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Child-education program for the reduction of health risks due to fluoride in water sources in the Chiang Mai Basin, Thailand

S. Takizawa, T. Takeda, A. Wongrueng and S. Wattanachira

ABSTRACT

Groundwater is the major source of drinking water in Lamphun Province in the Chiang Mai Basin, Thailand. However, groundwater contains high fluoride up to 16 mg F/L, which has caused dental and skeletal fluorosis. Although Thai Government installed RO membrane plants for the removal of fluoride from groundwater; and delivers RO-filtered bottled water that contains less fluoride than the Thai Standard of 0.7 mg F/L, it was found that the urinary fluoride levels are still high among the residents. To find the major sources of fluoride intake, fluoride contents in various water sources, such as village water supply, shallow and deep groundwaters, rain water and bottled water, were measured, and the local people's behavior on water uses was recorded by interview and questionnaire study. As a result, it was found that the highest risk of fluoride ingestion comes from cooking rice with fluoride-containing water because of a lack of knowledge on fluoride sources and fluoride chemistry. To reduce the health risks arising from fluoride intake, a hands-on educational program on the sources and risks of fluoride in water was developed and implemented in the local schools. The participatory educational program promoted active involvement of schoolchildren, but it was found that the effectiveness of education varied depending on the questions we asked. Therefore, it needs to be improved by an iterative and interactive educational program. In conclusion, it was found that the benefits of providing safe drinking water using such advanced technology as RO membrane can be maximized only when it comes along with a participatory educational program on fluoride sources and health risks.

Key words | cooking water, fluoride, groundwater, health risk, rice, risk education

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INTRODUCTION

Groundwater is an important source of drinking water in many countries and nearly a half of the world's population use groundwater for drinking and other purposes (UNESCO/IHP 1998). Small and medium-sized water systems are especially dependent on groundwater sources because of good quality, easy access and low cost of development. However, in some regions, groundwater contains naturally occurring contaminants such as arsenic and fluoride. Fluoride is enriched in groundwaters due to the presence of fluorite and other fluoride-bearing minerals. There are tens of millions of people suffering from fluorosis in the world (UNEP/WHO/UNICEF 2002). In many cases, it is difficult to prevent the occurrence of fluorosis cases because the risk and sources of fluoride intake are not well understood by local residents.

The objectives of this study were to monitor the fluoride concentrations in various sources of water used by the residents to identify the major source of fluoride intake, and to develop a participatory educational program for the schoolchildren based on our research findings.

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MATERIALS AND METHODS

Study area

Lamphun Province is located in the Chiang Mai Basin, Thailand. Lamphun is an ancient city, established about 1,300 years ago, and has an administrative area of 4,506 km^2 and inhabitants of 409,000 (Lamphun Province 2008). The annual rainfall in Lamphun Province is 700 mm to 1,300 mm between 1995 and 2005, which was comparatively less in Thailand. About 40–50% of the residents in Lamphun Province drink bottled water (National Statistical Office Thailand 2000), while the rest drink rain water, groundwater or piped water delivered by village water works. Table 1 shows various water sources used by the residents in Lamphun Province. The local residents had used dug wells and rain water before the small-scale water supply named "village waterworks" had been installed. Most of them, however, abandoned dug wells due to poor water quality, and many villagers worried about air-borne pollution of rain water. Since then, the village waterworks, which withdraw deep groundwater, had become the main source of their drinking water until, in the 1990s, the cases of dental and skeletal fluorosis increased among the residents of Lamphun Province. Since then many people have chosen bottled water for drinking. The WHO guideline value for fluoride in drinking water is 1.5 mg F/L, whereas the Thai drinking water standard is 0.7 mg F/L (Takeda & Takizawa 2007). Deep and shallow groundwaters in Lamphun Province far exceeded these guideline values.

Water sampling and analysis

Groundwater samples from the 133 sources of village waterworks were obtained and their fluoride contents were analyzed along with other water quality parameters. pH, ammonia nitrogen, ferrous iron, alkalinity were analyzed in the field using pH electrode, Hach DR890 colorimeter, and titration method. Concentrations of fluoride and other anions were analyzed by ion chromatograph, and major cations were analyzed by ICP-AES (Opima 3000, Parkin Elmer).

Household study and fluoride uptake by rice

Based on the school children's urine fluoride analysis (Takeda & Takizawa 2007), we selected four children with high fluoride concentration in their urine, and visited their houses to identify the major sources of fluoride intake. Water samples from different sources were obtained and analyzed for fluoride contents. Simultaneously, we made interview study for their uses. Rice and groundwater samples were also obtained from twenty households of the school children.

Table 1 | Various water sources used by the residents in Lamphun Province. (as of 2008)

	Cost*	Availability	Fluoride concentration	Major uses	Fluoride health risks
Deep groundwater in household	Low	Limited installation	Very high 15–16 mg F/L	Cooking Washing	High
Shallow groundwater	Free	Easy	Moderately high 1–6 mg F/L	Cooking Washing	Moderate
Rain water	Free	Seasonal	None	Drinking Bathing	None
Village waterworks	3 Baht/m^3	Available for most of the house	Very high 5–16 mg F/L	Cooking Washing Bathing	High
Bottled water†	10 Baht/20 L	Delivered to each house	Less than 0.5 mg F/L	Drinking	Almost none

*1 Thai Baht = 3.2 US cents.
†Mostly reverse osmosis (RO)-treated deep groundwater.

Table 2 | Student numbers from each participating school

School	Male	Female	Total	Age
A	43	30	73	12–16
B	31	18	49	9–12
C	15	17	32	7–12
D	47	52	99	12–15
E	27	22	49	10–12
F	11	27	38	12–13

Development and implementation of educational program

An educational program for school children was developed following the aforementioned water quality and household study. Because the major sources of fluoride intake has been identified as cooking water, not drinking water, the program put an emphasis on the chemical characteristics and various intake routes of fluoride. Illustrated boards were prepared to help school children's understanding. The educational program was implemented in three elementary schools (B, C, and E in Table 2) and three junior high schools (A, D and F). In total, 340 students (174 male and 166 female students) took part in the educational program. The age varied between 7 and 12 in the elementary schools; and 12 to 15 in the junior high schools (Table 2).

FLUORIDE CONCENTRATION IN GROUNDWATER OF VILLAGE WATERWORKS

Figure 1 shows the study area and the fluoride concentration in groundwaters that are used as sources of the village waterworks. The locations of Schools A–F are also depicted. The maximum concentration of fluoride was 16.1 mg F/L, and high fluoride groundwaters are located mostly on a line. Schools A–D are located in the high fluoride area, whereas Schools E and F are located in the low fluoride area.

One of the recently adapted countermeasures is construction of reverse-osmosis membrane filtration plants by Thai Government. So far, about 30 reverse-osmosis membrane plants have been commissioned in this area to remove fluoride from groundwaters. Those water treatment plants are operated either by the local communities or by commercial enterprises. They produce fluoride-free bottled water and deliver them to the local households. Matsui *et al.* (2006*a*,*b*) have made an extensive study on those RO membrane plants. One out of ten plants being investigated was not in operation due to poor water quality even after RO process. Three RO Membranes were built in locations where fluoride concentration in groundwater was not higher than the WHO standard of 1.5 mg F/L.

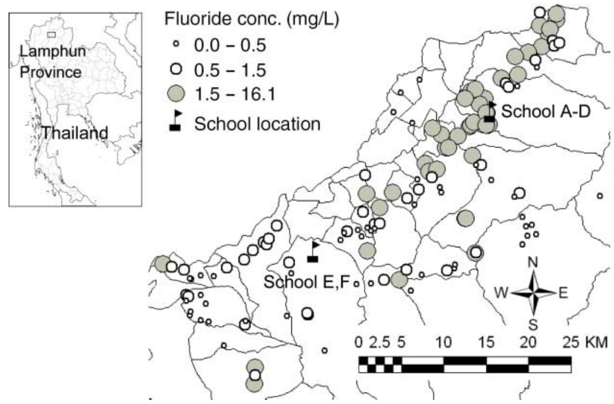

Figure 1 | Location of the study area and fluoride concentrations in groundwater.

WATER USE STUDY IN HOUSHOLDS

As shown in Table 3, all the households we studied had multiple sources of water and they use different waters for each purpose. There are mainly four types of waters: village waterworks, shallow groundwater, rain water and bottled water. The local people must pay for water from the village waterworks at three Baht per cubic metre. Bottled water costs ten Baht per 20 L. Shallow groundwater and rain water are almost free though they have to pay for pumps and roof-top rain water harvesting units. In all households, they drink either bottled water or rain water to avoid health risks of drinking fluoride-laden water delivered by village waterworks. Among the four households we visited two households used water from the village waterworks for rice soaking. The water from village waterworks comes from deep groundwater, which contained between 6.2 and 6.7 mg F/L. Hence, soaking rice in water rich in fluoride could be the main source of fluoride intake by the local residents. This finding revealed that, though the local residents were aware of the risk of fluoride in their drinking

Table 3 | Fluoride contents in various water sources in households

			water use				
Households number	**Water source**	**Fluoride (mg F/L)**	**Drinking**	**Rice soaking**	**Other cooking**	**Dish-washing**	**Bathing, gardening**
H01	V	6.2					X
	S	0.98		X	X		
	R	NS	X				
H02	V	6.7		X			
	S	2.3				X	
	R	0					X
	B	0	X		X		
H03	V	6.5		X			
	R	0			X		
	B	NS	X		X		
H04	V	NS					X
	S	0.7		X		X	
	R	0	X				
	B	NS	X				

Note: V, village waterworks; S, shallow groundwater; R, rain water; B, bottled water; NS, no sample.

water, they were not aware of fluoride intake by soaking rice into fluoride-laden water. This could be because the local people were not given any information on the nature of fluoride, how it could be taken up by humans, and the potential risks of fluoride in their cooking water. Other foods and beverages including meat, vegetables, soda and juice, were also analyzed but they contained very low amounts of fluoride. Hence, the possibility of fluoride intake from these sources was considered to be very low.

FLUORIDE UPTAKE BY RICE

Takeda & Takizawa (2007, 2008) revealed that the a large number of residents excrete high levels of fluoride in the urine despite the fact that most of them drink fluoride-free water such as bottled water and rain water. It was found that after soaking rice in fluoride-containing water, fluoride was taken up by rice. Hence, it was suggested that those households who use fluoride-laden village waterworks for rice soaking are likely to take in a high amounts of fluoride from their cooked rice. Table 4 shows the rice soaking methods of the households listed in Table 3. They soak rice into 1.3 to 1.5 times of water for 8 to 10 hours before steaming. In this process, rice absorbs fluoride from cooking water. In general, the fluoride content in soaked rice goes up as the soaking time is extended up to 24 hours. Hence, shortening the soaking time can lessen the fluoride intake from cooked rice though it may be difficult because of their preference of the taste of cooked rice.

The relationship between fluoride in soaking water and fluoride in cooked rice is plotted in Figure 2, which includes the data obtained from the four households listed in Tables 3 and 4. The fluoride contents in rice are proportional with the fluoride concentration in cooking water. The variation in fluoride contents in rice arise from the difference in soaking time and the ratio between rice and soaking water. Two outliers, i.e. high fluoride in cooking water but no fluoride in rice or *vice versa*, in Figure 2 may be obtained because a wrong water sample

Table 4 | Rice soaking method in households

Household	**Rice (kg)**	**Water (kg)**	**Water:rice**	**Soaking time (h)**
H01	1.54	2.14	1.39	10
H02	1.50	2.28	1.52	8–9
H03	2.30	3.24	1.41	10
H04	2.41	3.26	1.35	9

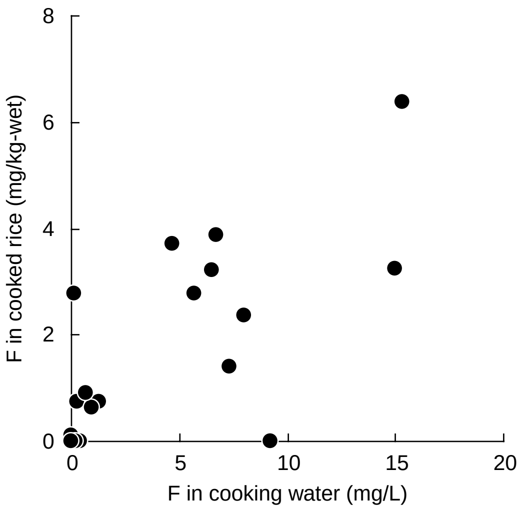

Figure 2 | Relationship between fluoride in cooking water and cooked rice.

was turned in, or because rice was not soaked before steaming.

The village waterworks connected to the school children's houses contained 5–9 mg F/L of fluoride, whereas deep well water in their households contained 15–16 mg F/L of fluoride. These are the major source of fluoride intake when they were used for rice cooking. The residents, however, use village waterworks for rice cooking because they do not know that fluoride is taken up by rice, or they cannot find an alternative water source which is affordable. In order to reduce the health risks arising from fluoride intake, it was found that teaching the residents about the possible sources of fluoride intake and how to avoid fluoride intake from cooked rice is very important provided that a lack of knowledge is a major reason of fluoride intake. If the communities had been engaged in the process of water supply and safety planning from the beginning, they would have had an opportunity to learn the problem of fluoride in the earlier stage. The first step of the community engagement should be to offer an educational program to learn the intake sources of fluoride and let the residents consider how to reduce the risks by choosing different water sources for each water use.

EDUCATIONAL PROGRAM IN SCHOOLS

A two-day fluoride education program was developed with the assistance of the local school teachers. On the first day, students were given some basic questions on their water sources and their knowledge about fluoride to assess the background knowledge of the participants. After the question session, the first lecture on the basic nature of fluoride was given to the students. At the end of the lecture,

Figure 3 | Water-safety educational program implemented in the local schools.

students received a few plastic bottles and were asked to bring their waters from different sources to the school on the second day. On the second day, fluoride test kits were handed over to the students for the self-testing of fluoride contents in their waters (Figure 3). Since a colorimetric method of fluoride analysis (Pack Test®) was used, the students could find the fluoride concentration of their water sources by themselves, which helped their understandings of the fluoride testing method and the presence of fluoride in various water sources. Figure 3 shows a photo of the lecture to explain how to use the fluoride test kit at a junior high school.

Figure 4 illustrates the sources of water in households. Each house has multiple water sources, which are used for different purposes. For drinking, most of the households used bottled water, but for cooking and other purposes many households use village water works and groundwater abstracted from their wells. This is due to unawareness of the risk of fluoride intake from cooking water, and also due to the high cost of bottled water. Hence, it was found very important to teach the risk of fluoride intake and to raise the awareness of the residents on water safety so that they can make the right choice of different water sources for each use.

Figure 5 shows the results of questionnaire study concerning the sources of fluoride intake before and after the educational program. Even before the educational program, 86 percent of the students answered that groundwater contains fluoride and can be a possible source of fluoride intake. On the contrary, only 19 percent of the students answered correctly that boiling cannot remove fluoride in water. Eighty one percent of the student considered that fluoride is a kind of microorganism that

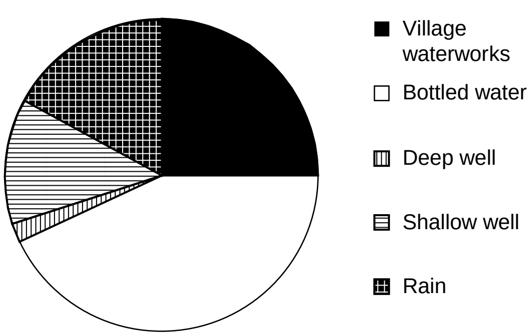

Figure 4 | Sources of water for different uses in households.

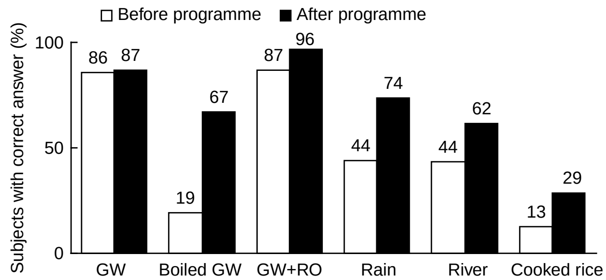

Figure 5 | Percentage of students with correct answer to the question "Does it contain fluoride?" (GW: groundwater, GW + RO: groundwater filtered with reverse osmosis membranes, river: river water).

can be inactivated or removed by boiling. This fact revealed the importance of the educational program. Thirteen percent of the students answered that cooked rice could be a source of fluoride intake before the educational program. The educational program showed different effectiveness in giving the right knowledge to the students depending on the questions. The number of students who selected the right answer to the question "whether boiled groundwater still contains fluoride or not," increased more than three-fold from 19 percent to 67 percent, whereas those who selected the correct answer for cooked rice increased only from 13 percent to 29 percent. The age of the participating students varies from seven years in the elementary schools to fifteen years in the junior high schools. Because the elementary school pupils, especially those in lower grades, are not yet given enough science education, it seemed that the explanation of fluoride transfer into rice and adsorption therein were difficult to understand. On the contrary, junior high school students had better understandings of this process. The program was developed to give the scientific knowledge about fluoride sources and intake into human body; hence, it may be too complicated especially with regards to rice cooking methods and fluoride absorption. The results of implementing an educational program suggested that we should develop a simpler and straightforward program for the lower grade pupils. It was also found that iterative education is very important to teach all the students about the risks and safety of water. No educational program can be expected to teach all the students about fluoride in water only by one-time implementation. Therefore, the educational program should be repeated several times in schools. It should be incorporated into the curricula of the schools where fluoride contents in village waterworks or wells are high. In addition to the education to the school children, it is also important to offer learning opportunities to the housewives, who play the most important role on the selection of various water sources for different uses in household. In order to effectively disseminate the fluoride risk information to the housewives we could ask cooperation of the temples because Buddhist events are an important opportunity to talk to the families who come to temples and temples have been a traditional place to get water. Therefore in any Buddhist events, we could give a short lecture to the families including housewives in cooperation with monks. Furthermore, fluoride testing programs should be implemented to identify families who use high fluoride-containing waters. An independent consultation should be given to those families to avoid high health risks arising from fluoride intake.

CONCLUSIONS

The residents in Lamphun Province, Thailand, have multiple water sources, including the village waterworks. Due to geological conditions groundwater in this area contains high concentration of fluoride. Although the residents know that fluoride intake from their drinking water poses health risks, they are not aware of the risks arising from fluoride intake through their cooking water. The local households had various sources of water, and they used different water sources for different purposes. It was well-known that fluoride in drinking water causes dental and skeletal fluorosis, hence many residents used bottled water for drinking. However, bottled water was too expensive for other uses such as cooking, many households used water supplied by the village waterworks for cooking. Our analysis revealed that the water supplied by the village waterworks contains more than 5–9 mg/L of fluoride. Hence it was found that cooked rice is the major source of fluoride intake among the residents in this area. In order to reduce health risks, a participatory educational program was developed and implemented in local schools. A questionnaire study before and after the educational program indicated that the program has successfully improved the knowledge of the participating children, but the effectiveness of the education varied between questions asked to them and the grades of the students. As a result, it was found that a simpler and straightforward educational program should be developed for the lower grade pupils, and iteration of such educational programs is very important to educate all the students. It should also be emphasized that fluoride-risk education to the housewives has a high potential for the reduction of health risks arising from fluoride in their cooking water.

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