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A study of fluoride groundwater occurrence in Nathenje, Lilongwe, Malawi

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Abstract

A study was carried out to determine fluoride concentration in groundwaters of Nathenje area situated in Lilongwe District in the central region of Malawi. Water samples were collected from 176 boreholes and shallow wells during different months in 2001 and 2002. Samples were then analysed for fluoride by using a fluoride electrode and an ion selective meter. The results showed that fluoride concentrations for the rainy season varied from <0.5 to 6.98 ± 0.01 mg/l with 52.9% of the boreholes above the World Health Organisation (WHO) maximum permissible limit of 1.5 mg/l. Fluoride concentrations for dry season ranged from <0.5 to 7.02 ± 0.02 mg/l with 50.8% of boreholes above 1.5 mg/l. Fluoride concentrations for the two seasons were significantly different from each other ($p < 0.05$). Fluoride data was used to produce a fluoride distribution map. From the map, it was observed that fluoride concentrations in this area followed a pattern. The central part of Nathenje had high fluoride concentration of between 2 and 7.02 mg/l and these high fluoride values seemed to extend eastwards beyond the boundary of the study area. However, the southern and western parts had <1 mg/l of fluoride. The high groundwater fluoride values seem to be associated with the weathered basement complex containing biotite that is a probable source of fluoride. The other suspected sources of fluoride in Nathenje groundwater could be due to the dissolution of hornblende, fluorite and amphibole, which are reported to occur in rocks and soils in this area. There was evidence of dental fluorosis in areas where the fluoride concentration was high.

Keywords: Fluoride; Fluorosis; Groundwater

1. Introduction

1.1. Fluoride occurrence

Fluorine is the most electronegative of all chemical elements and is therefore never found in nature in elemental form. Combined chemically in the form of fluorides, it ranks 17th in abundance of elements in the earth's crust representing about 0.06–0.09% of the earth's crust (World Health Organisation (WHO), 1994). It occurs in a combined form in rocks and soil in a wide variety of minerals such as fluorspar (fluorite) (CaF_2), cryolite (Na_3AlF_6), apatite ($Ca_5(PO_4)_3F$) and topaz $Al_2SiO_4(F,OH)_2$ (Buxton and Shernoff, 1999; WHO, 1994; Hamilton et al., 1982). During formation and in the presence of fluoride ions, the fluoride can substitute the hydroxide ion (OH^-) in certain minerals such as muscovite $(K_2Al_4)(Si_6Al_2O_{20})(OH,F)_4$ which is in the mica group and amphiboles such as amosite $(FeMg)_7(Si_4O_{11})_2(OH)_4$and also in hornblende $(Ca,Na)_{2-3}(Mg,Fe,Al)_5(Si,Al)_8O_{22}(OH)_2$ (Hurtado et al., 2000; Fleischer and Robinson, 1963). Owing to the universal presence of fluorides in earth's crust, all water contains fluorides in varying concentrations ranging from trace levels to several milligrams per litre (WHO, 1994). In surface fresh water such as rivers and lakes, fluoride concentrations are usually low, ranging from 0.01 to 0.3 mg/l (Murray, 1986). However,

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exceptionally high values can be found such that some lakes in Kenya have fluoride content >2000 mg/l. For example, Lake Nakuru, which is situated in the rift valley in Kenya, has a fluoride concentration of 2800 mg/l and it is reported that this is the highest natural fluoride concentration ever found in water (Murray, 1986). Some groundwater in Kenya, however, contains relatively low fluoride levels, even though concentrations may exceed the WHO guideline of 1.5 mg/l. For example, Bwibo et al. (1991) carried out a research on a small rural community located about 25 km Northeast of Nairobi. Most water samples from boreholes and wells contained fluoride of up to 9.5 mg/l (Nyaora, 1999).

Generally most groundwater sources have higher fluoride concentrations than surface water. As groundwater percolates through the weathered rock in the aquifers, it dissolves fluoride bearing minerals hence releasing fluoride into solution (Falvey, 1999; Cairncross and Feachem, 1991). The concentration of fluoride in groundwater is varied and depends on the geological formations traversed by water, temperature, pH, solubility of fluoride bearing minerals and the presence or absence of other precipitating or complexing ions (Parkhurst et al., 1996). Because of the large number of variables, the fluoride concentrations in groundwater can range from well under 1 mg/l to more than 35 mg/l (WHO, 1994).

Studies have shown that the problem of high fluoride content in groundwater is very acute in mainland Tanzania (Mjengera and Mkongo, 2002). Fluoride in drinking water exceeds WHO guideline of 1.5 mg/l in some of the groundwater supplies in Manyara, Arusha, Mara, Kilimanjaro, Mwanza, Shinyanga, Mbeya and Singida regions. Groundwater from Shinyanga area has fluoride content in the range of 110–250 mg/l. Other regions that are moderately affected are Tanga, Tabora, Kigoma and Dodoma. The high fluoride content is attributed to some geological processes such as volcanic activities, thermal springs and the presence of minerals such as fluorite and apatite in rocks. For example, borehole water in South Sanya corridor was found to contain up to 96 mg/l fluoride. An area west of Ngorongoro Crater had fluoride content in spring water between 40 and 140 mg/l (Mjengera and Mkongo, 2002).

India is one of the countries where fluoride concentrations of up to 38.5 mg/l have been reported. According to the Survey of the Status of Drinking Water Supply in Rural Habitation, conducted by the Rajiv Gandhi National Drinking Water Mission, there are about 9741 villages that have groundwater sources with fluoride contents of more than 1.5 mg/l (Agrawal, 1997).

High fluoride groundwater has also been reported in Mexico (Herrera et al., 2001). In Guadiana Valley Drinking Water Supply is obtained from underground wells and is characterised by a high content of fluoride. Hurtado et al. (2000) reported that in Los Altos de Jalisco, situated in central Mexico, communities use water with a fluoride concentration of up to 12.97 mg/l. Agrawal (1997) reports that in Sri Lanka, fluoride has a strong geographical control linked to climatic conditions, with high fluoride waters being restricted to the dry zone on the eastern side of the island. In some parts, wells have fluoride content >10 mg/l.

In northern China, high fluoride groundwater with fluoride concentration of up to 6.20 mg/l occurs in the Taiyuan basin (Qinghai et al., 2007). The study showed that high fluoride groundwater zones are mainly located in the discharge areas, especially in places where shallow groundwater occurs (the groundwater depth is <4 m). Modeling results indicated that in the recharge and flow-through area of the northern Taiyuan basin, interactions between groundwater and fluoride-rich minerals are the major factor for the increase of fluoride concentrations whereas in the discharge area of the northern basin, the evaporation as well as the mixing of karst water has greater contribution to the fluoride enrichment in groundwater.

A study was carried out on fluoride distribution in Ethiopia (Redda Tekle-Haimanot et al., 2005). Of the total 1438 water samples tested, 24.2% had fluoride concentration above the 1.5 mg/l guideline concentration recommended by World Health Organisation. The highest fluoride levels were recorded in the Rift Valley, where 41.2% of all samples exceeded the 1.5 mg/l level. Only 1.0% of the samples from the central and northwestern highlands and 10.0% in the southeastern highlands exceeded 1.5 mg/l. Larger proportions of deep wells (50.0%) and hot springs (90.0%) than shallow wells (27.2%) and cold springs (12.6%) exceeded the 1.5 mg/l level. The highest fluoride concentrations were recorded for Rift Valley lakes Shala (264.0 mg/l) and Abijata (202.4 mg/l) and the lowest in Lake Tana, and rivers, wells and springs in the highlands.

Groundwater is the most widely used drinking water source in the upper regions of Ghana. In most parts of the upper regions, groundwater fluoride ranges from 0.11 to 4.60 mg/l (Apambire et al., 1998). About 28% of the wells in the region have drinking water with fluoride concentration above the WHO recommended level. Apambire et al. (1998) recommended using geochemical health risk maps showing fluoride levels in groundwater so that health and water officials should have information on fluoride occurrence in groundwater.

Mgalela (1997) reported high fluoride groundwater in some parts of Gokwe district in Zimbabwe. He recommended a thorough mapping of all wells of this area to delineate those with fluoride content above optimum requirements.

In Malawi, the Ministry of Health and Population conducted a survey in Machinga on occurrence of high fluoride groundwater (MOH, 1996; Sibale et al., 1998). A few boreholes were sampled for fluoride determination in Machinga where fluoride content in water sources was as high as 8.6 mg/l (Sibale et al., 1998). In Nkhota Kota District, an area lying in the rift valley, water from hot springs has a