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Fluoride contamination of groundwater and its impacts on human health in Inner Mongolia area

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ABSTRACT: An investigation was conducted on fluoride contamination of groundwater and its impacts on human health in a rural district of Togtoh County, Inner Mongolia Autonomous Region, China. As a result of water quality analysis, a fluoride concentration higher than 1.5 mg/L was detected in 62% of the wells for water supply and the highest value was 8.0 mg/L. Because of the extra intake of fluoride from drinking water, dental fluorosis and skeletal fluorosis became popular endemic diseases in this area. The authors carried out investigations on the occurrence of fluorosis and found that the morbidity was as high as 53%. An analysis of the regional distribution of fluoride concentration of the groundwater and that of the morbidity of fluorosis showed that high occurrence of fluorosis was accompanied by high fluoride concentration. The results from two case studies are described in this paper. One shows the distribution of the morbidity of dental and skeletal fluorosis by age group in a village where fluoride contamination is extremely severe, and the other shows an example of the remarkable effect of water quality improvement on human health in another village. The influence of chloride on the young generation was stressed.

INTRODUCTION

In China there are many regions where a large population suffers from endemic diseases caused by extra intake of fluoride. The areas with high occurrence of dental fluorosis and/or skeletal fluorosis spread over more than 20 provinces and cover about one-fifth of the country's total area. More than 100 million people are sufferers to different extents. There are mainly four regions where the morbidity of fluorosis is high: (i) a wide stripe of east-to-west direction from the North-east 3 provinces through the North China provinces such as Hebei and Shanxi to the North-west provinces such as Shaanxi, Ningxia, Gansu and Xinjiang; (ii) the Bohai coastal area including part of Tianjin and Shandong; (iii) South China area such as Hubei and Guizhou provinces; and (iv) some parts of the Sichuan, Yunnan, Zhejiang, Fujian and Guangdong provinces [1]. The main sources of fluoride intake relate to water and air/smoke. In the north part of China, high fluoride concentration groundwater aquifers are the main contamination sources even though there are cases of contamination from burning fluoride baring coal. In the south part of China, apart from cases of fluoride contamination of crops resulting from fluoride-soils and fluoride pollution from industry, the intake of fluoride from drinking water is the most common case for the high occurrence of fluorosis.

Figure 1 shows the distribution of fluoride concentration in the groundwater aquifers in China [2]. It is apparent that a high fluoride concentration of the groundwater attributes to the high occurrence of fluorosis in the north part of China. Because of the limitation of water resources, the drinking water supply depends on shallow wells in many places in spite of the fact that the water has a fluoride concentration which is much higher than the drinking water quality standard value. Among such areas, the condition in the Inner Mongolia Autonomous Region is the most serious. According to a regional survey conducted in 1982 [3,4], fluoride concentrations higher than 1.0 mg/L (the Chinese drinking water quality standard value) were detected from 47% of the wells used for drinking water supply in the whole Inner Mongolia region, and 73 of the 100 counties were found to be areas where dental and/or skeletal fluorosis were present. The number of people suffering from dental fluorosis was as high as 1.9 million, and from skeletal fluorosis the figure was more than 230 000. Figures 2 and 3 show the distributions of dental and skeletal fluorosis, respectively, in the whole region [2].

The serious condition of fluorosis in the Inner Mongolia region has drawn attention from home and abroad. In the early 1980s, the Chinese government mobilised a movement for water quality improvement in the fluoride contaminated area. By using national and/or international finance, small scale water supply systems were constructed in a number of villages and certain measures were taken for the improvement of water quality including digging deep wells and treating water. At the same time, many foreign organisations conducted studies on the situation of endemic diseases related to fluoride contamination in this region.

The present study is part of an international cooperation study under the support of the Japan International Coopera-

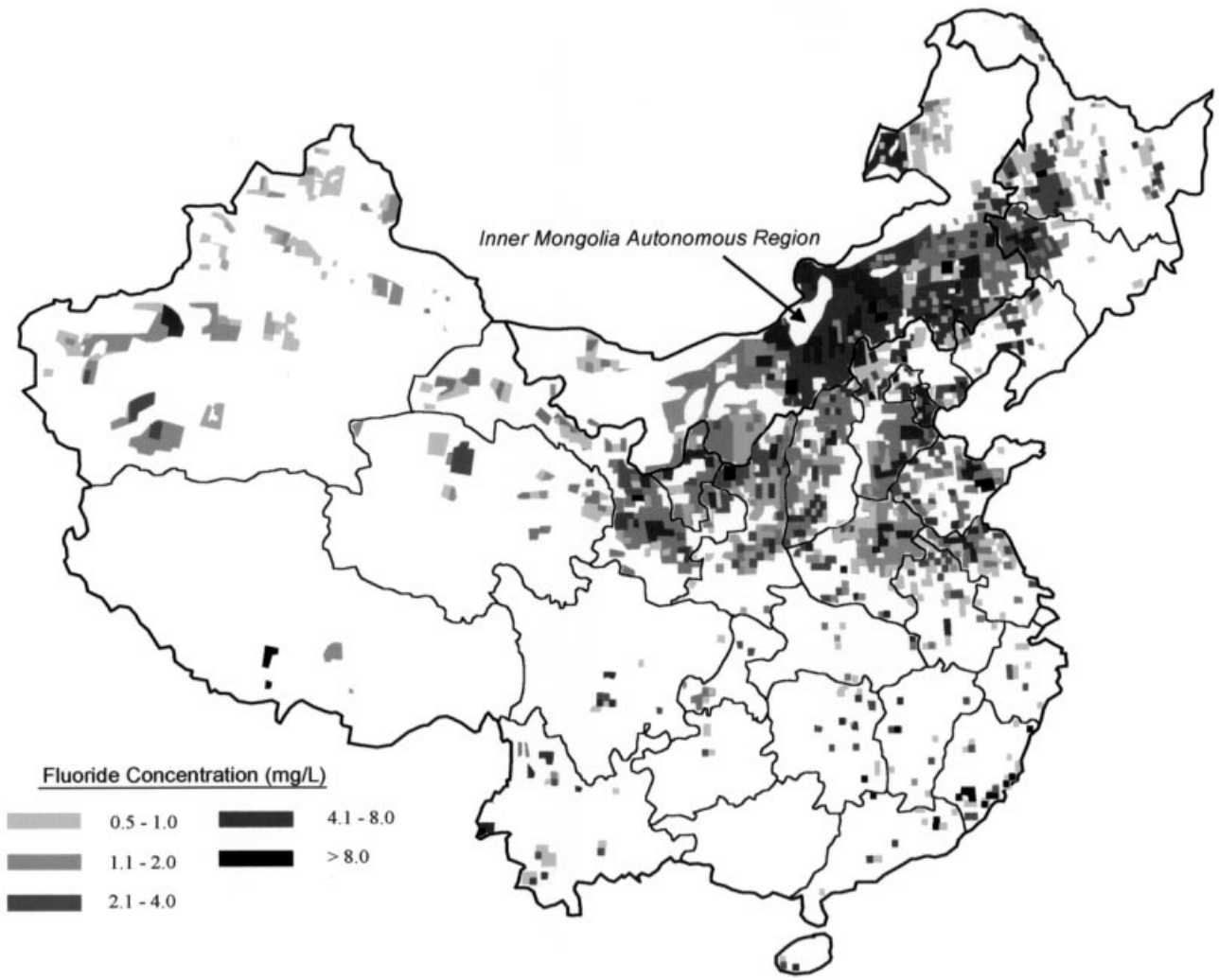

Fig. 1 Distribution of fluoride concentration in the groundwater aquifers in China (re-plotted using data from Central Patriotic Public Health Campaign Committee of China [2]).

tion Agency. The authors conducted a comprehensive investigation on fluoride contamination of groundwater and its impacts on human health in part of Togtoh County, Inner Mongolia Autonomous Region.

STUDY AREA

Description of the study area

Togtoh County is located on the outskirts of Huhhot City, the capital of the Inner Mongolia Autonomous Region. As can be seen from Figs 1–3, this area is in the centre of the region where fluoride concentration is high in the groundwater as well as the morbidity of dental/skeletal fluorosis. Although the Yellow River flows in the south-west of the county, it has not been used as a water resource for domestic water supply, partially because of its extremely high turbidity. Therefore, people depend on groundwater, mostly hand-dug shallow wells, for their drinking water supply.

The study area covers 550 km^2 (one-third of the area of the county) including 96 villages with a population of about 40 000.

Distribution of fluoride concentration in the study area

In order to understand the current state of fluoride contamination of the shallow groundwater aquifers in the study area, water samples were collected from more than 100 wells and water quality analysis was conducted. A fluoride electrode method was applied for fluoride measurement with a prelimin-

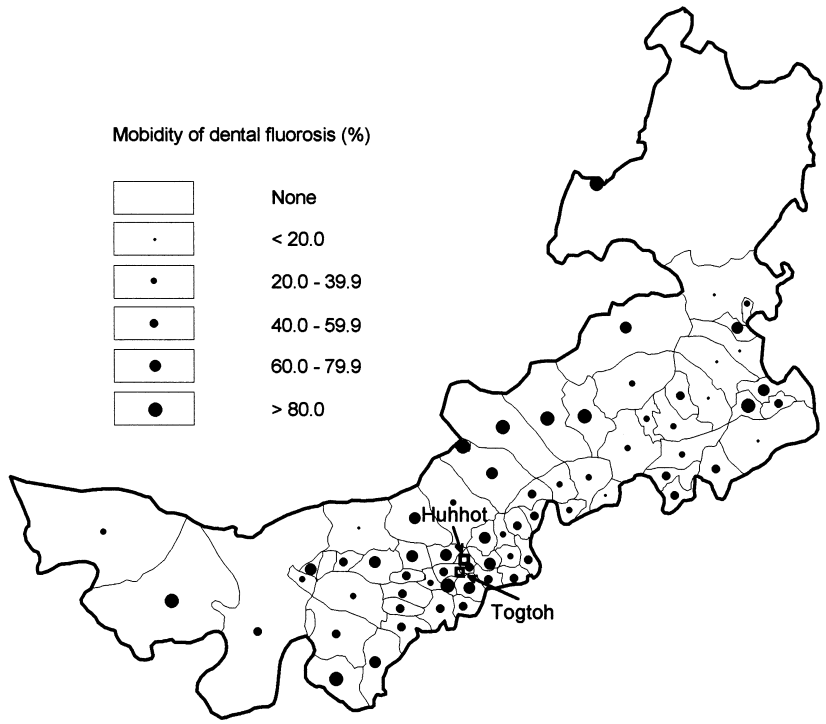

Fig. 2 Distribution of dental fluorosis in Inner Mongolia area (re-plotted using data from Central Patriotic Public Health Campaign Committee of China [2]).

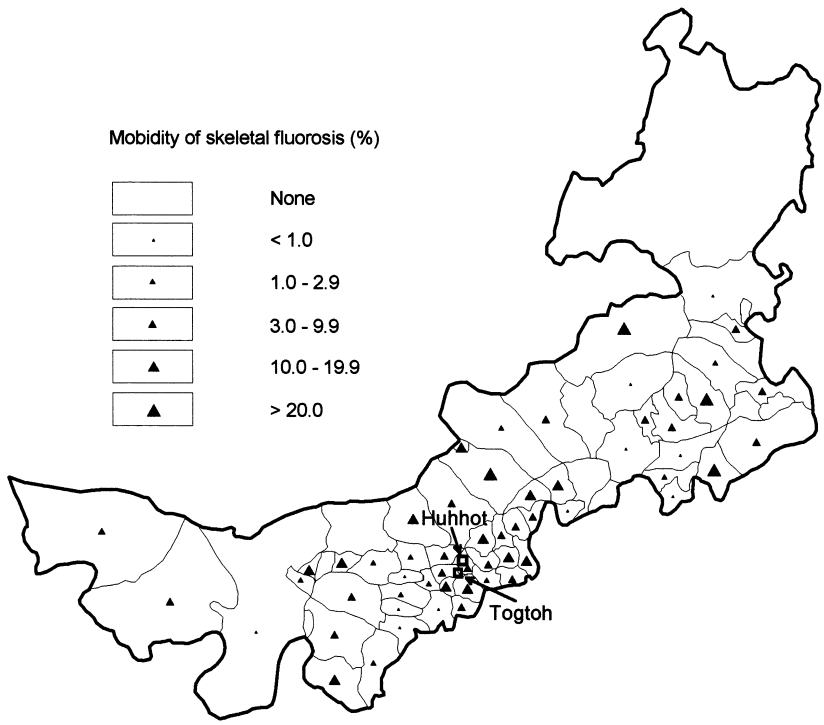

Fig. 3 Distribution of skeletal fluorosis in Inner Mongolia area (re-plotted using data from Central Patriotic Public Health Campaign Committee of China [2]).

ary distillation step to eliminate possible errors due to interfering ions such as chloride and so on as necessary. Most of these wells are used for domestic water supply without any treatment. As a result of water quality analysis, 75% of the samples showed fluoride concentrations higher than 1.0 mg/L, 62% higher than 1.5 mg/L, and the highest value was 8.0 mg/L. Arsenic contamination was also suspected at the beginning, but was only detected from two wells which are no longer being used for drinking water purposes.

Since the sampling points cover all the villages in the study

area, we took the measured fluoride concentrations as representative data showing the extent of fluoride contamination of groundwater aquifers at these locations. Using a data analysis computer program, a regional distribution map of fluoride concentration was obtained as shown in Fig. 4.

Investigation on fluorosis in the study area

Method of investigation

The investigation included a general investigation of the whole study area and a detailed investigation of some typical villages for case study purposes.

For the general investigation, fluorosis was investigated, as well as other endemic diseases related to arsenic contamination. Of the households in each of the villages in the study area, 25% were arbitrarily chosen as objects for the investigation. With the assistance of experienced doctors of endemic diseases, we conducted interviews and physical check-ups for each of the chosen families, and put the results on to an investigation sheet. The investigation sheet was composed of about 150 pieces of information including the general conditions of the family, information related to drinking water availability and usage, medical history of the family, self-statement of symptoms and physical disorders, physical condition parameters, clinical symptoms (head, face, organs of sense, teeth, body, limbs, hands, feet, nervous system, etc.). Among them, the appearance and defects of teeth, the deformity of backbone and limbs, the shrinkage of sinews, and the movability of joints were the main factors for diagnosing dental/skeletal fluorosis.

Based on the results of the above mentioned investigation, two villages were selected for case studies—one is a village with the highest morbidity of fluorosis, the other is a village where a remarkable improvement in human health has been achieved as a result of water quality improvement. For these two villages, more people were interviewed and given check-ups, with particular attention being paid to children and teenagers.

RESULTS

The results of general investigation of fluorosis in the study area were classified by analysing the information obtained from interviews and physical check-ups. In the medical field, there

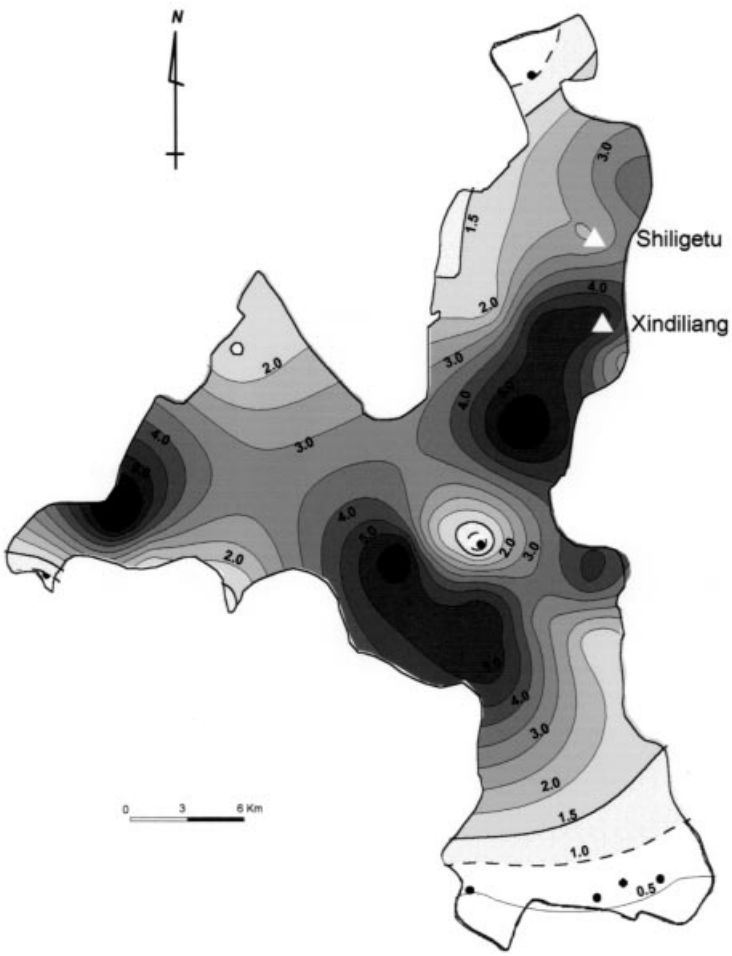

Fig. 4 Distribution of fluoride concentration in the shallow groundwater aquifers (Fluoride concentration as mg/L).

are special categories for dental and skeletal fluorosis. For example, the extent of dental fluorosis can be characterised by seven classes: normal, suspicious (loss of brightness and beginning of white spotting), slight minus (white spotting extended to one-quarter of the teeth), slight (turning to yellowish), middle (erosion to small holes), heavy minus (erosion extended to all the front teeth) and heavy (heavy damage on all the teeth with blackish appearance). As for skeletal fluorosis, the classification is more complicated and X-ray examination is often needed. Considering the great number of investigated samples and shortage of precise examination for this study, we used a 3-grade classification method to quantify the investigation result from an environmental viewpoint, i.e. (a) normal, (b) slight and (c) heavy for dental and skeletal fluorosis. The definitions for these three classes are shown in Table 1.

Based on the investigation results, a judgement was made for every person interviewed regarding dental and skeletal fluorosis. As a result, 14% people were found to be as Grade b, i.e. slight symptoms of dental/skeletal fluorosis, but 39% as Grade c, i.e. serious symptoms. Therefore, the morbidity of fluorosis in the study area was 53%. Among them, the cases of skeletal fluorosis comprised about one-quarter of the cases, all of whom showed symptoms of dental fluorosis.

In comparison with the 1982 study result [3,4] where the morbidity of fluorosis in the whole fluoride contaminated area in Inner Mongolia showed 46% of dental fluorosis and 5.6% of skeletal fluorosis, it can be concluded that the general condition in the study area is very serious.

It should be pointed out that the diagnosis of slight fluorosis, especially dental fluorosis, is more or less ambiguous on some occasions. In this study, we took yellowish teeth with slight erosion as the slight symptom of dental fluorosis but did not take into consideration the earlier stage of fluorosis characterised by loss of brightness and development of white spots on the teeth which is sometimes included in the morbidity of fluorosis.

During the investigation, only two people were suspected of having arsenic-related symptoms. This coincides with the water quality study results and proves that arsenic contamination is not dominant in the study area.

Morbidity of fluorosis and drinking water quality

It is noticeable that there exist differences in the morbidity of fluorosis among the investigated villages. In order to understand the interrelation between fluorosis and drinking water quality, we put the morbidity of fluorosis obtained from the above mentioned investigation for each village on to a map and conducted data analysis by computer. The result is presented in Fig. 5 which shows a regional distribution of the morbidity of fluorosis.

By comparing the distribution of the morbidity of fluorosis (Fig. 5) with that of fluoride concentration in the shallow groundwater aquifers (Fig. 4), it is apparent that high morbidity of fluorosis has happened in areas where fluoride concentration is extremely high, and for villages where water quality problem is less serious the morbidity of fluorosis is comparatively low.

Case study 1: Xindiliang Village

Through the general investigations on fluorosis, a morbidity as high as 95.5% was found in Xingdiliang Village—a small village with 35 households and about 130 villagers (see its location in Figs 4 and 5). The condition at this village has also been reported by Nagasaka *et al*. in 1992 [5]. Water supply in this village depends on a public well of 30 m deep with a simple pipe system to each household. The fluoride concentration of the well water has been reported as 2–4 mg/L, but by testing water samples for several times at different seasons, we measured the concentration as 5–6 mg/L (average 5.44 mg/L). Fluoride removal by activated alumina was tried in the 1980s but failed to be applied continuously.

We conducted additional investigations by visiting each household. The result is summarised in Table 2. From this table, it is seen that almost everyone over 10 years of age suffers from dental fluorosis and everyone over 40 suffers from skeletal fluorosis. Since everyone who had skeletal fluorosis also suffered from dental fluorosis, the morbidity of fluorosis based on the total number of investigated persons was 86.5%, which is lower than that of 95.5% from the general investigation for this

Table 1 Three-grade classification of dental and skeletal fluorosis

	Symptoms	
Grade	Dental fluorosis	Skeletal fluorosis
a Normal	No apparent abnormality	No apparent abnormality
b Slight	Yellowish teeth with slight erosion	Pain or difficulties with movement of the limbs
c Heavy	Extended erosion or heavy damage to the teeth	Apparent deformity of joint regions,limbs or backbones, shrinkage of muscles and more serious symptoms

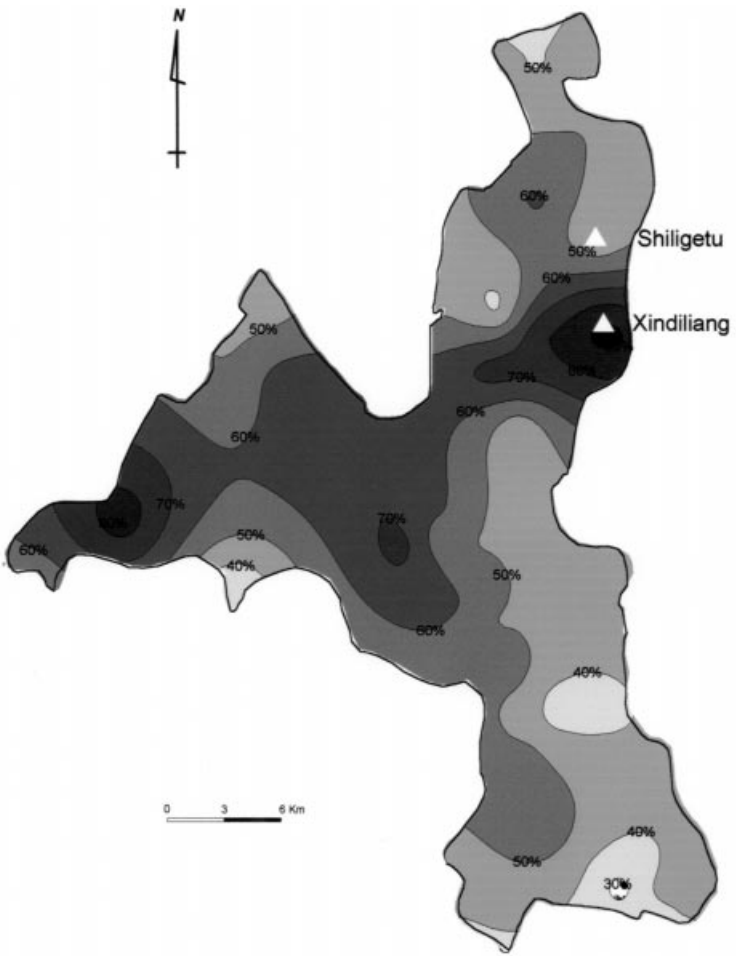

Fig. 5 Distribution of the morbidity of fluorosis in the study area (as per cent of population).

village. The gap is thought to be from the number of children under nine years of age. In the general investigation few children were interviewed but in the additional investigation we detected 13 children within the lowest age group. Generally speaking, the symptom of dental fluorosis does not appear until a child is at an age where their permanent teeth grow through. We found an eight year old boy whose first permanent tooth reached half height; in contrast with the remaining bright white milk teeth, the newly apparent permanent tooth was yellowish and with blackish spotting. Although children under such an age do not show any symptoms, in fact they are already potential sufferers of fluorosis.

The sufferers of skeletal fluorosis in their forties often feel pain in their limbs, joint sections or backbones. After the age of 50, certain parts of their bodies deform and their muscles shrink. Many elderly people become bow-legged. They cannot stretch their arms properly nor raise them over their heads. Some of them cannot raise their body to an upright position. One woman of 67 years was investigated and found to have been bed-ridden for several years. Every year she has to be hospitalised for a while, but no medicines can really cure her pain.

In the village, there are about 10 women who were born and brought up in other regions where there exists no fluoride contamination and who moved to the village after marriage. They described their teeth as beautiful and bright when they first arrived in the village. But as years passed, their teeth gradually lost their beauty and instead showed the symptoms of dental fluorosis, although not as seriously as the native villagers of the same ages. There is only one exception in the mother of the head of the Village. She is already 72 years old but has managed to avoid developing dental and skeletal fluorosis after more than 50 years of married life in this village. The intake of high concentration fluoride from drinking water impacts not only children but also adults who spend their growth period in a nonfluoride contamination environment. However, the growth period has important implications for the rest of one's life. The fact that there are no cases of skeletal fluorosis among people of this category provides the proof.

Case study 2: Shiligetu Village

Among all the villages investigated, Shiligetu Village (see Figs 4 and 5 for its location) is an example showing the importance of water quality improvement to human health. This

Table 2 Result of additional investigation of gluorosis in Xindiliang Village

	Male			Female			Total		
		Fluorosis			Fluorosis			Fluorosis	
Age	No. of samples	Dental	Skeletal	No. of samples	Dental	Skeletal	No. of samples	Dental	Skeletal
0–9	7	1 (14.3)	0 (0)	6	0 (0)	0 (0)	13	1 (7.7)	0 (0)
10–19	7	7 (100)	0 (0)	5	5 (100)	0 (0)	12	12 (100)	0 (0)
20–29	9	9 (100)	0 (0)	8	8 (100)	0 (0)	17	17 (100)	0 (0)
30–39	5	5 (100)	0 (0)	6	6 (100)	0 (0)	11	11 (100)	0 (0)
40–49	10	10 (100)	10 (100)	8	7 (87.5)	5 (62.5)	18	17 (94.4)	15 (83.3)
50–59	9	9 (100)	9 (100)	8	8 (100)	8 (100)	17	17 (100)	17 (100)
60 and older	7	7 (100)	7 (100)	9	8 (88.9)	8 (88.9)	16	15 (93.8)	15 (93.8)
Total	54	48 (88.9)	26 (48.1)	50	42 (84)	21 (42)	104	90 (86.5)	47 (45.2)

Note: Number in parentheses as morbidity of fluorosis in per cent.

Table 3 Investigation result of fluorosis in Shiligetu Village

		Fluorosis			
Age	No. of Samples	a	b	c	b + c
0–9	23	23 (100)	0 (0)	0 (0)	0 (0)
10–19	46	39 (84.8)	6 (13.0)	1 (2.2)	7 (15.2)
20–29	25	20 (80)	2 (8.0)	3 (12.0)	5 (20.0)
30–39	38	18 (47.4)	3 (7.9)	17 (44.7)	20 (52.6)
40–49	63	24 (38.1)	6 (9.5)	33 (52.4)	39 (61.9)
50–59	20	4 (20.0)	2 (10.0)	14 (70.0)	16 (80.0)
60 and older	29	18 (62.1)	0 (0)	11 (37.9)	11 (37.9)
Total	244	146 (59.8)	19 (7.8)	79 (32.4)	98 (40.2)

Note: a, Normal; b, Slight; c, Heavy.
Number in parentheses as morbidity of fluorosis in per cent.

village is fairly large, with 520 households and more than 2100 villagers. More than 20 years ago people used shallow wells for drinking water supply and the water was salty with a high fluoride concentration. In 1976 a deep well was drilled and fresh water was obtained for the whole village (a rare case in this area.). Water quality testing during this study showed a fluoride concentration of 1.3 mg/L which is slightly higher than the Chinese drinking water quality standard value

Table 4 Additional investigation result of dental fluorosis in Shiligetu Primary School

Grade	Age	No. of samples	Case of dental fluorosis	Morbidity (%)
1	6–7	24	0	0
2	7–8	30	0	0
3	8–9	29	0	0
4	9–10	32	0	0
5	10–11	37	0	0
6	11–12	42	2	4.8
Total		194	2	1.0

(1.0 mg/L) but lower than the acceptable limit of 1.5 mg/L set by WHO [6].

Table 3 summarises the occurrence of fluorosis in this village based on the general investigation results, and Table 4 shows the results of additional investigation on dental fluorosis of children in the village's primary school.

As is shown in Table 3, although the morbidity of fluorosis in this village is 40.2%, there are no cases of fluorosis among children under nine years old, and the morbidity of teenagers from 10 to 19 years old is also very low. In addition to this there is a trend for morbidity to increase with the age. Considering that the drinking water quality was improved 22 years ago in 1976, people under 22-year-old did not take in extra fluoride from drinking water at all, and people from 22 to 30-year-old had begun to drink safety water before their milk teeth were replaced by their permanent ones. The distribution of the morbidity of fluorosis among people of different age groups demonstrates the remarkable effect of water quality improvement on human health. The additional investigation result for children in the village's primary school (Table 4) provides further proof.

SUMMARY

This paper reports on the results of an investigation on fluoride contamination of groundwater and its impacts on human health which was conducted by a Sino–Japanese cooperative study group in a rural region of Inner Mongolia. The results reveal a serious fluorosis situation, an interrelation between drinking water quality, and the morbidity of fluorosis, and also the positive effect of water quality improvement on human health in two case studies.

The way forward in such areas is to supply water which conforms to set drinking water quality standards. Establishing new resources and introducing water treatment are two possible measures. However, since most of the fluoride-contaminated regions are poor rural areas with a low level of income and economic activity, it is often too expensive for a village to apply advanced technology for fluoride removal and operate and maintain such a water treatment system properly. Therefore, finding good quality water resources may be the most suitable solution. In the study area, many villages tried to drill deep wells for water supply but few of them succeeded as the Shiligetu Village did. Under such conditions, the construction of a regional water supply system which utilises good quality groundwater or surface water from a distant region will become necessary. To this aim, people expect government assistance and foreign aid.

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