Thai Environmental Engineering Journal Vol. 39 No. 3 (2025) : 53-61
www.eeat.or.th

People's Perception and Water Consumption Behavior in High Fluoride Risk Area

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Article History; *Received: 9 October 2025, Accepted: 15 December 2025, Published: 24 December 2025*

Abstract

Fluoride contamination in groundwater remains a persistent environmental and public health challenge in northern Thailand, where natural geological formations contribute to elevated fluoride concentrations. This study aimed to assess residents' awareness of fluoride-related risks, drinking water practices, and acceptance of defluoridation technologies in high-fluoride areas of San Kamphaeng District, Chiang Mai Province. A total of 205 residents were interviewed using a structured questionnaire. The results showed that bottled water was the most commonly used for household water consumption, accounting for 66.9% for drinking and 42.3% for cooking. However, some households in high-fluoride villages still relied on untreated groundwater, with drinking and cooking accounting for up to 4.2% and 14.3% of total daily water use, respectively. Although 92.7% indicated strong support for a community defluoridation system, most respondents demonstrated limited knowledge of fluoride contamination and its health implications. No significant effects of gender or age were observed regarding knowledge, perceived risk, perception of groundwater use, or the desire for defluoridation system. These findings underscore the need for strengthened public education and community-based communication strategies to promote safer water consumption and support long-term access to safe drinking water.

Keywords: People perception; Water consumption behavior; Fluoride contamination; Groundwater; and Tap water

Introduction

In many parts of the world, groundwater is used to produce drinking water because it is of higher quality and has less microbial contamination than surface water. Additionally, some regions have few sources of surface water or contaminated surface water. Therefore, groundwater is a better source of raw water for drinking water. However, due to geochemical properties, groundwater can occasionally become naturally contaminated. The two main examples of naturally occurring contaminants in groundwater are fluoride and arsenic. The presence of fluoride in drinking water can reduce the incidence of dental caries when its concentration lies in the optimal range of 0.5-0.7 mg/L [1]. On the other hand, excessive levels of fluorosis can result in a variety of issues, from mild dental fluorosis to disabling skeletal fluorosis as the level and duration of fluoride exposure increase [2]. The effects of fluoride overdose can be acute and chronic. Acute fluoride poisoning may cause symptoms such as nausea, vomiting, abdominal pain, and diarrhea, and in severe cases, it can be fatal. Chronic exposure, which is more common in communities relying on naturally contaminated groundwater, often results in dental fluorosis, characterized by white or brown discoloration on the tooth surface. In more severe cases, prolonged exposure can lead to skeletal fluorosis, causing bone deformities, joint pain, and even spinal abnormalities. In addition to dental and skeletal effects, fluoride toxicity has also been associated with damage to soft tissues. Further investigated the effects of high fluoride exposure on kidney and liver function, with findings providing strong evidence of significant renal and hepatic impairment at elevated fluoride doses [3].

In several regions of Thailand, including rural communities in Chiang Mai, groundwater is severely contaminated with fluoride, often exceeding the World Health Organization (WHO) guideline of 1.5 mg/L, leading to dental and skeletal fluorosis among affected populations. In Thailand, the national standard for fluoride in drinking water is set at a maximum of 0.7 mg/L, with a permissible limit of 1.0 mg/L (**Table 1**).

Table 1 Fluoride concentration standards in drinking water established by various regulatory bodies

Organization	Guideline value (mg/L)	Reference
WHO	≤ 1.5	[4]
Provincial Waterworks Authority	≤ 1.0	[5]
Ministry of Natural Resources and Environment	≤ 0.7 (max 1.0 mg/L permissible)	[6]
Department of Health	≤ 0.7	[7]
Ministry of Public Health	≤ 0.7	[8]

Fluoride removal from water can be achieved through coagulation, ion exchange, reverse osmosis, and adsorption. Coagulation removes fluoride via chemical precipitation and is cost-effective, but it offers only moderate removal efficiency. Ion exchange achieves high fluoride removal by replacing fluoride ions with other anions, though it requires regular regeneration and operational control. Reverse osmosis removes fluoride via membrane separation and achieves very high removal efficiency; however, it entails high costs, energy consumption, and wastewater generation. Adsorption removes fluoride via surface binding to materials such as activated alumina or bone char and is widely used due to its simplicity, low cost, and effective removal performance. However, the adoption of these techniques remains low.

Behavioral factors influencing people's safer water consumption in areas contaminated with fluoride are crucial determinants. Despite widespread documentation of fluoride contamination in groundwater, limited evidence exists on the relationship between residents' awareness of fluoride-free water and their actual water-consumption behaviors in high-fluoride-risk areas. This study, therefore, aimed to examine people's awareness of fluoride contamination and their water-consumption behaviors in high-risk areas for fluoride exposure, and also to educate risk perception and promote informed decision-making regarding daily water use.

Methodology

The study area was Buak Khang Municipality, San Kamphaeng District, Chiang Mai, Thailand **(Figure 1)**. As of 2025, the population of Ban Buak Khang Subdistrict was 8,772. The area had a high fluoride risk, with groundwater contamination ranging from 0.7 to 10 mg/L [9]. Data collection was conducted from May 2024 to December 2024. It involved engagement with community leaders who were invited to facilitate voluntary participation of residents in the survey. The study employed a convenience sampling method, and participants were required to meet the following inclusion criteria: be Thai, be at least 20 years old, live in high-fluoride-risk areas for at least 3 months, and be willing to participate in the survey. A final sample of 205 participants was included in this study. This number is consistent with prior behavioral and community-based survey research, such as a cross-sectional survey of 220 participants across five communities, in which the authors acknowledged that although the sample was smaller than ideal, it was adequate for the analyses performed and for interpreting the overall intervention package [10].

A structured questionnaire was used to collect information on respondents' demographic characteristics, awareness of fluoride and its associated health risks, water consumption behaviors, and acceptance of defluoridation technologies in communities exposed to high groundwater fluoride levels. The questionnaire items were adapted from previously validated instruments used in behavioral studies on safe water practices and fluoride-related health risks [11, 12]. The items were modified to fit the local context and research objectives, ensuring relevance to communities at risk of fluoride exposure. The questions were constructed based on knowledge of fluoride, living in a fluoride-risk area, perceptions of groundwater, and desire for a defluoridation system. The questionnaire was reviewed and approved by the Chiang Mai University Research Ethics Committee (CMUREC No. 67/172).

All data were analyzed using Microsoft Excel (version 2404, Build 16.0.17531.20120) and IBM SPSS Statistics (version 30.0.0.0 (172)) for descriptive analysis, chi-square tests, and independent t-tests.

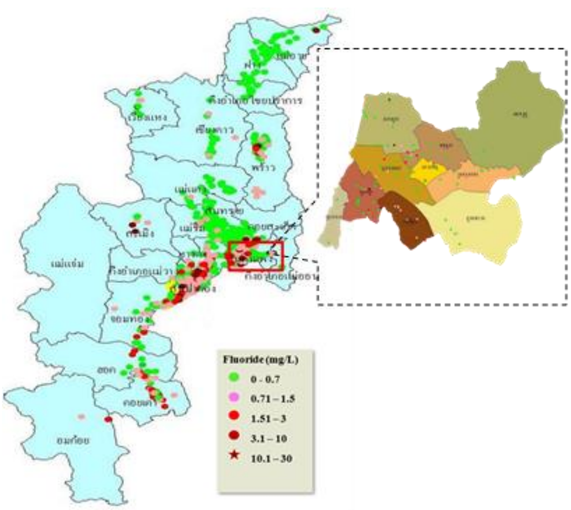

Figure 1 Fluoride contamination in groundwater in San Kamphaeng District [9]

Results and Discussion

The socio-demographic characteristics of 205 survey participants are presented in **Table 2.** Most participants were female (60.5%), with an average age of 56 years and an average of 46 years in fluoride-risk areas. Most of their careers included employees (56.1%), personal business (20.0%), farmers (13.2%), housekeepers (3.4%), and unemployed (1.0%).

Table 2 Socio-demographic characteristics of the respondents (N=205)

Characteristics	Value
Gender (%)	
Male	38.0
Female	60.5
Unspecified	1.5
Age (year)	
Mean ± S.D.	56.7±11.7
Living period (year)	
Mean ± S.D.	46.9±18.5
Career (%)	
Personal Business	20.0
Employee	56.1
Housekeeper	3.4
Farmer	13.2
Unemployed	1.0
Unspecified	6.3

Table 3 presents 10 questions administered to respondents regarding their understanding of fluoride contamination in water, perceived risk of high fluoride levels, perceptions of groundwater, and desire for a defluoridation system. Cronbach's alphas, which measure internal consistency, for questions on knowledge of fluoride and risk were 0.778 and 0.817, respectively. These numbers indicate acceptable (>0.7) to good (>0.8) levels [13].

The respondents had limited general knowledge of fluoride contamination; 21.0-32.2% demonstrated a correct understanding. The lowest score (21%) was for understanding that the safe level of fluoride in drinking water should be ≤0.7 mg/L. This demonstrates a lack of detailed knowledge about fluoride, which may be due to limited public communication and health education on fluoride risks, despite the broad promotion of public health interventions such as water safety [14, 15]. Few respondents recognized that they lived in regions at risk of fluoride exposure (18.0%) and that they could be exposed through drinking water and food preparation (34.1%). In addition, 32.7% of respondents reported that groundwater is safe for drinking, whereas the remaining 67.3% perceived it as unsafe. This reflects a substantial lack of confidence in groundwater quality. The survey also revealed that most respondents (92.7%) expressed a desire for a defluoridation system to treat their water.

The results show apparent inconsistency between low levels of knowledge and perceived risk and high demand for defluoridation systems. It may be due to respondents perceiving general signs of poor water quality or having observed health problems in their community, such as dental discoloration. As pointed out by Chamnanprai et al. [9], who reported dental fluorosis in 15.6% of children in Chiang Mai, based on a survey of 167 participants in high-fluoride areas, but did not fully elucidate the specific role of fluoride or its long-term health effects. Their demand for defluoridation may, therefore, be driven more by indirect risk perception or past experiences with unsafe water. Consequently, this underscores a significant discrepancy between perceived water safety and the actual fluoride-related risks, emphasizing the necessity for public education alongside the deployment of effective fluoride-removal technologies. This initiative should include the development of informational materials on the long-term toxicity associated with consuming fluoride-contaminated water. Furthermore, community meetings and public forums are vital for reinforcing the roles of local authorities and public health agencies in advocating for the use of fluoride-free water and for disseminating information on fluoride-related health risks through local communication channels, such as village audio announcements.

The analysis examined associations between demographic characteristics, including gender and age group, and the four constructs: knowledge of fluoride, living in a fluoride-risk area, perception of groundwater, and desire for a defluoridation system. No significant relationships were found between gender and fluoride knowledge (male = 1.18; female = 1.40; t = -0.99, p = 0.322), living in a fluoride-risky area (male = 0.71; female = 0.88; t = -1.061, p = 0.290), groundwater perception (male = 0.71; female = 0.65; t = 0.860, p = 0.391), or desire for a defluoridation system (male = 0.94; female = 0.92; t = 0.428, p = 0.669). Younger respondents, 20-40 years old, had a higher average score of knowledge items (1.59) than those in their 41-60 (1.27) and 61-85 (1.28), but no significant difference (F = 0.461, p = 0.631). When asked about perceived risk of living in a fluoride-exposed area, younger respondents reported the lowest average score (0.78) compared with those in the 41-60 (0.83) and 61-85 (0.81) age groups, but the differences were not statistically significant (F = 0.025, p = 0.976). Young respondents also had the lowest groundwater perception score (0.52), whereas 41-60 (0.68) and 61-85 (0.72) did not differ significantly (F = 1.840, p = 0.162). For the desire for a defluoridation system, young respondents showed the lowest score (0.89), while 41-60 (0.93) and 61-85 (0.94) did not differ significantly (F = 0.337, p = 0.714). In sum, they did not differ across demographic groups, indicating that these concerns are shared broadly within the community

Most respondents purchased water for daily drinking: bottled water (66.9%) and vending machines (13.5%). A small proportion (2.3%) of respondents drank water from filtered systems. Some respondents used groundwater (2.3%). **Figure 2** maps respondents' drinking water sources and the levels of fluoride contamination in water by villages. The respondents in villages with high fluoride levels (0.71-10 mg/L): Buak Khang Moo 1, Roi Phrom, Rong Kong Khoa, Buak Khang Moo 2, Ban Du, and Ko Sa Laemg reported their groundwater use for drinking, with the highest use at Roi Phrom 4.2%. This indicates that the respondents in villages with high fluoride levels are experiencing distressing fluorosis-related health problems. The health impacts of fluoride are chronic, not acute, meaning that prolonged exposure to high fluoride levels is required to adversely affect humans. The occurrence of dental fluorosis is directly dependent on groundwater fluoride content and the dietary intake of fluoride-containing drinking water [16]. Recent studies reported that high levels of fluoride intake would cause detrimental health effects such as dental fluorosis, skeletal fluorosis, and hypertension [17]. However, the severity of fluoride toxicity may vary with groundwater fluoride concentration, ingestion rate, duration of exposure, and local climate factors, such as air temperature, a key driver of daily water intake. For instance, exposure to groundwater fluoride levels above the safe limit led to the development of dental fluorosis (1.5-3 mg/L), skeletal fluorosis (3-6 mg/L), and bone crippling (>6 mg/L) in human individuals [18].

Regarding the water source for cooking, most respondents used bottled water (42.3%) and tap water (37.5%). The respondents also use groundwater for cooking, which accounted for a higher proportion (4.4%) than for drinking water. In Roi Phrom village, where high groundwater fluoride levels were detected, 14.3% of respondents reported using groundwater for cooking (**Figure 3**). Using groundwater or tap water containing fluoride at concentrations as high as 10 mg/L can be harmful to human health in the long term. When fluoride-containing water is used to soak rice or boil vegetables, fluoride accumulates in the rice or vegetables, causing indirect fluoride intake from food and potentially becoming a significant source of daily fluoride exposure. Thus, the fluoride intake from food cooked in boiling water is comparable to, or even greater than, that from drinking water [19]. These survey results suggest that even households that do not directly consume groundwater for drinking water may still face substantial fluoride exposure through food preparation. Prolonged consumption of such food may contribute to dental and skeletal fluorosis, particularly among children and the elderly. Therefore, raising public awareness of the risks of fluoride in cooking practices in addition to drinking is also essential.

The household water expenditure survey for domestic use. The findings indicate that the average monthly expenditure on drinking water was 191 ± 247.2 THB (1 THB ≅ 0.03 USD) per household, while the average expenditure on cooking water 184.5 ± 207.8 THB per household. Data from the Provincial Waterworks Authority indicated that community-level household water expenditures vary considerably depending on several factors, including the source of purchased water, the availability of local water resources, and the overall volume of household consumption. In general, such expenditures have been observed to range between 100 and 500 THB per household per month. In the present study, the combined average monthly expenditure for both drinking and cooking water among sampled households was 375.6 ± 352.1 THB.

When respondents were asked about their willingness to pay for drinking and cooking water, they reported substantially lower amounts, at 143.9 ± 164.9 THB per household per month. This discrepancy indicates that actual household expenditure was 1.61 times the preferred amount, thereby implying a considerable economic burden associated with accessing clean water for domestic consumption. Such findings may further reflect structural limitations, including inadequate local water sources and infrastructure deficiencies that constrain equitable access to safe water. Consequently, strategies to mitigate the financial burden of household water expenditure should prioritize the promotion of safe, affordable alternative sources. Examples include using certified piped water or adopting household-level treatment technologies, such as filtration and disinfection systems. In parallel, public participation in efficient and safe water management should be strengthened to align with community needs.

Table 4 shows the respondents' satisfaction with the current water's color, odor, and taste. Median satisfaction scores were 5 out of 6 for all parameters. The independent t-test analysis revealed no statistically significant differences between genders concerning satisfaction with water color or odor ($p > 0.05$). However, for cooking water, a significant difference in taste satisfaction was observed between males and females ($t = -1.981$, $df = 200$, $p = 0.049$), with females reporting lower satisfaction than males. This suggests that women may be more sensitive to, or have higher expectations for, the taste of water used for cooking, which could influence household water-use preferences and practices. As reported from previous studies, females generally perform better in taste function tests compared to males [20], and women are more likely to perceive tap water taste negatively than men [21].

Table 3 Residents' understanding of fluoride contamination in water and risk (N=205)

Construct	Cronbach's alpha	Item	Percentage of correct understanding/ acceptance (%)
Knowledge on Fluoride	0.778	Safe level of fluoride in drinking water ≤0.7 mg/L	21.0
		High fluoride water cannot be detected by the naked eye or smell	32.2
		High fluoride water cannot be safely treated by boiling or filtering with a household filter	30.2
		Fluoride in water should be treated by reverse osmosis or adsorption system	20.5
		Fluoride is added in water, milk, or salt to prevent dental caries in some countries	27.8
Living in a fluoride risky area	0.817	I live in area at high fluoride risk	18.0
		I may expose to high fluoride levels through drinking water or cooking	34.1
		My community may expose to high fluoride levels through drinking water or cooking	29.3
Groundwater Perception	-	I think groundwater is drinkable	32.7
Desire for defluoridation	-	My household want defluoridation system for water consumption	92.7

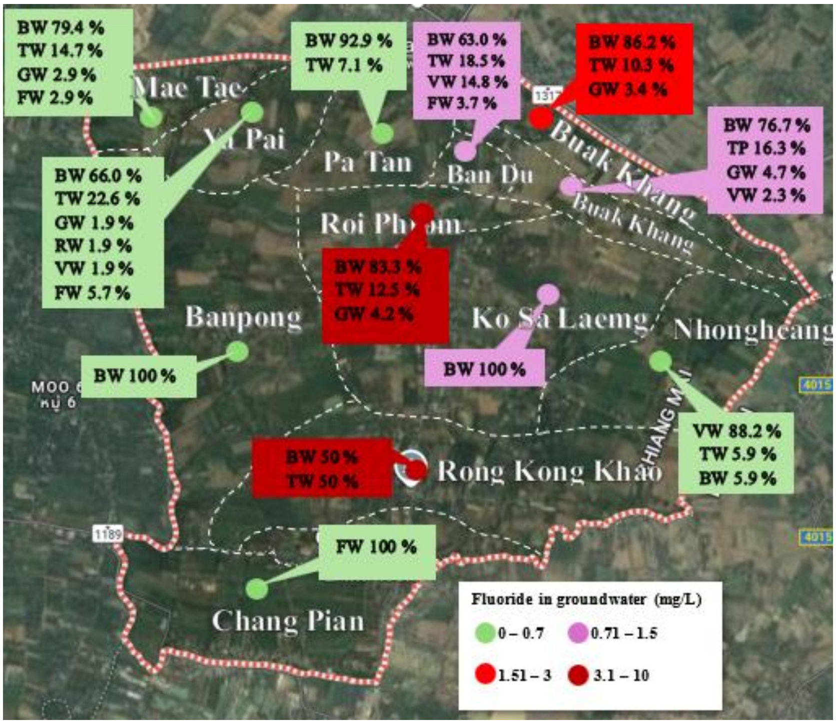

Figure 2 Water sources used for drinking in the study area.
Description: RW=Rainwater, GW=Ground water, TW=Tap water, BW=Bottled water, VW=Vending machine water, FW=Filtered water home use. Proportion equals 100% for each village.

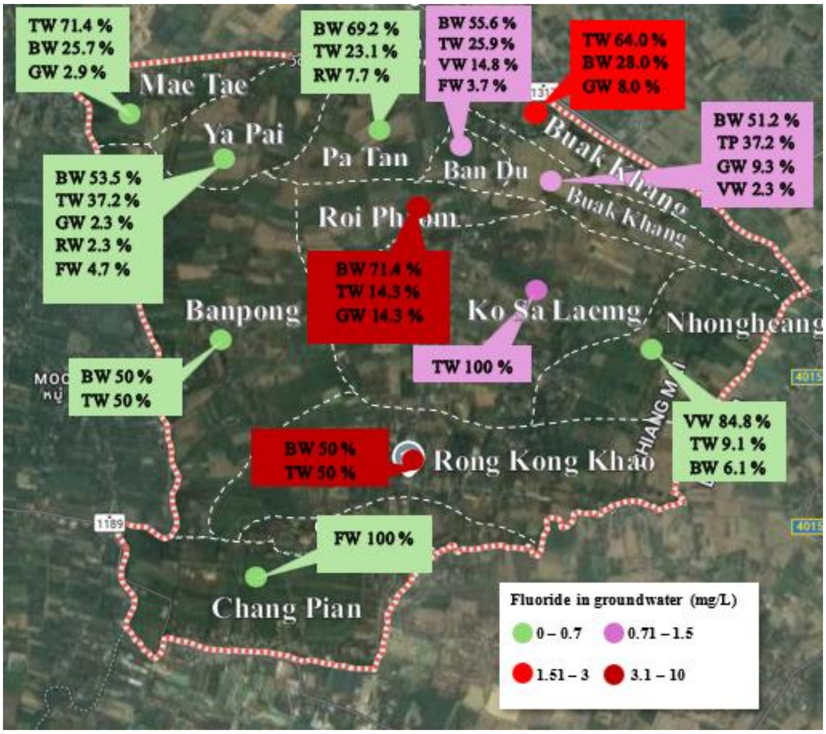

Figure 3 Water sources used for cooking in the study area.
Description: RW=Rainwater, GW=Ground water, TW=Tap water, BW=Bottled water, VW=Vending machine water, FW=Filtered water home use. Proportion equals 100% for each village.

Table 4 Households' satisfaction with water consumption

Purpose	**Mean ± S.D.**		**Median***
Drinking	Male (N=79)	Female N=126)	All (N=205)
Color	4.4 ± 1.8	4.7 ± 1.4	5
Odor	4.2 ± 1.9	4.6 ± 1.6	5
Taste	4.8 ± 1.2	4.7 ± 1.4	5
Cooking	Male (N=79)	Female (N=126)	All (N=205)
Color	4.2 ± 2.0	4.1 ± 2.1	5
Odor	3.9 ± 2.1	3.8 ± 2.2	5
Taste	4.5 ± 1.7	3.8 ± 2.1	5

*Response level provided from 6 = strongly satisfied to 1 = strongly dissatisfied.

Conclusions

The present study provides insight into local water consumption behaviors and levels of understanding of fluoride risk among residents living in a high-fluoride-contaminated area, Buak Khang municipality, San Kamphaeng district, Chiang Mai, Thailand. The study found that participants living in high-fluoride areas demonstrated limited knowledge of fluoride contamination and low awareness of its health risks. Neither gender nor age was significantly associated with knowledge, perceived risk, perception of groundwater use, or desire for the defluoridation system. Although bottled water was commonly used for drinking and cooking purposes, reliance on groundwater and tap water in some locations indicates ongoing exposure risks. Furthermore, the results revealed that groundwater used for cooking accounted for a higher proportion than groundwater used for drinking. Despite limited awareness of the risks of fluoride, respondents strongly desire a defluorination system for their water. This reveals a gap between perceived safety and actual risks, highlighting the need for public education and effective fluoride removal. Policy-focused recommendations include routinely monitoring household and community water quality, promoting the use of household defluoridation technologies, and encouraging the use of fluoride-safe water for drinking and cooking. These recommendations ensure that residents have access to clean water in their daily lives, in line with Sustainable Development Goal 6 on Clean Water and Sanitation.

The questionnaire and interview methods employed in this study were instrumental in enhancing respondents' knowledge and awareness regarding fluoride-related issues following participation. Moreover, these methods provided valuable insights into the knowledge, perceptions, and behaviors of individuals residing in areas at risk of fluorosis. However, the results were based on a limited sample of 205 participants; future research could expand the sample to more representative groups. The method used also relied on self-reported data, which may introduce recall or perception biases inherent to questionnaire-based surveys. Additionally, the study employed a cross-sectional design, providing a snapshot of awareness, behaviors, and water conditions at a specific point in time but not capturing potential seasonal or temporal variations. Future research may incorporate longitudinal assessment.

Acknowledgements

The authors would like to thank Mr. Suchart Tapun at Banbuakkhang School and the community leader in Buakkhang Municipality for their help and support and thank all interview participants for their participation. We would like to express our sincere thanks to the Department of Environmental Engineering, Faculty of Engineering, Chiang Mai University, for its invaluable support with facilities and scientific equipment. This research was supported by Teaching Assistant and Research Assistant Scholarships from Chiang Mai University.

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