eritrea

Eritrea is located at the northern part of the Horn of Africa; between latitudes $12^{\circ}\ 40''$ and $18^{\circ}\ 02^{I}$ north of equator and longitudes $36^{\circ}\ 30''$ and $43^{0}\ 20''$ east. It has a land area of about 125,700 km^2, inclusive of the islands, and a coastline spanning some 1,720 kilometers. It shares borders with Sudan in the north and west, Ethiopia in the south and Djibouti in the southeast (Figure 1).



Source: National Adaptation Plan of Action for Climate Change-Eritrea 2007 (NAPA)

Figure 1: Map of Eritrea

Eritrea's physical landscape is characterized by the central and northern highlands extending for about 350 km north to south; the flat coastal plains of the eastern lowlands; and the flat plains of the western lowlands that are interspersed with low hills. The altitude across the country varies considerably, from 1,500 to 2,400 meters above sea level in the highland areas, from 0 to 500 meters in the eastern lowland areas; and from about 700 to 1,400 meters in the western lowlands.

As of 2003, the population of Eritrea is estimated at 3.56 million with an annual growth rate of about 2.7 percent. Much of the population is clustered in the cooler areas of the central highlands. More than 80% of the population lives in rural areas (NAPA, 2007).

<u>Climatic Patterns</u>

Eritrea's climate regime is highly variable, being influenced by the expanding Sahel-Saharan desert, but also influenced by the nation's proximity to the Red Sea and the land's physical features. Altitude and topography play major roles in determining local climates in general and temperature in particular. Typically, mean annual temperature declines by 1 °C for each 200-meter rise in elevation. Ambient average temperatures vary considerably, with the eastern lowlands having an annual mean of 31 °C while reaching as high as 48 °C: In the highland areas, the annual mean is 21 °C with a maximum of 25 °C. In the western lowland areas, the annual mean is 29 °C with a maximum of 36 °C.

The whole country can be divided into six agro-ecological zones representing two rainfall regimes (Figure 2), summer and winter. Precipitation patterns and amounts are affected by the differences of these physiognomic regions. Summer rains are brought by south-westerly monsoon winds and are concentrated mainly in the months of July and August. These rains mostly affect the central highland and the western lowland areas. The winter rains typically occur from November to March and are influenced by the north-easterly continental winds. These rains affect coastal areas and the eastern and southern escarpments (NAPA, 2007).

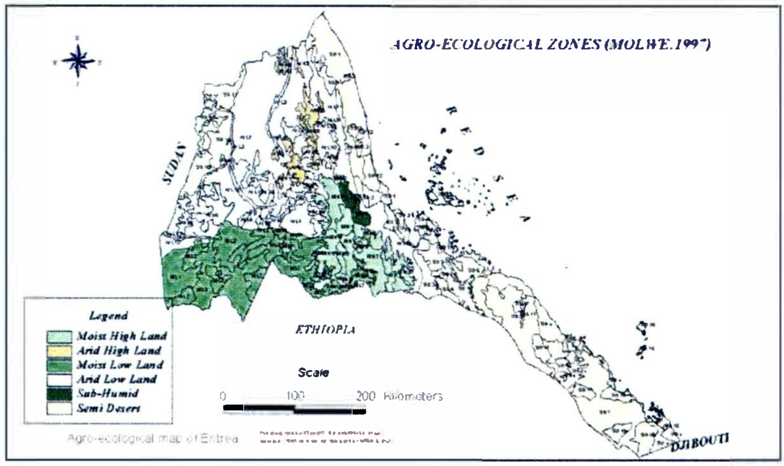


Figure 2: Agro-Ecological Zone of Eritrea (Source: MLWE, 1997)

Eritrea has a mostly arid climate with about 70 percent of its land area classified as hot and arid, receiving an average annual rainfall of less than 350 mm. The main rainy season in most parts of the country is from June to September. There is also a short rainy season involving a small number of highland areas which occurs between March and May. In the eastern coastal areas and parts of the adjacent escarpment, the rainy season is between December and February. The eastern lowland has an average annual rainfall between 50 and 200 mm. Northern areas; given that they fall within the eastern limit of Sahelian Africa, receive less than 200 mm/year of rain. Southern areas experience average annual precipitation of 600 mm, with the central highland areas receiving about 400-500 mm per year (Figure 3).

Another very important feature of rainfall patterns in Eritrea is the extreme variability within and between years, and the spatial variation of the precipitation over very short distances. The Southwest monsoon winds are responsible for both major and minor summer rains in Eritrea. The northern and north-eastern continental air streams are responsible for the winter rains along the coast and in southern part of the escarpment of the central highlands. The northern and north-eastern winds are dry in their nature but take on additional moisture while crossing the narrow Red Sea water body (NAPA, 2007).

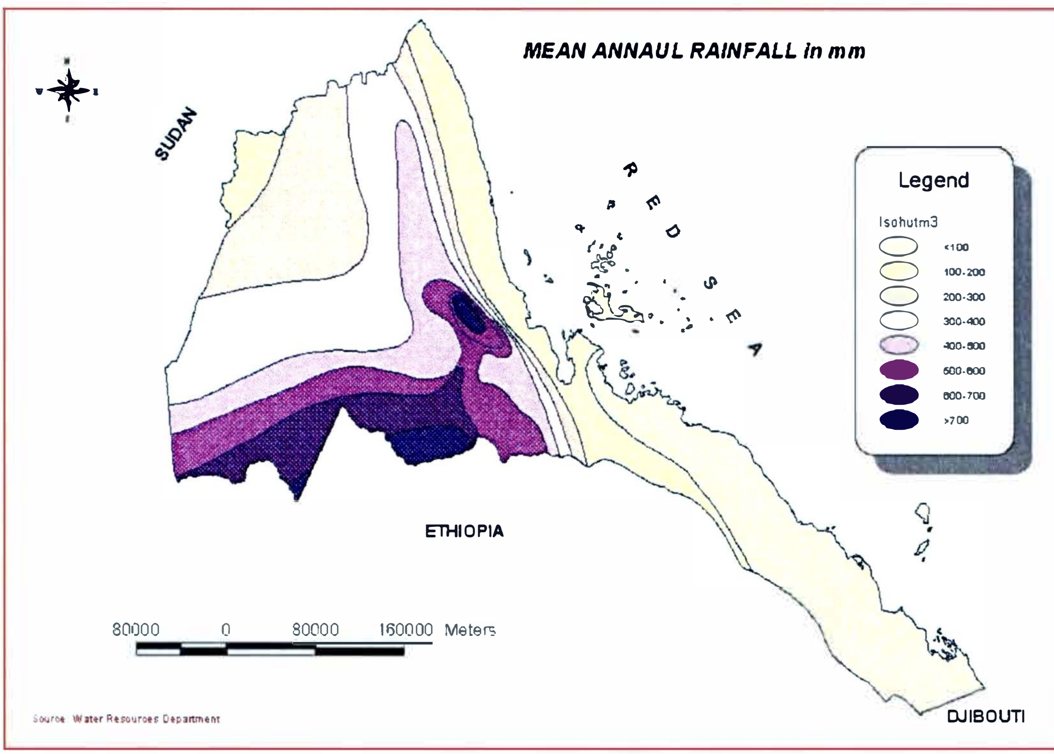


Figure 3: Mean Annual Rainfall- Eritrea (Source: Department of Environment, 2001)

Population and Regions

People

Eritrea's population is composed of nine ethnic groups, most of which speak Semitic or Cushitic languages. The Tigrinya and Tigre make up four-fifths of the population and speak different, but related and somewhat mutually intelligible, Semitic languages. In general, most of the Christians live in the highlands, while Muslims and adherents of animist traditional beliefs live in lowland regions. Tigrinya and Arabic are the most frequently used for commercial and official transactions (Table 1). In urban areas, English is widely spoken and is the language used for secondary and university education.

Table 1: Eritrea Population, Social, Economic and Health Indicators

Population (2004)	3.6 million
Annual growth rate	2.5%
Health	
Infant mortality rate	45/1,000
Life expectancy	52 yrs
Economy	
Agriculture	80%
Industry and commerce	20%.
Religions	
Christian	50%
Muslim	48%
indigenous beliefs	2%

Source: US State Department, 2008

Regions and Administration

Eritrea is divided into six regions (Table 2) and further subdivided into districts ("sub-zobas"). The geographical extent of the regions is based on their respective hydrological properties (Eritrean Profile, 2004).

Table 2: Eritrea Region Population and Total Area

Regions	**Total Population**	**Area in Km^2**
Maakel	538,749	1300
Debub	755,379	8000
Anseba	457,078	23,200
Northern Red Sea	459,056	27,800
Southern Red Sea	203,618	27,600
Gash Barka	564,574	33,200

Source: Eritrea Demography and Health Survey, 2002

The Area of Investigation

Preliminary surveys carried out by The Water Resource Department of Eritrea, National Water Wells Inventory Study of 2001 revealed that the mean fluoride distribution for most of the country is within acceptable levels except for the region of Northern Red Sea and also some villages within the Anseba Region.

The study area covers 19 villages which were selected based on general observations of water fluoride levels and the people suffering from dental caries and teeth disorder. The area falls in the midland to lowland portions of the country along the Anseba River and Northern Red Sea regions of Eritrea.

Northern Red Sea Region

The Northern Red Sea region of Eritrea is one of the country's six regions. It extends along the northern half of the Red Sea, and includes the Dahlak Archipelago and the coastal city of Massawa (Fig 4). The region borders the Anseba, Central and Southern regions to the west, and the Southern Red Sea region to the east and has an area of around 27,800 km^2 (Eritrea Profile, 2004).

Geography and Climate

The Northern Red Sea region has a total population of 459,056 and, like in many other regions in Eritrea, water has become so scarce, and the groundwater is the only option for the region (SOE, 2006).

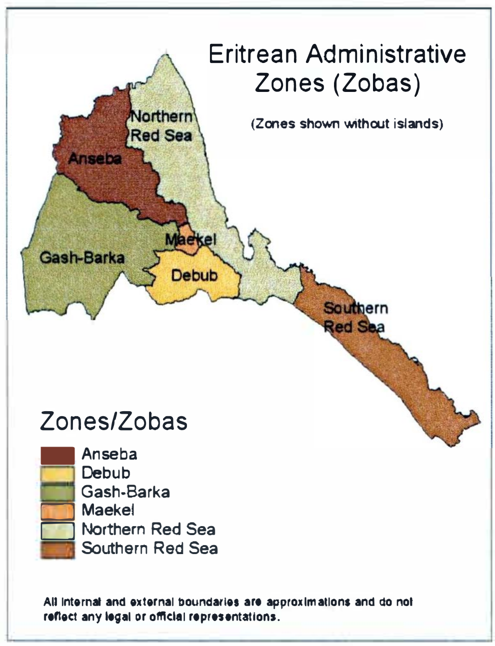


Figure 4: Eritrea Administration Map (Source MLWE, 2001)

The Northern Red Sea Region shares border with Anseba region in the north and west, with Maakel and Debub Regions in the west and in the south with Southern Red Sea Region and in the east with the Red Sea (Figure 4). The rugged topography found throughout the region consists of scarps, precipitous slopes, very deep valleys, which are aligned with the North-South trending faults, steep hills and, a stepped topography interrupted by intermountain basins and plains (such as Ala, Seled, Ailet, Sebarguma, Damas) (SOE,2006).

Most of the rains in this area come from frontal systems descending from the north and east. The upper edge of this area is the most humid in the country. The intermountain basins and plains have both lithological and topographic significance. Water brought by surface runoff and ephemeral streams has percolated down and been stored as groundwater for a long period. The ground water potential, the plain topography and the thick fertile soil are all favorable conditions for the development of irrigation agriculture. The alternate occurrence of basins and gorges along some valleys could also enable the construction of dams for irrigation and seasonal water management.

Population

The Northern Red Sea region has an area of around 27,800 km^2 and a total population of 459,056 (SOE-2006). Generally, the region has 12 sub regions and 194 villages. Sub regions like Ghinda and Afabet have 105 villages and 11 villages respectively. Out of those total villages, those villages which are affected by high fluoride level have a total population of 6000 and 5500 respectively (Ministry of Local Government, 2002).

Socio-Economy

Agriculture and tourism are the dominant economic sectors of this region. Rain fed agriculture in the intermountain basins is, however, severely limited due to rain shortages and the high evaporation rate. This is because the area is seriously affected by deforestation due to its long period of human settlement and agricultural activities. Forests are cleared in order to pave way for agricultural activities. This has led to a change in underground water recharge rate. The result is that most of the water sources for drinking water consist of boreholes and shallow wells (WRD Habteab Zerai & Tewolde Solomon 1993).

Crop production is primarily subsistence in nature, and the major crops grown are sorghum (Sorghum bicolor), pearl-millet (*Pennistum glaucum*), finger-millet (*Eleusine Coracana*), and barley (*hordeum vulgare*) (Eritrea-UNCCD, 2002).

With the exception of a few areas of spate irrigation, agro-pastoralism is practiced in this area and livestock production is based on transhumant pastoralism. The distances covered are, however, much more limited than for those in the Western Lowlands. Livestock are grazed on natural pasture for a few months in the rainy season (December to March), depending on the duration of the rains, and then moved to the eastern escarpment slopes for the dry seasons. The dominant animals are goats, which are kept for some milk but mainly for meat sales. In areas of spate irrigation livestock are fed with crop residues, sorghum rations and sown forage is grown. Dairy animals are stall-fed (Country Pasture Profile, FAO-2007).

Important to the local economy, the region is a popular tourist area due to its closeness to the Red Sea and the port of Massawa. Water is generally used for domestic, livestock, industrial and irrigational purposes. Further complicating the study, the quality of water is also affected by salt water intrusion from the Red Sea. In some parts of the region, where boreholes are the major sources of water, the fluoride level has been noted to be high (WRD, 2006).

Geology

The geological formation along the Red Sea coast line and the Southern Danakil plain are younger and consists of Tertiary and Quaternary sediments deposited via the Red Sea and Afar Rift System, which cuts through the area from south to north and is accompanied by many fault lines. During the Tertiary Era, sandstone and limestone were formed along the eastern coast, where at present lagoons and salt plains are found (Mohr 1961, 1987 cited in Ogbasighi, 2001).

Anseba Region

Anseba is an inland region of Eritrea, located in the west of the country. Its capital is Keren and it has an area of about 23,000 km². It is named after the river around which the region is situated (Eritrea Profile, 2004).

The source of the river is in the central Eritrean Highland Plateau, in the suburbs northwest of the capital, Asmara. It then descends northward into the northwestern lowlands, traversing the mountains of Rora Habab and Sahel before flowing out into the Red Sea in the neighboring country of Sudan in the vicinity of the port of Suakin. Other towns in this region include Halhal. The region borders Gash-Barka to the south, the Central Region to the south-east and the Northern Red Sea Region to the east and north, and the nation of Sudan to the west. It has an area of 23,200 km² and a total population of 457,078 (SOE, 2006).

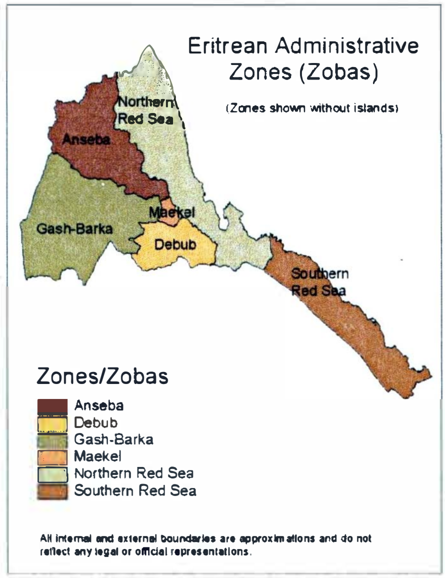


Figure 5: Eritrea Administration Map (Source MLWE, 2001)

The Anseba Region shares border with Northern Red Sea region in the north and east, with Maakel and Gash Barka Regions in south and south west (Figure 5).

The Anseba Highlands extend on both sides of the upper Anseba River and extend from Adi-Tekelezan area northwest to Keren. The highlands are separated from the Halhal Highlands by the Tonkulas Valley.

The area has been fairly dissected by the shifting courses of the Anseba River (and its tributaries) as well as the head-streams of the Barka River and thus, is characterized by deeper and wider valleys. This physiographic unit contains two contrasting landform assemblages along the Anseba River Valley (SOE, 2006). The western part is higher and more rugged. It is more of mountainous terrain. Jagged and steep hillsides and deep stream valleys such as that of the Shotel River (a tributary of the Barka) are common. Flat-topped remnant surfaces of the original plateau are rare.

Climate and Water

This region has altitudes between 750 m and 1,500 m, with an average rainfall of up to 500 mm. The western escarpment is a transitional zone between the Central Highland Zone and South-western lowland zones. Water is a scarce commodity in this region and the main uses of water are domestic consumption, livestock watering and irrigation. 121 "water points" are described as functional in 2001, all using various lifting systems such as, rope and buckets. Per capita water consumption in the region is estimated to be 11 liter/day, which is about half of what is recommended by the World Health Organization (Anseba Region Annual Report 2004).

Population

The Anseba Region has an area of about 23,000 km² and a total population of 457,078 (SOE, 2006).Moreover the region has 10 sub regions and 425 villages (Ministry of Local Government, 2002). Out of this, 8 villages like Gush, Hadish-Adi, Wasdenba, Halibmentel, Derok, Juffa, Begu, and Geleb are affected by high level of fluoride distribution in the groundwater (WRD, 2006). These eight villages have a total population of 13,293 and account for almost 3 % of population of the region (Ministry of Local Government, 2002).

Agriculture and Livestock

A large proportion of the populations are agro-pastoralists and there are nomadic pastoralist groups whose main activity is livestock rearing (primarily camels, cattle and small ruminants). There are also semi-sedentary agro-pastoralists whose main activity remains livestock rearing, but where the cultivation of sorghum, pearl millet (*Pennisetum americanum*) and sesame is significant. There are also sedentary producers practicing mixed crop/livestock production where crops are more important and the family lives in one village all year round.

Recently, medium and large-scale commercial farmers, favored by distribution of land concessions by the government and the availability of greater amounts of capital when compared to local farmers, have entered the area. There is also mechanized large-scale rain fed cultivation of sorghum and sesame and/or medium scale irrigated plantations of bananas and citrus supplying the capital city Asmara and export markets (Country Pasture Profile, FAO-2007).

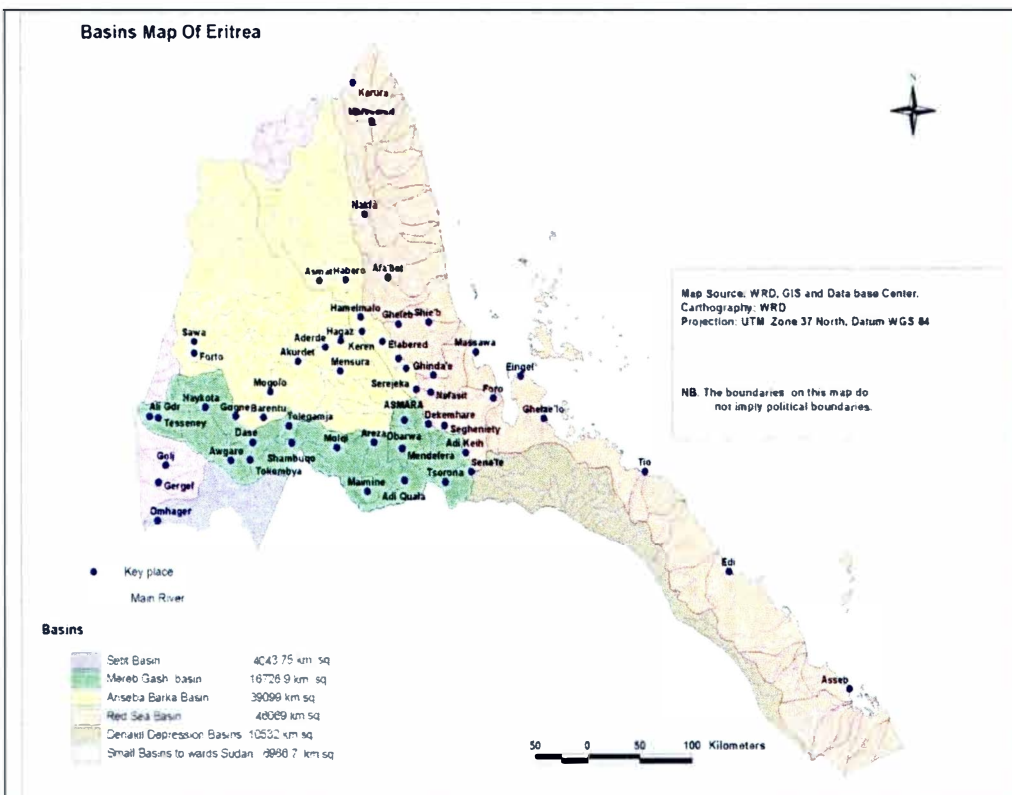


Figure 6: Basins Map of Eritrea (Source: WRD, 2006)

Red Sea and Anseba Basins flow through regions of the Northern Red Sea and Anseba regions. Those basins serve a main source of water supply for agricultural activities and other domestic demand of the area (Figure 6).

Geology and Soil of the Anseba Region

A review of the geological formations within the study area shows that most of the villages are underlaid by granotoid intrusive of K rich granites, biotite granite, and granodiorite. Mica schists and amphibole schists of medium grade and chlorite schists of low-grade metamorphism with pegmatite intrusions and aplitic dykes are the main recognized lithological units (WRD, 2001; Viswanatham and Michael, 2006).

Soil Types

Soils of Eritrea vary from region to region in terms of texture, fertility and other natural characteristics (Kayouli et al., 2002). Available soil maps are estimated and downscaled products from global soil maps. As indicated in soil map of the country, the western part of the country which includes the largest part of the Anseba region is dominated by vertisols and fluvisols and alluvium (FAO, Soil Map Eritrea, 1994 and Geological Map of Keren area WRD, 2001).

CHAPTER II

LITERATURE REVIEW

Environmental Occurrence of Fluoride

Fluorine is the lightest member of the halogen group and is one of the most reactive of all chemical elements. It is not, therefore, found as fluorine in the environment. It is the most electronegative of all the elements (Hem, 1989) which means that it has a strong tendency to acquire a negative charge, and in solution forms F– ions. Other oxidation states are not found in natural systems, although uncharged complexes may be found. Fluoride ions have the same charge and nearly the same radius as hydroxide ions and may replace each other in mineral structures (Hem, 1985). Fluoride thus forms mineral complexes with a number of cations and some fairly common minerals of low solubility contain fluoride.

Fluorine in the environment is therefore found as fluorides which together represent about 0.06–0.09 percent of the earth's crust. The average crustal abundance is 300 mg kg–1 (Tebutt, 1983). Fluorides are found at significant levels in a wide variety of minerals, including fluorspar, rock phosphate, cryolite, apatite, mica, hornblende and others (Murray, 1986). Fluorite (CaF2) is a common fluoride mineral of low solubility occurring in both igneous and sedimentary rocks. Fluoride is commonly associated with volcanic activity and fumaroles gases. Thermal waters, especially those of high pH, are also rich in fluoride (Edmunds and Smedley, 1996). Minerals of commercial importance include cryolite and rock phosphates. The fluoride salt cryolite is used for the production of aluminum (Murray, 1986) and as a pesticide (USEPA, 1996). Rock phosphates are converted into phosphate fertilizers by the removal of up to 4.2 percent fluoride (Murray, 1986); the removed and purified fluoride (as fluorosilicates) is a source of fluoride that, in many countries, is added to drinking-water in order to protect against dental caries (Reeves, 1986, 1994).

Fluoride is found in all natural water at some concentration. Seawater typically contains about 1 mg/L while fresh water rivers and lakes generally exhibit concentrations of less than 0.5 mg/L. In groundwater, however, low or high concentrations of fluoride can occur, depending on the nature of the rocks and the occurrence of fluoride-bearing minerals. Concentrations in water are limited by fluorite solubility, so that in the presence of 40 mg/L calcium it is typically limited to 3.1 mg/L (Hem, 1989).It is the absence of calcium in solution which allows higher concentrations to be stable (Edmunds and Smedley, 1996). High fluoride concentrations may therefore be expected in ground waters from calcium-poor aquifers and in areas where fluoride-bearing minerals are common. Fluoride concentrations may also increase in ground waters in which cation exchange of sodium for calcium occurs (Edmynds and Smedley, 1996).

Fluorosis has been described as an endemic disease of tropical climates, but this is not entirely the case. Waters with high fluoride concentrations occur in large and extensive geographical belts associated with a) sediments of marine origin in mountainous areas, b) volcanic rocks and c) granitic and gneissic rocks. A typical example of this first extends from Iraq and Iran through Syria and Turkey to the

Mediterranean region, and hence from Algeria to Morocco. Other important examples come from the southern parts of the USA, southern Europe and the southern parts of the former USSR.

Thus high concentrations of fluoride in water are generally found in groundwater (WHO, 2000). Dangerous levels of fluoride that are increasingly found in groundwater in south and south-eastern Asia are of growing concern (WHO, 2000).

The most well-known and documented area associated with volcanic activity follows the East African Rift systems from the Jordan valley down through Sudan, Ethiopia, Uganda, Kenya and the United Republic of Tanzania. Many of the lakes of the Rift Valley System, especially the soda lakes, have extremely high fluoride concentrations; 1,640 mg/L and 2,800 mg/L respectively, in the Kenyan lakes of Elmentaita and Nakuru (Nair *et al.*, 1984), and up to 690 mg/L in the Tanzanian Momella soda lakes. In Kenya, detailed survey of fluoride in groundwater was undertaken by Nair *et al.* (1984). Of over 1,000 groundwater samples taken nationally, 61 percent exceeded 8 mg/L, almost 20 percent exceeded 5 mg/L and 12 percent exceeded 8 mg/L. The volcanic areas of the Nairobi, Rift Valley and Central provinces had the highest concentrations, with maximum groundwater fluoride concentrations reaching 30-50 mg/L. Most of the sampled wells and boreholes were providing drinking-water, and the prevalence of dental fluorosis in the most affected areas was observed to be very high (Manji and Kapila, 1986). A similar picture emerges for the United Republic of Tanzania, where 30 percent of waters used for drinking exceeded 1.5 mg/L fluoride (Latham and Gretch, 1967) with concentrations in the Rift Valley of up to 45 mg/L.

High groundwater fluoride concentrations associated with igneous and metamorphic rocks such as granites and gneisses have been reported in many nations including India, Pakistan, Thailand, China, Srilanka, and in many nations of Southern and Western Africa. In China, endemic fluorosis has been reported in all 28 provinces, autonomous regions and municipalities except Shanghai. Both shallow and deeper ground waters are affected; in general the deeper ground waters have the higher concentrations. In Sri Lanka, Dissanayake (1991) found concentrations of up to 10 mg/L in ground waters in the Dry Zone, associated with dental and possibly skeletal fluorosis. In the Wet Zone, the intensive rainfall and long-term leaching of fluoride and other minerals from the crystalline bedrock are probably responsible for the much lower concentrations.

Limited studies were undertaken to estimate fluoride content in groundwater in certain parts of rural Eritrea. A standard procedure was adopted for fluoride detection. Results indicate elevated concentration of fluoride in groundwater. The highest concentration was found to be above the safety level for consumption. The geological bases for the high concentration of high fluoride have been recognized. Extensive dental fluorosis has been observed in the population exposed to drinking water of high fluoride content (WRD and Srikanth et *al*, 2002).

Fluoride is one of the chemicals that have been shown to have significant health effects in the people through drinking-water. Fluoride has beneficial effects on teeth at low concentrations in drinking-water, but excessive exposure to fluoride in drinking-water, or in combination with exposure to fluoride from other sources, can give rise to a number of adverse effects (WHO, 2006).

Removal of Excessive Fluoride

Occurrence of fluoride at excessive levels in drinking-water in developing countries is a serious problem. Its detection demands analytical grade chemicals and laboratory equipment and skills. Similarly, the prevention of fluorosis through management of drinking-water is a difficult task, which requires favorable conditions combining knowledge, motivation, prioritization, discipline and technical and organizational support. Many filter media and several water treatment methods are known to remove fluoride from water. However, many initiatives on defluoridation of water have resulted in frustration and failure (COWI, 1998). Therefore, in any attempt to mitigate fluoride contamination for an affected community, the provision of safe, low fluoride water from alternative sources should be investigated as the first option. In cases where alternative sources are not available, defluoridation of water is the only measure remaining to prevent fluorosis. Bone charcoal, Nalgonda, activated alumina and clay is the most promising and widely used defluoridation methods (WHO, 2006).

Bone Charcoal Defluoridation Filters

Bone char or bone char gravels are bones which have been heated to high temperatures, above 400 °C, and crushed (Jacobsen, 2005). In contact with water, the bone charcoal is able, to a limited extent to absorb a wide range of pollutants while altering color, taste and odor components. Moreover, bone charcoal has the specific ability to take up fluoride from water. This is believed to be due to its chemical composition, mainly as hydroxyapatite, $Ca_{10}(PO4)_6(OH)_2$, where one or both the hydroxyl-groups can be replaced with fluoride. The principal reaction is hydroxyl-fluoride exchange of apatite: $Ca_{10}(PO4)_6(OH)_2 + 2F^- Ca_{10}(PO4)_6 F_2 + 2 OH^-$ (Jacobsen, 2005)

The proper of bone charcoal is crucial to optimize its properties as a defluoridation agent and as a water purifier. Unless carried out properly, the bone charring process may result in a product of low defluoridation capacity and/or deterioration in water quality. Water treated with poor bone charcoal may taste and smell like rotten meat and as such be aesthetically unacceptable. Once consumers are exposed to such a smell or taste, they may reject the bone charcoal treatment process and it may be difficult to persuade them to try water from the process again.

It is therefore essential to ensure that the bone charcoal quality is always good. Even single failures in the production may be disastrous for a defluoridation project (Dahi and Bregnhøj, 1997).

Another disadvantage of this method is its limited supply in the world market. The best available option is therefore to prepare bone charcoal at the village or household level for local use (Jacobsen and Dahi, 1998).

Bone charcoal is prepared by heating ground bone in retorts or in pots stacked in a furnace resembling a potter's kiln, without or with only limited admission of atmospheric oxygen. Ground bone is prepared industrially by degreasing, boiling, washing and drying, prior to grinding and sifting out. The ground bone is normally available from the manufacturing of bone meal used as a fodder additive (Mantell, 1968).

It is feasible to regenerate bone charcoal saturated with fluoride by allowing equilibrium with 1 percent solution of sodium hydroxide followed by washing or neutralization of the surplus caustic soda American Water Works Association 1971(AWWA). Regeneration is probably only cost effective at a large-scale water works level or in the case of a shortage of the medium. At village-community and household levels, it may be environmentally acceptable to use the saturated bone charcoal as a fertilizer and soil conditioner (WHO, 2006).

Household Filter

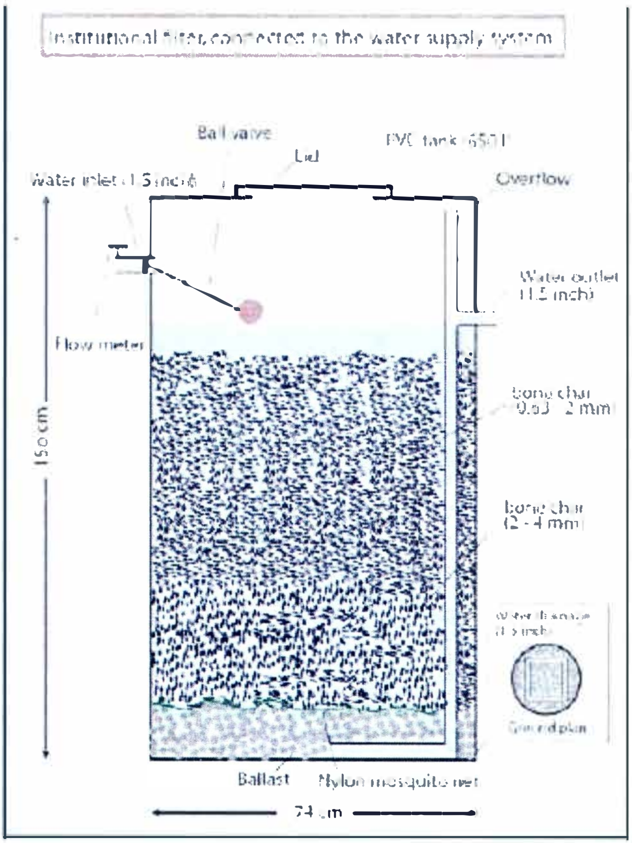
The household bone char deflouridation systems are comprise of one of two 20 liters buckets depending on the design. This filter is designed to supply a household (5-12 people) with fluoride-free water for drinking and cooking. The filters are robust and inexpensive, but they do not utilize the filter material as efficiently as the community scale filters. The filter material cannot be regenerated; it must be changed after saturation. The household filters are made in two sizes. The small type contains 12 liters of filter material and the bigger one contains 24 liters. The bone char filtration media reduces fluoride concentration from an initial concentration of 5-15mg/L to less than 1.5 mg/L (Jacobsen P.2005). Changing the media to new media in a household bone char filter is a simple process and requires no technical skill.

Source: Eawag Aquatic Research, 2008.

Figure 7: Household Filter

Institutional Filter

Institutional scale filters are designed for institutions or larger kitchens where filters cannot be connected to the normal water supply systems. These filters are constructed using standard PVC tanks of 650 liters, containing about 450 liters of filter material. No regular maintenance is required; the daily operation does not differ from operating a standard water storage tank. Depending on the concentration of fluoride in the raw water and filter size, the filter material needs regeneration or changing at regular intervals, typically every ½ to 3 years (Snell 2005).

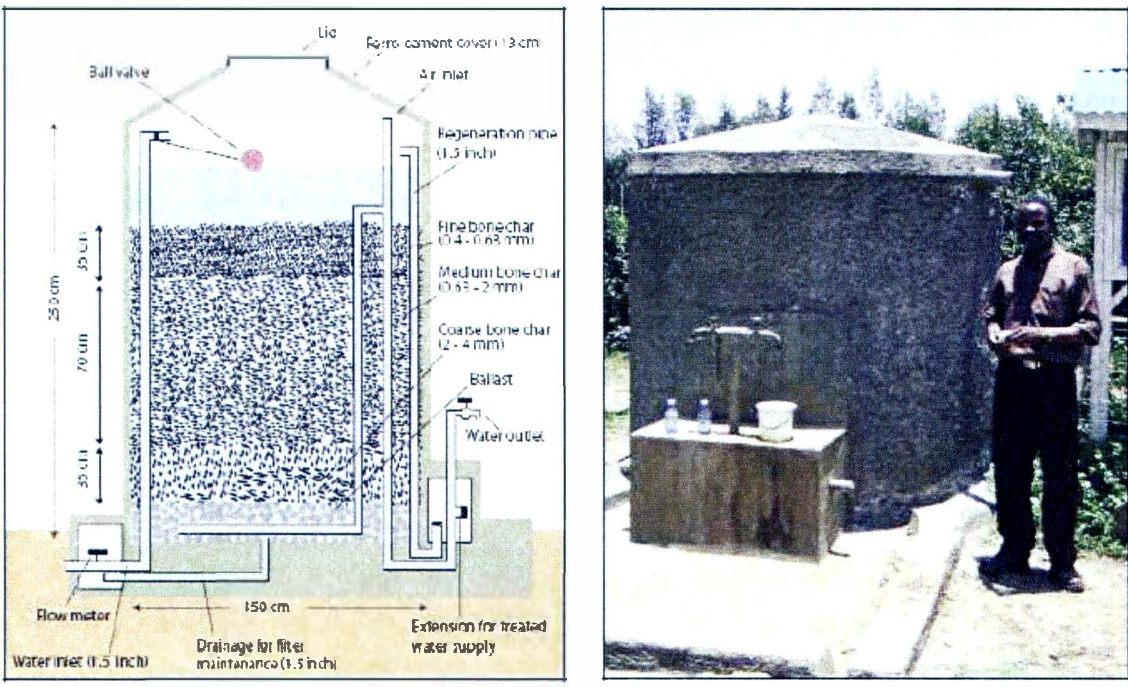


Source: Eawag Aquatic Research, 2008.

Figure 8: Institutional Filter

Community Filter

The community scale bone chars defloridation system can supply 1,000 to 5,000 or more people with safe water for drinking and/or cooking. They are suitable where users collect their water at a central water point. The community plant is basically a 4 or 12 m^3 ferrocement tank filled with filter material and equipped with screen and connections for regenerating the filter. The structure is quite solid and suitable for public places. The size ranges from 2,500, 5,000 or 10,000 liters of filter material (Jacobsen, 2005). The appropriate choice depends on the consumption of water and the fluoride concentration in the water. As with as the institutional filter, a community scale filter needs regeneration of the filter material when it's saturated with fluoride. This should be done at regular intervals, typically every 3 – 23 month, depending on the consumption and fluoride concentration.



Source: Eawag Aquatic Research, 2008.

Figure 9: Community Filter

Finally, all three types of bone charcoal filters can be made locally using cheap, locally available, robust and corrosion resistant materials such as plastic, concrete, ferrocement or galvanized iron sheets. In such cases, the unit price would be affordable to most motivated communities (WHO, 2006).

Nalgonda Method

In the Nalgonda Method, alum and lime are added to the raw water. Fluoride attaches itself to the flocs of aluminum hydroxide, which are formed and can be removed from water together with precipitated flocs (CDN Handout, 2005). The use of the Nagonda Method has apparently has some success in India and the method can be implemented both in households and in water works (NEERI, 1987). The main advantages in the Nagonda technique are the low cost and the local availability of lime and alum. There are some major drawbacks like the lack of required efficiency, the requirement of adding chemicals continuously and the high amount of residual sulfate in the treated water. This is especially the case when the fluoride content in the water is high (Snell, 2005).

Activated Alumina

Activated alumina is the most successful and the most often used absorbent for fluoride removal. Boruff first studied the absorbent properties of activated alumina in 1934 and contact beds of activated alumina have now been used for many years in municipal water treatment plants throughout the world. In many cases the use of activated alumina appears to be technically feasible and economically viable. It is available in a range of granule sizes and is able to absorb as much as 1.4g fluoride per 100g product (Azizian F., 1993). At normal pH values fluoride is absorbed from and hydroxide is released to the water. For regeneration, the process can be reversed by raising the pH values. Main advantages are the simplicity of normal operation and the efficiency; fluoride can be reduced to practically any desired levels (Snell, 2005).

Clay

Clay is an earthy sedimentary material composed mainly of fine particles of hydrous aluminum silicates and other minerals and impurities. Clay is fine-textured, plastic when moist, retains its shape when dried and sinters hard when fired. These properties are utilized in manufacture of pottery, brick and tile. Both clay powder and fired clay are capable of absorption of fluoride as well as other pollutants from water. The ability of clay to clarify turbid water is well known. This property is believed to have been known and utilized at the domestic level in ancient Egypt (WHO, 2006).

Clay and similar media can be regenerated, at least partially. It would not, however, be cost effective in most cases. Based on testing of the capacity of clay to remove fluoride from water different studies reach different conclusions about the capacity and usability of the method in general. Thus, Zevenbergen *et al.* (1996) conclude that "*the Ando soil appears to be an economical and efficient method for defluoridation of drinking water*".

More over it has been stated by Padmasiri (1998) that the clay process is only cost effective if the freshly burnt broken bricks of good quality are available on site or adjacent to the users and if the filter is prepared using low cost, locally available materials.

Another concern related to the use of clay is that clay and most other soil minerals which demonstrate defluoridation capacities are primarily cation-exchangers. Toxic heavy metals and a wide range of other pollutants may also be retained in the clay strata when rain water percolates soil (WHO, 2006). Therefore, care has to be taken in order to ensure that when any clay soil material is used in a defluoridation process, proper precautions related to these minerals must be observed.

Finally, research and development and experience in this field continue to develop different defluoridation methods. Among the several different methods discussed, it must be remembered that what may work in one community may not work in another. What may be appropriate at a certain time and stage of urbanization may not be at another. Therefore, it is most important to select an appropriate defluoridation method carefully if a sustainable solution to a fluorosis problem is to be achieved.

CHAPTER III

RESEARCH METHODS

For 2006, 44 and 53 water point samples data were collected and analyzed for villages in the Anseba and the Northern Red Sea Regions respectively from The Water Resources Department of Eritrea. Analyzed data for parameters including pH, electric conductivity, alkalinity, fluoride, and calcium, bicarbonate, and water hardness were obtained. Location of wells and the depth of each well were documented. In addition, dental caries disease data at the sub region level were also analyzed.

To explore the spatial distribution of fluoride in groundwater the hydrochemistry data and the boundary data were joined in a Geographic Information System (GIS) and the inverse distance method was used to interpolate unsampled areas in sub regions based on the sample points. Moreover, a risk classification map was made using fluoride level distribution. Finally, multiple regression analysis was conducted to explore the relationships between hydrochemistry parameters and fluoride distribution (Antony, 2003).

In the following sections methods used for data collection, processing and analysis will be explained in more detail.

Data Collection

Data for the study area were gathered from secondary sources. Demography, health, water quality and point location data were collected from the published government documents, journals and articles. Specific characteristics of water quality data, population and demographic data used are described below.

Water Quality Data

Water quality data were collected from the Water Resources Department of Eritrea. This department is responsible for investigating and exploring surface and groundwater resources of the country. Water quality data included calcium, magnesium, bicarbonate, water hardness, and electric-conductivity and pH parameters for each test location, as well as well depth and well distribution location.

The boundary maps for the areas of investigation were also obtained from their database. The water quality data in the sub regions selected for this analysis constituted 44 and 53 groundwater samples in the Anseba region and Northern Red Sea region respectively, including boreholes and hand dug wells (WRD, 2007). Borehole water samples for the entire country were collected and analyzed by the Water Resource Department staff members of the water quality controlling laboratory unit. The test methods follow the "Standard Methods for the Examination of Water and Wastewater" published by the American Public Health Association and American Water Works Association (WRD, 2006).

Equipment

According to The Water Resource Department, the following equipment was used for water point samples data collection.

ELE Paqualab Water Quality Meter: ELE Paqualab is a portable testing system for key drinking water quality parameters. It used to measure physical and chemical characteristics of water such as temperature, conductivity, turbidity, pH, NH_3 and Cl. The Paqualab allows the laboratory to carry it to the test sites so that accurate results are obtained sooner even in remote areas (WRD, 2007).

A fluoride (ion selective) electrode is used to measure accurately and economically fluoride ions in aqueous solution. The Fluoride Ion-Selective Electrode has a solid-state mono-crystalline membrane. The electrode is designed for the detection of fluoride ions (F^-) in aqueous solutions and is suitable for use in both field and laboratory applications(WRD,2007).

The Metrohm 713 pH meter is used to measure the pH and temperature of the water samples (WRD, 2007).

Demographic and Health Data

Demographic and health data, such as population distribution and dental caries for villages were extracted from the Eritrean Demographic and Health Survey Year 2002 Report and the Health Information Management System Annual Report (2006).

The Eritrea Demographic and Health Survey report: The 2002 Eritrea Demographic and Health Survey (EDHS) was the second National Demographic and Health Survey (DHS) in the series that started in 1995. The National Statistics and Evaluation Office (NSEO), Office of the President, conducted the 1995 and 2002 EDHS surveys. The major objective of both surveys was to collect and analyze data on fertility, mortality, family planning, and health. The reports were intended to facilitate evaluation of ongoing national health programs and assist in designing new strategies for improving population and health programs in Eritrea (Eritrea Demographic and Health Survey, 2002).

The Health Information Management System Annual Report was prepared by The Ministry of Health Information Units located in almost every region of the country. Every hospital and clinic was requested to provide information on, health and disease records of their outpatient and inpatient departments. Additional information would be incorporated from the administrative records of the regional offices. Data were also collected based on surveys by the Health Information Unit experts. The Health Information Unit is responsible for data recording, processing, analyzing and securing the privacy of information for patients, and redistributing the final product for stakeholders and data users in responsible manner. Epidemiological data on dental caries incidence rate for Eritrea is scarce. Generally, low levels of dental caries have been reported and for comparison in this study dental caries data were extracted from the Eritrean Health Information Management System Report, 2006 and maximum fluoride distribution for the regions of Anseba and Northern Red Sea at sub regions level were also taken from the Eritrean Wells and Inventory Survey (2006).

Processing the Data

After collecting water quality data, well location, health, demographic and other related data from different sources, they were transferred to Excel (Microsoft, 2007) spread sheets for further analysis.

Certain portions of the location data were given in degrees, minutes and seconds format (DDMMSS) while others were in UTM (Universal Transverse Mercator). To unify all well location data and to make them readable in geographic information system (GIS), they were all converted to decimal degree format. After reviewing all stored data, the tables were converted in to dBase IV format to be readable in GIS. All spatial data were then projected into WGS 84(World Geodetic System of 1984).

The spatial data layers for villages in the Anseba and the Northern Red Sea region were acquired from the Environmental System Research Institute (ESRI) shape file created in 2006. To overlay spatial layers with all well location data, the spatial data layers were projected to WGS 84 format. The health data were also combined with the point location data in Excel spread sheet and saved in the dBase IV format to be readable in GIS. Finally, the tabular information was imported to GIS and joined to the geographic features data using the common location of the spatial features.

Analysis of Data

Distribution of fluoride in the groundwater is affected by the chemical composition of the hydrochemistry elements in the aquifer system. Different statistical analysis methods were used to find the relationship between the concentration of fluoride and other hydrochemistry elements in groundwater, as well as to explain the importance of the chemical type of groundwater as the controller of the fluoride content.

Multiple statistical methods were used in the analysis, including regression analysis, Pearson's linear correlation, the Inverse Distance Weight (IDW) interpolation method, graduate symbol and spatial analysis reclassification. In the analysis, (Fluoride levels mg/L) is the dependent variable in the regression analysis. The independent variables are:

- Calcium(Ca in mg/L)
- Magnesium(Mg in mg/L)
- Bicarbonate (HCO_3 in mg/L)
- Total water Hardness (in mg/L)
- Electric Conductivity (EC in µs/cm)
- pH
- Total alkalinity (in mg/L)
- Fluoride (F in mg/L)
- Well Depth (in meter)

Regression Analysis

Regression analysis is a very important tool to indicate and examine the functional association between variables by simplifying the relationship between variables and evaluating the importance of the variables and correctness of the model (Rogerson, 2001).

For these reasons, regression analysis method was chosen to assess the relationship and spatial distribution among different hydrochemistry elements and fluoride. The independent variables and the dependent variables were first run through descriptive statistics to get a basic understanding of the variables (mean and standard deviation). Regression analysis was then applied: $Y = a + b_iX_i$

Y represents the dependent variable (fluoride value) and X stand for the independent variables of the Hydrochemistry elements. The significant level from the output was then analyzed and any insignificant variables were excluded ($\alpha>0.10$). After all insignificant variables were taken out, the regression analysis was run once more, to see the significance and effect of variables that have significant relationships.

Pearson's Correlation

Pearson's correlation reflects the degree of linear relationship between two variables (Rogerson, 2001). Pearson's correlation method was used to see the relationship between dental caries disease and fluoride distribution level at the sub regions. The application of the method was based on the fact that elevated fluoride level during enamel maturation can also result in dental flourosis and different studies in South Africa and Nigeria proved that significant increase in the number of decayed, missing, or filled teeth(dental caries) surfaced in children with dental fluorosis (Agency for Toxic Substances and Disease Registry,2003).

Inverse Distance Weighted (IDW)

Inverse Distance Weighted method was used to interpolate the well point fluoride distribution samples in the surface for sub regions in the Anseba and the Northern Red Sea regions. This method was chosen for the assumption that the interpolating surface should be influenced mostly by nearby points and less by the more distant points (Colin Child, 2004).

Risk Zoning

Drinking water containing optimum levels of fluoride (0.5–1.5 mg/L, depending on climatic conditions and the relative contribution of non-aqueous sources of fluoride to overall fluoride load in individuals) confers protection against dental caries without causing fluorosis.

The World Health Organization has set the guideline value at 1.5 mg/L of fluoride, but mild forms of dental fluorosis begin to occur at higher levels. Above 1.5 mg/L, prolonged intake of fluoride can cause dental fluorosis; 3–6 mg/L, skeletal fluorosis; more than 6 mg/L, crippling skeletal fluorosis (WHO 1984b; Brouwer et al. 1988).

Simple classification of risk zoning was made by reclassifying interpolated surfaces. Three zones are created area with ≤ 1.5 mg/L no risk area, area with fluoride level ≥ 1.5-3.0 mg/L (moderately risky) and area with fluoride level > 3.0 mg/L (high risk areas) using the fluoride concentration level. These levels corresponds to the WHO and Anthony, 2003 risk classification method.

A graduate symbol map for point water quality location was created to show the spatial distribution of fluoride and the symbol for each village was drawn proportional in size to the level of fluoride distribution value.

CHAPTER IV

RESULTS AND DISCUSSION

Results

This chapter discusses the result of the spatial analysis of Inverse Distance Weighted (IDW) method and the regression analysis. The regression analysis will be examined first for groundwater well point fluoride levels. Relationships between the independent variables and fluoride concentrations will be examined and discussed. Results of the spatial interpolation of fluoride distribution using the Inverse Distance Weighted method will also be discussed and examined. Finally, linear correlation of Health and fluoride and graduate symbol results will be discussed.

Spatial Distribution of Fluoride in Eritrea

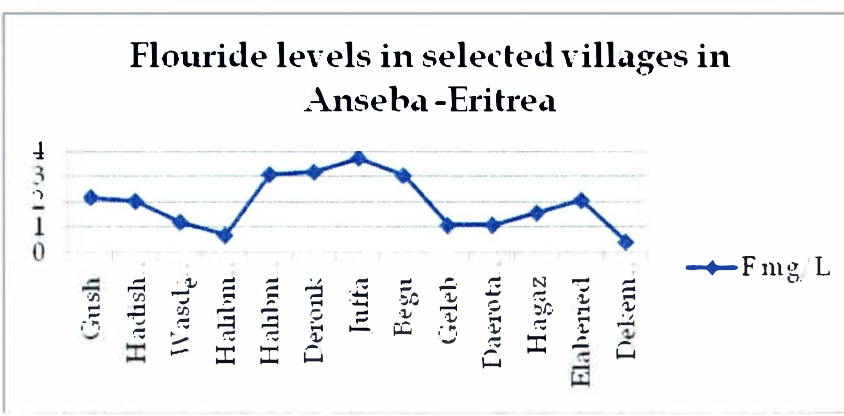
Fluorine (F_2) is a greenish diatomic gas. Because of its high reactance fluorine rarely occurs free in nature. Fluorine is also so highly reactive that is never encountered in its elemental gaseous state except in some industrial processes and found at significant level in variety of minerals, including fluorspar, rock phosphate,cryolite,apatite,micahomeblended and others(Murray,1986).

A preliminary survey carried out by The Water Resource Department of Eritrea National Water Wells Inventory Survey of 2001 revealed that the mean fluoride levels were 0.99 mg/L in the Gash Barka region, 0.16 mg/L in the Maakel region, 0.27 mg/L in the Southern Red Sea region, 2.10 mg/L in the Northern Red Sea region, 0.16 mg/L in the Anseba region and 0.56 mg/L in the Debub region

(Fluoride in Drinking-water, WHO 2006). Except for the Northern Red Sea region and some villages in the Anseba region the level of fluoride distribution in groundwater wells are within the acceptable level (WRD, 2001). According to the World Health Organization standard, a 1.5 mg/L fluoride distribution is an acceptable level for human health.

Fluoride Distribution in the Anseba Region

Groundwater is the most appropriate and widely used source of drinking water for many rural communities in the Anseba region. Preliminary studies and surveys conducted by The Water Resources Department indicated that mean fluoride distribution for the Anseba region is 0.16 mg/L. which is within the safe standard of the WHO requirement. Contrary to this fact there are some villages with in this region with high fluoride distribution.



Source: Water Resource Department, 2006.

Figure 10: Fluoride Levels in Selected Villages in the Anseba Region – Eritrea

Figure 11 shows that villages like Gush, Hadish-Adi, Halibmentel (Karwerba), Dernok, Juffa, Begu, Hagaz and Elaberied have a higher fluoride concentration than other villages in the Anseba region. The concentration varied from 1.56 mg/L in village of Hagaz to 3.73 mg/L in village Juffa, which exceeds the WHO fluoride level water quality standard.

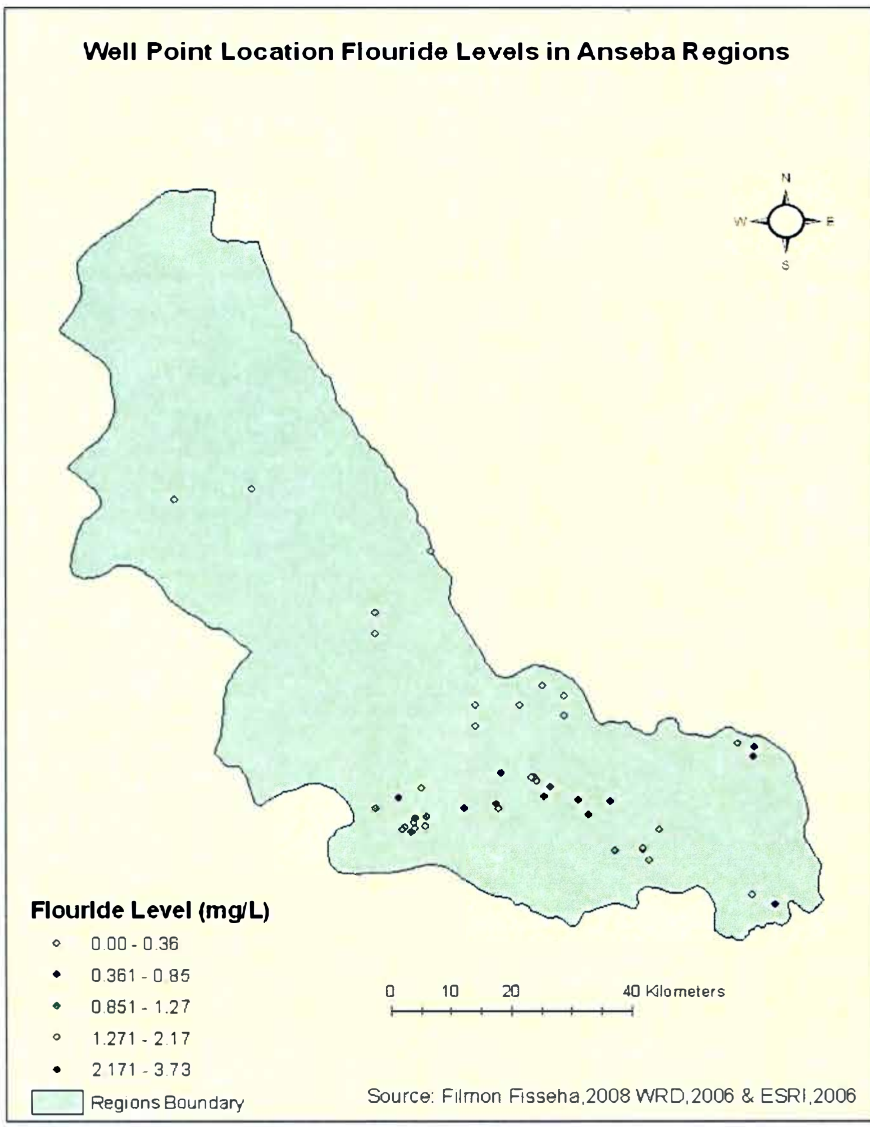


Figure 11: Fluoride Levels of Wells in the Anseba Region

Fluoride Distribution in the Northern Red Sea Region

Similar to villages in the Anseba region, some villages in the Northern Red Sea region also have high fluoride distribution in the groundwater. Analyzed sample data for fifty three well points were acquired from the Water Resources Department of Eritrea for comparison (Figures 12 & 13).

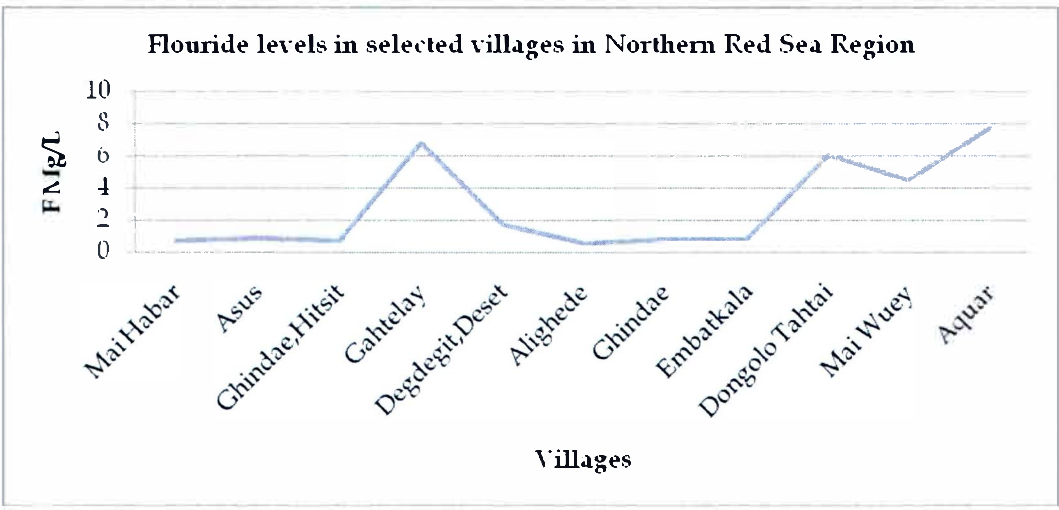


Figure 12: Fluoride Levels in Selected Villages in the Northern Red Sea Region

Figure 13 shows that villages like Aquar, Mai Wuey, Dongolo Tahtai Degdegit, and Deset and Gahtelay have high fluoride distribution. The concentration varied from 1.75 mg/L in Degdegit up to 7.7 mg/L in Aquar Village. This excessive fluoride distribution in drinking water can cause serious health problems particularly dental flourosis, skeletal flourosis and dental caries.

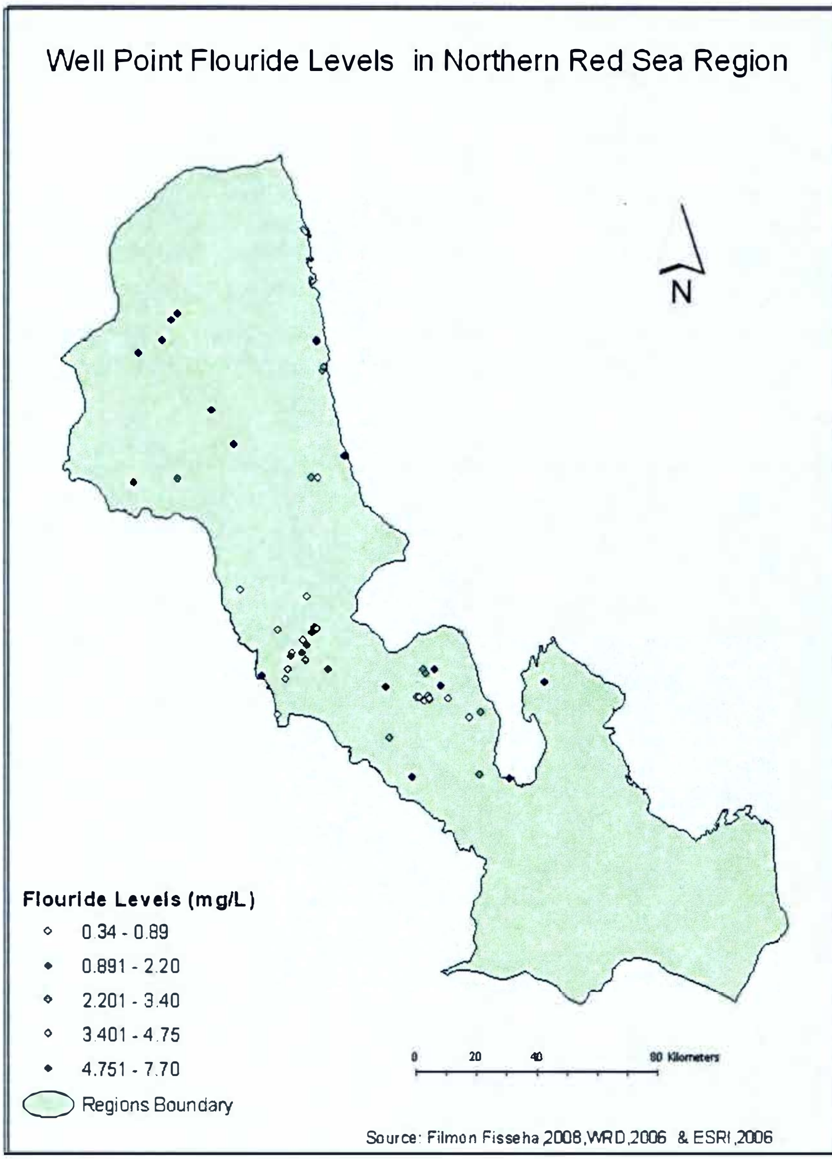


Figure 13: Fluoride Level of Wells in the Northern Red Sea Region

Fluoride distribution maps were prepared in GIS to show the spatial distribution of fluoride level for selected villages in the Anseba and the Northern Red Sea regions and values were classified using the graduate symbol methods. The graduate symbol map (Figure 13)for the Anseba region shows that villages located at 10-15 km southwest and southeast from the Anseba region capital city (Keren) have high levels of fluoride concentration compared to any other well point sample in the region. Similarly the graduate symbol map for the Northern Red Sea region (Figure 14) shows that the villages of Aquar, MaiWuiey, Erafailelei and Ghindae have high fluoride distribution. Sub regions of Ghindae, Foro and Afabet contain the highest fluoride concentrations when compared to other sub regions in the region.

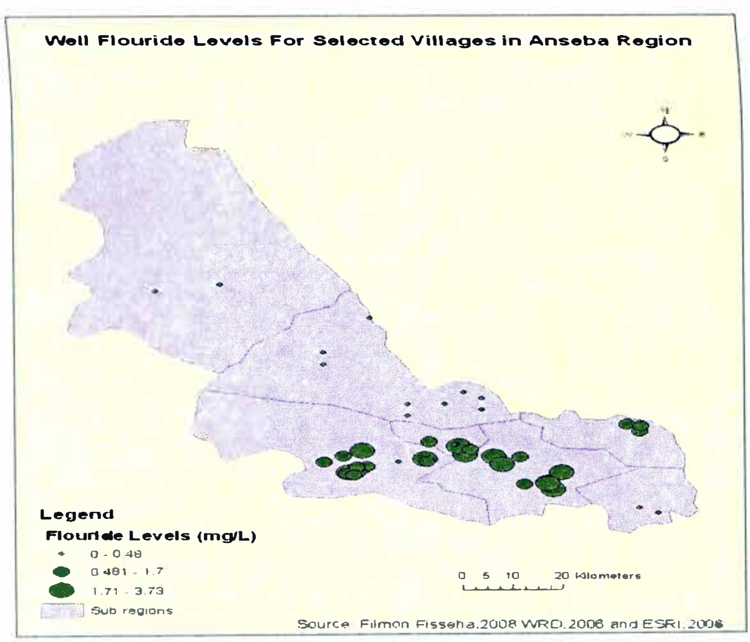


Figure 13: Fluoride Concentrations of Wells in the Anseba Region

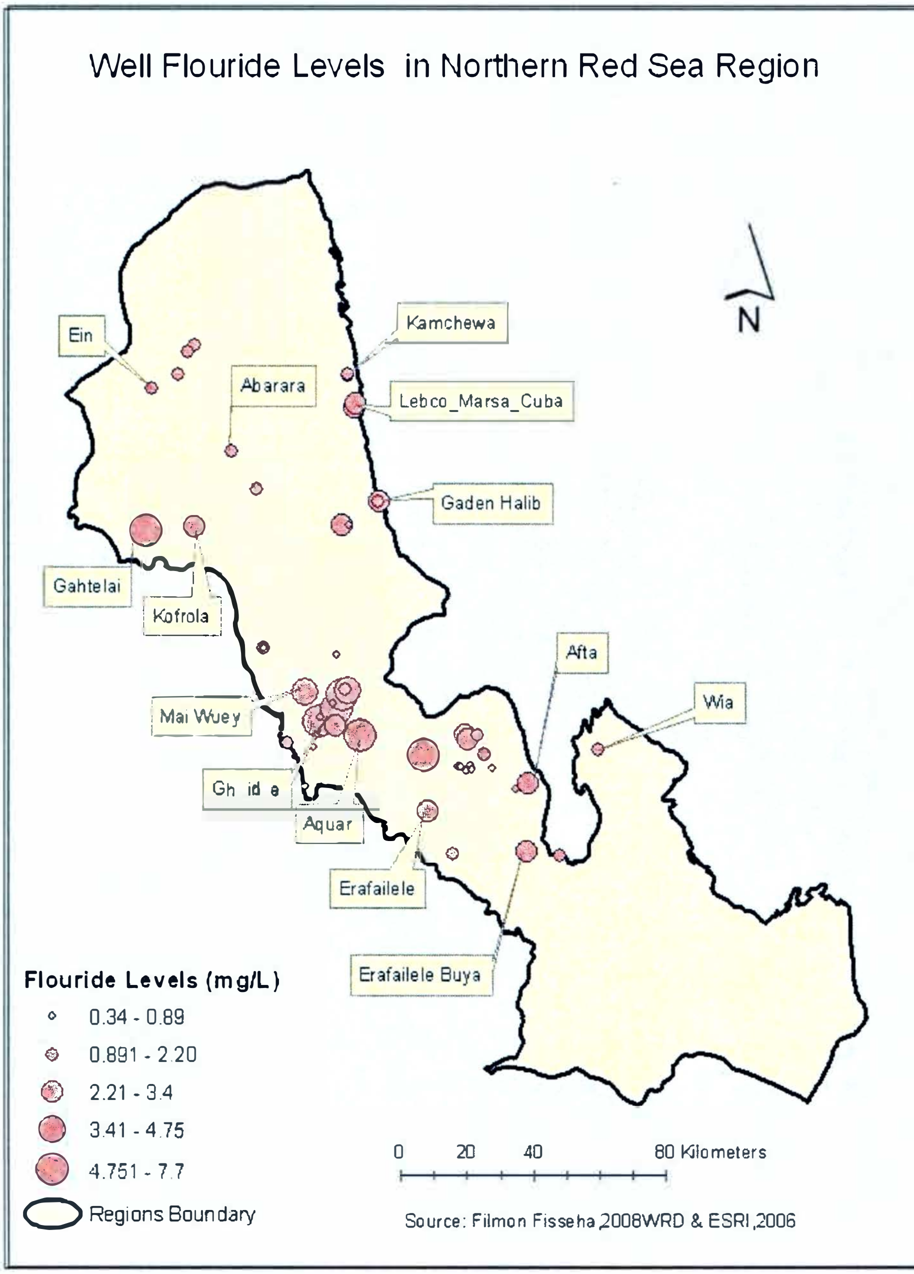


Figure 15: Fluoride Level of Wells in the Northern Red Sea Region

Anseba Region

The Inverse Distance Weight interpolation (IDW) method was used for five sub regions (Keren, Elaberied, Geleb, Aditekelzanie, and Hagaz) in the Anseba region and the final result shows that out of 7,500 km^2 total area of the sub regions 83% have less than 1.5 mg/L, 16.4 % have value between 1.5-3.0 mg/L and 0.58% of the areas have a value of greater than 3.0 mg/L.

Figure 16: Fluoride Distribution in Groundwater in the Anseba Region

Northern Red Sea Region

The Inverse Distance Weight (IDW) interpolation method was also used for seven sub regions (Afabet, Karora, Sheib, Ghindae, Massawa, Foro, Gelealo, and Ghindae) in the Northern Red Sea region. The final result shows that out of 23,620 km^2 total area, 2.4 % have fluoride $\leq$1.5 mg/L, 87 % account for fluoride content of 1.5 - 3.0 mg/L, 8.8 % account for fluoride level of 3.0-6.0 mg/L and the remaining 1.7 % account for fluoride levels greater than 6.0 mg/L.

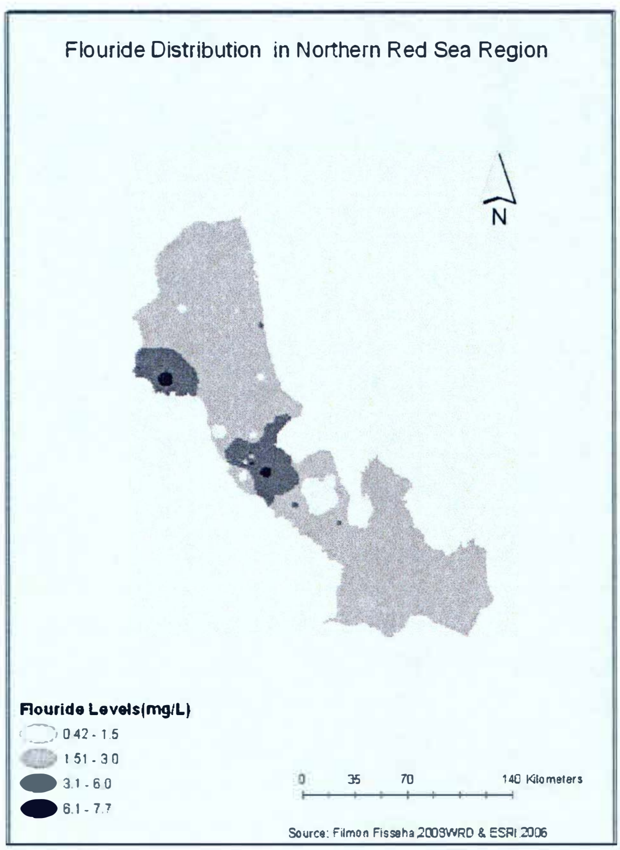


Figure 17: Fluoride Distribution in Groundwater in the Northern Red Sea Region

Risk Area Classification

Anseba Region

The interpolated fluoride distribution map was further classified. Based on the World Health Organization guideline which states that at values of above 1.5 mg/L, prolonged intake of fluoride can cause dental fluorosis; intake of 3–6 mg/L can cause skeletal fluorosis; and with an intake of more than 6 mg/L, crippling skeletal fluorosis may occur(WHO 1984b; Brouwer et al. 1988). A similar classification method was also used by Antony (2003), with areas of ≤1.5 mg/L fluoride level designated as non risk areas, and areas with 1.5-3.0 mg/L fluoride level labeled as moderately risky, and areas with > 3.0 mg/L fluoride level classified as high risk areas. The interpolated map result for the Anseba region shows that almost 17 % of the total areas fall in the moderate and high risk categories (Figure 18). Sub regions like Keren and Elaberied are areas affected by high fluoride.

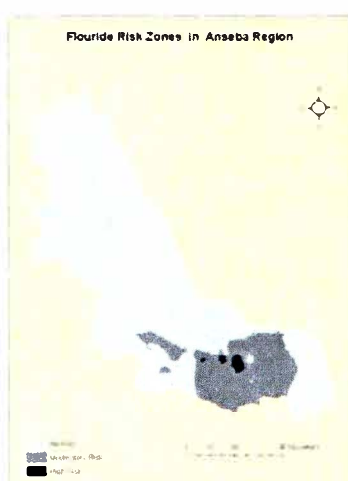


Figure 18: Fluoride Risk Zone in the Anseba Region

Northern Red Sea Region

Similarly to the Anseba region the interpolated map for the Northern Red Sea region was further reclassified into No Risk, Moderate Risk, and High Risk Area and Very High Risk Area. The final result shows that 87 percent of the total area in the Northern Red Sea Region falls into the moderate risk zone, and 8.8 percent under high risk area and 1.7 percent is in the very high risk Area category (Figure 19). Sub regions like Ghindae, Foro and Gahetlai are the main area affected by high fluoride distribution.

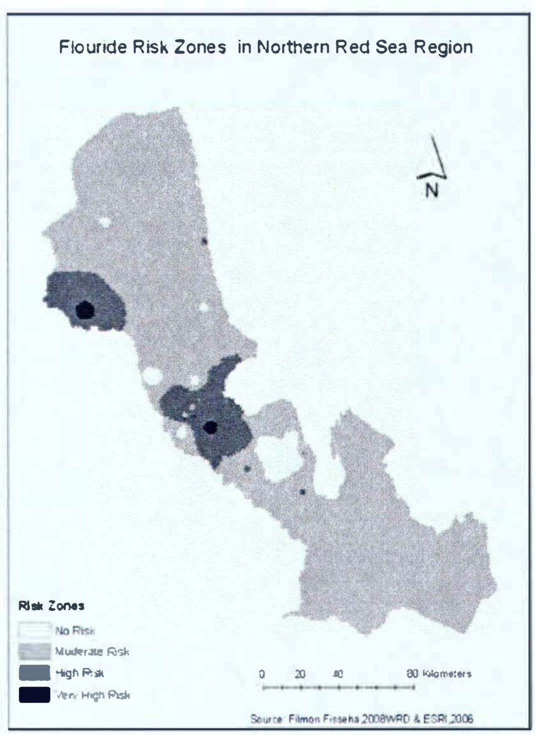


Figure 19: Fluoride Risk Zone in the Northern Red Sea Region

Hydrochemistry and Statistical Analysis

The concentration, distribution, and behavior of fluoride in the Anseba and the Northern Red Sea regions in relation to water hydrochemistry elements were investigated. The average fluoride content in different areas varied from 0.34 to 7.7 mg/L, depending considerably on soil chemistry (pH, level of calcium, iron and silica), geology (granular composition) and climate of the area.

The chemical composition of ground water is affected by the occurrence of several factors including the downwards fracture of the rocks and the water exchange rate. Groundwater that has a long residence time in host rocks reflects the chemical composition of rocks, geochemistry of aquifiers, and hydrodynamics (Haamer, 2006).

Anseba Region

The hydrochemistry of the aquifers reflects the influence of the geological surroundings. Based on this fact, regression analyses were used to determine the relationship between different hydrochemistry elements and fluoride.

Table 3: Hydrochemistry of Drinking Water Sources
in Villages in the Anseba Region

Villages	Ca	Mg	HCO3	T-hardness	EC	pH	T-alkalinity	F	Depth
	mg/L	mg/L	mg/L	mg/L	µS/cm		mg/L	mg/L	Meter
Gush	64	18	405	236	1101	6.87	332	2.17	20
Hadish-Adi	88	24	634	320	1175	7.16	520	2.02	25
Wasdenba	61	12	127	204	586	6.22	104	1.2	5
Halibmentel	56	26	195	248	789	7.51	160	0.68	45
Halibmentel (Karwerba)	133	46	317	524	1565	7.05	260	3.08	50
Deronk	69	28	210	288	902	7.27	172	3.18	55

Villages	Ca	Mg	HCO3	T-hard ness	EC	pH	T-alka-linity	F	Depth
Juffa	64	31	322	228	728	7	264	3.73	60
Begu	75	13	240	244	1102	7.21	240	3.03	60
Geleb	64	19	148	240	619	7.1	148	1.07	40
Daerotay (Hagaz)	82	28.8	508	324	2680	7.36	416	1.08	40
Hagaz	78.4	25.92	302.6	304	1708	7.26	248	1.56	50
Elaberied	59.2	35.52	292.8	296	721	7.26	240	2.05	50
Dekemhare	70.24	15.07	239.12	238.4	634	6.83	145	0.41	10

Source: WRD, 2006.

The mean fluoride level for sample sites used in regression analysis is 1.94 mg/L (Table 4) and the mean fluoride level for the entire Anseba region is 0.16 mg/L threshold level. These results suggest that in certain areas of the region fluoride level exceed 0.16 mg/L.

Table 4: Descriptive Statistics of Fluoride Concentration and Independent Variables in the Anseba Region

Variable	Observation	Mean	Std. Deviation	Min	Max
Ca	13	74.14154	20.02556	56	133
Mg	13	24.79308	9.617714	12	46
HCO_3	13	303.1169	143.1825	127	634
T-hardness	13	284.1846	81.55107	204	524
Ec	13	1100.769	592.9147	586	2680
pH	13	7.084615	0.3216007	6.22	7.51
T-alkalinity	13	249.9231	117.1213	104	520
F	13	1.943077	1.057421	0.41	3.73
Depth	13	39.23077	18.46688	5	60

The statistical analysis was prepared using the stepwise regression method till the refined significant variables were identified. The preliminary regression analysis model has an adjusted R square of 0.6659, indicating that 66.6 percent of the variation in fluoride can be explained by independent variables.

Table 5: Summary of Preliminary Regression Analysis

Source	SS	df	MS	Number of observation	13
				F(8, 4)	3.99
Model	11.9232633	8	1.49040791	Prob > F	0.0987
Residual	1.49441344	4	0.373603361	R-squared	0.8886
				Adjusted R-squared	0.6659
Total	13.4176767	12	1.11813973	Root MSE	0.61123

Table 6: Coefficients of the Regression Analysis

F	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Ca	-0.0366909	0.0571377	-0.64	0.556	-0.19533	0.121949
Mg	-0.0801437	0.0874695	-0.92	0.411	-0.323	0.162711
HCO_3	0.0136973	0.0131795	1.04	0.357	-0.02289	0.05029
T -hardness	0.0162587	0.0193651	0.84	0.448	-0.03751	0.070025
Ec	-0.0007282	0.0004385	-1.66	0.172	-0.00195	0.000489
pH	-3.781472	1.422279	-2.66	0.056	-7.73035	0.167408
T-alkalinity	-0.0097025	0.014721	-0.66	0.546	-0.05057	0.03117
Depth	0.1022679	0.034186	2.99	0.04	0.007352	0.197184
_cons	23.88271	9.216007	2.59	0.061	-1.70503	49.47045

The Coefficient regression analysis indicates that variables of pH at 0.06 levels and depth at 0.05 levels are significant (Table 6), while the variables of Ca, Mg, HCO_3, Hardness, EC, and T-alkalinity were not considered significant. Variable HCO_3, Hardness, and EC were retained for further analysis because their values were relatively close to the 0.05 significant levels. The variables of Ca, Mg and T-alkalinity were removed from the analysis because their level of significance was low.

The purpose of the preliminary regression analysis was to find variables which were significant and variables which had p-value close to a level of significance and those variables were then kept for further analysis. A second regression analysis was run with those identified significant variables and the adjusted R square was 76.6 percent of the variation in fluoride (Table 7).

Table 7: Summary of the Second Regression Analysis

Source	SS	df	MS	Number of observation	13
				F(5, 7)	8.84
Model	11.5827517	5	2.31655034	Prob > F	0.0062
Residual	1.83492503	7	0.262132147	R-squared	0.8632
				Adjusted R-squared	0.7656
Total	13.4176767	12	1.11813973	Root MSE	0.51199

The increase in adjusted R square from the preliminary analysis can be associated with the removal of the insignificant variables. In the refined model variables HCO_3, pH and depth remain significant (Table 8).

Table 8: Coefficient of the Refined Regression Model

F	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
HCO_3	0.0045115	0.0013792	3.27	0.014	0.00125	0.007773
pH	-3.004645	0.7266868	-4.13	0.004	-4.72299	-1.2863
Depth	0.075666	0.0124857	6.06	0.001	0.046142	0.10519
_cons	19.10387	4.718506	4.05	0.005	7.946373	30.26136

$$Y = 19.10387 + 0.0045115X_1 - 3.004645X_2 + 0.075666X_3$$

($X_1 = HCO_3$, X_2 = pH and X_3 = Depth)

The refined regression analysis model shows that bicarbonate and well depth have a positive relationship and pH factor has a negative relationship with fluoride level. This means as the value of bicarbonate and well depth increase the concentration level of fluoride increases and at the sometime as the concentration of pH value decreases fluoride level increase.

Northern Red Sea Region

For the Northern Red Sea region twenty-eight complete hydrochemistry elements records were used in the regression analyses to determine the relationship between different hydrochemistry elements and fluoride. Parameters like calcium, magnesium, ferrous, sodium, potassium, sulfate, bicarbonate, hardness, EC, pH, alkalinity, and fluoride were some of the elements used in the analysis.

Table 9: Hydrochemistry of Drinking Water Sources for Villages in the Northern Red Sea Region

Mai Habar	121	50.42	79	4.3	0.03	0	427.6	150	110	21.3	0.77	0.01	0.71	350	510	1227	7.15
Asus	49.6	15.45	91.3	14	0.01	0.1	307.4	50	56	42.1	0.22	0.1	0.86	252	187.6	802	7.96
Ghindae,Hitsit	150	83.59	105	3.7	0	0.7	356.2	350	155	30.56	1.2	0.01	0.73	292	720	1619	7.92
Gahtelay	111	100.2	484	0	0.63	0	414	312.5	670	8.41	0.6	0.09		340	690	3460	8.02
Degdegit,Deset	304	168.9	2259	24	0.03	0.39	270.8	1440	3119.6	97.43	2.27	5.09		222	1455	8340	7.9
Alighede	114	40.1	52.2	8.4	0.03	0	311	100	127.62	15.94	0.85	0.3	0.59	255	450	1122	7.81
Ghindae	146	63.79	92	3.5	0.04	0.29	549	115	170	8.19	1.02	0.02	0.79	450	627.5	1613	7.68
Embatkala	165	46.17	44.7	3.8	0	0.2	317.2	120	201.5	18.6	1.16	0.2	0.81	260	602	1704	7.84
Dongolo Tahtai	24.8	3.77	146	2	0.2	0.17	190.3	110	76.2	3.1	0.5	0		156	62	900	7.96
Aquar	50.4	7.68	188	0	0.19	0.2	345.3	80	128	3.96	0.02	0.01		283	158	1700	7.68
Mai Wuey	12	2.29	130	1	0.05	0.1	225.7	37	62	2.21	0	0		185	42	980	7.92
Aquar	62	4.86	314	26	0.37	0.15	695.4	83	125	1.33	0.75	0.01		570	175	1729	7.67
Gahtelai	20.8	5.83	209	14	0.03	0.1	385.5	105	72	2.21	0	0		316	76	1057	7.41
Gahtelai	18	4.86	216	10	0.03	0.1	420	75	90	2.66	0.01	0		345	65	1060	7.3
Aquar	52.8	12.64	286	22	0.05	0.2	658	140	68	0	0.81	0.01		540	184	1755	6.48
Hideli	122	24.3	66	7.2	0	0.09	354	100	98	19.8	0.45	0	0.7	290	405	1139	7.76
Hideli	84	34.63	58	7.9	0.1	0.2	293	96	0	21.3	0.34	0.1	0.75	240	352.5	1061	7.64
Hideli	109	44.96	30	7.2	0.1	0	280	100	103	15.5	0.61	0.1	0.75	230	457	1135	8.14
Hideli	106	46.17	70	6.5	0	0	396	160	45	30.1	0.65	0	0.66	325	455	1205	7.17

Table 9 – continued

Hideli	114	41.31	67	7.5	0	0	339	168	78	17.7	0.64	0	0.75	277	455	1225	7.28
Hideli	100	45.56	64	7	0	0.2	365	145	55	16.8	0.65	0	0.53	300	437.5	1118	7.15
Wia	160	84.56	220	9	0	0	395	450	240	21.3	1.81	0	0.79	324	748	2080	7.17
Wia	114	53.6	271	6.4	0.1	0.1	268	450	212	14.6	1.56	0.1	1.85	220	504	1913	7.61
Wia	162	76	193	8.2	0	0.2	402	450	210	20.8	1.9	0	1.9	329	720	2010	7.08
Wia	170	86.26	149	6.8	0	0	250	525	240	17.7	1.7	0	2.6	205	780	1968	7.99
Wia	187	108	171	7.2	0	0	371	385	300	11.1	2	0	2.1	304	912	2560	7.11
Wia	186	107	181	7.6	0	0	395	390	292	10.6	2	0	2.05	905	905	2560	7.13
Alighede	114	40	52	8.4	0	0	311	100	128	15.9	0.85	0.3	0.59	225	450	1122	7.81

Source: WRD, 2006

The mean fluoride level for samples sites used in regression analysis is 2.44 mg/L (Table 10) and the mean fluoride level for the entire Northern Red Sea region is 2.10 mg/L threshold level. This result suggests that in certain areas of the region fluoride level exceeds 2.10 mg/L.

Table 10: Descriptive Statistics of Fluoride Concentration and Independent Variables in Villages in the Northern Red Sea Region

Variable	Observation	Mean	Std. Dev.	Min	Max
F	28	2.440714	2.34661	0.53	7.7
Ca	28	111.75	64.15594	12	304
Mg	28	50.10464	40.30127	2.29	168.89
Na	28	224.5396	411.6141	30	2258.6
k	28	8.341428	6.495751	0	25.96
Fe	28	0.071071	0.137392	0	0.63
Mn	28	0.124643	0.154044	0	0.7
HCO3	28	367.5904	113.7141	190.32	695.4
SO4	28	242.375	277.023	37	1440
Cl	28	258.2829	574.9325	0	3119.6
NO3	28	17.54286	18.5652	0	97.43
NNH3	28	0.905	0.669884	0	2.27

Variable	Observation	Mean	Std. Dev.	Min	Max
NO2	28	0.230286	0.956301	0	5.09
M-alk	28	321.0714	148.0162	156	905
Hardness	28	485.1821	320.6163	42	1455
Ec	28	1791.571	1418.642	802	8340
pH	28	7.562143	0.399716	6.48	8.14

Similar to the Anseba region, statistical analysis for the Northern Red Sea region was done using the stepwise regression analysis method.

Table 11: Summary of Fluoride Distribution Stepwise Regression Analysis Results for the Northern Red Sea Region in Eritrea

Regression analysis results	Result 1	Result 2	Result 3	Result 4	Result 5
Ca	0.345 (0.248)	0.373 (0.218)	0.368 (0.212)	0.327 (0.171)*	0.324(coefficient) (0.167)*(error)
Mg	0.591 (0.414)	0.640 (0.362)	0.620 (0.349)*	0.560 (0.288)*	0.552 (0.282)*
Na	-0.029 (0.022)	-0.028 (0.021)	-0.022 (0.017)	-0.010 (0.005)**	-0.010 (0.004)**
k	0.060 (0.083)	0.047 (0.067)	0.051 (0.064)	0.026 (0.050)	
fe	-3.798 (4.455)	-4.424 (3.738)	-5.184 (3.302)	-6.077 (2.768)**	-6.167 (2.702)**
Mn	0.606 (2.102)				
HCO_3	0.010 (0.007)	0.011 (0.006)	0.009 (0.005)*	0.008 (0.003)**	0.009 (0.003)***
SO_4	0.019 (0.011)*	0.019 (0.010)*	0.016 (0.008)*	0.009 (0.003)***	0.009 (0.003)***
Cl	0.009 (0.013)	0.007 (0.011)	0.007 (0.010)		
NO_3	-0.072 (0.032)* *	-0.069 (0.029)* *	-0.068 (0.028)* *	-0.064 (0.025)**	-0.062 (0.024)**
$N\text{-}NH_3$	-0.927 (1.360)	-0.991 (1.290)	-0.866 (1.227)		
NO_2	1.108 (2.966)	1.346 (2.738)			

Regression analysis results	Result 1	Result 2	Result 3	Result 4	Result 5
M-alk	0.002 (0.002)	0.002 (0.002)	0.002 (0.002)		
Hardness	-0.162 (0.099)	-0.173 (0.087)*	-0.168 (0.084)*	-0.149 (0.070)**	-0.147 (0.068)**
Ec	0.005 (0.002)**	0.005 (0.002)**	0.005 (0.002)**	0.004 (0.001)***	0.004 (0.001)***
pH	0.977 (1.275)	1.215 (0.933)	1.260 (0.901)	1.539 (0.754)*	1.557 (0.737)**
Constant	-6.626 (11.247)	-8.801 (8.022)	-8.890 (7.783)	-10.958 (6.492)	-11.188 (6.335)*
Observations	28	28	28	28	28
R-squared	0.92	0.92	0.92	0.91	0.91

Fluoride is Dependent Variable
Standard errors in parentheses
* Significant at 10%; ** significant at 5%; *** significant at 1%

The model was re-run five times until the refined results were obtained. In the refinement process Mn, NO_2, Cl, N-NH_3, NO_2, M-alk and K were removed from the analysis because of their insignificant relationship with the fluoride.

The final model shows that Ca and Mg have significant level of relationship with fluoride at 0.1 levels. Elements like Na, fe, NO_3 and Hardness have a very significant relationship at 0.5 level and elements like HCO_3, SO_4 and EC have a very strong relationship with fluoride at 0.01 level.

The regression analysis model result has an R square of 0.91, indicating that 91 percent of the variation in fluoride can be explained by independent variables.

$$Y = -11.188 + 0.324X1 + 0.552X2 + -0.010X3 - 6.167X4 + 0.009X5 + 0.009X6 - 0.062X7 - 0.147X8 + 0.004X9 + 1.557X10$$

(X1= Ca, X2= Mg, X3 = Na, X4 = fe, X5=HCO3, X6= SO4, X7= NO3, X8= Hardness, X9= Ec X10 = pH)

The final result of the regression analysis shows that elements like sodium, ferrous (iron), nitrate, and water hardness have negative relationships with fluoride concentration. As the concentration of those elements increase the fluoride concentration decreases. On the other hand, elements like calcium, magnesium, bicarbonate, sulfate, electric conductivity and pH factors show positive relationship with the fluoride concentration. As the fluoride concentration increases, the values of those elements also increase.

Health and Fluoride

Fluoride is one of the chemicals that has been shown to have significant effects on human health through drinking-water. Fluoride has beneficial effects on teeth at low concentrations in drinking-water, but excessive exposure to fluoride in drinking-water, or in combination with exposure to fluoride from other sources, can give rise to a number of adverse effects (WHO, 2006).

The relationship between fluoride levels and tooth decay has been explained as follows: "elevated fluoride levels during enamel maturation can also result in dental fluorosis, which is characterized by hypomineralization of subsurface layers of enamel. In the mildest forms of dental fluorosis, the tooth is fully functional but has cosmetic alterations, almost invisible opaque white spots. In more severely fluorosed teeth, the enamel is pitted and discolored and is prone to fracture and wear. Several studies have found significant increases in the number of decayed, missing, or filled tooth surfaces in children with severe dental fluorosis." (Agency for Toxic Substances and Disease Registry, 2003).

In most industrialized countries, the traditional high prevalence of caries in children and adolescents has declined during recent decades. In sub-Saharan African countries however, where the caries prevalence in the child populations is low, the situation is less clear-cut. Some studies report no change; other findings indicate an increase or a decline in the prevalence of caries, great variations are seen between and within countries, as well as within different groups of the populations (Wondwossen et al., 2004).

A strong and positive relationship between caries and dental fluorosis on an individual level was identified by Grobler et al. (2001). But the study was conducted only with South African children living in high-fluoride areas. Similar results have been reported from Nigeria, where the lowest incidence of dental caries was observed in areas with fluoride concentrations in the drinking water supplies below 0.4 mg/L (Ismail El-Nadeef and Honkala, 1998).

Statistically speaking, dental caries does not rank among the more serious diseases in Eritrea. On an individual level, however, dental caries cause great suffering and, as dentists are in short supply, oral health is a problem of growing concern in the country (Eritrean Health Management Report, 2006).

Focusing on the general health effects of fluoride, this study was designed to investigate the concentration of fluoride in groundwater in selected villages in the western part and eastern escarpment of Eritrea and its correlation with dental caries at sub regions level.

Linear regression analysis was used to identify the relationship between dental caries prevalence and fluoride concentration. Pearson's correlations coefficient (r) result showed the presence of a strong correlation between high fluoride concentration and dental caries diseases for the Anseba and the Northern Red Sea region.

Anseba Region

Dental caries and maximum fluoride levels for the Anseba region were compared to determine the relationship between fluoride distribution and its health effects.

Table 12: Prevalence of Dental Caries in the Anseba Region

Sub regions	No. Patients	Percentage	Total Pop.	Fluoride mg/L
Aditekeliezan	136	3.3	33770	0.00-0.41
Elaberied	365	8.9	45750	0.6-3.8
Geleb	305	7.0	35800	0.78-1.07
Keren	2011	49.0	78830	0.79-3.73
Hagaz	595	15.0	66810	0.83-1.91
Halhal	98	2.0	36350	0.00-0.04
Habero	125	3.0	48340	0.00-0.68
Asmat	91	2.0	36330	0.00-0.06
Kerkebet	210	5.0	29760	0.00-1.2
Hamelmalo	136	3.0	27060	0.00-0.78
Total	4072	100		

Source: Ministry of Health, 2006

Table 12 shows that dental caries for areas with higher fluoride distribution in the groundwater accounts for 73% of the total disease distribution in the Anseba region. The sub regions of Keren, Hagaz and Elaberied which include the villages of Gush, Juffa and Dernok have reported 49%, 15% and 9% of the identified dental caries disease report. Conversely, the prevalence of dental caries for areas with low fluoride concentration was low (Table 12).

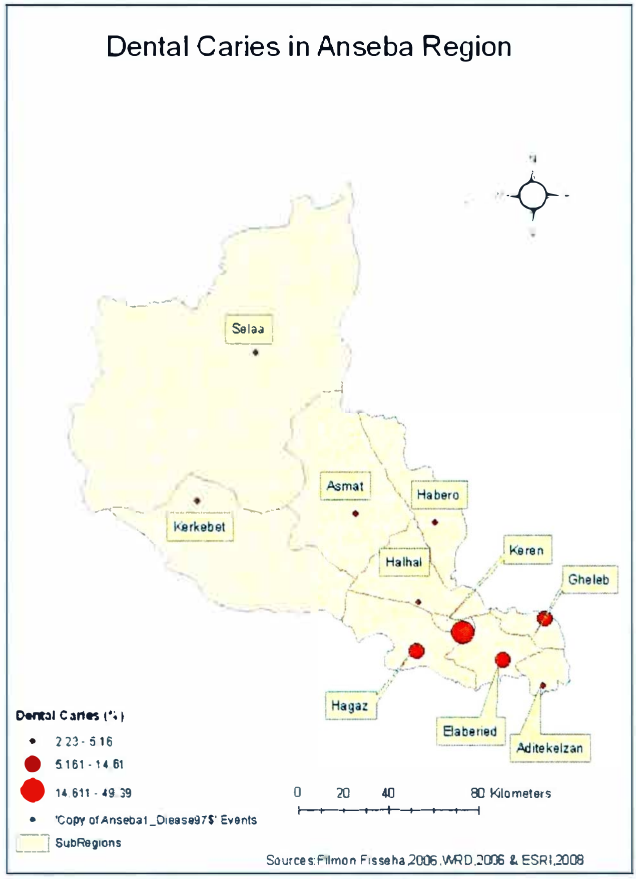


Figure 20: Dental Caries Distribution in the Anseba Region

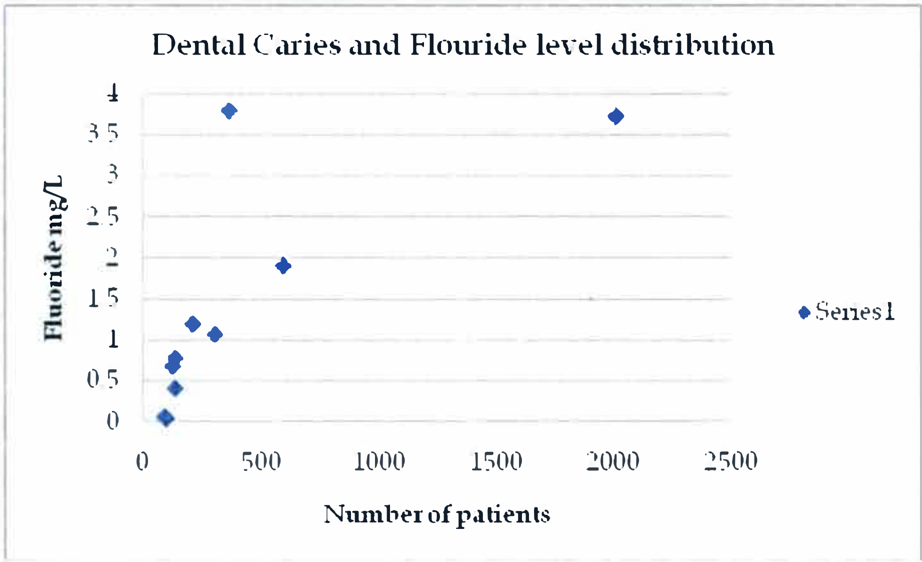


Figure 21: Scatter Plot Dental Caries and Fluoride Level Distribution

Figures 20 and 21 show the dental caries prevalence at the sub regions level and the scatter plot shows that the value for Keren sub region is so high and excluded from the correlation analysis because of its extreme value. This high rate of dental caries prevalence could be associated with the presence of high number of population in the city and access to better health care facilities. Moreover, regional Referral hospital is located in the city and people will travel from other nearby villages for Seek of medical treatment. The final result shows that a very strong Pearson's r (0.69) P (0.03) correlation exist between high fluoride concentration and a high number of dental caries.

Northern Red Sea

A similar comparison was made for maximum fluoride distribution and fluoride concentration level in the Northern Red Sea region.

Table 13: The Northern Red Sea Region of Dental Caries

Sub regions	No. Patients	Percentage	Total Pop.	Fluoride mg/L
Gelealo	36	2.6	32460	1.56 - 2.5
Foro	125	8.8	49410	0.79 – 3.1
Massawa	665	47.0	36700	0.53 - 0.75
Ghindae	378	27.0	66170	0.34 - 7.7
Sheib	21	1.0	56610	0.89 - 2.2
Afabet	28	2.0	107610	1.34 - 1.9
Nakfa	58	4.0	56870	1.34 - 1.9
Karora	101	7.0	45760	1.5 - 1.94
Total	1412	100		

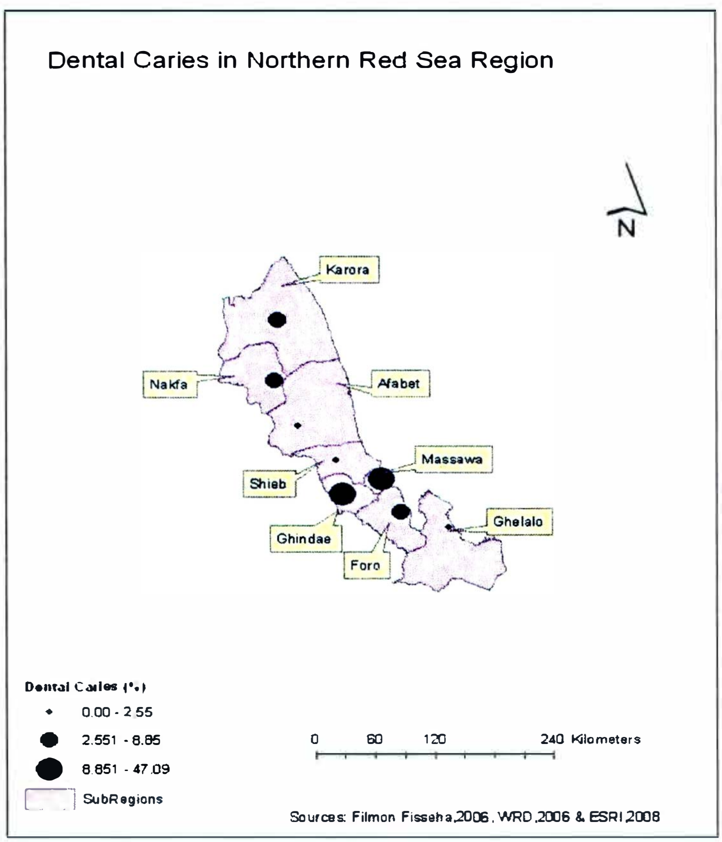


Figure 22: Dental Caries Distribution in the Northern Red Sea Region

As with the Anseba region, linear regression analysis was used to see the correlation between fluoride and dental caries prevalence rate for the sub region of the Northern Red Sea. Fluoride concentration in the sub regions of Ghindae, Foro and Karora is high compared with other sub regions in the Northern Red Sea region (Table 13 & Figure 21). Dental caries in those sub regions accounts for 42.9% of the overall total report for the Northern Red Sea regions (Table 13). The linear regression analysis result also shows the existence of a very strong correlation between maximum fluoride concentration and dental caries prevalence rate. The Sub regions of Massawa, because of its high value, was excluded from the regression analysis and the final result shows that Pearson's r (0.96) P (0.0005).

Discussion

Anseba Region

The stepwise regression analysis model shows that bicarbonate and well depth have a positive relationship and pH factor has a negative relationship with fluoride level. This means as the value of bicarbonate and well depth increase the concentration level of fluoride increases and at the sometime as the concentration of pH value decreases fluoride level increase (Table 8).

In addition to that, result of the fluoride distribution map shows that high concentration of fluoride in Hadish-Adi, Dernok, Halibmentel (Karwereba), Gush, and Juffa villages (Figures 13 & 15).

Furthermore, the Inverse Distance Weight interpolation (IDW) result for the Anseba region shows that out of 7500 km^2 total area 17% have fluoride levels of 1.5-3.0 mg/L and greater than 3.0 mg/L fluoride level in their groundwater (Figure 15).

This high level fluoride distribution in these sub regions is associated with granite pegmatite intrusion (coarse-grained igneous rock) and soil type of the area (Geological Map of Keren, WRD, 2001).

Fluorspar, a fluoride rich element, is found as a Cryolite mineral and contains 45% of fluoride in pegmatite granite rock (C.R, Rao, 2003). It is also commonly observed that fluorite and fluoro apatite are present as accessory minerals granite (Bulusu et al., 1979) and metamorphic rocks (Deer et al., 1966).

Based on the geological map of the Keren area villages like Juffa, Karwereba and Gush are set under the litological class of granite (pegmatite). This litological contact with granite (pegmatite) is the possible cause of high fluoride distribution compared to other villages in the surrounding area. Similarly, villages like Geleb, which is found in the same area are classified as an area dominated by chlorite schist (Geological Map Keren area, WRD 2001 and Soil Map of Eritrea, 1994). Chlorite schist (metamorphic rock) contains fluorapatite, which has 3-4% fluorine (C.R, Rao, 2003).

In addition to that, Fluorite (fluorspar, CaF_2) is the most important fluoride-bearing mineral and this element is mainly stored in clay soils, groundwater and lakes in volcanic areas (Edmunds and Smedley, 1996).According to World Food and Agricultural Organization (FAO) 1994 Soil Map classification of Eritrea, and the Geological Formation Map of Keren area (WRD, 2001) the Anseba region is dominated by vertisols and alluvium soil types. Both vertisol and alluvium have high content of clay soils (Wikepedia, 2008). The presence of high content of clay soil also could be assumed as potential contributing factor for the high fluoride level distribution in the area.

Additionally, a result of regression analysis shows that negative correlation between pH and fluoride concentration. This means with the increase of pH value the fluoride level decreases. This result agrees with other similar studies showing fluoride concentration was observed to be high in low pH value environments (Rose et al., 1979). On the other hand, positive relationships between fluoride level, well depth and HCO_3 have been observed. This means with increase of depth and HCO_3 the fluoride level increases. Similar result was also observed in different studies, where a positive correlation was demonstrated between fluoride and HCO_3 (Gizaw 1996). Likewise, positive relationship between well depth and fluoride level is very strong when compared to any other elements. As depth increases the level of fluoride distribution increases. This correlation indicates that the source of fluoride is likely to be fluorite and/or patite minerals present in the Precambrian granite or granitic-gneiss of the underground basement (Babulal et al., 1979).

Northern Red Sea Region

The concluding result of the regression analysis shows that elements like sodium, ferrous (iron), nitrate, and water hardness have negative relationships with fluoride concentration. As the concentration of those elements increase the fluoride concentration decreases. On the other hand, elements like calcium, magnesium, bicarbonate, sulfate, electric conductivity and pH factors show positive relationship with the fluoride concentration. As values of those elements increase the fluoride concentration also increases (Table 11).

Moreover, result of fluoride distribution maps for selected villages in the Northern Red Sea region shows that villages of Aquar, MaiWuiey, Erafailelei and Ghindae have a high fluoride distribution. Particularly, sub regions of Ghindae, Foro and Afabet contain the highest fluoride concentration compared to other sub regions in the region (Figure 14).

Similarly, results of Inverse Distance Weight Map (IDW) for sub regions in the Northern Red Sea region (Afabet, Karora, Sheib, Ghindae, Massawa, Foro, Gelealo, and Ghindae) 97.5 % of the area fall under moderate, high and very high risk category (Figure 16).

The high fluoride distribution in these areas is associated with the geological formation of the areas, particularly the presence of high volcanic rocks and sediments of marine origin mountainous areas. The natural concentration of fluoride in groundwater depends on the geology, chemistry, physical characteristics and climate of the area. Generally hot springs and well water tend to contain higher concentrations of fluoride than surface waters from lakes and streams (Edmunds and Smedley, 1996).

The Northern Red Sea region is located on the eastern escarpment of Eritrea. This escarpment consists of scarps of precipitous slopes, very deep valleys which are aligned with the N-S trending faults, steep hills, and a stepped topography interrupted by intermountain basins and hot springs as the result of Neoproterozoic terranes and Tertiary to recent volcanic rocks (Thomas Schluter, 2006).

The geological formation along the Red Sea coast line and the Southern Danakil plain are younger and consists of Tertiary and Quaternary sediments with the Red Sea and Afar Rift system, which cuts through the area from south to north accompanied by many fault lines. During Tertiary, sandstone and limestone were formed along the eastern coast, where at present lagoons and salt plains are found (Mohr 1961, 1987 cited in Ogbasighi, 2001).

In addition, this region is part of the Great Rift Valley system which is well known all over the world for its high fluoride content. The main source of fluoride in the Rift Valley is the presence of fluoride-rich volcanic rocks and volcanic activity, which releases magmatic fluorine generally as hydrogen fluorine, through volcanic degassing. Additionally, volcanic rocks, thus containing high levels of fluorine, transfer fluoride to ground waters through water-rock interaction processes in the aquifers (Kungolos et al., 2006). High fluoride concentrations also develop as a product of chemical weathering (Kilham and Hecky, 1973). There are two major belts with known high fluoride levels where extensive studies have been carried out. One belt is the East African Rift from Eritrea to Malawi and the other is the belt which stretches from Turkey through Iraq, Iran, Afghanistan, India and Northern Thailand to China (Snell, 2005).

Fluoride is commonly associated with volcanic activity and fumaroles gases (a vent that emits hot gases, usually associated with past or current magmatic activity below) and the interaction of water with volcanic ashes and volcanic sedimentary rocks. Thermal waters, especially those of high pH, are also rich in fluoride

(Edmunds and Smedley, 1996).

Positive correlation between calcium and fluoride exists due to the presence of limestone. Observing the geological overview of the area, the Northern Red Sea region is generally, classified as the eastern escarpment of the country land form and mainly dominated by alluvial deposit, coral reefs, eluvial and colluvial deposits, talus, sheet flows, dunes and beach deposits, granites and quartz (Thomas Schluter, 2007). Similarly, prior studies in India coastal areas also reach with the same conclusion (Babulal et al., 2003).

It has been shown that calcium and electric conductivity (EC) have a very strong positive correlation with fluoride level. This could originate from evaporative enrichment. In general, areas of high fluoride overlap areas with high electrical conductivity (EC) and high fluoride and EC in aquifers originate from evaporative enrichment (Gupta et al, 2004).

Furthermore, a positive correlation between high evaporation and maximum fluoride distribution has been observed. The Northern Red Sea region is mainly located in eastern escarpment of the country. This region is generally classified as semi desert and arid low land with average temperature of 31 °C and low amount of rainfall (Eritrea Agro-ecological Zones Map, 1997). High fluoride concentration in these areas could be associated with the arid climate. In arid areas, groundwater flow is slow and reaction times between water and rocks are therefore high. Fluoride build-up is less apparent in the humid tropics because of high rainfall inputs and their diluting effect on groundwater chemical composition (British geological survey, water quality Fact sheet: Fluoride).

Likewise, the EC strong positive correlation also exists between bicarbonate (HCO_3) and fluoride. This indicates that ground water with high HCO_3^- concentrations helps to dissolve some fluoride-rich minerals (Moghaddam and Fijani, 2007).

As with the bicarbonate, there is a very strong positive correlation between sulfate and fluoride were observed in the regression analysis. This could be due to the geological formation of the areas; the Red Sea is situated as part of the great African Rift Valley and was created as a result of Tertiary volcanic rock formation. A fumaroles gas (rich in Sulfur dioxide and hydrogen sulfide) was released with magma during the volcanoes (Thomas Schluter, 2006).

Observing the water samples points for the Northern Red Sea region, hot springs are noted to have particularly high fluoride content .The high concentrations of fluoride in this lake are mainly caused by evaporation and fluoride-rich volcanic rocks (Gizaw, 1996).

Comparison of the Anseba and the Northern Red Sea Region

The Regression analysis for the Anseba region shows positive correlation between fluoride level and well depth and HCO_3 and negative correlation with pH (Table 8).This supported the idea that the high fluoride concentration of the area is as a result of pegmatite intrusion hosted by granitic batholiths. In contrast to this, in the Northern Red Sea region fluoride concentration shows positive correlation with Ca, Mg, pH, Ec, SO_4 and HCO_3 and negative correlation with Na, fe, NO_3 and Hardness

(Table 11). The sources of fluoride in this area is associated with volcanic rocks and sediments of marine origin due to the fact that part of the region is situated close to Great Rift Valley system and the existence of a very strong positive correlation between high fluoride level and geothermal spring water. Moreover, the presence of very strong correlation between sulfate and fluoride level as the result of fumaroles gas prove the idea of high fluoride distribution as the effect of volcanic rocks.

The existence of a positive correlation between calcium and fluoride level also support the idea of fluoride distribution caused by sediments of marine origin in the mountainous area in the Anseba and the Northern Red Sea region. According to the Geological Overview Map of Eritrea, both regions are partly covered by limestone and coral reefs and the concentration of fluoride in groundwater supplies varies enormously depending on the geological characteristics of the aquifer and the presence of other minerals such as calcium which may limit fluoride solubility (WHO, Fluoride Monograph, 2006).

Finally, the Anseba Region is dominated by vertisols and alluvium soil type. Both vertisol and alluvium have a high content of clay soils (Wikipedia, 2008) and the presence of the clay soil also could be a potential contributing factor for the high fluoride level distribution in the area.

The pH value of the hydrochemistry shows a very strong negative correlation with fluoride in the Anseba and very strong positive correlation for samples in the Northern Red Sea region. This is due to the presence of high clay soil in the Anseba region (Eritrea Soil classification Map, FAO, 1994). Clay soil is an acidic medium (lower pH), and fluoride is absorbed in clay (Saxen and Ahmed, 2004).However in the case of the Northern Red Sea region, all the water samples were found to be alkaline, and in an alkaline medium, fluoride is desorbed. Thus, alkaline pH is more favorable for fluoride dissolution activity (Saxen and Ahmed, 2004). So fluoride is high.

Fluoride and Health

Different studies in different countries indicate that the presence of a significant relationship between excessive fluoride intake and prevalence of dental caries .The second molar is the tooth most severely affected by dental fluorosis and dental caries. The incidence of dental caries increased with the increasing severity of dental fluorosis, both in moderate- and high-fluoride areas. Thus, a positive relationship between dental caries and dental fluorosis was observed, in both areas (Blackwell Munksgaard, 2004).

Sub regions like Keren, Elaberied and Hagaz from the Anseba regions which have a high fluoride distribution account for 73 percent of the total dental caries prevalence rate in the region. Similarly, sub regions like Ghindae, Foro and Karora which are known for high fluoride distribution also account for 42.5 percent of dental caries prevalence rate in the Northern Red Sea region (Table 13). Moreover the Person's correlations analysis for both regions showed a very strong correlation between fluoride distribution and dental caries. Therefore, the need to find out at what concentration fluoride gives maximum benefit to human health is very important.

CHAPTER V

CONCLUSIONS

Fluoride has widely been the focus of public and scientific interest because of its important role in the health of human beings. The beneficial effect of fluoride in protecting the teeth from bacteria is well known while the toxic effect for human health, due to an over abundance of fluoride in take in drinking water and food is a cause for concern. In Eritrea although different water and health related studies address the concern of fluoride pollution for water quality very few studies was made to see the fluoride distribution and its health effect at village level. In this study Regression analysis was used to determine the correlation between hydrochemistry elements and fluoride concentration. In addition to that Inverse distance weight interpolation, risk zoning and Pearson's linear correlation methods were used to examine the spatial distribution of groundwater fluoride concentration, delinate risk zones of the area and compare fluoride and dental caries relationship. The fluoride level distribution of well sample points for selected villages in the Anseba and the Northern Red Sea region were found to be higher than the recommended standard by the World Health Organization. Excessive presence of fluoride can cause serious health problems for the people settled in these areas.

In addition to that, results from the risk classification map for five sub regions in the Anseba Region shows that 17% of the total area falls under moderate and high risk categories (Figure 17). Similarly, the risk classification map for sub regions in the Northern Red Sea Region shows that 97.5 % of the total area falls under moderate, high and very high risk categories (Figure 18).

The chief cause of this excessive fluoride presence in the aquifer is related to the geological formation of the area. In the Anseba Region the high presence of fluoride is associated with the pegmatite intrusion hosted by granitic batholiths and the presence of clay soil which cause absorption of fluoride in the soil. However, in the Northern Red Sea region excessive concentrations of fluoride is related to the presence of volcanic rocks and volcanic activities as part of the Great Rift Valley geological formation (hot springs) and sediments of marine origin in mountainous areas because of its proximity to the Red Sea.

Fluoride dissolution and deposition in groundwater is controlled by hydrochemistry of water elements, which varies considerably in the study area. The regression analysis shows that fluoride concentrations are associated with HCO_3, pH, Ca, Mg, Na, SO4, EC, and Water hardness. Hydrochemistry elements like HCO_3, Ca, Mg, EC pH, SO_4 have positive correlation and Na, fe, NO_3 and Hardness show very negative correlations with fluoride content.

Furthermore, very strong correlations were also observed in the Anseba and the Northern Red Sea Region between dental caries prevalence rate and maximum fluoride concentration. Due to the toxicity of fluoride it would be important to undertake a systematic and detailed study to find out at what concentration fluoride gives maximum benefit to human health.

Limitations of the Study

There are several limitations to this study. The first constraint is accessing data, such as maps and satellite imageries on land used, land cover, geology, soil, population, and health and water quality data. Although some data were collected for this study, the coverage and number of sample data was sparse. For example there were only 44 well points data for the Anseba region and 53 well point data for the Northern Red Sea region. In addition, out of 44 well points only 13 were complete records for the Anseba and only 28 of 53 well points records were complete records for the Northern Red Sea region .As a result the regression analysis was done using only those with completed data. Lack of those data makes the regression analysis very difficult and the analysis was qualitative.

Another limitation of this study was the absence of sufficient literature on fluoride and health in the country. Thus the study relied heavily on the literature prepared by other nearby countries and the findings are less specific.

CHAPTER VI

RECOMMENDATIONS

Currently groundwater abstracted from wells is directly consumed without fluoride removal. To avoid the detrimental health effects that come as the result of excessive fluoride consumption water supply wells must be selected very carefully and wells that are operating at the moment should be carefully mapped out and monitored and, if needed, water treatment should be provided.

Occurrence of fluoride at excessive levels in drinking-water in developing countries is a serious problem. Its detection demands analytical grade chemicals and laboratory equipment and skills. Similarly, the prevention of fluorosis through management of drinking-water is a difficult task, which requires favorable conditions combining knowledge, motivation, prioritization, discipline and technical and organizational support. Many filter media and several water treatment methods are known to remove fluoride from water. However, many initiatives on defluoridation of water have resulted in frustration and failure (COWI, 1998). Therefore, in any attempt to mitigate fluoride contamination for an affected community, the provision of safe, low fluoride water from alternative sources should be investigated as the first option.

Defluoridation of water is more expensive than other normal water treatment methods, but costs can be kept low if defluoridated waters are used for cooking and drinking only. This can be achieved by use of a 'Point of Use Treatment Method. This treatment method allows fluoride contaminated water to continue to be used for washing and other external uses.

Generally, bone charcoal (household, institutional and community filters) Nalgonda, Activated Aluminia and Clay defluoridation methods are the most recommended and widely used methods and are used by developing countries to minimize the risk of fluoride concentration in drinking water (WHO, 2006).

Finally, further studies, are recommended to address the issues using a mixture of qualitative and quantitative methods.

Management Suggestions

Water pollution management is a major task in Eritrea. To protect the water quality and standard, the Water Resource Department is undertaking different initiatives. The Department developed a Water Resource Strategic Management Plan, a National Environment Management Plan and Guidelines, and national water regulation directives. Other activities like research, human resource development, and community awareness can also be mentioned as ongoing activities to improve the institution and technical capacity of the department. As part of the water quality protection and improvement programs, Maps of Fluoride Distribution for selected villages in the Anseba and the Northern Red Sea Regions of Eritrea and the results from the model could be used in illustrating areas of concern, in prioritizing implementation of management programs and in water resources protection and best management practices techniques.

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