The occurrence and distribution of fluoride in groundwaters of Kenya

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ABSTRACT Water samples from 1286 boreholes from different parts of Kenya were analysed for their fluoride concentrations. The majority of the samples (61.4%) had fluoride ion concentrations above 1.0 parts per million, whilst 19.5% had above 5.0 ppm. Excess levels of fluoride were found to occur in most parts of the country, especially in the Nairobi, Rift Valley, Eastern and Central Provinces which contain approximately 59.5% of Kenya's population. The high fluoride areas tended to coincide with the geographic locations of volcanic rock in and around the Rift Valley region. It was also observed that the deeper the boreholes, the greater the tendency for higher concentration of fluoride in groundwater. The findings show that there is need to defluoridate groundwater in most regions of the country for the health of the majority of the Kenyan population if, as demanded by the increase in population, groundwater resources are to be exploited.

Existence et répartition du fluorure dans les eaux souterraines du Kenya

RESUME Des échantillons d'eau de 1286 puits de régions différentes du Keny a ont été analysés pour obtenir leur concentration de fluorure. La majorité des échantillons (61.4%) présentait plus de 1.0 parties par million d'ion fluorure, pendant que 19.5% en présentaient plus de 5.0 ppm. Des niveaux excessifs de fluorure ont été trouvés dans la majeure partie du pays; spécialement à Nairobi, dans le Rift Valley et les provinces de l'Est et du Centre du pays où est installée approximativement 59.5% de la population du Kény a. Les régions où il y a beaucoup de fluorure semblent coïncider avec les zones de roches volcaniques dans et autour de la Rift Valley. On a aussi observé que les puits les plus profonds ont une tendance a une plus forte concentration de fluorure. Les résultats prouvent qu'il y a une nécessité sérieuse de défluorérer l'eau dans des puits dans la plupart du pays pour la santé de la majorité de la population Kenyane, surtout avec l'augmentation de la population qui exige l'usage des ressources en eaux souterraines.
INTRODUCTION

Dental fluorosis has been known to be endemic to Kenya for many years (Akpabio, 1970; Bakshi, 1974; Bohdal et al., 1968; Munoz et al., 1964; Nair & Manji, 1982; Neville & Bras, 1953; Ockerse, 1953; Ongweny, 1973) and is considered today as one of the major dental public health problems of Kenya. Dental fluorosis is associated with the ingestion of high levels of fluoride ion in the diet (Dean, 1936), and in Kenya the major source of the ion is thought to be from drinking water, especially in those regions of the country associated with volcanic rocks and hot springs (Williamson, 1953). Other important sources of fluoride have been identified and these include foods and drinks (Gitonga & Nair, 1982), as well as dust in some of the lake regions; for example, around Lake Nakuru the dust has been shown to have concentrations of fluoride of between 2800 and 5600 ppm (Williamson, 1953).

The majority of Kenya's rainfall, at least that part of it which does not evaporate, passes through the surface soil and is stored underground. Groundwater is thought to form the major sources of water for the majority of Kenya's population. Though the country is well supplied with numerous rivers and streams, the majority contain water only during the rainy seasons (Ojany, 1974). Access to groundwater is made by digging holes in river beds, or by drilling wells and boreholes (of which there are several hundreds in Kenya).

Although the government of Kenya plans to supply the entire population with piped water by 2000 AD, less than a third of the country's population has access to improved water supply. Most of the rural population still continue to fetch water from rivers, streams, springs, boreholes and shallow wells, and use it without any form of treatment (Gitonga & Nair, 1982) except chlorination when the Ministry of Water Development of Kenya is involved in centralised distribution of water from boreholes.

All urban centres have improved water supply systems but in many cases, including the capital city Nairobi, these are not sufficient to supply all the inhabitants. For this reason the peripheral population of the urban areas are in a similar situation to those in the rural areas, being dependent on supplies of untreated water.

In Kenya, the only form of treatment carried out on groundwater is chlorination for urban supplies, and no treatment is provided for rural water supplies with boreholes as a source. For surface waters where there is visible turbidity, full treatment is provided; such treatment includes coagulation and flocculation with lime, sedimentation, filtration, chlorination, and pH adjustment (Gitonga & Nair, 1982).

The first attempt to study the occurrence and distribution of fluoride ion concentrations in groundwaters of Kenya was probably by Williamson (1953). The study examined results available from analyses carried out by the Government Chemist of fluoride levels in borehole waters. The spatial distribution of some 200 boreholes was plotted on a map of the country, indicating that many parts of Kenya suffered from excessively high levels of fluoride.

In some areas extremely high levels of fluoride ion concentrations were reported - for example the highest levels in wells was 39.0 ppm, in boreholes, 43.50 ppm, in Lake Elementaita 1640 ppm and in Lake
Nakuru 2800 ppm.

A similar conclusion was reported by Ongweny (1973) who plotted the spatial distribution of the fluoride ion concentrations of some 500 samples of water from boreholes. Both studies provided some indication of the areas of the country where excess fluoride may be found, though information was either lacking or inadequate to provide a comprehensive picture of the occurrence and distribution of fluoride in groundwaters for many parts of the country.

Over the last four years a study sponsored by the International Development Research Centre (Canada) and the Ministry of Water Development (Kenya) was carried out by researchers in the Department of Mechanical Engineering and the Department of Dental Surgery of the University of Nairobi. Samples of water from 1286 boreholes and wells from different parts of the country were analysed for their fluoride ion concentrations. This paper is based on the results obtained in that survey, and is an attempt to describe the occurrence and distribution of fluoride in waters from boreholes and wells in Kenya. Dental data related to the prevalence of fluorosis were also collected and are summarized by Gitonga & Nair (1982).

METHODS AND MATERIALS

There are numerous problems involved in attempting to survey the fluoride levels of groundwaters. Whilst there are known to be several hundred boreholes and wells in Kenya, accurate information about the exact number and their locations is often lacking. Many boreholes and wells may be situated in areas that are not easily accessible to investigators, whilst no records may be available of the existence of others. Attempts to construct a sampling frame for the population of boreholes and wells are thus riddled with difficulties. Such difficulties are exacerbated by the fact that the fluoride ion concentrations of water from one borehole may vary dramatically from one week to another, and from one season to another, depending on the amount of water drawn in a given period, and depending on the amount of rainfall during the year. The picture is further complicated by the fact that boreholes and wells may be of different depths and may thus pass through rocks containing different concentrations of fluoride. Variations in the amount of limestone at different depths may also influence the amount of available fluoride. Moreover, two boreholes of similar depth situated 100 m apart may often contain dramatically different concentrations of fluoride ion in solution. The logistics of attempting a survey of this nature are thus quite substantial, and it was felt that no clearcut method for collecting samples for analysis could be developed which could avoid such difficulties. With the aid of the Ministry of Water Development, however, it was possible to arrange the collection of water samples from some 1290 boreholes and wells which were currently being utilized. The location of the boreholes or wells was known for all but a few samples: those about which there was no information available have been excluded from the analysis which follows.

Analysis of water for fluoride content was carried out at the Public Health Engineering Laboratory of the Civil Engineering
Department of the University of Nairobi, at the laboratory of the Government Chemist, and at the Water Laboratory of the Ministry of Water Development. All samples were analysed in a similar manner using a "fluoride meter" having a fluoride ion activity electrode and a reference electrode. Details of the method used are described by Gitonga & Nair (1982).

For the purpose of this paper, the results of fluoride ion concentrations (in parts per million) were grouped together according to the province and the district from which the sample was obtained. For administrative purposes Kenya is divided into eight provinces, each subdivided into a number of districts (Fig.1).

![Location map](image-url)
Fluoride in groundwaters of Kenya

Though the fluoride ion concentration of each water sample was recorded, the results presented here are in terms of the number and reading of 0.0-0.4 ppm, 0.5-1.0 ppm, 1.1-3.0 ppm, 3.1-5.0 ppm, 5.1-8.0 ppm, and >8.1 ppm. The maximum value for each district and province have also been provided here.

In order to illustrate the geographical distribution of the findings, Figs 1 and 2 were drawn showing the proportion of boreholes in each district found to have fluoride concentrations above, respectively, 1.0 ppm and 5.0 ppm.

It should be noted that the findings reported here relating to Nairobi Province refer to the boreholes in use primarily in the peri-urban areas of the city. Central Nairobi is supplied by centralized municipal supplies obtained from surface waters that are relatively low in fluoride (between 0.4 and 1.2 ppm).

RESULTS

In all, 1286 samples of water were analysed; 183 from Nairobi Province, 13 from Western Province, 93 from Coast Province, 31 from Nyanza Province, 181 from Eastern Province, 76 from North Eastern Province, 313 from Rift Valley Province, and 396 from Central Province (Fig.1).

Of the samples analysed, 248 (19.3%) had fluoride ion concentrations between 0.0 and 0.4 ppm; 247 (19.2%) between 0.5 and 1.0 ppm; 411 (31.9%) between 1.1 and 3.0 ppm; 129 (10.0%) between 3.1 and 5.0 ppm; 99 (7.7%) between 5.1 and 8.0 ppm; and 152 (11.8%) of 8.1 and over (Table 1).

<p>| TABLE 1 Number of groundwater samples in each district in Kenya containing various levels of fluoride (in ppm) |</p>
<table>
<thead>
<tr>
<th>Province/District</th>
<th>0.1-</th>
<th>0.5-</th>
<th>1.1-</th>
<th>3.1-</th>
<th>5.1-</th>
<th>&gt;8.1</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.4</td>
<td>1.0</td>
<td>3.0</td>
<td>5.0</td>
<td>8.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NAIROBI</td>
<td>18</td>
<td>18</td>
<td>36</td>
<td>24</td>
<td>29</td>
<td>58</td>
<td>183</td>
</tr>
<tr>
<td>CENTRAL PROVINCE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kiambu</td>
<td>88</td>
<td>69</td>
<td>100</td>
<td>28</td>
<td>21</td>
<td>32</td>
<td>338</td>
</tr>
<tr>
<td>Kirinyaga</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Murang'a</td>
<td>5</td>
<td>4</td>
<td>6</td>
<td>3</td>
<td>-</td>
<td>1</td>
<td>19</td>
</tr>
<tr>
<td>Nyandarua</td>
<td>5</td>
<td>7</td>
<td>11</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>27</td>
</tr>
<tr>
<td>Nyeri</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>-</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Total Province</td>
<td>102</td>
<td>84</td>
<td>120</td>
<td>36</td>
<td>21</td>
<td>33</td>
<td>396</td>
</tr>
<tr>
<td>COASTAL PROVINCE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kilifi</td>
<td>20</td>
<td>9</td>
<td>14</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>48</td>
</tr>
<tr>
<td>Kwale</td>
<td>8</td>
<td>6</td>
<td>6</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>22</td>
</tr>
<tr>
<td>Mombassa</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Taita Taveta</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>Tana River</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>(Lamu)</td>
<td>-</td>
<td>-</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Total Province</td>
<td>38</td>
<td>21</td>
<td>25</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>93</td>
</tr>
</tbody>
</table>
Western Province was found to have the highest proportion (76.9%) of boreholes with fluoride concentrations below 0.5 ppm (though the
FIG. 2  Percentage of boreholes sampled in each district with fluoride concentrations ≤ 1 ppm.

FIG. 3  Percentage of boreholes sampled in each district with fluoride concentrations > 5 ppm.
number of samples from that province was small), whilst North Eastern Province had the lowest proportion in that range (9.2%). In the range 0.5-1.0 ppm, Nyanza and North Eastern Provinces had the highest proportions (29.0% and 28.9% respectively), whilst Nairobi had the lowest (9.8%). Nairobi had the highest proportion of boreholes with fluoride concentrations above 8.0 ppm, whilst North Eastern, Coast and Nyanza Provinces had the lowest.

The rank order of provinces in terms of the proportion of samples that had concentrations of fluoride above 1.0 ppm was as follows: Nairobi (80.3%), Rift Valley (70.3%), Central (53.0%), Nyanza (45.2%), Coast (36.6%), and Western (7.7%).

However, the ranking changed when the proportion of samples having fluoride concentrations above 5.0 ppm were examined. These were: Nairobi (37.5%), Eastern (22.1%), Rift Valley (17.9%), Central (13.6%), Nyanza (9.7%), North Eastern (7.8%), Western (7.7%), and Coast (4.3%).

Ranking the province in order of the maximum values of fluoride concentrations recorded (Table 2) provided: (1) Rift Valley, (2) North Eastern, (3) Nairobi, (4) Central, (5) Eastern, (6) Coast, (7) Nyanza and (8) Western.

**TABLE 2 Maximum fluoride ion concentrations (ppm) recorded for water samples taken in each province**

<table>
<thead>
<tr>
<th>Province</th>
<th>District</th>
<th>Fluoride conc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nairobi</td>
<td>Murang'a</td>
<td>30.2</td>
</tr>
<tr>
<td>Central</td>
<td>Taita Taveta</td>
<td>22.0</td>
</tr>
<tr>
<td>Coast</td>
<td>Machakos</td>
<td>15.0</td>
</tr>
<tr>
<td>Eastern</td>
<td>Wajir</td>
<td>19.3</td>
</tr>
<tr>
<td>North Eastern</td>
<td>Kisumu</td>
<td>36.2</td>
</tr>
<tr>
<td>Nyanza</td>
<td>Bungoma</td>
<td>10.4</td>
</tr>
<tr>
<td>Rift Valley</td>
<td>Nakuru</td>
<td>57.0</td>
</tr>
<tr>
<td>Western</td>
<td></td>
<td>7.1</td>
</tr>
<tr>
<td>Nationally</td>
<td></td>
<td>57.0</td>
</tr>
</tbody>
</table>

Whilst the exact rank order changed according to the particular criterion used above, broadly speaking Nairobi, Rift Valley, Central and Eastern Provinces tended to maintain their positions at the top of the "league", whilst Nyanza, Coast and Western Provinces tended to remain at the bottom.

Nationally, 61.4% of the samples examined had a fluoride ion concentration above 1.0 ppm, whilst 19.5% were above 5.0 ppm.

The districts which were found to have all fluoride levels at or below 1 ppm were: Busia, Kakamega, Tana River, Kisii, Siaya, Elgeyo Marakwet, and Kirinyaga. Of these, Tana River, Kisii and Kirinyaga had maximum fluoride concentrations of less than 0.5 ppm.

Figures 2 and 3 illustrate the findings geographically, indicating the proportion of samples from each district that were, respectively, above 1.0 ppm and above 5.0 ppm. It may be seen that,
with the exception of a few districts in the west, one district centrally, and one in the east, most of the country appeared to have more than 10.0% of samples showing concentrations above 1.0 ppm (Fig.2). In general, those districts which had a large proportion of samples with fluoride concentrations above 1 ppm were also the districts which were found to have a large proportion of sampling containing more than 5.0 ppm (Fig.3). No information was available from two districts: Lamu (Coast Province), and Nandi (Rift Valley Province).

DISCUSSION

The findings of this survey confirmed the observations of previous investigators that, in general, Kenya has extremely high levels of fluoride ion in its groundwaters (Ongweny, 1973). Some caution is necessary in interpreting the findings of the present study too rigidly for the reasons outlined in the section Methods and Materials. Because the fluoride concentrations of any one borehole varies substantially throughout the year, the values given here do not necessarily reflect the actual levels that may exist at all times; nor do they reflect the actual or constant exposure to fluoride of the population of Kenya. Rather, they may provide some indication as to the potential exposure to fluoride that may exist from groundwater sources. It should be emphasized here that it is not known what proportion of the population utilizes such groundwaters for drinking purposes. During the survey no information was collected about the utilization pattern of boreholes and wells from which the samples were obtained. Clearly, future studies should seek to obtain such information.

The number of samples obtained from some districts was relatively small and firm conclusions cannot be drawn about the amount of fluoride to be found in the groundwaters of these places. In many cases relatively few samples were obtained either because the areas were sparsely populated, or because there were adequate supplies of surface waters for the population; in the west, for example, Lake Victoria provides an important source of water for the population. In both cases, fewer boreholes or wells would have been drilled.

Despite these cautionary points, the picture nevertheless emerges of a country where most districts were found to have high levels of fluoride ion in groundwaters. It is a matter of some concern for health workers in Kenya that some two-thirds of our groundwaters were found, in this study, to have levels above 1.0 ppm, whilst nearly one-fifth showed readings above 5.0 ppm. The extremely high concentrations of fluoride found in all provinces of the country are of no less concern.

Nairobi, Rift Valley, East and Central Provinces were found to have the highest proportion of borehole samples which showed a reading above 1.0 ppm of fluoride and were amongst the provinces showing the highest concentrations of fluoride, confirming the descriptions reported by Sheikh (1981). These provinces account for approximately 59.5% of Kenya's population (the total population of Kenya in 1979 was estimated to be 15 327 061 (Central Bureau of Statistics, 1981)). Nyanza, Coast and Western Provinces, which
tended to occupy the lower end of the high fluoride "league" contain about 38.1% of the population. Whilst North Eastern Province which showed relatively high fluoride levels is a sparcely populated area containing approximately 2.4% of the population.

The impression obtained from mapping the findings (Figs 2 and 3) is that of high fluoride levels in groundwaters to be found in a broad band passing from the north, along the borders with Sudan and Ethiopia, southwards to the border with Tanzania. This north-south band coincides approximately with the position of the Rift Valley which cuts through Kenya and the countries south of Kenya.

It is worth noting that the occurrence of fluorosis has been reported from both Ethiopia (Olsson, 1979) in the north, and from Tanzania (Gretch & Latnam, 1961) in the south. A further band of high fluoride is apparent (Figs. 2 and 3) stretching from the central part of Kenya northeastwards to the borders with Ethiopia and Somalia.

The high fluoride areas indicated by Figs 2 and 3 appear to show quite a close association with the distribution of volcanic rock occurring in the Rift area of Kenya (Fig.4). This volcanic rock is known to be rich in fluorides, particularly in the form of fluoride (or fluospar), CaF$_2$, thought to be formed by the action of fluorine gases passing through limestone in the course of volcanic activities which took place during the formation of the Rift Valley (Nyamweru, 1980). (Fluorite is in fact mined commercially in Kenya in the Kerio Valley.) That fluoride concentrations in groundwater samples examined in this study should show a distribution similar to that of the fluoride-rich volcanic rocks found in Kenya suggests that despite the limitations in the method of obtaining samples discussed above, a reasonably accurate picture of the fluoride distribution in groundwaters of Kenya may have been obtained.

Dental fluorosis has been reported to be endemic to Kenya by a number of investigators (Akpabio, 1970; Bakshi, 1974; Bohdal et al., 1968; Munoz et al., 1964; Nair & Manji, 1982; Neville & Brass, 1953; Okerse, 1953; Ongweny, 1973) and the high prevalence of this condition may possibly indicate that groundwaters form an important source of fluoride in the diet. If the samples examined in this study are indicative of the fluoride levels in drinking waters consumed by the population, then only Kisii District (Nyanza Province) and Kirinyaga District (Central Province) are possibly in need of fluoridation of their water supplies to within the range of 0.5-1.0 ppm.

FIG. 4    Distribution of Eocene to recent volcanic rocks (shaded areas) in the Rift area of Kenya (Nyamweru, 1980).
All remaining districts are in need, to a greater or lesser extent, of partial defluoridation of water to obtain optimum levels. Those districts in which less than 50.0% of the water samples had more than 1 ppm were: Kirinyaga and Nyeri, in the Central Province; all districts in Coast Province; Kitui, Marsabit and Meru in Eastern Province; Kisii, Siaya and South Nyanza in Nyanza Province; Baringo, Elgeyo Marakwet, Trans Nzoia, Turkana and Uasin Gishu in Rift Valley Province; and all districts in Western Province. All other districts had more than 50.0% samples above 1.0 ppm.

Clearly if the waters examined here are being drunk by humans then the majority of groundwater sources in Kenya are in need of defluoridation. The logistics of carrying out such an exercise are substantial. Since there are several hundred boreholes and wells in Kenya, it would prove excessively expensive to provide small defluoridation plants for each such source of water, using presently known methods of partial defluoridation (Walvekar & Quereshi, 1982). There is an urgent need for research to be carried out to investigate economic and cost-effective methods of partial defluoridation. In the longer term, only the provision of piped water from centralized water plants where partial defluoridation may be undertaken economically will effectively overcome the problems of excess levels of fluoride.

In a third world country such as Kenya, where the majority of the population has poor access to water, public health workers must of necessity exercise some sensitivity when raising the need for partial defluoridation of water to optimum levels, no matter how strongly this need may be felt.

Priorities must be set, and these may be encapsulated in the slogan "Water First - then purification". Yet we are faced with the dilemma that the lack of purity of water contributes to the widespread occurrence of preventable disease - in this instance, fluorosis - which itself entails an economic cost on the limited resources of the country.

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