EARTHWATCH
GLOBAL ENVIRONMENT MONITORING SYSTEM

ENDEMIC FLUOROSIS - A GLOBAL HEALTH ISSUE

A technical report for the
Human Exposure Assessment Locations Project

United Nations
Environment Programme

World Health
Organization

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CONTENTS

1. INTRODUCTION

Fluoride is one of the essential trace elements, a lack of which is manifested as dental caries throughout many parts of the world, yet excess fluoride is responsible for more serious disease (WHO, 1984b). High intakes of dietary fluorides have been shown to cause fluorosis in men, women and children as well as in agricultural animal species. High-fluoride levels also affect plant growth. Fluorosis has been described by Belyakova and Zhavoronkov (1978) as one of the most widespread endemic diseases.

The first reports of occurrence of dental fluorosis date back to 1888 where "black teeth" in a family in Durango in Mexico were described by Kühns. Subsequently, erosion of dental enamel was described by Vainicher among inhabitants in Naples, Italy in 1891, and Italian migrants to the U.S.A. from towns near Naples (Eager 1901; cited by Belyakova and Zhavoronkov, 1978). Subsequently, dental fluorosis was described in the early 1900s at locations in the U.S.A. including Nevada, Colorado, western Texas, New Mexico, Virginia, Arizona, North and South Dakota, Idaho, southern California, Utah, Illinois and Minnesota (Black and McKay, 1916; Fleischer, 1962) and subsequently, in many other countries around the world.

Endemic fluorosis is manifested as dental fluorosis with the appearance of yellowish to brownish striations or mottling of teeth, and/or skeletal fluorosis where osteosclerosis, ligamentous and tendinous calcification and extreme bone deformity result (WHO, 1984b). Endemic fluorosis is global in scope, occurring on all continents and affecting many millions of people, although no accurate world-wide data exist on total numbers affected. Some numbers are, however, available at the national level. In China, 38 million have been reported to have dental fluorosis and 1.7 million exhibit skeletal fluorosis (Anon., 1990). In India, Susheela and Das (1988) suggest that around 1 million people suffer the serious and incapacitating skeletal fluorosis. People in Kenya and Tanzania too are reported to suffer from fluorosis with several million exposed to high-fluoride concentrations.

Using the Chinese dental : skeletal fluorosis ratio, India could have approximately 20 million people with dental fluorosis. Indeed Mangla (1991) mentions that fluorosis affects an estimated 25 million people in India. Thus in India and China alone, over 60 million people may exhibit endemic dental fluorosis. When the distribution in Africa and the eastern Mediterranean is taken into account in particular, the global value could approach 70 million. Zahvoronkov and Strochkova (1981) proposed that the global total affected by the disease was approximately 20 million, but this estimation is too low and is only half of the recorded numbers reported from China alone.

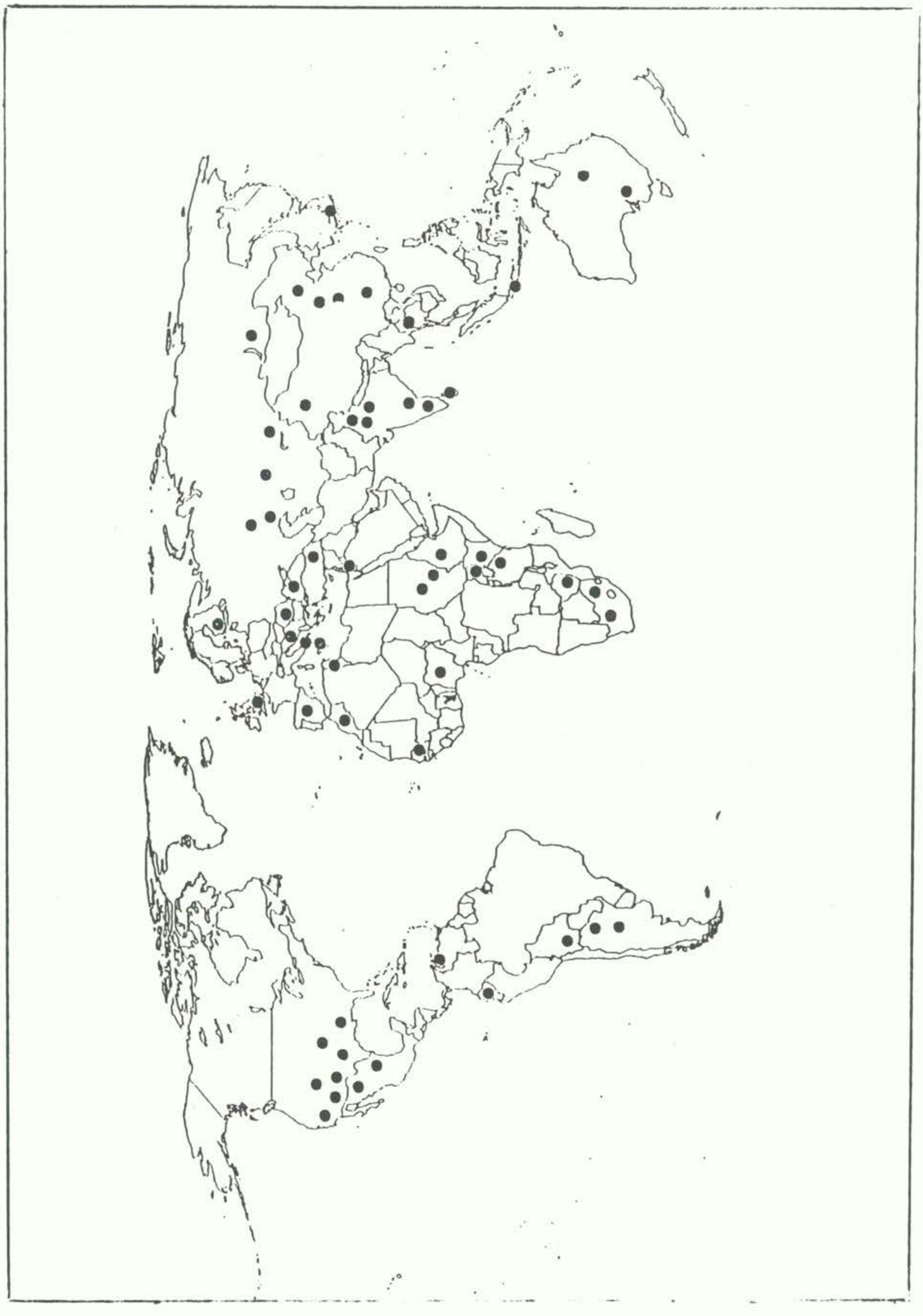
High-fluoride concentrations and potential human and agricultural-animal impacts can also be produced by anthropogenic emissions from aluminium smelters and brick kilns in particular, as well as other occupational exposures. Such incidents are not considered as endemic fluorosis and are omitted from this report. They have, however, been recently reviewed by USPHS (1991) from a public health point of view. Another topic also omitted is the occurrence of organo-fluorine compounds produced by particular plant species which also give rise to nutritional diseases in humans and animals (McEwan, 1964).

2. WORLD-WIDE OCCURRENCE

Fluorosis is often described as an endemic disease of tropical climates. High-fluoride rocks, soils and hence ground waters associated with particular geological formations, occur in what can be described as large geographic belts. Typical examples include a belt extending from Turkey across the eastern Mediterranean into Africa and down the east coast to South Africa. Other belts extend from Turkey across to India, China, Korea and Japan. In the Pacific, fluorosis has also been recorded in Australia and Indonesia and in South American countries such as Bolivia, Argentina and Equador. In earlier years, fluorosis has been recorded in European countries such as the U.K., The Netherlands, Italy, Hungary, Greece and Spain. The U.S.A. and Canada too have areas of high-fluoride concentrations along with Mexico. High-fluoride concentrations, including fluorosis, have been recorded in republics of the former U.S.S.R., Bulgaria and Hungary. World-wide occurrences of endemic fluorosis are illustrated in Figure 1. Endemic fluorosis country by country is discussed in Section 4.

High-fluoride levels in soils and waters can also be associated with geothermal areas and volcanic activity throughout the world. High-fluoride levels are not, however, only found in tropical climates. The Narsaq River in west Greenland, for example, contains elevated levels of fluoride - 2 mg l^{-1} in summer and 10-20 mg l^{-1} in winter where fish have been reported to accumulate fluorides to high levels (Christensen, 1987).

Figure 1 Map showing the world-wide occurrence of endemic fluorosis whether of the dental or skeletal type. The map has been stylized to illustrate the global extent of fluorosis rather than indicate the exact location of all known occurrences of this endemic disease.



3. AETIOLOGY OF FLUOROSIS AND EXPOSURE ROUTES

Fluorosis is an ancient disease, being recorded as dental fluorosis in the skull of the Xujiayao Man dated at around 100,000 B.C. in China. Other early Chinese texts refer to "yellow teeth" now recognized as fluorosis (Anon., 1989).

Traditionally, fluorosis is considered to arise from drinking high-fluoride surface, shallow- and deep-well waters, although foods containing elevated levels of fluoride grown on fluoride-rich soils, or from irrigated soils, are consumed by many people. Indeed, a number of examples appear in the literature where fluoride concentrations in water do not correlate with the severity of fluorosis (refer Section 4). The inadvertent consumption of high-fluoride dusts on vegetables from fluoride-rich soils or inhalation of such dusts are additional exposure pathways although they have not been adequately evaluated.

High-fluoride teas also provide a large source of fluoride to many people especially in Asia and the western Pacific. Traditionally in Indonesia, for example, the mean fluoride concentration in infused tea is around 2 mg l^{-1} (Effendi and Wibowo, 1984). In parts of China, however, brick tea contains up to 600 mg kg^{-1} giving rise to a concentration in solution of 3 mg l^{-1} (refer Section 4 (iv), (a) China). Skorkowska-Zieleniewska (1983) has shown that, on the basis of heavy tea and coffee drinking, the urinary loading of fluoride is similar to endemic or industrial fluorosis, i.e., 5-10 mg fluoride l^{-1}.

Another unusual dietary source is the consumption of high-fluoride salt where 4-5 mg fluoride day^{-1} is ingested. Typical areas are China, Thailand, Myanmar (Burma) and Vietnam (Section 4). Similarly in Tanzania, the use of high-fluoride sodium bicarbonate encrustrations from soda lakes in cooking, can lead to the ingestion of approximately 5 mg fluoride day^{-1} (Aswathanarayana, Lahermo, Malisa and Nanyaro, 1985) (refer Section 4 (ii), (d) Tanzania). The inhalation of fluorides from indoor air, following the combustion of high-fluoride coal in parts of China, is another major exposure route giving rise to severe fluorosis over extensive areas.

Traditionally, fluorosis is characterized by the relatively clear-cut symptoms of dental fluorosis or the more debilitating skeletal fluorosis. Measurements of fluoride concentrations in drinking water compared with guideline values can be used to indicate the potential for fluorosis development although many environmental and nutritional factors including other fluoride sources can modify such interpretations. For example, the "safe level" of fluoride in rural Thailand has been calculated to be 0.4 to 0.6 mg fluoride l^{-1} in water (refer Section 4 (ii), (b)). Yet the WHO guideline for drinking-water quality is 1.5 mg l^{-1} (WHO, 1984a) and some countries fluoridate their water to approximately 1 mg l^{-1}. Such differences largely relate to differences of temperature and hence, volume of water consumed, i.e., the fluoride dose. Measurements of environmental levels of fluorides can, therefore, provide useful data on the extent of fluoride-rich rocks, surface and ground waters etc., although these provide only an indication of exposure potential.

Measurements have been made of fluoride absorption, retention and distribution in blood and on excretion via urine, faeces etc. (WHO, 1984b), although many of these studies relate to occupationally-exposed workers. Several reports have appeared on the relationship between fluoride levels in plasma (which contains much of the fluoride) and fluoride intake indicating that it can be a useful indicator medium (Rajyalakshmi, and Rao, 1985). Since the principal route of fluoride excretion is via the urine, urinary fluoride has also been used to estimate dose (WHO, 1984b). In the case of fluoride exposure via drinking water, it has been reported that the fluoride concentration in urine of groups of people is comparable with that in the drinking water (Rajyalakshmi and Rao, 1985).

About half of the fluoride absorbed by humans is rapidly taken up by bone by replacing hydroxide ions in bone apatite. Fluoride remobilization from bone is reported to be reversible (Rajyalakshmi, Rao and Krishna, 1987). Excretion of fluoride via the urinary route from skeletal fluorosis patients has been shown to take place slowly and over many years (Rao, Murthy and Murthy, 1979; Grandjean and Thomson, 1983).

WHO (1984b) suggests that hair and nails may be useful indicators of long-term fluoride exposure although little reliable data is available. Further research into biological monitoring methods are certainly required.

Depending on geographic and geological conditions, many people suffering from fluorosis may have multiple-exposure pathways. A major world-wide study is required to assess the magnitude and significance of all pathways, for until such data are available, the elimination of fluorosis as a major world-wide health issue cannot adequately be effected.

4. ENDEMIC FLUOROSIS BY COUNTRY

Endemic fluorosis is for convenience discussed country by country in this section. Such reports should not, however, be taken to indicate that all people, or all villages, in an affected area are exposed to elevated levels of fluorides in water, food, smoke, dust etc. Geological conditions, giving rise to fluoride-rich water and soil, can vary over relatively short distances. Exposure routes, nutritional conditions, climatic differences and societal variations can also markedly affect the development of fluorosis as is discussed below.

In the absence of analytical quality control information in many of the reports cited, no opinion can be expressed on the validity of the analytical data detailing concentrations of fluorides in the various environmental media analyzed. All of the results presented are considered to be accurate, precise and reliable. It is not known, for many of the reports, whether the concentrations reported vary markedly throughout the year, or whether the values quoted represent "typical" concentrations. Likewise, no comment has been made on the reliability of the epidemiological data.

Reporting of the studies cited does not imply an opinion of their validity whatsoever either on the part of the World Health Organization (WHO), or, the United Nations Environment Programme (UNEP) Global Environment Monitoring System.

(i) Eastern Mediterranean

Typical examples of endemic fluorosis, both dental and skeletal, are associated with certain geological formations particularly those of marine origin. Belts of fluorosis extend from Turkey through Syria, Jordan, Oman, Yemen (Kumar and Kemp-Harper, 1963), Egypt, Libya and Algeria to Morocco and from Egypt through the Rift Valley to Sudan (Smith, Harris and Kirk, 1953; Emslie, 1966), Ethiopia (Littleton, 1963), Uganda, Kenya, Tanzania to Zimbabwe and parts of South Africa (refer Section 4 (ii)). In all cases, high-fluoride concentrations occur in drinking water often from ground-water supplies, for example, up to 5.6 mg l^{-1} in Oman (Gamble and Biggin, 1987), although the intake of dust from the fluoride-containing soils, food grown on such areas, as well as lake and river fish, contributes to a multiple-exposure pathway. Other environmental factors, such as altitude and temperature and nutritional factors such as calcium intake, modify simple dose-response relationships. Several countries where reliable data have been published are discussed in more detail below.

a. Turkey

Endemic fluorosis, both dental and skeletal types, has been described from areas in Turkey (Tuncel, 1984). Drinking water in the endemic fluorosis area of Dogu-be-Yazit contained 3.5 to 12.5 mg l^{-1} which had resulted in skeletal fluorosis in males aged over 40 years. In those over 60 years of age, a significantly higher incidence of Moenckeberg calcifications, seen as ring-like calcifications, was observed following X-ray analyses compared with control groups living in areas of 0 to 0.45 mg fluoride l^{-1}. Moenckeberg calcifications in the iliac and femeral arterial areas were seen in 26 per cent of those suffering from skeletal fluorosis. According to the statistical analyses, the degree of calcification was correlated with the severity of fluorosis, although its cause was not examined.

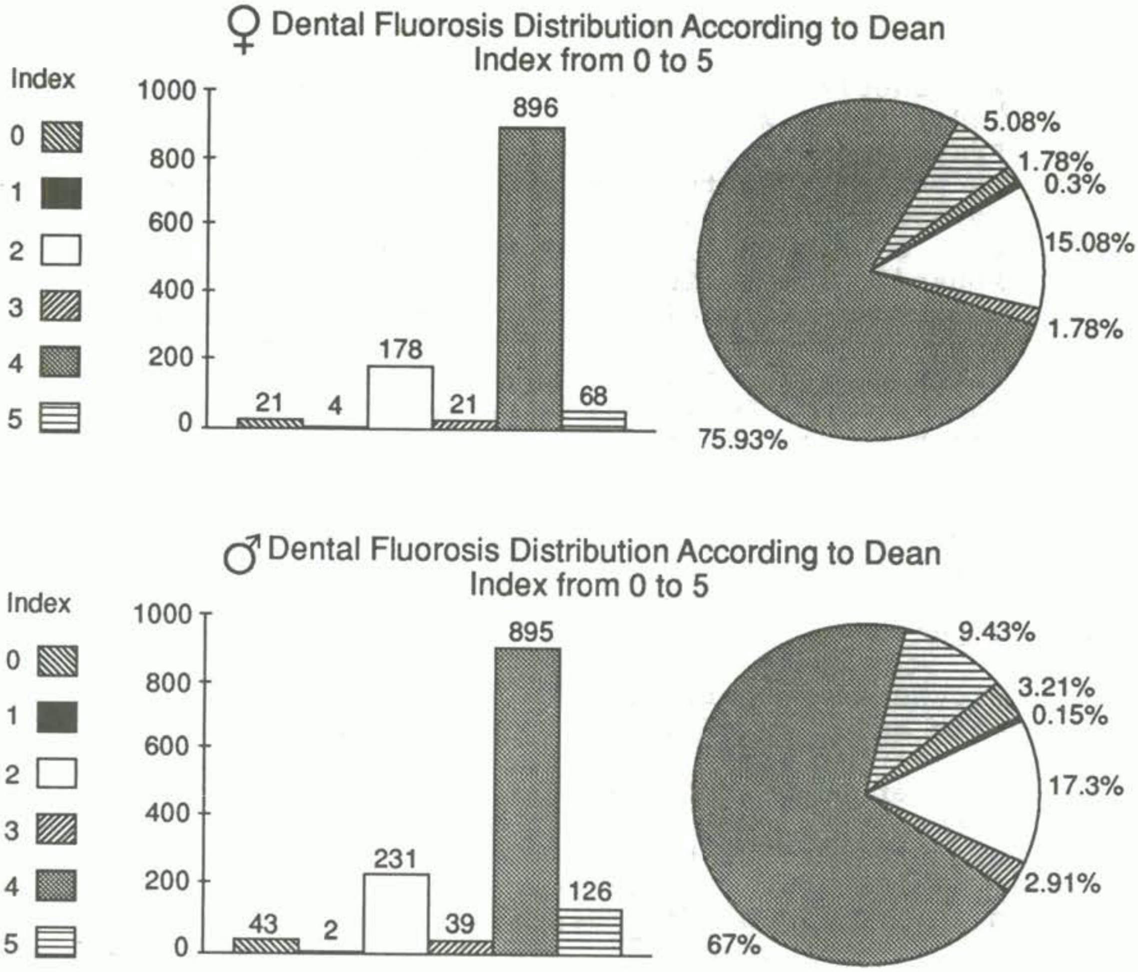
b. Jordan

Reports from the Jordanian Ministry of Health have indicated that the fluoride concentrations in drinking water range from 0.40 to 1 mg l^{-1} in most parts of the country except near the Al-Hassa phosphate mines where it was 2 mg l^{-1}. In one study, 2,516 school children from 26 schools in 12 cities from north to south were examined and only 64 were free from dental fluorosis (Bilbeissi, Fraysse, Mitre, Kerebel and Kerebel, 1988). Around 70 per cent of the children could be considered to have severe dental fluorosis at scale 4 on the Dean Index of 0 to 5 (Figure 2) (The Dean Index is described in Appendix I). Drinking water from taps ranged from 0.21 to 0.98 mg l^{-1}, although well water contained higher concentrations. The finding of such severe dental fluorosis with relatively low fluoride concentrations was unexpected. Daily tea drinking, as well as low nutrition and high mean temperatures, must also be taken into account. The low levels of fluoride in drinking water where severe fluorosis occurs are well within the range where fluoridation of water is authorized in some countries.

c. Israel

Ground-water surveys have been carried out on the two main aquifers of Israel, the central coastal plain aquifer in 1973 (Kanfi and Ronen, 1976) and the mountain aquifer in 1975 (Ronen and Kanfi, 1978) which provide approximately 80 per cent of Israel's total ground-water production. Of the 1,119 wells sampled on the coastal plain aquifer, the average fluoride concentration was 0.20 ± 0.21 mg l^{-1} (mean ± S.D.) with a range of < 0.01 to 1.70 mg l^{-1}. In 95 per cent of the wells, the fluoride concentration was below 0.7 mg l^{-1}, the desired level. In the mountain aquifer, 215 wells were sampled. The average concentration was 0.31 ± 0.17 mg l^{-1} (mean ± S.D.). With a range of < 0.01 to 0.80 mg l^{-1}. In most of the wells, the fluoride concentration was below the desired level according to national drinking-water standards.

Figure 2 Distribution of dental fluorosis in 2,516 children aged 6-13 years in Jordan in relation to the severity on the Dean Index (Bilbeissi et al., 1988).



d. Morocco

A number of reports have described dental fluorosis in children and adults at locations in Morocco (Poulsen, Müller, Naerum et al., 1972; Poulsen and Müller, 1974; Haikel, Cahen, Turlot and Frank, 1989). Even dental fluorosis has been reported in the primary dentition and in a range of farm animals (Murray and Wilson, 1948).

Based on the Dean system of a six-point scale, mean scores up to 4.7 were found at locations throughout Morocco. In some areas, notably Khouribya, endemic fluorosis was considered to be due primarily to inhalation of high-fluoride phosphate dust from the phosphate mining area (Haikel, Voegel and Frank, 1986), although high-fluoride waters have also been implicated in the same area (Murray and Wilson, 1948).

(ii) Africa

Extensive areas of high-fluoride ground waters and some surface waters occur in many countries, especially in the eastern sectors of this continent. Fluorosis occurs in Ethiopia and Somalia in the north through Kenya, Uganda to Tanzania, Zimbabwe and South Africa (Nair, Manji and Gitonga, 1984).

a. Ethiopia

The volcanic Rift Valley, where many of the major settlements occur, extends from north to south of the country. The fluoride concentration of drinking water at various points in the valley range from 1-36 mg l^{-1}. Most of the water comes from boreholes, particularly deep boreholes. Endemic fluorosis is prevalent in many cities (Olsson, 1979).

The prevalence rate of dental fluorosis in children ranged from 69-98 per cent (Haimanot, Fekadu and Bushra, 1987). Skeletal fluorosis has also been reported. In the Wonji-Shoa sugar estates, for example, where the disease has been recorded, radiological evidence showed that 65 per cent of the 300 persons examined were affected. Of these, 30 (10 per cent) had crippling skeletal fluorosis and over 500 persons were retired because of their inability to perform strenuous work.

b. Sudan

Dental fluorosis has been recorded in children from Abu Deleig in the Butana Desert, east of Khartoum. The total incidence was 60 per cent (134 boys examined) and drinking water from nine of the 10 wells contained between 1.1 and 4.0 mg l^{-1} fluoride (Smith et al., 1953). A larger study covering 995 persons (489 females and 477 males), of which 645 were between 15 and 19 years of age, 177 were 10 to 14 years of age, and 54 under 10 years of age. Of the remainder, 111 covered the ages 20 to 60 and for eight, the ages were not stated. The average fluorosis gradings based on the Community Index of Mottling (Dean, 1942) by place of origin and degree of dental fluorosis are shown in Table 1 (The Community index F_{ci} is described in Appendix I). In fact, 39 per cent of all patients examined showed some degree of dental fluorosis. In the Butana, nearly 90 per cent had some mottling of the teeth and in nearly 50 per cent this was assessed as moderate to severe. By contrast, those coming from the south showed no mottling.

The concentrations of fluoride in well water in localized areas in the Sudan relate to the occurrence of dental fluorosis and have been mapped (Figure 3a and 3b). It was also reported that Khartoum tap water contained between 0.12 and 0.32 mg fluoride l^{-1} and that the White Nile increased from 0.4 mg l^{-1} to 1 mg l^{-1} in June. No skeletal fluorosis was recorded by the authors.

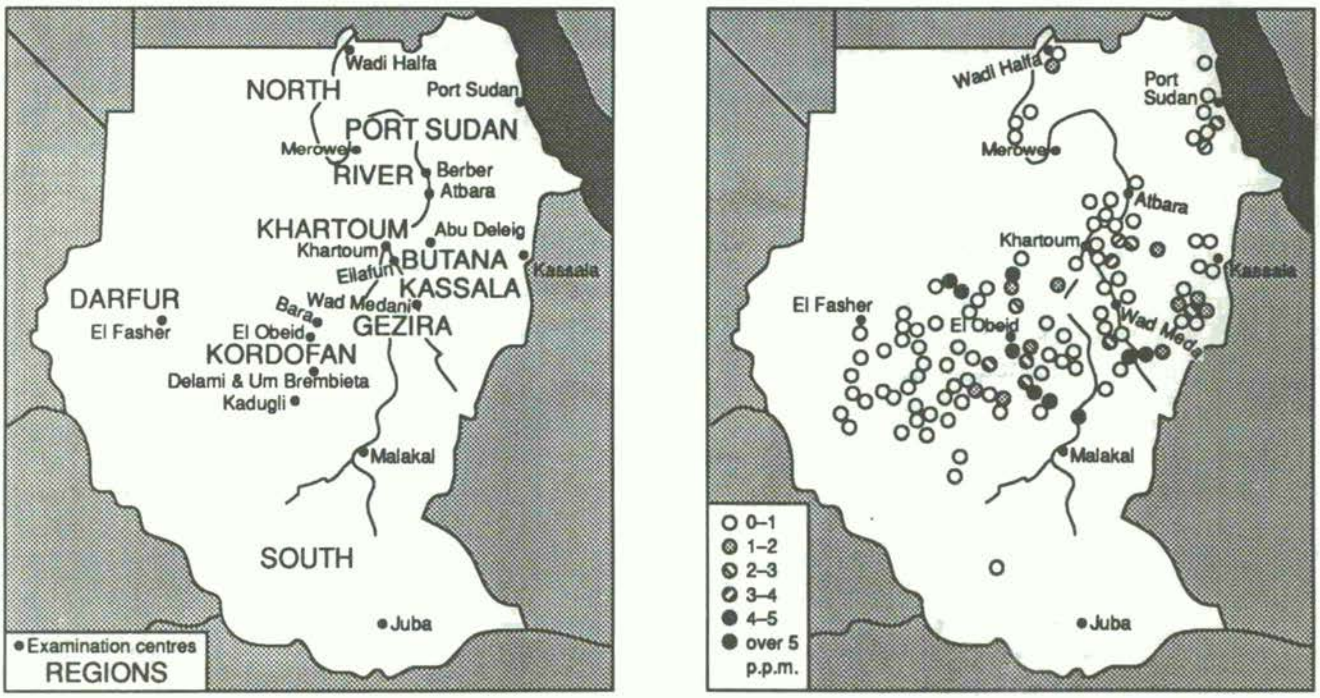
<u>Table 1</u> Average fluorosis gradings under the Community Index of Mottling (Dean, 1942) for persons from different geographical locations in the Sudan (Emslie, 1966).

Place	Gradings	
Butan	2.2	(107)
Kordofan	1.3	(232)
Gezira	0.8	(58)
North	0.7	(73)
Port Sudan	0.7	(8)
River	0.6	(92)
Kassala	0.4	(28)
Darfur	0.3	(16)
Khartoum	0.2	(123)
South	0.0	(64)
Not stated	0.5	(194)

Number of persons examined in parenthesis

<u>Figure 3</u> Map of Sudan showing: (A) regional locations used in the dental fluorosis study, and (B) concentration of fluoride in well waters (Emslie, 1966).

<u>A</u> <u>B</u>



c. Kenya

Dental fluorosis, which is endemic in Kenya, constitutes one of its major public health problems (Ockerse, 1953). Drinking water is the main source of the fluoride ion, especially in the Rift Valley associated with volcanic rocks and hot springs, although crops and local fish as well as dust from some lake basins are important local sources. Ground and surface water provide the major source for domestic water for most people in Kenya, and since the majority of Kenya's population live within the Rift Valley region, fluorosis is a health problem of major concern.

A detailed study of fluoride concentrations in over 1,000 ground waters has been made by Nair et al. (1984) and Nair and Gitonga (1985). Nationally, 61 per cent of boreholes had fluoride concentrations which exceeded 1 mg l^{-1} and almost 20 per cent were above 5 mg l^{-1} (Table 2). The Nairobi, Rift Valley, eastern and central provinces contain around two-thirds of the population where the highest fluoride levels are found. Thus around 10 million people are potentially exposed to excessive fluoride levels, but further data are needed on annual variations of concentrations of fluoride in well waters and the contribution of water to total exposure. In a WHO/FAO/UNICEF study (Bohdal, Gibbs and Simmons, 1968), 44 per cent of the 19,000 people examined had dental fluorosis. In a more recent study, Manji and Kapila (1986a) reported the highest level of fluorides was 39 mg l^{-1} from wells and 43.5 mg l^{-1} from boreholes. In over 60 per cent of samples from boreholes, fluoride was above 1 mg l^{-1}, approximately 20 per cent above 5 mg l^{-1}. Nair et al. (1984) stated that "if the thousand or so waters examined in the study are being drunk by humans then the majority of ground-water sources in Kenya are in need of defluoridation".

Earlier, Williamson (1953) had recorded fluoride levels as high as 43.5 mg l^{-1} from boreholes in Kenya and lake water as high as 1,640 mg l^{-1} and 2,800 mg l^{-1} in Lake Elementaita and Lake Nakuru respectively. Similar data has been reported by Nair and Gitonga (1985) (Table 3).

Table 2 Percentage distribution of high-fluoride ground waters in various provinces in Kenya (Nair and Gitonga, 1985).

	Range of fluoride concentration (mg l^{-1})						
Province	0.1 - 0.4	0.5 - 1.0	1.1 - 3.0	3.1 - 5.0	5.1 - 8.0	>8.0	Number of samples
Nairobi	9.8	9.8	19.7	13.2	15.8	31.7	183
Rift Valley	14.0	15.7	38.7	13.7	8.0	9.9	313
Eastern	11.7	23.1	37.0	6.1	9.4	12.7	181
North-eastern	9.3	28.9	44.7	9.2	3.9	3.9	76
Central	25.8	21.2	30.3	9.1	5.3	8.3	396
Nyanza	25.8	29.1	25.8	9.7	6.4	3.2	31
Coast	40.9	22.6	26.8	5.4	1.1	3.2	93
Western	77.0	15.0			8.0		13
Total for Kenya	19.3	19.2	31.9	10.1	7.7	11.8	1,286 100 per cent

Table 3 Fluoride concentration in some of the major Kenyan lakes (Nair and Gitonga, 1985).

Lake	Fresh/Saline	F-mg l^{-1}
Victoria	Fresh	0.6-3
Naivasha	Fresh	8.0-15
Baringo	Fresh	18
Turkana	Saline	100
Bogoria	Saline	1,000-2,800
Nakuru	Saline	1,800-2,800

River samples also have been analyzed by Nair and Gitonga (1985) where 19 of the 150 samples (12.6 per cent) had more than 1 mg l^{-1} (Table 4). In one sample the concentration was 34 mg l^{-1}.

Table 4 Fluoride concentration in 150 river-water samples in Kenya (Nair and Gitonga, 1985)

F-mg l^{-1}	Samples	Percentage
0.1-1.0	131	87.3
1.1-2.0	11	7.3
2.1-3.0	4	2.6
3.1 and above	4	2.6

Many foods in Kenya contain low concentrations of fluoride, around 0.1 to 1 mg kg^{-1} although foods from high-fluoride soils may contain higher values (Manji and Kapila, 1986a). Kenyan tea leaves contain up to 400 mg kg^{-1} although only around two-thirds go into solution on infusion (Manji and Kapila, 1986a). Tea infusions, as consumed, contain up to 16 mg l^{-1}. Kenyan lake fish also contain high-fluoride levels of over 500 mg kg^{-1} compared with other sea fish where values are low (Bergh and Haug, 1971).

Dust containing high levels of fluoride also contributes to fluorosis. Dust around Lake Nakuru, in the Nakuru Municipality and dust in the houses, contained 5,600, 1,240 and 150 mg kg^{-1} respectively. (Manji and Kapila, 1986a). Such dust can therefore be inhaled and contaminates foodstuffs and vegetables which are not washed. Occupationally-exposed workers to soda ash at Magadi have been reported to suffer from skeletal fluorosis.

The prevalence of dental fluorosis in rural Kenya is high and may reach 100 per cent (Manji, Boelum and Fejerskov, 1986a) even among different ethnic groups. Severe forms of dental fluorosis have been reported from almost all areas of Kenya (Manji and Kapila, 1986b). Even in Nairobi primary schools, 44 per cent were reported in 1984 to have fluorosis in their permanent teeth. Children living at higher altitudes have been reported to be more susceptible to dental fluorosis at a given concentration of fluoride in drinking water although effects of temperature may also be involved (Manji, Boelum and Fejerskov, 1986b).

Due to lack of resources, few studies have been undertaken to examine skeletal fluorosis and its incidence in Kenya (Nair and Gitonga, 1985). Typical symptoms have been described by Manji and Kapila (1986b), especially in Turkana. Dental fluorosis in Ugandans who emigrated to Kenya have been reported by Ockerse (1953).

d. Tanzania

Both dental and skeletal fluorosis have been reported as major health issues in Tanzania for many years (MacQuillan, 1944; Grech and Latham, 1964; Grech, 1966). In the Rift Valley regions most affected by high fluorides, Mara, Arusha, Mwanza, Shinyanga and Singida, drinking-water supplies contain excessive concentrations of fluorides. In Singida, 72 per cent of the waters tested exceeded 1.5 mg l^{-1} (Gumbo, 1985). The natural waters in parts of northern Tanzania: the Maji Ya Chai river (12-14 mg l^{-1}), the Ngare Nanyuki river (21-26 mg l^{-1}) and pond waters of Kitefu (61-65 mg l^{-1}), the thermal springs of Jekukumia (63 mg l^{-1}) and the soda lakes of Momella (up to 690 mg l^{-1}) are characterized by abnormally high-fluoride concentrations; being among some of the highest in the world (Aswathanarayana et al., 1985).

Latham and Grech (1967) carried out a detailed study of the concentrations of fluoride in drinking waters in the Arusha District in northern Tanzania (which includes the rivers mentioned above) as well as an examination of dental fluorosis in a total of 1,243 persons. Of these, X-ray studies were undertaken on 112 people who were not chosen at random but who were believed to be a serious risk having consumed water with a high-fluoride concentration for long periods of time. The population of Arusha District is approximately 150,000 persons. Concentrations of fluoride in drinking waters ranged from 1.1 to 45.5 mg l^{-1} as shown in Table 5. The places Maji Ya Chai, Oldonyo Sambu, Ngare Nanyuki and Olmotoni-Selian were chosen on different sides of Mount Meru. Three schools were also selected as part of the survey, Arusha Primary School, Arusha Secondary School (both in Arusha township) and West Meru Upper Primary School near Tangeru (see also Table 5).

The very high prevalence of dental fluorosis is shown in Table 6. No group had fewer than 80 per cent of persons with dental fluorosis. Of the 1,243 persons examined, 95 per cent were affected. The lower rate at Ngare Nanyuki was considered to be influenced by an influx of new residents during the previous decade.

The results from the X-ray survey showed that skeletal changes associated with fluorosis occurred in 87 per cent of the persons. Many of the bone changes recorded were very marked. The authors also recommended preventive measures for defluoridation of drinking water.

Overall, in Tanzania 30 per cent of drinking water exceeded 1.5 mg l^{-1}. Of 251 children examined in Arusha, 78 per cent had skeletal fluorosis and deformity of legs (Manji and Kapila, 1986b) showing that exposure to high-fluoride levels can give rise to marked skeletal fluorosis not only in adults, but also in children.

Exposure to fluorides in the endemic fluorosis areas of northern Tanzania arises not only from ingestion of fluoride-rich drinking water, but also from the consumption of "Magadi" which are sodium bicarbonate encrustations derived from waters of soda lakes and playas. Magadi, which is used to assist rapid cooking of legumes, can contain up to 6 mg fluoride g^{-1} of salt (Aswathanarayana et al., 1985) (refer Section 6: Conclusions).

Table 5 Fluoride concentrations in drinking waters from locations in the Arusha District, northern Tanzania where the dental and skeletal fluorosis survey was undertaken (Latham and Grech, 1967).

Sources of water for each location	Fluoride content $mg\ l^{-1}$
1. Maji Ya Chai	
(a) river	18.6
2. Oldonyo Sambu	
(a) pipeline	14.3
(b) spring	14.4
3. Ngare Nanyuki	
(a) river	24.0
(b) tributary near village	45.5
(c) furrow	24.8
(d) spring	6.0
4. Olmotoni-Selian	
(a) Olmotoni river	5.9
(b) Selian river	6.4
5. Arusha Township	
(a) municipal water supply	2.5
(b) Temi river (in township)	2.2
(c) unnamed stream near quarry	3.0
6. West Meru School Area	
(a) Magumira river	1.1
(b) Mbembe river	2.7
(c) Tengeru river	2.0

Table 6 Incidence of fluoride mottling of teeth in the Arusha district, Northern Tanzania (Latham and Grech, 1967).

	Place	No. examined	No. of persons with fluorotic mottling+ Grade 0	Grade 1	Grade 2	Grade 3	Persons with mottling (numbers)	Persons with mottling (per cent)
1.	**Maji Ya Chai**							
	(a) non-school	188	2	8	28	150	186	98.9
	(b) school	192	0	2	30	160	192	100.0
2.	Oldonyo Sambu	30	5	8	8	9	25	83.3
3.	**Ngare Nanyuki**							
	(a) non-school	111	17	10	10	74	94	84.7
	(b) school	133	23	9	13	88	110	82.7
4.	Olmotoni-Selian	121	3*	6	4	107	117	97.5
5.	**Arusha**							
	(a) Upper Primary School	103	2	14	29	58	101	98.1
	(b) Secondary School	60	1	5	18	36	59	98.3
6.	**West Meru**							
	Upper Primary School	305	9	12	27	257	296	97.0
	Total	1,243	62*	74	167	939	1,180	94.9

* One edentulous not included
\+ 0 = normal 1 = mild 2 = moderate 3 = serious

e. Uganda

The prevalence of dental fluorosis in 1,399 persons (predominantly 5-19 years of age) in four different geographic districts in Uganda with fluoride concentrations in the drinking water, varying from 0.1 to 3 mg l^{-1}, has been reported (Möller, Pindborg, Gedalia and Roed-Petersen, 1970). A "fairly good" agreement between the fluoride concentrations in drinking water and the severity of dental fluorosis was recorded. Highest values were reported for the Toro district followed, in decreasing order, by Acholi, Bugisu and Kigezi districts. In the Toro district, the percentage of population with dental fluorosis ranged up to 91.3 per cent (Community Index of Dental Fluorosis, F_{ci} = 1.74) where fluoride concentration in drinking water (river, well, lake) was 2-3 mg l^{-1}. On average, 24.3 per cent of the population examined exhibited dental fluorosis with an average F_{ci} = 0.25.

A slightly higher incidence of dental fluorosis was found in males compared with females, but it was not known whether this was related to differences in food consumption. A similar difference in severity of dental fluorosis has been reported from Thailand (Leatherwood, Burnett, Chandravejjsmarn and Sirikaya, 1965) and in skeletal fluorosis in parts of India (Jolly, Singh, Mathur and Malhotra, 1968; Jolly, Lal, Sharma, 1980).

Möller et al. (1970) suggested that a Ugandan manual worker would consume about 6 l of water a day, or approximately three times as much as an average resident in Europe. Hence the higher water intake would increase the total intake of fluorides from this source and help explain the differences in the F_{ci} in Uganda compared with other countries (Table 7). Thus, if the Community Index of 0.4 to 0.6 is used as a borderline for objectionable dental fluorosis (Galagan and Lamson, 1953), a value of approximately 0.5 mg l^{-1} fluoride would be permissible. Comparable European values exceed 1 mg l^{-1} fluoride as can be seen in the Table. No skeletal fluorosis was recorded in Uganda which contrasts with severe skeletal fluorosis already described in Tanzania.

Table 7 Community index of dental fluorosis (F_{ci}) in different countries (Möller et al., 1970).

Fluoride in water mg l^{-1}	U.S.A. (Dean et al., 1942)	England (Forrest, 1956)	Denmark (Möller, 1965)	Denmark (Möller et al., 1970)
0.05			0.0	
0.10	0.0			
0.20			0.0	0.0–0.3
0.30	0.1		0.0	0.2
0.40	0.3			0.3
0.50				
0.60				0.8
0.70				0.8
0.80				
0.90		0.3		
1.00				
1.25	0.3–0.5		0.2	
1.50			0.4	
1.75				
2.00	0.7	0.8	0.6	
2.25				
2.50	1.3			1.7
3.00	1.8			
3.50		1.9	1.6	

f. Zimbabwe

The general fluoride concentration in borehole waters in Zimbabwe ranges up to 0.3 mg l^{-1} although occasional high levels in drinking-water supplies of rural communities have been recorded. One investigation carried out in two rural areas, namely Gokwe (north-west in the low veld) and Chimanimani (Eastern Highlands) Districts showed that although approximately 50 per cent of the drinking-water samples analyzed contained less than 0.5 mg l^{-1}, a significant percentage of samples had unacceptably high levels (Tobayiwa, Musiyambiri, Mazorodze, Sapahla and Chironga, 1990). High fluoride levels - up to 10 mg l^{-1} - were associated with water drawn from artesian wells (Gokwe) and hot springs (Chimanimani) and from boreholes in both districts. Endemic dental fluorosis was found to be prevalent in 200 school children (selected at random from five schools in each district) with over 60 per cent of teeth affected and over 20 per cent severely damaged.

Skeletal fluorosis was not looked for but "judging from the quality of the water being consumed, this problem may already be present or be an emerging problem". Fluorosis is seen as a significant problem which could be avoided to some extent by testing new water supplies for potability prior to commissioning.

g. <u>South Africa</u>

Endemic Fluorosis, both dental and skeletal, has been reported to affect thousands of people in South Africa (Ockerse, 1941a and 1941b; Jackson, 1962). Fifteen endemic fluorosis sites were reported with the Pretoria district alone where the fluoride concentrations in well water varied between 1.4 to 13.9 mg l^{-1}. Elevated concentrations of fluoride were also measured in shallow ground waters at Kenhardt, north-east Karoo and related to fluorosis in local people. Mottling of the teeth was 100 per cent in areas in and around Kenhardt and Pofadder (Ockerse, 1941b). Marked dental fluorosis was also seen in deciduous teeth in children, even under the age of two years, although other nutritional factors were considered to be involved in the aetiology of the disease (Jackson, 1962).

h. <u>Nigeria and Senegal</u>

Relatively little is known of the fluoride concentrations in drinking waters in West Africa compared with East Africa. Extreme cases of both endemic dental and skeletal fluorosis associated with high-fluoride ground waters have been described from studies at various locations in Senegal (Travi and Le Coustour, 1982; Brouwer, BackerDirks, DeBruin and Huutvast, 1988). In advanced skeletal fluorosis there was obvious rigidity of the vertebral column and other symptoms of "crippling fluorosis".

A study reported by Wilson (1954) mentioned the occurrence of a "mild degree" of dental fluorosis in members of six aboriginal tribes on the central plateau, Nigeria, where the fluoride concentrations in water varied between 0.2 to 0.4 mg l^{-1}. Dental fluorosis was also recorded in children in Niger province and in adults in Adamowa, Bauchi and Bornu provinces. In Maiduguri town in Bornu fluoride concentrations ranged from 0.1 to 1.2 mg l^{-1} with 15.8 per cent of the girls at a school showing a "moderate degree" of mottled enamel.

(iii) <u>South Asia</u>

High-fluoride geologic formations also extend from Turkey through Iran, Iraq, Jordan, Afghanistan, Kazakhstan, India to northern Thailand and China. Detailed studies on fluorosis in people have been carried out especially in India and Thailand where many reliable data have been produced. Epidemiological studies have also shown that dental fluorosis is endemic in the lowland, dry zone of Sri Lanka, which is considered to be an area in which excessive quantities of fluorides are present in the drinking water suplies (Jinadasa, Weerasooriya and Dissanayake, 1988; Jinadasa and Dissanayake, 1992).

a. India

Endemic fluorosis remains a challenging national health problem in India and is associated with areas where fluoride-bearing minerals opatite, fluorapatite, fluorite and triplite occur thus releasing fluorides in to ground waters, sub-soil water, surface waters as well as surface soils and hence crops and dusts. Nevertheless, the leachable fluoride content in the soils and rocks is more significant in contributing the fluoride-rich water rather than the presence of high concentrations of fluoride-bearing minerals, for example, up to 4 mg g^{-1} in the rock (Chari, Seshadri, Rao and Naidu, 1971; Ramesam and Rajagopalan, 1985). Thirteen of India's 32 states and territories have naturally high levels of fluoride in their waters (Mangla, 1991). The most seriously affected areas are Andhra Pradesh, Punjab, Haryana, Rajasthan, Gujrat, Tamil Nadu and Uttar Pradesh (Kumaran, Bhargava and Bhakuni 1971; Teotia, Teotia and Kunwar, 1971; Teotia, Teotia, Singh, Rathour, Singh Tomar, Nath and Singh, 1984). Surveys have shown, for example, that dental and skeletal fluorosis were widespread in 6,000 villages (out of 33,000) in Rajasthan having concentrations of fluoride in water of more than 2 mg l^{-1} (Gopal, Bhargava, Ghosh and Rai, 1983). Depending on local geology and location of community wells, low-fluoride ground waters can also be found even in fluorosis-endemic villages of Andhra Pradesh (Chari et al., 1971). The number of people affected by dental fluorosis in India is estimated at 25 million (Mangla, 1991). Approximately one million have been reported to be crippled by skeletal fluorosis while many millions must be at risk from the high exposure (Teotia et al., 1984). Severe forms of skeletal fluorosis have been reported in the Sangrur, Bhatinda and Ferozpur districts of Punjab, the Nalgonda, Prakasam, Guntur, Karimnagar, Anantapur and Kurnool districts of Andhra Pradesh, the Rai Baraeli area of Uttar Pradesh, the Baroda district of Gujarat and the Coimbatora and Salem districts in Tamilnadu (Krishnamachari, 1985). The occurrence of high-fluoride water, soils and fluorosis has been widely mapped throughout affected localities.

Concentrations in water in two endemic fluorosis villages, Sikri and Uzera, have been found to range from 2.4 to 11.5 mg l^{-1} in shallow boreholes 40-50 ft depth. In deeper boreholes, from 56-110 ft, the fluoride concentrates were lower and ranged from 0.75 to 2.5 mg l^{-1} (Teotia et al., 1984).

Data in Table 8 show the relationship between the fluoride content of drinking water in the Nalgonda district of Andhra Pradesh and severity of fluorosis (Rajyalakshmi and Rao, 1985). The incidence of skeletal fluorosis also varies with fluoride concentration in the water and ranged from 24 per cent to 78 per cent in the five villages studied (Table 9).

Table 8 Fluoride concentration water, serum and degree of fluorosis in 17 villages in Nalgonda District, Andhra Pradesh, India. Village 1-4 are the control group (Rajyalakshmi and Rao, 1985).

	Fluoride in water (mg l^{-1})	Serum fluoride (mg l^{-1})	Degree of fluorosis
1.	0.8	0.01	Nil
2.	1.5	0.03	Nil
3.	2.0	0.02	Nil
4.	1.8	0.04	Nil
5.	3.5	0.15	Mild
6.	3.0	0.18	Mild
7.	5.0	0.4	Severe
8.	6.5	0.3	Moderate
9.	7.5	0.4	Severe
10.	8.2	0.4	Mild
11.	8.4	0.6	Moderate
12.	8.5	0.4	Moderate
13.	9.0	0.3	Severe
14.	9.2	0.2	Mild
15.	9.4	0.4	Severe
16.	9.8	0.4	Severe
17.	10.2	0.3	Severe

Table 9 Incidence of skeletal fluorosis and the fluoride concentration of drinking waters in the endemic fluorosis villages in Nalgonda district, Andhra Pradesh, India (Rajyalakshmi and Rao, 1985).

Village	Range of fluoride (mg l^{-1})	Skeletal fluorosis (per cent)
Madhavayadavalli	4.4 - 7.5 (5.6)	24
Sivannagudem	3.2 - 5.6 (4.8)	32.5
Yellareddygudem	2.8 - 20.0 (6.9)	35
Batlapally	3.2 - 8.6 (7.8)	71.6
Velagapally	4.2 - 9.7 (8.2)	77.8

Data in parenthesis indicates mean value.

Skeletal fluorosis was shown by Siddiqui (1955) to develop in migrants within four years of arrival in fluorosis areas in Nalgonda, and has been described in children aged 6-11 years (Teotia et al., 1971) in Uttar Pradesh, rather than only in adults as occurs in some countries. In this latter example, the drinking water fluoride concentration ranged from 10-13.5 mg l^{-1}.

A repeat visit a decade later to villages in the Andhra Pradesh, where severe endemic fluorosis has been described (Jolly et al., 1968), showed that the disease pattern had not changed (Jolly et al., 1980). The incidence of dental fluorosis ranged from 48-83 per cent (water concentrations from 3.3-14 mg l^{-1}) while skeletal fluorosis ranged from 16-66 per cent (Table 10).

In another follow-up study, in this case in Bindapur village - a zone of endemic fluorosis near Dehli, piped water containing low levels of fluoride, 0.6 mg l^{-1}, was brought in 1969 to eliminate fluorosis (Bagga, Gupta, Gulati and Goel, 1980). Dental fluorosis was 65.4 per cent in the village (1963) and 62.7 per cent in a nearby village (1979). In the 1980 study, the percentage was 61.9 per cent indicating no statistically significant change took place, especially in children born after mid 1970. The data on fluoride concentrations in milk, vegetables, animals and other foodstuffs revealed that a marked daily intake of fluorides still occurred. Values between 6-12 mg day^{-1} were recorded which the authors considered high enough to produce fluorosis. High levels of fluorides in soil, and hence in vegetables and other foods, were also reported by Jolly et al. (1980) and were considered to contribute towards fluoride intoxication.

Low calcium levels, poor nutrition and other socio-economic factors can all be implicated as important factors influencing the severity of the disease and the levels at which fluoride becomes a health risk (Bagga et al., 1980; Jolly et al., 1980; Rajyalakshmi and Rao, 1985). An interesting observation is that in India, severe forms of skeletal fluorosis occur in areas with a water-fluoride content as low as 1.5 to 2 mg l^{-1}. In the case of skeletal fluorosis, it is the total daily intake of fluoride and the duration of fluoride intake which are important factors contributing to total exposure rather than the concentration of fluoride in water alone (Krishnamachari, 1985). More important, is the finding that villages having water sources with similar levels of fluoride have varying degrees of fluorosis prevalence, both skeletal and dental. Difference of calcium content as already mentioned, play an important protective role against the bioavailability of fluoride (Krishnamachari, 1985). Recent studies of Rajyalakshmi et al. (1987) indicated partial relief of clinical symptoms of skeletal fluorosis in patients from the Nalgonda district provided with defluoridated water and nutritional supplements. Fluoride already absorbed was remobilized and excreted in the urine.

Table 10 Incidence of skeletal fluorosis in 2,986 adults (older than 21 years of age) from endemic fluorosis villages in the Punjab, India (Jolly et. al. 1980).

Name of Village	Mean Water Fluoride (mg l^{-1})	Total Incidence (per cent)	**Males**		**Females**	
			Examined	Incidence (per cent)	Examined	Incidence (per cent)
Khara	9.95	66.34	225	82.5	168	44.7
Salabatpura	14.14	64.5	185	76.4	135	48.2
Rajia	3.7	44.7	248	56.4	210	31.0
Bajakhana	3.3	44.5	318	49.8	235	37.4
Bhikhi	4.27	40.6	280	48.7	165	27.0
Ganja Dhanaula	3.24	19.6	192	26.5	228	13.8
Gurney Kalan	3.38	16.3	265	19.6	132	9.8

b. Thailand

Both dental and skeletal fluorosis have been described from areas in Thailand, particularly the northern and western parts where natural fluoride deposits of geological origin occur (Phantumvanit, Songpaisan and Koontongkaew, 1986). Many epidemiological studies have concentrated in northern Thailand, especially in the province of Chiang Mai where the fluoride concentrations in water have been variously reported as from 0.25 to 0.80 mg l^{-1} (Leatherwood et al., 1965), 1.0 to 1.6 mg l^{-1} (Anon. in Phantumvanit et al., 1986) and from 0.1 to 5.0 mg l^{-1} in well water, especially in San Kampang and Doi Saked districts (Phantumvanit, Songpaisan, Visarurath and Patimanukasem, 1982). The incidence of dental fluorosis has also been variously reported depending on the study and on the province; for example, up to 91 per cent of the participating subjects showed dental fluorosis in the area where the water concentrations ranged between 1.0 to 1.6 mg l^{-1}.

A detailed study of fluorides in drinking water and dental fluorosis has been reported by Phantumvanit et al. (1986). Concentrations of fluoride in well waters were grouped into bands at 0.1 intervals for the range of 0.1 to 1 mg l^{-1} and at 0.5 intervals for the 1.0 to 3.0 mg l^{-1} and values exceeding 3 mg l^{-1} were grouped together (Figure 4).

The results show the increase in dental fluorosis with increasing fluoride concentrations in well water. Groups with 0.1 to 0.2 mg l^{-1} showed fluorosis in only 5 to 8 per cent of the cases studied. According to Dean's classification, the maximum tolerable range for negligible public health concern for fluorosis (F_{ci} = 0.4) occurs at 0.5 to 0.6 mg l^{-1} fluoride in water. At this level, 28 per cent of the people were affected by fluorosis. The group with 2.5 to 3 mg l^{-1} fluoride in their drinking water recorded 100 per cent fluorosis.

A highly positive correlation (r = 0.93) was shown between the fluoride concentration in water and F_{ci} (Figure 5). Thus 0.4 to 0.6 mg l^{-1} fluoride should be the "safe level" for fluorosis prevention within the climate and nutritional levels in the rural area. This value is lower than the 0.6 to 0.8 mg l^{-1} used for water quality control and fluorosis prevention advocated earlier in Thailand. The safety limit for Denmark has been proposed at 1.5 to 2 mg l^{-1} and the WHO guideline for drinking-water quality is 1.5 mg l^{-1}.

Figure 4 The incidence of dental fluorosis in 649 children aged 13-16 in Chiang Mai, north Thailand grouped according to the Dean Index and scored Community Fluorosis Index (F_{ci}) as different concentrations of fluoride in drinking water (Phantumvanit et al., 1986).

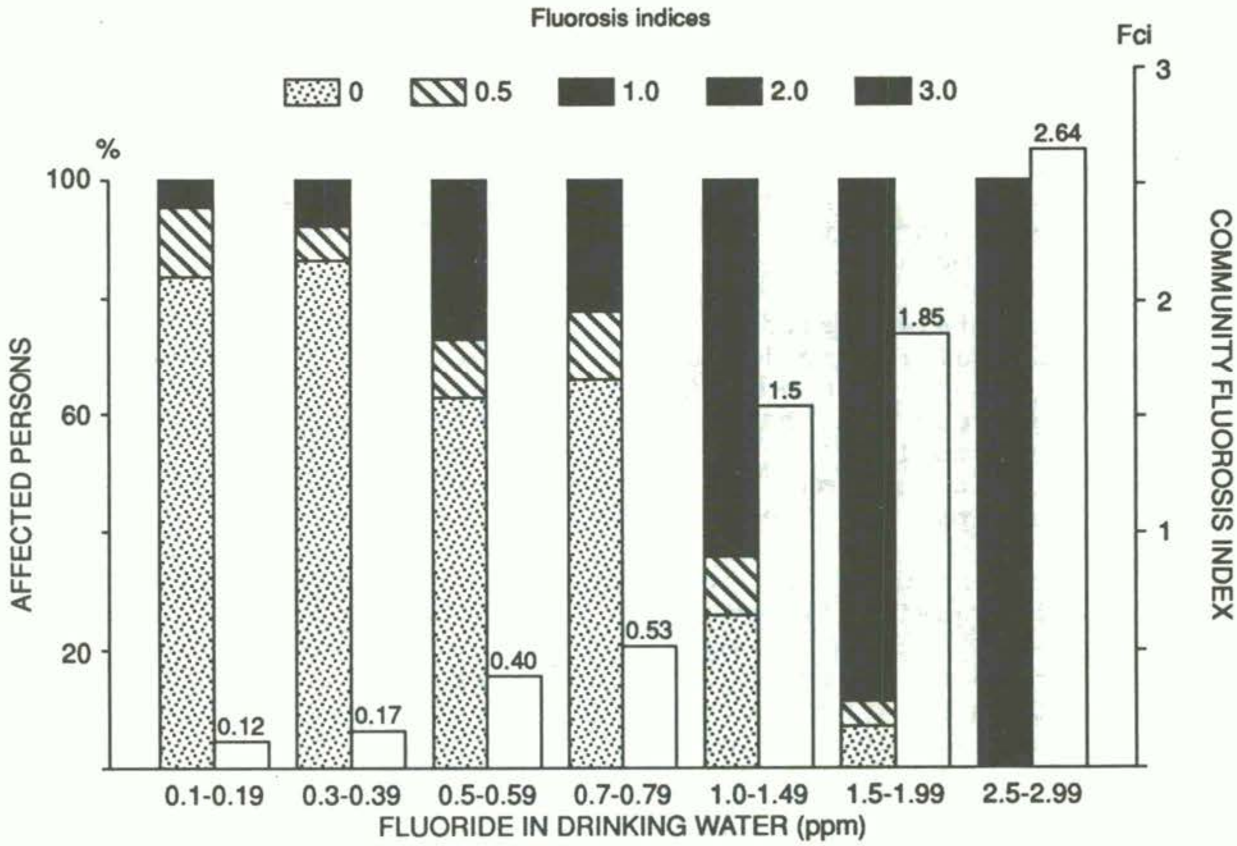
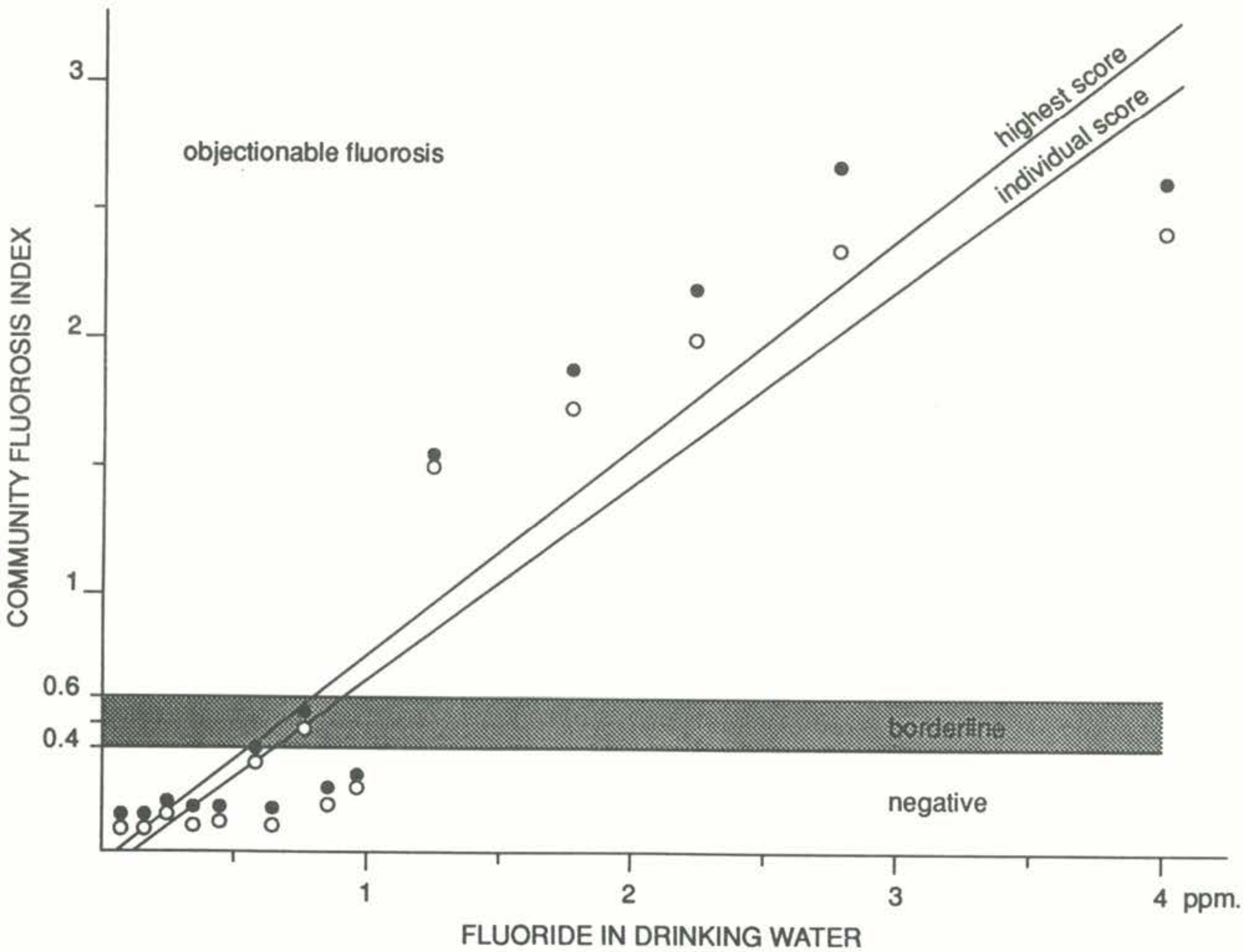


Figure 5 The relationship between the Community Fluorosis Index (F_{ci}) and the fluoride concentration in drinking water as assessed by the highest and of the individual scores of fluorosis (Phantumvanit et al., 1986).



(iv) **Western Pacific**

Many major studies have been undertaken on the extent and degree of endemic fluorosis in China and in relatively small areas of Japan.

a. China

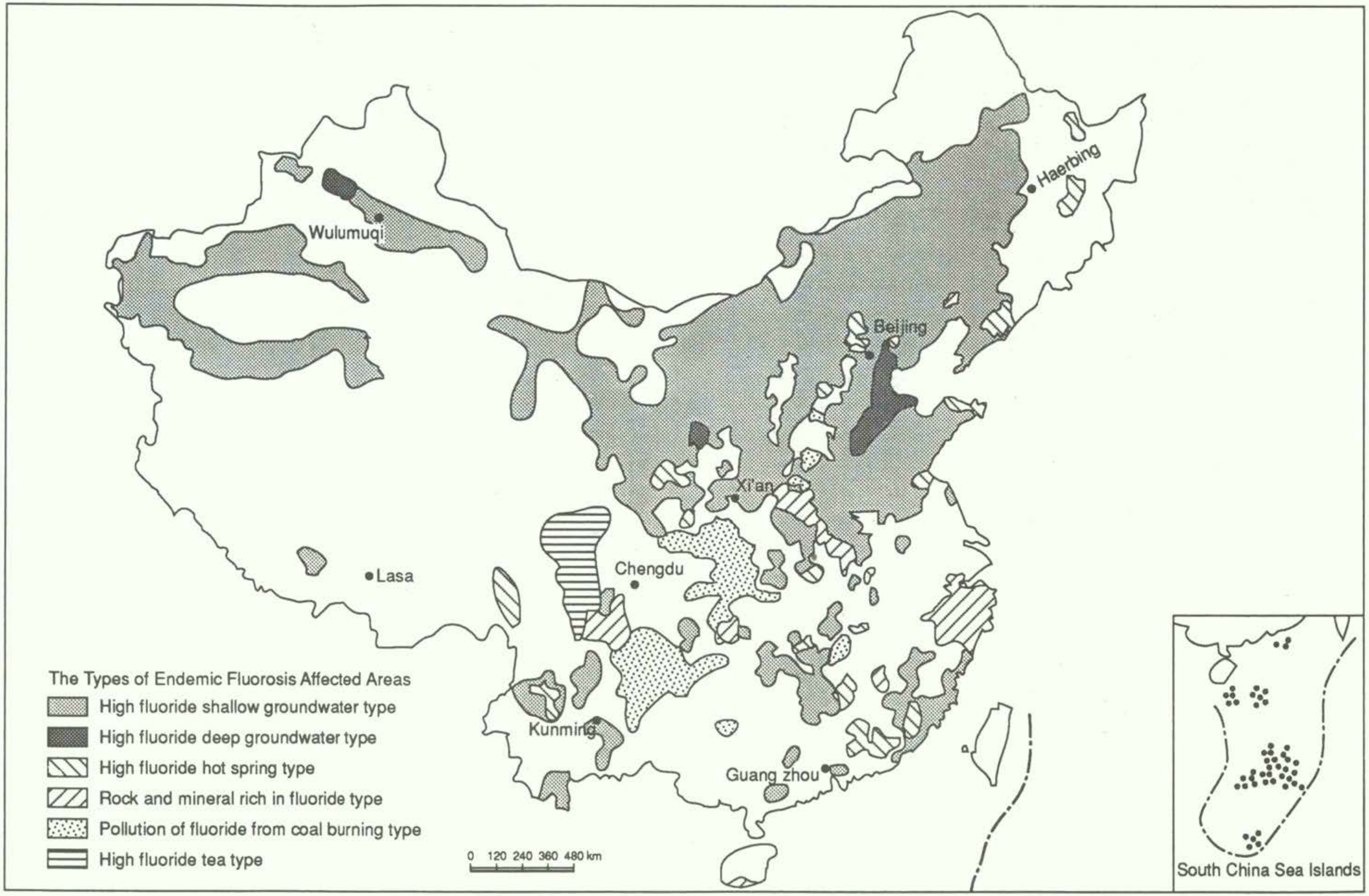
Endemic fluorosis occurs in all 28 provinces, autonomous regions and municipalities of the country except Shanghai (Anon., 1990). It is prevalent on plateaus, in mountainous districts, plains, coastal areas, urban and rural areas. The population exposed in the 125,817 affected villages totalled 85.61 million with 41.4 million people being surveyed with respect to fluorosis. Based on the numbers surveyed and extrapolated to the population exposed, enables the number of people affected to be calculated. Thus 37.53 million people suffer from dental fluorosis and 1.71 million from skeletal fluorosis (Anon., 1990). The morbidity rate being 42.8 per cent for dental fluorosis and 2 per cent for skeletal fluorosis although this varies with province, county and village (Table 11).

Table 11 Dental and skeletal fluorosis incidence at various locations in China (Anon., 1990).

Province	Villages	Population (million)	Dental Fluorosis (per cent)	Skeletal Fluorosis (per cent)
Henan	10,280	6.45	88.73	1.44
Shaanxi	13,133	4.30	72.60	4.14
Hubei	835	0.71	69.95	0.97
Liaoning	2,865	0.99	55.26	4.40
Jilin	3,378	1.16	54.71	6.44
Inner Mongolia	11,593	5.22	47.61	5.12
Heilongjiang	6,473	4.17	38.96	1.86
Guangdong	257	0.40	6.04	0.13
Sichuan	3,376	5.40	11.40	0.01
Xizang (Tibet)	1	0.0002	0.0	76.84

Figure 6 Provinces of China referred to in the text.

Figure 7 Endemic fluorosis map of China characterized by major source of fluorides (Anon., 1989).



Endemic fluorosis is mainly distributed in Shaanxi, Shanxi, Henan, Shandong, Hubei, Heilongjiang, Liaoning, Jilin provinces, Inner Mongolia and Tianjin (Anon., 1989). More than 100 counties in Hubei and Henan provinces are affected by dental fluorosis. The endemic fluorosis areas can be divided into five major types of ecological environment on the basis of the source of fluoride. These are shallow ground water, deep ground water, hot springs, fluoride and apatite mines and high-fluoride coal combustion (Figure 7).

All three intake routes - drinking water, food and air, have been implicated in endemic fluorosis although the significance of each route has not received adequate study in many areas. The water quality standard is 1 mg l^{-1}.

High levels of fluoride are usually found in the drinking water of the northern arid and semi-arid plains while the high contents of fluoride in rocks and soils of the Yunnan-Guizhou plateau are reflected in high concentrations of fluoride in crops (Chen Guojie, 1988). The irrigation of crops with high-fluoride waters provides a further fluoride source via the diet.

The incidence of endemic fluorosis can be considered via the exposure route.

A. <u>High-fluoride Water</u>

I. Shallow Ground Water

This type of fluorosis affects the largest area of China, mainly in arid and semi-arid areas of northern China including Heilongjiang, Jilin, Liaoning, Inner Mongolia, Hubei, Shandong, Shanxi, Shaanxi, Henan, Ningxia, Gansu, Qinghai and Xinjiang. The fluoride arises from the rock formations and in low-lying areas including saline and alkaline soils. Values are generally below 5 mg l^{-1}, but may reach 32 mg l^{-1} (Anon., 1989). Figure 8 shows the fluoride concentration in ground water and the prevalence of dental fluorosis along a transect in Shanxi province.

II. Deep Ground Water

This type of fluorosis is distributed mainly along the coastal plains of the Bohai Bay affecting areas in Liaoning, Tianjin, Hubei and Shandong. The fluoride is high around 7 mg l^{-1} and can exceed 20 mg l^{-1} (Anon., 1989). Variations in fluoride levels in deep ground water compared with shallow ground water in the plains of Tianjin are shown in Figure 9.

Figure 8 Fluoride concentration in drinking water and dental fluorosis incidence along a transect in Shanxi Province (Anon., 1989).

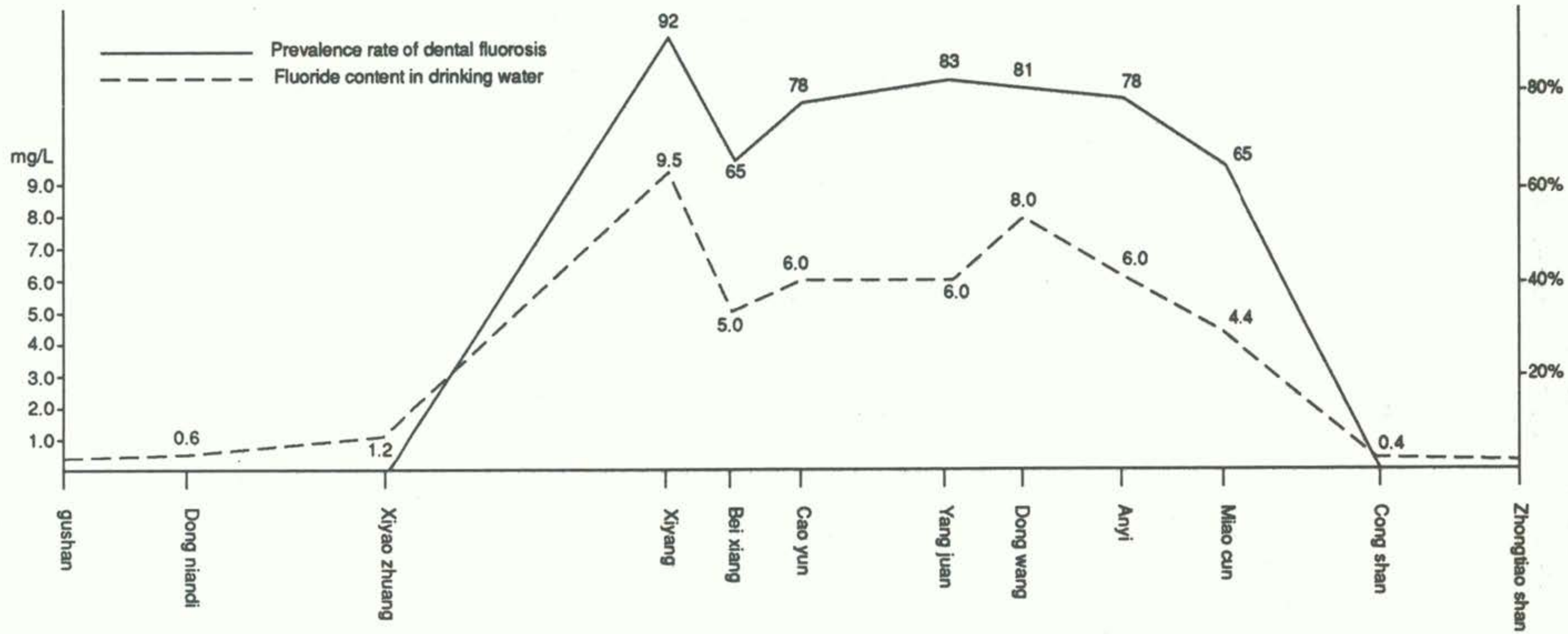
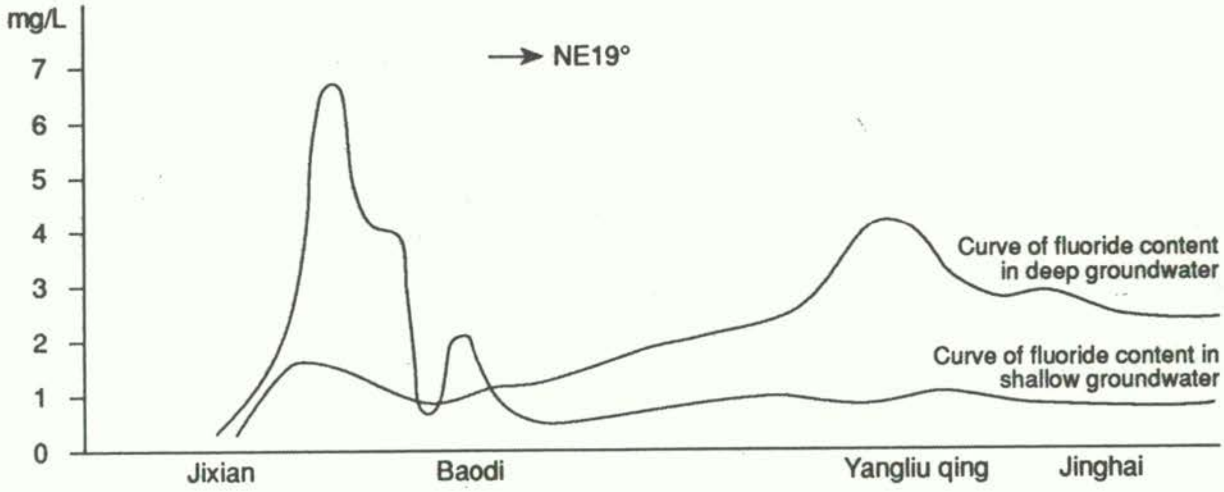


Figure 9 Shallow and deep ground-water profiles for fluoride concentrations along a transect in the plains of Tianjin (Anon., 1989).



III. High-fluoride Hot Springs

Fluoride concentrations are high as a result of high-fluoride hot-spring water seepage into surrounding areas. The disease areas are related to the geological structural fracture zones. Typical areas are Fengshun in Guangdong, Nanqing in Fujian and others in Shandong, Hubei, Beijing, Shanxi and Yunnan provinces (Figure 7).

IV. High-fluoride Mines

High-fluoride levels in water are found corresponding to fluorite and apatite mines in Liaoning, Henan and several other locations (Figure 7).

B. <u>High-fluoride Food</u>

I. Plants and Soil

High concentrations of fluorides are found in a range of rocks and soils in China. In the north-east plains of China the mean total soil fluoride is reported as 507 mg kg^{-1}, increasing in the order chernozem > chestnut soil > solonchak and solonetz > meadow soil > aeolian sand soil (Meng Xianxi, Zhang Liping and Wang Zongyi, 1988), while in 92 cultivated soils and 11 natural soils the value was 379 and 281 mg kg^{-1} respectively (Li Ribang, Tan Jianan, Wang Wuyi and Wang Lizhen, 1982; Li Ribang, Tan Jianan, Wang Lizhen, Zheng Daxian and Wang Wuyi, 1985; Li Ribang, Wang Lizhen, Tan Jianan and Wang Wuyi, 1988). In these latter soils, the water soluble fluoride was 1.40 mg l^{-1}.

No correlation was found between total soil fluoride and endemic fluorosis, the disease being related to the fluoride content of the shallow ground water in the area (Li Ribang et al., 1988). Average fluoride levels in vegetables were higher than grains, approximately 1.07 compared with 0.64 mg kg^{-1} respectively (Meng Xianxi et al., 1988). In another study Li Ribang et al. (1988) quoted values for grain of 1.85 to 4.05 mg kg^{-1}. Maize, wheat and rice were quoted as 4.18, 2.77 and 2.85 mg kg^{-1} respectively based on an analysis of over 100 samples. Despite foods containing elevated levels of fluorides, the authors considered on the basis of absence of correlations, that high-fluoride water was more important than the fluoride in food (Li Ribang, Zheng Daxian, Wang Lizhen and Tan Jianan, 1986).

II. High-fluoride Tea and Salt

In some semipastoral areas of Aba and Garze prefecture, Sichuan province, fluorosis can be caused by drinking high-fluoride tea (Anon., 1989). This endemic fluorosis, 73 per cent dental fluorosis prevalence and 97 per cent skeletal fluorosis, occurred among Tibetan inhabitants who drink brick tea (Bai Xuexin et al., 1986). The tea itself contained 622 + 155 mg kg^{-1} fluoride while the infused tea contained 2.76 + 0.36 mg l^{-1}. A daily intake of approximately 14 mg fluoride was estimated which accounted for 90 per cent of the total fluoride intake. Dental fluorosis usually occurred above 1 mg day^{-1} fluoride but the incidence varied with dietary factors.

Endemic fluorosis has also been caused by high-fluoride salt found in some areas, especially in Pengshui and Qianjiang counties of Sichuan province. The local salt (Yushan salt) can contain fluoride at a concentration of approximately 200 mg kg^{-1} (Anon., 1989). High-fluoride salts are also produced in other South-east Asian countries such as Thailand, Myanmar (Burma) and Vietnam.

C. High-fluoride Coal - Air

Both dental and skeletal fluorosis can be found in China in areas where drinking water is low in fluoride (less than 1 mg l^{-1}). These disease areas are characterized by the burning of local coal and occur mainly in the mountainous regions of, for example, south-west China such as Enshi in Hubei, Bijie and Zhijin in Guizhou, Ziyang and Zhenba in Shaanxi, Zhenxiong and Zhaotong in Yunnan, Xingwen and Gongxian in Sichuan. The disease is also prevalent in north China such as Mentougou in suburban Beijing.

Clay and coal are used as fuel in stoves without ventilation in the disease areas (Anon., 1989). The clay has a fluoride concentration of more than 9,000 mg kg^{-1} (Anon., 1988). There is controversy as to whether the inhalation of high-fluoride levels present in the air, or the ingestion of maize and chilli dried in the rooms heated by the clay-coal mixture represents the major exposure pathway (Li Ribang et al., 1982; Li Fucheng, Zhou Linye, Fang Shijie, Wei Zhandao, Xiao Kaiqi, Yu Yanni, Chao Zumao, Liu Jialia and Cheng Xuguang, 1988). In some areas in Jiangxi province, especially in Pingxiang, residents drink high-fluoride teas as well. Fluoride values in urine were reported from 1,162 samples from people in Jiangxi province to be 2.83, 2.97, 6.61 and 0.76 mg l^{-1} for residents from areas of high-fluoride water, coal smoke, high-fluoride water plus coal smoke and controls respectively (Anon., 1988).

b. Japan

Dental fluorosis has been reported from various locations in Japan. The fluoride concentrations of drinking water from 22 deep wells in the Tsugaru plains of north Japan, an area of endemic fluorosis, ranged from 0.30 to 2.27 mg l^{-1} (mean 0.90) (Matsuda, 1986). Hot-spring water, not used as drinking water ranged from 0.41 to 3.57 mg l^{-1}. On a comparative basis, hot-spring water from 25 locations in China ranged from 0.06 to 14.0 mg l^{-1} (mean 4.48).

Fluoride concentrations in samples of tap water for 51 stations in Kobe, Osaka, Nishinomiya and Takarazuka cities in 1989 ranged from N.D. to 0.50 mg l^{-1} (mean ± S.D., 0.09 ± 0.08) which are below the Japanese water standard of 0.8 mg l^{-1} (Adachi, Akamatsu, Iwaisako, Senkoku and Kobayashi, 1991). Mean fluoride concentrations in the tap waters of these four cities was 0.13, 0.08, 0.07 and 0.37 mg l^{-1} respectively. The three cities draw water from Lake Biwa while Takarazuka water originates in Rokko mountains. A further 51 samples were taken from underground sources. Of those, 46 were from Kobe city and five from Rokko mountains where granitic rocks contain higher concentrations of fluoride. The mean ± S.D. fluoride concentration of the underground water was 0.33 ± 0.3 mg l^{-1} while samples from Rokko contained 0.73 mg l^{-1}. Deep well waters (greater than

30 m) contained 0.50 ± 0.07 mg l^{-1} fluoride while shallow ground waters (less than 10 m) contained 0.11 ± 0.03 mg l^{-1}. The geochemical origin of fluoride in the ground waters of the area has been reported by Tsurumaki and Sakuramoto (1985).

Endemic dental fluorosis has also been recorded in southern Japan at Dogo hot-spring district, Ehime prefecture, Shikoku where concentrations in spring water range from 11-17 mg l^{-1} (Baba and Kawahara, 1950). Dental fluorosis was recorded in 32 children drinking well water with a fluoride concentration of 3.6 mg l^{-1} (range 0.9-11 mg l^{-1}), but not in eight children drinking well water with an average fluoride concentration of 0.25 mg l^{-1}. The percentage of third-year middle-school children with fluorosis in normal schools in the area ranged from 5-20 per cent. Limited data suggested that the average height of boys from the fluoride excess area was significantly lower than that from the non-fluoride-rich area. Elevated concentrations of fluoride in ground waters and dental fluorosis have also been reported from the Nobi area (Kobayachi, 1958).

c. Australasia

Elevated levels of fluoride in ground waters from the Great Artesian Basin in South Australia of up to 4 mg l^{-1} have been reported, similar to values recorded in Queensland, although lower values were recorded in other Australian artesian basins from various locations in Australia (Ward, 1954). The fluoride concentrations in hot-spring water from parts of Australia and New Zealand geothermal areas are also elevated.

(v) Canada and Americas

What is now known as dental fluorosis, was reported in the early 1900s and recognized as an endemic disease by Black and McKay (1916). A number of publications refer to the development of varying degrees of dental fluorosis in people in certain areas in the U.S.A. including locations in Arizona, Virginia, New Mexico, California, Texas etc. (Churchill, 1931; Galagan and Lamson, 1953; Murden, 1953; WHO, 1984b), although the degree of mottling of teeth varied with fluoride concentrations, climate, nutrition etc. Very many large-scale ground-water and soil surveys of the conterminous United States have been undertaken (Fleischer, 1962; Shacklette, Boerngen and Keith, 1974), as well as large numbers of local and state-wide surveys designed to locate the source and origin of the high-fluoride waters (see, for example, Corbett and Manner, 1984). In Wisconsin, a statewide ground-water monitoring survey where 905 wells were sampled, showed that in 334 of them the fluoride concentration exceeded the preventive action limit of 0.44 mg l^{-1} and in 122 it exceeded the enforcement standard of 2.2 mg l^{-1} (Talbot, 1990). Many reports appeared particularly on dental fluorosis in the early years from some locations within the states already mentioned, but alternative water sources and better nutrition has all but eliminated this health condition. In recent years in the U.S.A. the emphasis has shifted to the fluoridation of low-fluoride drinking water to national standards. Such actions have given rise to much public debate. Drinking-water standards and maximum contaminant levels in public water supplies introduced by the United States Environmental Protection Agency in 1986 are discussed by Rajagopal and Tobin (1991).

Natural fluoride levels in water supplies from various parts of Canada range from N.D.-3.1 mg l^{-1} for Ontario, 0.05-3.6 for Manitoba and from 0.1-4.5 for Alberta, whereas those samples from Newfoundland and Labrador, Nova Scotia, New Brunswick, Québec, British Columbia and North West Territories contained less than 0.1 mg l^{-1} (Anon., 1979). Dental fluorosis was described in Canada in earlier years, but as with the U.S.A., the emphasis in recent years has been on fluoridation of low-fluoride water supplies rather than on concentrations in natural drinking water.

Elevated concentrations of fluoride in waters and associated dental fluorosis have been recorded in Mexico and Argentina, Bolivia and Equador (Paraje, 1950).

(vi) European Region

In the early part of this century, dental fluorosis was recognized and studied in people from locations across Europe including Spain, Italy, Yugoslavia, Great Britain (Wilson, 1939; Bromehead, 1941; Ortiz Vazquez, Martinez Landete and Vinuelas Garcia, 1952; Tomic, 1955; Forrest, 1956).

In the Aldenencabo area of Escalona (Toledo) in Spain, for example, drinking water contained up to 21 mg l^{-1} fluoride (Ortiz Vazquez et al., 1952). Endemic dental fluorosis was recorded in 96 out of the 100 inhabitants older than 10 years. Of these, approximately 30 per cent were described as having severe dental fluorosis.

a. Western Europe

In recent years, with high calcium intakes and high nutritional status and with municipal water supplies containing relatively low concentrations, dental fluorosis is now scarcely recorded in western Europe. Detailed maps of fluoride concentrations in ground and surface waters of the United Kingdom, France, Germany (some Landers only) and several other countries has enabled public health concerns to shift away from fluorosis to the fluoridation of water naturally containing low concentrations of fluoride. For example, regional distributions of fluoride concentrations in spring waters have been mapped in Finland, indicating areas where fluoride concentrations exceed 2.1 mg l^{-1} as well as areas down to less than 0.1 mg l^{-1} (Lahermo, Llmasti, Juntunen and Taka, 1990).

In the U.K., dental fluorosis up to 5 (moderate) on the Dean scale was noted in the 1930s among school children in parts of Buckinghamshire and Bedfordshire, particularly when well water, either derived from or in contact with clays, was consumed (Bromehead, 1941). Since that early report, fluoride-bearing rocks and soils have been mapped, along with fluoride concentrations in public water supplies based on data forwarded by the water undertakers. Waters containing natural fluoride concentrations of 1 to 1.5 mg l^{-1} are routinely mixed with unfluoridated water to give a concentration below 0.9 mg l^{-1} (HMSO, 1989). Median concentrations in U.K. ground waters vary, ranging from approximately 0.06 mg l^{-1} to 1.4 mg l^{-1} in the Chalk of the London Basin (Edmunds, Cook, Kinniburgh, Miles and Trafford, 1989). Ground-water supplies in the Chalk of the London Basin were reported earlier to average 2 mg l^{-1} and many exceed 3 mg l^{-1} (WRB, 1972).

b. Former U.S.S.R. Republics

Extensive studies have been undertaken in the former U.S.S.R. republics on the geochemistry of fluoride in rock-soil-plant ecosystems and in surface and well waters, and its effects on human health (Arutyunov, Babel, Belyakova and Zhavoronkov, 1969; Belyakova, 1969, 1977, 1978; Belyakova and Zhavoronkov, 1975; Avtsyn and Zhavoronkov, 1981). These studies have been built upon the classical biogeochemical studies of A. P. Vinogradov, V. V. Koval'skii and V. I. Vernadskii.

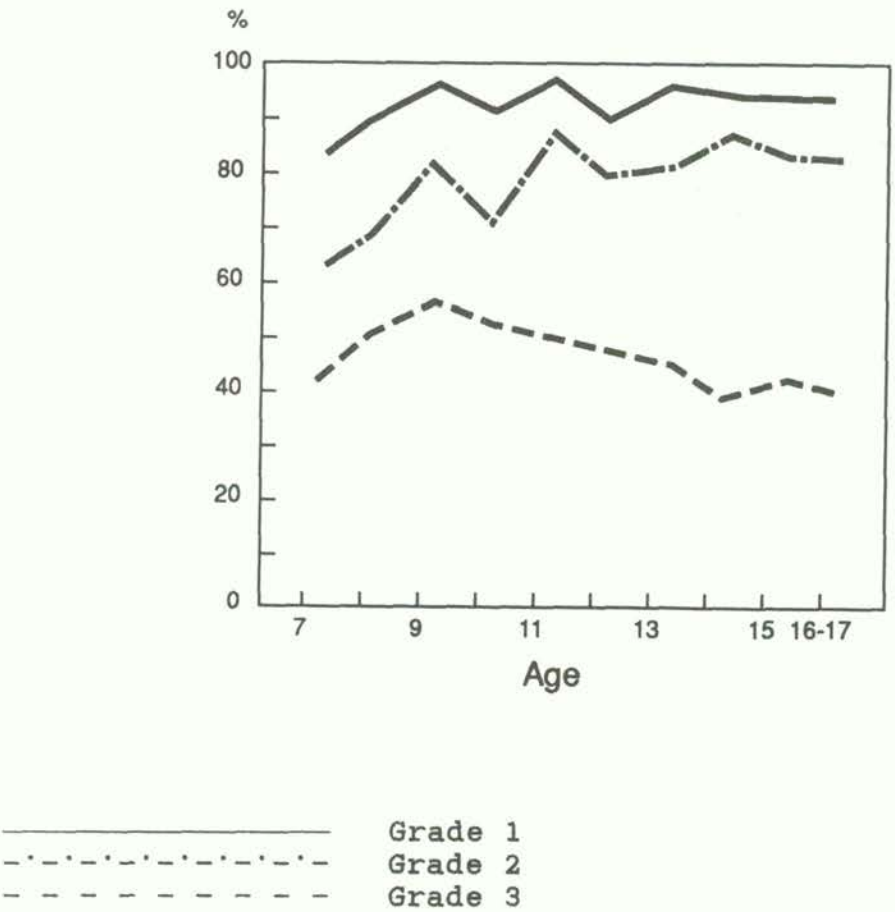
Endemic fluorosis areas are located in the north Kazakhstan region in the Pavlodar Kokchetau and Karaganda provinces (Zahvoronkov and Strochkova, 1981; Belyakova and Dzyadevich, 1971) in Bucak in the Ukraine where concentrations are the highest for the region (Kas'jenenko, 1981). High-fluoride ground waters have also been reported from Moldova and Argun region, eastern Siberia (Shinkaryuk, Aron and Volk, 1983; Filippova, Vlasov, Bogdanova, Shpeizar, Aprelkova, Demina and Charchidi, 1983).

In the Bucak region, 600 X-ray films were taken of the hands and cervical spine of people to check for skeletal fluorosis. At around 4 mg l^{-1} fluoride in drinking water, bone density was reduced while at 8-10 mg l^{-1} fluoride, a distinct decrease in density was observed along with osteoporosis (Kas'jenenko, 1981).

With children born in the endemic areas of north Kazakhstan consuming drinking water with 4 mg l^{-1} fluoride, the incidence of dental fluorosis was 91.8 per cent and maximum concentration in human blood was 0.62 mg l^{-1} (Zahvoronkov and Strochkova, 1981). Lake water in the area reached 11 mg l^{-1}, while in locally grown foods, such as cabbages, fluoride reached 3 mg kg^{-1}.

The Shchuinsk region of Kokchetau province in north Kazakhstan is a major area of endemic fluorosis (Belyakova, 1978). Fluoride in drinking water exceeds 3 mg l^{-1} while vegetables and other foods also contain elevated concentrations of fluoride. The number of children with dental fluorosis from Shchuinsk are shown in Figure 10.

Figure 10 Number of people suffering from dental fluorosis of the permanent teeth in Shchuinsk Kokchetau province, northern Kazakhstan as percentages of the total number examined (Belyakova, 1978).



6. CONCLUSIONS

Endemic fluorosis is widespread throughout the world affecting many tens of millions of people. It is often caused by the consumption of drinking water containing high-fluoride concentrations. Nutritional conditions as well as environmental conditions can modify the incidence and severity of the disease indicating that factors, such as, calcium intake, nutritional level and age need to be included in exposure estimations and measurements. The estimates of fluoride exposure from drinking water depends not only on the concentration of fluoride in the water, but also on the volume of water consumed. Climatological factors, and hence volume of water consumed, have usually not been measured. Relationships between temperature and fluid intake have been reported by Galagan and Vermillion (1957). This and other studies show that people in tropical countries consume, on average, three times as much water as those from temperate countries. Hence, fluorosis can be detected in people consuming drinking water containing less than 1 mg fluoride l^{-1} in tropical countries (e.g., Thailand refer Section 4 (iii) (b)) compared with absence of dental fluorosis following fluoridation of drinking water to 1 mg l^{-1} in temperate countries.

The other exposure routes including food and air can be highly significant but insufficient attention has been given to the quantification and estimation of their contribution to the total fluoride exposure in people from endemic disease areas. At best, only simple methods of estimating intake from multiple exposure pathways have been undertaken usually based on generalized intakes from various sources. In one example, Aswathanarayana et al. (1985) estimated that the daily ingestion of fluoride per capita in northern Tanzania was about 16 times (range 10 to 30) the "normal" ingestion of a person in temperate locations (Table 12) i.e., 32 mg day^{-1} compared with 2 mg day^{-1}. The estimated intake of 2 mg day^{-1} for persons from temperate locations can be compared with the estimated value of 1 mg day^{-1} for intake from food and water where fluoride has not been added (WHO, 1984a) with a value of 2.7 mg day^{-1} in areas where water is fluoridated (Kumpulainen and Koivistoinen, 1977).

Table 12 Estimated intakes of fluoride for people from northern Tanzania compared with those from a temperate region (mg day^{-1} $capita^{-1}$) (from Aswathanarayana et al., 1985).

Source	Northern Tanzania	Temperate Location
Water	3 l x 8 mg l^{-1} = 24 mg	2 l x 0.2 mg l^{-1} = 0.4 mg
Tea	10 g tea x 100-220 $\mu g\ g^{-1}$ d.w. = 1-2 mg	1 mg
Magadi ("salt")	5 g x 1 mg g^{-1} = 5 mg	-
Diet	1 mg	0.6 mg
Total	32 mg day^{-1} $capita^{-1}$	2 mg day^{-1} $capita^{-1}$

Another example of multiple exposure pathways deserving detailed study concerns the fluoride exposure of villagers in mountainous ares in south central China (Figure 7) where high-fluoride coal is readily available as a major domestic fuel source. Coal burning without adequate ventilation can give rise to high-fluoride concentrations in indoor air of up to 500 $\mu g\ m^{-3}$. The situation is complicated for the villagers consume corn and other vegetables dried within the high-fluoride atmosphere (Li Ribang et al., 1982; Li Fucheng et al., 1988). Concentrations of fluoride in corn (or is it on corn?) can exceed 100 mg kg^{-1} thus giving rise to high dietary exposure. The water used to make tea and to cook the foodstuffs also becomes contaminated by the fluoride from the combustion of the high fluoride coal. The villagers thus use high-fluoride hot water when making tea.

Detailed studies are required not only to ascertain concentrations of fluoride in air and food but also to measure the daily intakes from each of the exposure pathways. Preliminary results suggest that up to 25 per cent of the daily fluoride intake can arise from inhalation of fluoride in air from the combustion of high-fluoride coal and approximately 75 per cent from the contamination of the dietary items. By way of contrast, in other areas of China drinking of high-fluoride teas many account for 90 per cent of the fluoride exposure.

Results from multiple exposure studies will highlight the significance and importance of each of the pathways for determining dose for the percentage of fluoride absorbed within the body from each of the pathways is critical for the evaluation. Only then will it be possible for effective control measure to be implemented with the certainty of lowering the rate of endemic fluorosis at the local level.

7. RECOMMENDATIONS

1. Detailed exposure studies should be initiated in a number of countries to determine the contribution to total exposure of the intake of high-fluoride drinking water and/or high-fluoride crops and fish, and/or high-fluoride dust and/or high-fluoride coal smoke and/or the drinking of high-fluoride teas, use of high-fluoride "salt" and how they relate to the onset of endemic fluorosis. Such studies are particularly important as some reports do not confirm a relationship between fluoride concentration in drinking water and fluorosis, while in others a reduction of fluoride in drinking water has not reduced the incidences of fluorosis.

2. Since concentrations of calcium, other trace elements and general nutritional factors are reported to be involved in reducing the development of fluorosis, such factors should be measured along with those of the fluoride ion.

3. As climate and altitude have also been implicated in the volume of drinking water consumed by people in temperate versus tropical regions and the prevalence of fluorosis, measurements of such factors should be considered.

4. Assessing the severity of dental fluorosis and monitoring of skeletal structures are necessary to ensure correct diagnosis and help establish dose-response relationships for complex exposure regimes.

5. A sufficiently large number of people should be examined at each site and detailed analytical measurements reported to ensure that analytical quality control (AQC) and statistical interpretations are reliable and valid.

6. Detailed assessments of human exposure to fluoride via the major pathways should be undertaken in all areas where endemic fluorosis has been reported. Unless such studies have been undertaken, expensive remedial measures will be adopted which may not reduce exposure and eliminate the disease.

7. Further research is urgently required to develop inexpensive defluoridation processes for bulk water supplies in areas where exposure via drinking water comprises the major component of total exposure.

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8. REFERENCES

ADACHI Atsuko, Akamatsu Noriko, Iwaisako Keiko, Senkoku Miho and Kobayashi Tadashi 1991 Fluoride levels in tap and underground water samples for Kinki Area in Japan, *Bull. Environ. Contam. Toxicol.* **46**, 677-680.

ANON. 1979 Criteria document in support of a drinking water standard for fluoride, *Canadian Public Health Association*, Ottawa.

ANON. 1988 An epidemiologic survey of endemic fluorosis in Jiangxi province. In: *Abstracts International Symposium on Environmental Life Elements and Health*, Beijing, 34.

ANON. 1989 *The Atlas of Endemic Diseases and their Environments in the People's Republic of China*, Science Press, Beijing.

ANON. 1990 *Drinking Water Atlas of China*, China Cartographic Publishing House, Beijing.

ARUTYUNOV, V. D., Babel, I. V., Belyakova, T. M. and Zhavoronkov, A. A. 1969 Fluorosis as a biogeochemical endemic connected with an excess of fluorine in natural waters. In: *Micro-elements in the Landscapes of the Soviet Union*, Moscow, 50-61 (In Russian).

ASWATHANARAYANA, U., Lahermo, P., Malisa, E. and Nanyaro, J. T. 1985 High fluoride waters in an endemic fluorosis area in Northern Tanzania. In: *Proc. 1st Intern. Sympos. on Geochemistry and Health*, Ed. I, Thornton, Science Reviews, Northwood, U.K., 243-249.

AVTSYN, A. P. and Zhavoronkov, A. A. 1981 *The Pathology of Fluorosis*, Science Publishing House, Siberian Division, Novosibirsk (In Russian).

BABA, Hiroshi and Kawahara, Shunko 1950 Relation between mottled teeth, the amount of fluoride contained in drinking water and inferior physical constitution, in and around Dogo hot-spring district, Ehime Prefecture, Shikoku Region, *Shikoku Acta Medica* 1, 78-88 (In Japanese).

BAGGA, O. P., Gupta, R., Gulati, P. V. and Goel, A. 1980 A follow-up study of fluorosis a decade after a change in the source of drinking water: a preliminary report, *Fluoride* 13, 25-30.

BAI XUEXIN and nineteen co-authors 1986 A new type of fluorine poisoning caused by drinking the brick tea, *Chinese J. Endemiology* 5, 110-113 (In Chinese).

BELYAKOVA, T. M. 1969 Levels and features of the migration of fluorine in the soils of the steppe zone of northern Kazakhstan. In: *Micro-elements in the Landscapes of the Soviet Union*, Moscow, 194-203 (In Russian).

BELYAKOVA, T. M. 1977 Fluorine in soils and plants in connection with endemic fluorosis, U.S.S.R. Academy of Sciences, *Soil Science* 8, 55-63 (In Russian).

BELYAKOVA, T. M. 1978 Fluorine in the biogeochemcial food chain of the Shchuinsk biogeochemical province of Kazakhstan. U.S.S.R. Academy of Sciences, *Proc. Biogeochemical Laboratory* 15, 131-141 (In Russian).

BELYAKOVA, T. M. and Dzyadevich, G. S. 1971 Features of the distribution of fluorine in the waters of the Steppe landscapes of Kazakhstan in connection with endemic fluorosis, Moscow University Bulletin, *Geography* 6, 79-85 (In Russian).

BELYAKOVA, T. M. and Zhavoronkov A. A. 1975 Concentration of fluorine in some components of the natural environment and human tissues and fluids in the Shchuinsk focus of endemic fluorosis. In: *Geochemical and Soil Aspects in the Study of Landscapes*, Moscow State University, Moscow, 210-224 (In Russian).

BELYAKOVA, T. M. and Zhavoronkov A. A. 1978 A study of endemic fluorosis on the continents of the terrestrial globe, U.S.S.R. Academy of Sciences, *Proc. Biogeochemical Laboratory* 15, 37-53 (In Russian).

BERGH, H. and Haug, J. 1971 The fluoride content and food value of Kenya Lake fish, *East Afr. Agri. For. J.* **36**, 392-400.

BILBEISSI, M. W., Fraysse, C., Mitre, D., Kerebel, L. M. and Kerebel, B. 1988 Dental fluorosis in relation to tea drinking in Jordan, *Fluoride* **21**, 121-126.

BLACK, G. V. and McKay, F. S. 1916 Mottled teeth: an endemic developmental imperfection of the enamel of the teeth heretofore unknown in the literature of dentistry, *Dent. Cosmos* 58, 129-156.

BOHDAL, M., Gibbs, N. E. and Simmons, W. K. 1968 *Nutrition Survey and Campaign against Malnutrition in Kenya*, Report to the Ministry of Health of Kenya on the WHO/FAO/UNICEF Assisted Project, Mimeograph.

BROMEHEAD, C. N. 1941 Fluorosis in England, *Lancet* **240**, 673-674.

BROUWER, I. D., BackerDirks, O., DeBruin, A. and Huutvast, J. G. A. 1988 Unsuitability of World Health Organization guidelines for fluoride concentrations in drinking water in Senegal, *The Lancet*, 30 January, 223-225.

CHARI, K. V., Seshadri, C. V., Rao, R. J. and Naidu, M.G.C. 1971 Location of low-fluoride ground waters in the fluorosis-endemic villages of Ongole District, Andhra Pradesh, *Indian J. Environ. Health* **13**, 182-186.

CHEN GUOJIE 1988 Geographical Environmental Characteristic of Endemic Fluorosis in China. In: *Abstracts International Symposium on Environmental Life Elements and Health*, Beijing, 6.

CHRISTENSEN, B. 1987 Uptake and release of fluoride in arctic char, *Environ. Toxicol. Chem.* **6**, 529-533.

CHURCHILL, H. V. 1931 The occurrence of fluorides in some waters of the United States, *J. Industr. Engin. Chem.* **23**, 976-998.

CORBETT, R. G. and Manner, B. M. 1984 Fluoride in the ground water of north-eastern Ohio, *Ground Water* **22**, 13-17.

DEAN, H. T. 1942 The investigation of physiological effects by the epidemiologic method. In: *Fluorine and Dental Health*, F. R. Moulton (Ed.), A.A.A.S. No. 19, Lancaster Science Press, Washington, D.C. 23-31.

DEAN, H. T., Arnold, F. A. and Elvove, E. 1942 Domestic waters and dental caries, *U.S. Public Health Rep. (Washington)* **57**, 115-1179.

EDMUNDS, W. M., Cook, J. M., Kinniburgh, D. G., Miles, D. L. and Trafford, J. M. 1989 Trace element occurrence in British ground waters, *British Geol. Survey Res. Report* **SD/89/3**, British Geol. Survey, Keyworth.

EFFENDI, I. and Wibowo, D. 1984 Fluoride in Tea, *Odontostomatol Trop.* **7**, 163-167.

EMSLIE, R. D. 1966 A dental health survey in the Republic of the Sudan, *Brit. Dent. J.* **120**, 167-178.

FILIPPOVA, G. R., Vlasov, N. A., Bogdanova, L. L., Shpeizar, G. M., Aprelkova, N. F., Demina, N. V. and Charchidi, L. A. 1983 Fluorine content and several principles governing its migration in ground waters of the Argun Region, *Gidrokhim. Mater.* **85**, 41-48 (In Russian).

FLEISCHER, M. 1962 Fluoride content of ground water in the conterminous United States, *U.S. Geol. Survey Misc. Geol. Investigations* I-387, U.S. Geol. Survey, Washington D.C.

FORREST, J. R. 1956 Caries incidence and enamel defects in area with different levels of fluoride in the drinking water, *Br. Dental J.* **100**, 195-200.

GALAGAN, D. J. and Lamson, C. G. 1953 Climate and endemic dental fluorosis, *U.S. Publ. Hlth Rep.* **68**, 497-508.

GALAGAN, D. J. and Vermillion, J. R. 1957 Determining optimum fluoride concentrations, *U.S. Publ. Hlth Rep.* **72**, 491-493.

GAMBLE, D.H.F. and Biggin, C. M. 1987 Ground-water supply and advanced water treatment in Oman, *J. Inst. Water Eng. Sci.* **41**, 55-74.

GOPAL, R., Bhargava, T. N., Ghosh, P. K. and Rai, S. 1983 Fluoride and nitrate levels in ground waters of arid districts of Rajasthan, India, *Annals Arid Zone* **22**, 87-93.

GRANDJEAN, P. and Thomson, G. 1983 Reversibility of skeletal fluorosis, *Br. J. Ind. Med.* **40**, 456-461.

GRECH, P. 1966 Fluorosis in young persons: a further study in Northern Tanganyika, Tanzania, *Br. J. Radiol.* **39**, 761-764.

GRECH, P. and Latham, M. C. 1964 Fluorosis in the northern region of Tanganyika, *Trans. Roy. Soc. Trop. Med. Hygiene* **58**, 566-573.

GUMBO, F. J. 1985 Water quality monitoring in Tanzania, *Water Qual. Bull.* **10**, 174-180.

HAIKEL, Y., Voegel, J. L. and Frank, R. M. 1986 Fluoride content of water, dust, soils and cereals in the endemic dental fluorosis area of Khouribga (Morocco), *Archs. Oral Biol.* **31**, 279-286.

HAIKEL, Y., Cahen, P-M., Turlot, J-C. and Frank, R. M. 1989 Dental caries and fluorosis in children from high and low-fluoride areas of Morocco, *J. Dent. Children*, Sept-Oct, 378-381.

HAIMANOT, R. T., Fekadu, A. and Bushra, B. 1987 Endemic fluorosis in the Ethiopian Rift Valley, *Trop. Geogr. Med.* **39**, 209-217.

HMSO 1989 *Digest of Environmental Protection and Water Statistics, Vol. II* (1988), Her Majesty's Stationery Office, London.

JACKSON, W.P.U. 1962 Further observations on the Kenhardt Bone Disease and its relation to fluorosis, *S. Afr. Med. J.* **36**, 932-936.

JINADASA, K. B. P. N., Weerasooriya, S. V. R. and Dissanayake, C. B. 1988 A rapid method for the defluoridation of fluoride-rich drinking waters at village level, *Intern. J. Environ. Studies* **31**, 305-312.

JINADASA, K. B. P. N. and Dissanayake, C. B. 1992 the effect of selenium on fluoride - day interactions: possible environmental health implications, *Environ. Geochem. Health* **14**, 3-7.

JOLLY, S. S., Singh, B. M., Mathur, O. C. and Malhotra, K. C. 1968 Epidemiological, clinical and biochemical study of endemic dental and skeletal fluorosis in Punjab, *Br. Med. J.* **4**, 427-429.

JOLLY, S. S., Lal, H. and Sharma, R. 1980 Trace elements in endemic fluorosis in Punjab, *Fluoride* **13**, 49-57.

KANFI, Y. and Ronen, D. 1976 *Ground-water quality in the Coastal Plain aquifers of Israel*, Water Commission Report No. 76/1 (In Hebrew).

KAS'JENENKO, A. S. 1981 Incidence of atmospheric fluoride upon the state of health of a population in the hydrogeochemical province of Bucak, *Fluoride* **14**, 44-45 (Abstracted from *Vrach Delo* **12**, 105-111, 1978).

KOBAYACHI, S. 1958 Fluorine in ground waters in the plains of Nobi, Japan, *Kagau Lasshi* **79**, 539-543 (In Japanese).

KRISHNAMACHARI, K.A.V.R. 1985 Geographical distribution of human fluorosis in India. In: *Proc. 1st Intern. Sympos. on Geochemistry and Health*, Ed. I, Thornton, Science Reviews, Northwood, U.K., 158-163.

KUMAR, S. P. and Kemp-Harper, R.A.K. 1963 Fluorosis in Aden, *Brit. J. Radiol.* **36**, 497-500.

KUMARAN, P., Bhargava, G. N. and Bhakuni, T. S. 1971 Fluorides in ground water and endemic fluorosis in Rajasthan, *Indian J. Environ. Hlth* **13**, 316-324.

KUMPULAINEN, J. and Koivistoinen, P. 1977 Fluorine in foods, *Residue Rev.* **68**, 37-55.

LAHERMO, P., Llmasti, M., Juntunen, R. and Taka, M. 1990 The Geochemical Atlas of Finland, Part I: The hydrogeochemical mapping of Finnish ground water, Geological Survey, Espoo.

LATHAM, M. C. and Grech, P. 1967 The effects of excessive fluoride intake, *Amer. J. Public Hlth* 57, 651-660.

LEATHERWOOD, E. C., Burnett, G. W., Chandravejjsmarn, R. and Sirikaya, P. 1965 Dental caries and dental fluorosis in Thailand, *Amer. J. Public Hlth* **55**, 1792-1799.

LI **FUCHENG**, Zhou Linye, Fang Shijie, Wei Zhandao, Xiao Kaiqi, Yu Yanni, Chao Zumao, Liu Jialia and Cheng Xuguang 1988 A Report of Aluminium - Fluoride combined toxicosis by food chain. In: *Abstracts International Symposium on Environmental Life Elements and Health*, Beijing, 24.

LI RIBANG, Tan Jianan, Wang Wuyi and Wang Lizhen 1982 A study of fluoride as the source of endemic dietary fluorosis in Guizhou Province, China, *National Med. J. China* **62**, 425-428 (In Chinese).

LI RIBANG, Tan Jianan, Wang Lizhen, Zheng Daxian and Wang Wuyi 1985 The fluoride content in cultivated soil under different geographical conditions in China and its relation to endemic fluorosis, *Geog. Res.* **4**, 30-41 (In Chinese).

LI RIBANG, Zheng Daxian, Wang Lizhen and Tan Jianan 1986 A study of fluoride absorption by plants in soil-plant ecological system, *Acta. Geogr. Sinica* **41**, 123-131 (In Chinese).

LI RIBANG, Wang Lizhen, Tan Jianan and Wang Wuyi 1988 Fluoride in soil and endemic fluorosis. In: *Abstracts, International Symposium on Environmental Life Elements and Health*, Beijing, 88.

LITTLETON, N. W. 1963 Dental caries and periodontal diseases among Ethopian civilians, *U.S. Public Health Reports* **78**, 631-640.

MacQUILLAN, C. J. 1944 Chronic fluoride poisoning in the Arusha district, Tanganyika territory, *E. African Med. J.* **21**, 131-134.

MANGLA, B. 1991 India's dentists squeeze fluoride warnings off tubes, *New Scientist* **131**, 16.

MANJI, F., Boelum, V. and Fejerskov, O. 1986a Dental fluorosis in an area of Kenya with 2 ppm Fluoride in the drinking water, *J. Dent. Res.* **65**, 659-662.

MANJI, F., Boelum, V. and Fejerskov, O. 1986b Fluoride, altitude and dental fluorosis, *Caries. Res.* **20**, 473-480.

MANJI, F. and Kapila, S. 1986a Fluorides and fluorosis in Kenya, Part I, The occurrence of fluorides, *Odontostomatol Trop.* **9**, 15-20.

MANJI, F. and Kapila, S. 1986b Fluorides and fluorosis in Kenya, Part II, The occurrence of dental and skeletal fluorosis, *Odontostomatol Trop.* **9**, 71-74.

MATSUDA, K. 1986 The quality of drinking water and hot spring water from an endemic dental fluorosis area in northern Japan, *Fluoride* **19**, 173-180.

McEWAN, T. 1964 Isolation and Identification of the Toxic Principle of Gastrolobium grandiflorum, *Nature (Lond.)* **201**, 827.

MENG XIANXI, Zhang Liping and Wang Zongyi 1988 Fluoride in the ecological environment of south-western Song-Nen plain. In: *Abstracts, International Symposium of Environmental Life Elements and Health*, Beijing, 136.

MÖLLER, I. J. 1965 Dental Fluorose og Caries, Rhodos, Intern. Sci. Publ., Copenhagen (In Danish).

MÖLLER, I. J., Pindborg, J. J., Gedalia, I. and Roed-Petersen, B. 1970 The prevalence of dental fluorosis in the people of Uganda, *Arch. Oral. Biol.* 15, 213-225.

MURDEN, X. D. 1953 Natural fluoride well water added to Portsmouth surface supply, *J. Amer. Water Works Assoc.* **45**, 363.

MURRAY, M. M. and Wilson, D. C. 1948 Fluorosis and nutrition in Morocco: dental studies in relation to environment, *Br. Med. J.*, 5 March, 97-100.

NAIR, K. R., Manji, F., and Gitonga, J. N. 1984 The occurrence and distribution of fluoride in ground waters of Kenya. In: *Challenges in African Hydrology and Water Resources* (Proceedings of the Harare Symposium, July 1984), IAHS publ. no. **144**, 75-86.

NAIR, K. R. and Gitonga, J. N. 1985 Correlation between occurrence of fluoride in ground and surface water resources and dental fluorosis in Kenya, *Fluoride* 18, 4-11.

OCKERSE, T. 1941a Endemic fluorosis in the Pretoria district, *S. Afr. Med. J.* **15**, 261-266.

OCKERSE, T. 1941b Endemic fluorosis in the Kenhardt and Gordonia districts, Cape Province, South Africa, *J. Amer. Dent. Assoc.* **28**, 936-941.

OCKERSE, T. 1953 Chronic endemic fluorosis in Kenya, East Africa, *Brit. Dent. J.* **95**, 57-60.

OLSSON, B. 1979 Dental findngs in high-fluoride areas in Ethopia, *Community Dent. Oral Epidemiol.* 7, 51-56.

ORTIZ VAZQUEZ, J., Martinez Landete, E. and Vinuelas Garcia, A. 1952 Contribución al conocimiento de la fluorosis dental crónica endémica en Espana ("Esmalte moteado"), *Rev. Esp. Enfermed. Aparato Digest. y Nutr.* **11**, 204-216 (In Spanish).

PARAJE, R. 1950 Contributions to the studies of fluorine, vanadium and arsenic in water of the southern part of the province of Cordoba (Argentina), *Revista de la Asociacion Bioquimica Argentina* **15**, 211-232 (In Spanish).

PHANTUMVANIT, P., Songpaisan, Y., Visarurath, S. and Patimanukasem, P. 1982 Fluoride mapping in Chiangmai, Thailand, *Osterr. Z. Stomatol*. **79**, 303-304.

PHANTUMVANIT, P., Songpaisan, Y., and Koontongkaew, S. 1986 Water quality and dental fluorosis: A public health problem in Thailand, *Water Qual. Bull*. **11**, 88-91.

POULSEN, S., Müller, I. J., Naerum, J. and Pedersen, P. 1972 Prevalence of dental caries in 2,383 Moroccan school children aged 8 and 12, *Archs. Oral Biol*. **17**, 1165-1175.

POULSEN, S. and Müller, I. J. 1974 Gingivitis and dental plaque in relation to dental fluorosis in men in Morocco, *Archs. Oral Biol*. **19**, 951-954.

RAJAGOPAL, R. and Tobin, G. 1991 Fluoride in drinking water: a survey of expert opinions, *Environ. Geochem. Hlth* **13**, 3-13.

RAJYALAKSHMI, K. and Rao, N.V.R. 1985 Fluorosis in Nalgonda District in relation to chemical characteristics of potable water and staple food, *Fluoride* **18**, 198-203.

RAJYALAKSHMI, K., Rao, N.V.R. and Krishna, N. 1987 Investigations on the relevance of defluoridated water and nutritional supplements in fluorosis endemic areas in Andhra Pradesh, India, *Fluoride* **20**, 189-190.

RAMESAM, V. and Rajagopalan, K. 1985 Fluoride ingestion into the natural waters of hard-rock areas, Peninsular India, *J. Geol. Soc. India* **26**, 125-132.

RAO, S. R., Murthy, K.J.R. and Murthy, T.V.S.D. 1979 Urinary fluoride excretion in endemic fluorosis, *Fluoride q. Rep*. **12**, 188-194.

RONEN, D. and Kanfi, Y. 1978 *Ground-water quality in the Yarkon Tanninim aquifer (Israel)*, Water Commission Report No. 78/1 (In Hebrew, English Abstract).

SHACKLETTE, H. T., Boerngen, J. G. and Keith, J. R. 1974 Selenium, fluorine and arsenic in surficial materials of the conterminous United States, *U.S. Geol. Survey Circular* **692**, U.S. Geol. Survey, Washington D.C.

SHINKARYUK, V. G., Aron, P. L. and Volk, M. S. 1983 Hydrogeochemical evaluation of fluorine-containing ground waters of Moldavia for choice of a defluorination method and purification equipment, *Soversh. Melior. S-Kh. Sist*., 4-10 (In Russian).

SIDDIQUI, A. H. 1955 Fluorosis in Nalgonda District, Hyderabad, Deccan, *Br. med. J*. **2**, 1408-1413.

SKORKOWSKA-ZIELENIEWSKA, J. 1983 In heavy tea and coffee drinkers "nutritional status" of fluoride in relation to that of other mineral elements, *Fluoride* **16**, 20-23.

SMITH, D. A., Harris, H. A. and Kirk, R. 1953 Fluorosis in the Butana, Sudan, *Trop. Med. Hygiene* 56, 57-58.

SUSHEELA, A. K. and Das, T. K. 1988 Fluoride toxicity and fluorosis: diagnostic test for early detection and preventive medicines adopted in India. In: *Abstracts, International Symposium on Environmental Life Elements and Health*, Beijing, 89.

TALBOT, L. 1990 Wisconsin Water Quality Assessment Report to Congress 1990 Publ. WR-254-90, Wisconsin Department of Natural Resources, Madison, Wisconsin.

TEOTIA, S.P.S., Teotia, M. and Kunwar, K. B. 1971 Endemic skeletal fluorosis, *Arch. Dis. Childhood.* **46**, 686-691.

TEOTIA, S.P.S., Teotia, M., Singh, D. P. Rathour, R. S., Singh, C. V., Tomar, N.P.S., Nath, M. and Singh, N. P. 1984 Endemic fluorosis: change to deeper bore wells as a practical community - acceptable approach to its eradication, *Fluoride* 17, 48-52.

THYLSTRUP, A. and Ferjerskov, O. 1978 Clinical appearance of dental fluorosis in permanent teeth in relation to histologic changes, *Commun. Dent., Oral Epidemiol.* 6, 315-328.

TOBAYIWA, C., Musiyambiri, M. L., Mazorodze, O., Sapahla, S. and Chironga, L. 1990 *Water Quality Survey (Zimbabwe): a study of the fluoride and nitrate levels in rural water supplies*, IDRC 3-P-86-0226, Government Analysts Laboratory, Causeway, Zimbabwe.

TOMIC, D. 1955 The concentrations of fluorine in the drinking water of Gorskog Kotara, *Acta Pharm. Jug.* 3, 129-132 (In Slav.).

TRAVI, Y. and Le Coustour, E. 1982 Dental fluorosis and sub-surface waters in Senegal, *Eau Que* 15, 9-12 (In French).

TSURUMAKI, M. and Sakuramoto, Y. 1985 The origin of the high-fluoride ground waters in Kinki District, *Nippon Chikasui Gakai Kaishi* 27, 1-16 (In Japanese).

TUNCEL, E. 1984 The incidence of Moenckeberg calcifications in patients with endemic fluorosis, *Fluoride* 17, 4-8.

USPHS 1991 Toxicological profile for fluorides, hydrogen fluoride and fluorine (F): draft for public comment, U.S. Dept of Health and Human Services, Public Health Service, Washington.

WARD, L. K. 1954 Fluorine in South Australian underground waters, *Report of Investigations No. 1*, South Australia Department of Mines, Adelaide.

WHO 1984a *Guidelines for drinking water quality*, Vol. 1, Recommendations, WHO, Geneva.

WHO 1984b *Fluorine and Fluorides*, Environmental Health Criteria, Vol. 36, WHO, Geneva.

WILLIAMSON, M. M. 1953 Endemic dental fluorosis in Kenya, A preliminary report, *East Afr. Med. J.* 30, 217-233.

WILSON, D. C. 1939 Distribution of Fluorosis in India and in England, *Nature (Lond.)* **144**, 155.

WILSON, D. C. 1954 Fluorine content of some Nigerian waters, *Nature (Lond.)* 173, 305.

WRB 1972 *The Hydrogeology of the London Basin with Special Reference to Artificial Recharge*, Water Resources Board, Reading.

ZAHVORONKOV, A. A. and Strochkova, L. S. 1981 Fluorosis: geographical pathology and some experimental findings, *Fluoride* **14**, 182-191.

APPENDIX I

Classification of dental fluorosis following the Dean (1942) method is widely used throughout the world. It is based on a six-point scale according to the colour, surface texture and occurrence of defects in the enamel. The following outline briefly describes the classification.

Type	Weight	Brief description
Normal	0	The enamel is translucent with a smooth and glossy surface and creamy white in colour.
Questionable fluorosis	0.5	Slight variations from the normal enamel - a few white flecks. It is used when a definite diagnosis is uncertain yet not "normal".
Very mild fluorosis	1	Small opaque paper white areas scattered over the tooth but covering less than 25 per cent of the tooth.
Mild fluorosis	2	More extensive opaque areas but covering less than 50 per cent of the tooth.
Moderate fluorosis	3	All enamel surfaces are affected. Frequent brown stains are a disfiguring feature. Signs of attrition.
Severe fluorosis	4	All enamel surfaces affected with discrete pitting. Widespread brown stains with corroded-like appearance of the tooth.

One of the problems of determining the weighting lies in the "questionable" fluorosis category. The "questionable" changes occur with increasing frequency at higher fluoride exposure levels. Their relationship to fluoride exposure in population studies is therefore not questionable, although the aesthetic significance may be. Thus the "questionable" changes should be more properly be given more statistical weight than 0.5 following the Dean index. Several revisions of the scoring system have been proposed.

Thylstrup and Fejerskov (1978) have extended the method developed by Dean and have come up with an index based on histological changes seen in different degrees of fluorosis with grades 0-4 describing preruptic fluorotic changes and grades 5-9 describing changes that occur after teeth have erupted, i.e., pitting, chipping and staining. Grade 4 describes the severest histological form of fluorosis. This latter index was used in the study in Zimbabwe (Tobayiwa et al., 1990).

In addition to assessing the degree of dental fluorosis in the individual, Dean (1942) devised a means of calculating the prevalence and degree in a group or community. Thus he termed the Community index of dental fluorosis (F_{ci}). It represents the average severity of scores assigned to individuals. It is thus determined by means of the formula:

$$F_{ci} = \frac{\Sigma \text{ (frequency x statistical weight)}}{\text{number of individuals}}$$

APPENDIX II

The description and classification of countries and territories in this study and the arrangement of the material do not imply the expression of any opinion whatsoever of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries, or regarding its economic system or degree of development.

"Short name" below refers to the abbreviated name used within the body of this report.

Short name	Full name
Afghanistan	Democratic Republic of Afghanistan
Algeria	People's Democratic Republic of Algeria
Argentina	Argentine Republic
Australia	Commonwealth of Australia
Bolivia	Republic of Bolivia
Bulgaria	People's Republic of Bulgaria
Canada	Canada
China	People's Republic of China
Egypt	Arab Republic of Egypt
Ecuador	Republic of Ecuador
Ethiopia	Socialist Republic of Ethiopia
Finland	Republic of Finland
France	French Republic
Germany	Germany
Greece	Hellenic Republic
Greenland	Greenland
Hungary	Hungarian People's Republic
India	Republic of India
Indonesia	Republic of Indonesia
Iran	Islamic Republic of Iran
Iraq	Republic of Iraq
Israel	State of Israel
Italy	Italian Republic
Japan	Japan
Jordan	Hashemite Kingdom of Jordan
Kazakhstan	Republic of Kazakhstan
Kenya	Republic to Kenya
Korea	Republic of Korea
Libya	Socialist People's Libyan Arab Jamahiriya
Mexico	United Mexican States
Moldova	Republic of Moldova
Morocco	Kingdom of Morocco
Myanmar (qv Burma)	The Union of Myanmar
Netherlands	Kingdom of the Netherlands
New Zealand	New Zealand
Nigeria	Federal Republic of Nigeria
Oman	Sultanate of Oman
Senegal	Republic of Senegal
South Africa	Republic of South Africa
Spain	Spanish State

Short name	Full name
Sri Lanka	Democratic Socialist Republic of Sri Lanka
Sudan	Democratic Republic of the Sudan
Syria	Syrian Arab Republic
Tanzania	United Republic of Tanzania
Thailand	Kingdom of Thailand
Turkey	Republic of Turkey
U.K.	United Kingdom of Great Britain and Northern Ireland
U.S.A.	United States of America
Uganda	Republic of Uganda
Ukraine	Ukraine
Viet Nam	Socialist Republic of Viet Nam
Yemen	Yemen Arab Republic
Yugoslavia	Socialist Federal Republic of Yugoslavia
Zimbabwe	Republic of Zimbabwe