Journal of
Health Science and Alternative Medicine

J Health Sci Altern Med (2025)
DOI: 10.14456/jhsam.2025.5

Original Article Open Access

Water Supply Quality and Health Impacts on Hill Tribe People: A Case Study of the Akha Hill Tribe Village, Chiang Rai, Thailand

Claire Roberts [1], Laura Rozek [1], Rachaneekorn Mingkhwan [2], Nuttapohn Kiangkoo [2], Peerawit Janta [3], Suntorn Sudsandee [4*]

[1] School of Public Health, University of Michigan, USA
[2] Department of Social and Environmental Medicine, Faculty of Tropical Medicine, Mahidol University, Bangkok, Thailand.
[3] Department of Water Resources and Environmental Engineering, School of Engineering and Technology, Asian Institute of Technology, Thailand
[4] Environmental Health Program, School of Health Science, Mae Fah Luang University, Chiang Rai, Thailand.

Received	August 31, 2024
Accepted	June 5, 2025
Published	August 31, 2025

***Corresponding author:**
Suntorn Sudsandee, Environmental Health Program, School of Health Science, Mae Fah Luang University, Chiang Rai, Thailand.

E-mail:
suntorn.sud@mfu.ac.th

ABSTRACT

Introduction: The hill tribes in northern Thailand, including the Akha village, live in mountainous and remote areas without access to safe water from the Provincial Waterworks Authority (PWA) service. The main water supply in Akha village is mountain water, and it is without any treatment process. This study aimed to assess the quality of mountain water supply and evaluate the health risk from dermal and oral exposures in the Akha hill tribe village.

Methods: Fifteen water samples were collected from water storage tanks using grab sampling techniques. The water supply quality was analyzed for turbidity, pH, total dissolved solids (TDS), hardness, total coliform bacteria (TCB), fecal coliform bacteria (FCB), cadmium (Cd), iron (Fe), mercury (Hg), and lead (Pb). All parameters were compared with PWA tap water standards. The U.S. EPA model was applied to assess health risks from the four heavy metals for adults and children in the Akha village.

Results: The analysis revealed that 80% of samples exceeded the PWA standard for turbidity, 13% for pH, and 87% for Fe. TCB and FCB were detected in all mountain water samples. The hazard indices (HIs) for Cd, Fe, Hg, and Pb exposures via dermal and oral routes were below 1.

Conclusion: Despite the poor water supply quality, the HIs for heavy metal exposure were below the risk threshold. Nonetheless, it is crucial for local and national policy-makers to support initiatives that provide knowledge and financial subsidies for water treatment in these remote areas to ensure safe drinking water for the hill tribe communities.

Keywords: Hill tribe; Mountain water supply; Water supply quality; Hazard quotient; Hazard index

Introduction

The United Nations (UN) set the Sustainable Development Goals (SDGs), especially SDG 6 water and sanitation, for developing countries and poor people, who can access safe water and sanitation. In 2017, an estimated 5.3 billion people worldwide drank safe, contamination-free water, 6.8 billion people in the world used at least one essential water supply service, but 785 million people did not have access to safe drinking water [1].

Hill tribes are groups of people living in remote mountainous areas. In northern Thailand, many communities cannot access the water supply service provided by the Provincial Waterworks Authority (PWA). The primary water sources in these areas are untreated and contaminated by soil, household wastewater, and agricultural activities in the mountains. Previous studies have found that tap water and drinking water in these communities exceed the standards for drinking and tap water in terms of turbidity, pH, iron, and the presence of total coliform bacteria (TCB), fecal coliform bacteria (FCB), and *E. coli*. Health impacts such as diarrhea and parasitic infections, which are associated with consuming untreated water, are still prevalent in hill tribe villages in northern Thailand [2,3,4]. Despite support from various organizations in providing facilities and knowledge for water treatment processes, the quality of tap water remains poor water quality.

For this primary survey, in one Akha hill tribe village, there were 108 households and a population of 570 persons in Mae Fah Luang District, Chiang Rai. The Akha are a group of hill tribe people who migrated from south of China. The hill tribe uses untreated water for daily life, such as bathing, cooking, and drinking. The untreated mountain water is at high risk of impacting human health. This study aimed to assess the quality of mountain water and evaluate the health risk from dermal and oral exposures in the Akha hill tribe village.

Methods

Study sites

The study sites are located in Chiang Rai Province, northern Thailand. In Akha villages, they manage the water system themselves. The study area provided by GPS (global positioning system) is **20°14'57.12" N, 99°40'48.25"E** to 20°15'0.83" N, 99°40'31.73"E at the average height range of 680 – 798 meters above sea level (masl), as shown in **Figure 1**.

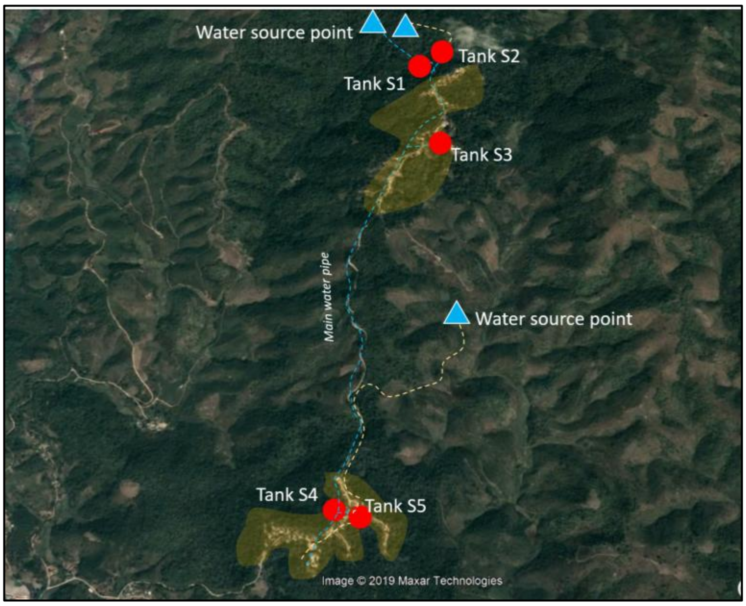

Figure 1: Study sites of the mountain water supply in Akha village

Water treatment data collection

The Human Ethics Committee approved this study from Chiang Rai Provincial Public Health Office (CHPPHO No. 43/2564). A water supply survey was conducted to gather data on the water treatment practices of responsible persons in Akha village. At the same time, the two leading participants were asked to relate the water management in their villages for at least 2 years. This research studied the water source from reservoirs like a weir on the mountain.

Water resource collection

A grab sampling technique collected 15 water samples from water sources in Akha villages in the rainy season (September 2021). Water samples were collected from the top surface water (T), approximately 30 cm below the surface (deep average), the middle layer (M) at about 100 cm depth, and the bottom layer (B) at approximately 200 cm depth from the surface in water storage tanks (S1-S5) located in hill tribe villages. The approximate volume of water of S1-S5 tanks was an average of 150 m^3. Because the large tanks can collect a huge volume over long periods, the pathogens can re-grow, chemical species change, and there is sediment accumulation. The water collection points from the water tanks and the elevations are determined by the global positioning system (GPS). Polyethylene (PE) bottles and glass bottles were used to store the mountain water from a water sampler. A four-liter collection of water samples in PE bottles was chilled in an icebox at 4 °C.

Water sample analysis

A liter of water samples was determined to determine turbidity, pH, total dissolved solids (TDS), and hardness. For cadmium (Cd), mercury (Hg), iron (Fe), and lead (Pb), one liter of water in a PE bottle was preserved by adding 20 ml of concentrated nitric acid (65.0%, ultrapure grade) to preserve metal analyses. A liter glass bottle was used to collect water samples for total coliform bacteria (TCB), fecal coliform bacteria (FCB), and *E.coli* detection analysis. A water sample has been kept away from the sunlight and chilled in an icebox at 4 °C, shipped to a Mae Fah Luang University laboratory, and analyzed within 24 hours. In addition, one liter in a PE bottle is used to estimate alum doses by the Jar test method.

The turbidity was measured by a turbidity meter (Turb 43 IE, WTW, Wissenschaftlich, Weiheim, Germany). A pH meter determined the pH (pH 34i SET 2, WTW, Wissenschaftlich, Weinheim, Germany). The TDS was measured by a TDS meter (TDSTestr11, Waterproof, Oakion, USA). The harness was measured by the hardness test kit VUNIOUE, *v*-color 0300, volumetric titration, and the EDTA method. In addition, the TCB and FCB were analyzed by the 9221 B, E, and BAM standard methods [5].

The Cd, Fe, and Pb concentrations were determined using a Polarized Zeeman Atomic Absorption Spectrophotometer, AAS (Hitachi HighTechnologies, Tokyo, Japan) at the Faculty of Tropical Medicine Laboratory, Mahidol University, and the total mercury concentrations were determined using an MA-3000 Mercury Analyzer (Nippon Instruments, Tokyo, Japan). Each sample was analyzed in duplicate and reported on a milligram per liter (mg/L). The heavy metals standard (Merck, Darmstadt, Germany) for deionized water samples was the quality control of the metal analysis method, and it was performed by spiking known concentrations.

Statistical analysis

All water supply qualities were analyzed using SPSS Version 24.0 for mean, SD., and percentage.

Health risk assessment by heavy metal exposure

Oral route

Four heavy metals, which are attributed to noncarcinogenic exposure, were estimated by calculating the HQ and HI using the U.S. EPA risk assessment model presented in equations (1) and (2), respectively.

$$HQ = CDI/RfD = C \times IR \times EF \times ED/(BW \times AT \times RfD) \text{ -----------------------(1)}$$

$$HI = HQ_{Cd} + HQ_{Fe} + HQ_{Hg} + HQ_{Pb} \text{ ---(2)}$$

where CDI is the intake of the heavy metal concentrations of interest through drinking water [6, 7], and RfD is the oral reference dose for the heavy metal of interest. RfDs of Fe are 700 µg/kg-day and Cd is 0.3 mg/kg-day. Pb was 1,500 µg/kg/day, which was calculated by using the equation HQ=C/MRL, where C is the concentration, and MRL is the minimal risk level [8] because the RfD of Pb has not been set.

In equation (1), C is the concentration (µg/L) of the heavy metal of interest in the water samples, where IR is the drinking water intake rate of approximately 2.0 L/day [9, 10], EF is the exposure frequency (365 day/year), ED is the exposure duration for 30 year for an adult [11], BW is the body weight of 60 kg, and AT is the averaging time of 365 day/year × 30 years = 10,950 days.

Dermal route

For Cd, Fe, Hg, and Pb concentrations in tap water, a quantitative health risk assessment was performed using the dermal route. Heavy metals attributed to noncarcinogenic exposure were calculated hazard quotient (HQ) and hazard index (HI) following the US EPA model and other researchers [12, 13, 14, 15] as shown in Eq.(3) and Eq. (4).

$$HQ = CDI_{dermal} / RfD_{dermal} = (C_{water} \times SA \times Kp \times ET \times ED \times CF \times ABS) / (BW \times AT \times RfD_{dermal}) \text{------(3)}$$

$$HI = HQ_{Cd} + HQ_{Fe} + HQ_{Hg} + HQ_{Pb} \text{ -----------------------(4)}$$

Where CDI_{dermal} is a chronic daily intake by dermal (µg/kg/day); RfDdermal is a reference of dose in dermal absorption of heavy metal (µg/kg/day) [16, 17, 18]; C_{water} is the measured concentration of metal in water (µg/L); SA is exposure skin area (1,800 cm^2 for an adult, 6,600 cm^2 for children); *Kp* is dermal permeability coefficient (cm/h); ET is the exposure time (0.58 h/day for adult, 1 h/day for children); ED is exposure duration (70 years for adult, 6 years for children); CF is unit conversion factor (0.001 L/cm^3); ABS is dermal absorption factor; BW is average body weight (60 kg for adult, 15 kg for children); AT is the average time (10,950 days for adult, 2,190 days for children)

Results

Mountain water supply quality

The water supply quality of community-based water supply systems in Akha village was investigated. According to the turbidity results presented in **Table 1**, twelve out of fifteen water samples (80%) did not meet the PWA water standards of less than 4 NTU. Exceptions were found in three water samples from S3T, S3M, and S3B. For tank No. S3, the water is sourced from a small stream on the mountain within a conservation area, which is free from human activities such as agriculture and habitation.

Furthermore, pH values exceeding the acceptable range for tap water were detected in 2 out of 15 samples (13%) in **Table 1**. Both of these samples, S1T and S1M, were mountain water from tank S1, and their pH levels were lower than the PWA tap water standard of 6.5 to 8.5

The average concentrations of Cd, Hg, Fe, and Pb in mountain water samples were 0.15, 0.11, 943.59, and 1.90 µg/L, respectively (**Table 1**). Overall, the descending order of heavy metals based on average concentrations was Fe>Pb>Cd>Hg. The concentrations of heavy metals in all mountain water samples analyzed in this study did not exceed the PWA tap water standards, except for Fe, which was elevated in all mountain water samples. Thirteen out of fifteen water samples (87%) did not meet the PWA standard of less than 300 µg/L for Fe.

Total coliform bacteria (TCB) and fecal coliform bacteria (FCB) were found in all mountain water samples. TCB levels ranged from 11 to 460 MPN/100mL, while FCB levels ranged from 3 to 150 MPN/100mL in **Table 1**.

Table 1: Water quality of the mountain water of the Akha hill tribe village

Study site	Elevation (masl)	Sample ID	Water quality									
			Turbidity (NTU)	pH	Total dissolve solid (mg/L)	Hardness (mg/L) as CaCO3	Cd (µg/L)	Hg (µg/L)	Fe (µg/L)	Pb (µg/L)	Total Coliform Bacteria (MPM per 100 ml)	Fecal Coliform Bacteria (MPM per 100 ml)
S1	798	S1T	4.43	6.34	40	40	0.28	0.11	889.95	1.20	150	9.2
		S1M	5.14	6.49	40	30	0.11	0.08	1046.10	2.91	21	15
		S1B	4.56	6.74	40	30	0.13	0.07	877.28	0.60	20	9.2
S2	777	S2T	9.72	6.55	40	20	0.14	0.08	952.55	1.63	93	28
		S2M	8.76	7.17	50	20	0.13	0.13	265.20	1.80	15	15
		S2B	9.14	6.81	40	20	0.16	0.17	626.10	2.29	29	14
S3	775	S3T	3.64	6.86	40	30	0.13	0.05	749.68	2.69	460	20
		S3M	3.79	6.91	40	40	0.13	0.05	1060.60	0.86	75	3
		S3B	3.61	6.91	40	50	0.13	0.04	873.05	1.29	460	15
S4	683	S4T	8.44	6.85	50	40	0.14	0.06	713.50	1.40	15	3
		S4M	9.08	6.88	50	30	0.13	0.17	289.85	1.71	11	3.6
		S4B	9.37	6.90	50	40	0.17	0.18	819.18	3.92	460	43
S5	680	S5T	12.90	6.83	40	40	0.14	0.30	1019.10	1.71	460	150
		S5M	12.80	6.78	40	30	0.17	0.04	1673.70	1.83	240	14
		S5B	14.20	6.91	40	30	0.17	0.09	1594.00	2.66	460	21
Range			3.61-14.20	6.34-7.17	40-50	20-60	0.11-0.28	0.04-0.30	265.20-1673.70	0.60-3.90	11-460	3-150
Average			7.97	6.80	42.67	32.67	0.15	0.11	943.59	1.90	not calculated	not calculated
Tap water standard			4.00	6.50-8.50	600	300	3	1	300	10	No detection	No detection
% Exceeded standard			12/15 (80%)	2/15 (13%)	0/100 (0%)	0/100 (0%)	0/15 (0%)	0/15 (0%)	13/15 (87%)	0/15 (0%)	15/15 (100%)	15/15 (100%)

Remark:
T; Top of the tank
M; Middle of the tank
B; Bottom of the tank

Health risk assessment

The US EPA models for dermal risk assessment were applied to calculate the hazard quotient (HQ) and hazard index (HI) for human exposure to Cd, Fe, Hg, and Pb from tap water use and drinking, as shown in **Table 2**.

The highest HQ from heavy metal absorption to dermal for Hg in children (HQ_{Hg}Chidren) was $1.7x10^{-8,}$ and the lowest for Fe in adults (HQ_{Fe}Adult) was $1.8x10^{-11}$. The sequence of the HQ of dermal exposure from the highest to the lowest is HQ_{Hg}Dermal>HQ_{Pb}Dermal>HQ_{Cd}Dermal> HQFeDermal in both adult and children assessments (**Table 2**). When comparing the HQs for dermal exposure between adults and children, we found that HQ_{Adult} is lower than $HQ_{Children}$.

The HQ from ingestion to oral for four metals, the highest value for Fe in children (HQ_{Fe}Children) was $1.9x10^{-1}$, and the lowest for Cd in adults (HQ_{Cd}Adult) was $3.1x10^{-5}$. The sequence of the HQ of ingestion from the highest to the lowest is HQ_{Fe}Oral>HQ_{Pb}Oral>HQ_{Hg}Oral>HQ_{Cd}Oral in both adult and children assessments (**Table 2**). When comparing the HQs for oral route exposure between adults and children, we found that HQ_{Adult} is lower than $HQ_{Children}$. Although the HQ_{Fe}Oral was lower than 1, Fe concentrations in mountain water were higher than PWA standards and the WHO limit. The Akha villager who is responsible for mountain water treatment should add a process for Fe removal.

The HI values summarized both HQs of the dermal and oral routes for nervous system impacts. The HI for adult (HI_{Adult}) was 0.19, and this value is lower than 1. For children, the $HI_{Children}$ was 0.37, and this value is lower than 1. Comparison of the HIs between adults and children, we found that HI_{Adult} is lower than $HI_{Children}$ (**Table** 2).

Table 2 Hazard quotient (HQ) and hazard index (HI) for adults and children by dermal and oral exposure.

Assessment	Cd		Fe		Hg		Pb		HI
	skin	oral	skin	oral	skin	oral	skin	oral	
HQ_{Adult}	$2.7x10^{-11}$	$3.1x10^{-5}$	$1.8x10^{-11}$	$1.9x10^{-1}$	$6.8x10^{-9}$	$3.3x10^{-5}$	$3.6x10^{-10}$	$4.3x10^{-4}$	**HI_{Adult} = 0.19**
$HQ_{Childen}$	$6.8x10^{-11}$	$6.2x10^{-5}$	$4.5x10^{-11}$	$3.7x10^{-1}$	$1.7x10^{-8}$	$6.7x10^{-5}$	$9.0x10^{-10}$	$8.7x10^{-4}$	**$HI_{Children}$ = 0.37**

Discussion

Turbidity is a visible characteristic of water, indicating the presence of suspended particles. Approximately 80% of mountain water sources exceed the Public Water Authority (PWA) tap water standards. This issue is particularly prevalent in hill tribe villages, where untreated mountain water is commonly used. These waters often contain high levels of organic and inorganic matter [4]. Elevated turbidity can hinder the disinfection process, as particles may protect harmful microorganisms from being effectively neutralized by disinfectants [19]. In hill tribe villages, where agricultural activities such as corn, tea, and coffee growth are soil preparation during the rainy season, will run off small particles to the water resources. The turbidity typically would be high during the rainy season because soil erosion after heavy rainfall causes flow into weirs. In addition, turbidity is a factor for determining the type and level of water treatment that is needed since it could indicate heavy contamination of some chemical compounds, such as alum and polyaluminum chloride (PAC), which need to be improved before their use.

The pH exceeded 13% of mountain water samples in the storage tanks, which had high turbidity and settled the sedimentation. The low pH of water bodies can indeed result from the degradation of organic matter. When organic matter decomposes, it produces acidic byproducts such as carbon dioxide and organic acids, which lower the pH of the water. This process impacts the acid-base balance and redox conditions in aquatic environments, influencing the overall water chemistry and quality [20]. Both total dissolved solids (TDS) and hardness from all mountain water samples met the PWA tap water standards.

More than 87% did not meet the PWA standard of less than 300 µg/L for Fe. Fe is commonly found in natural soils and bound with inorganic matter. It is often detected in mountain water, particularly in hill tribe villages, where it frequently exceeds tap water standards [4]. This is due to the natural dissolution of iron from soil and rocks into water as it percolates through the earth, a process which can be influenced by the mineral composition of the soil and rock in the region . Fe contamination in tap water can cause significant staining and can have nervous system impacts if ingested in excess [21]. When iron is present in water, even at low concentrations, it can leave reddish-brown stains on clothes and fixtures, making laundry and cleaning difficult. This staining occurs because iron particles stick to the materials, and the stains are notably hard to remove [22]. Although Pb, Cd, and Hg were lower than the PWA standard, these three heavy metals are harmful to human health in small amounts by ingestion over long periods.

Heavy metals exposure, the dermal absorption shows that the HQs are lower than 1. The HQ for dermal exposure to heavy metals is generally low because the skin acts as a barrier that significantly limits the absorption of these substances [23]. In the same way, HQs of the oral exposure of heavy metals were higher than dermal exposure. Although the HQ_{Fe}Oral was lower than 1, Fe concentrations in mountain water were higher than PWA standards and the WHO limit. The Akha villager who is responsible for mountain water treatment should add a process for Fe removal.

Our studies are similar to those of researchers who found that the HI for tap water was below 1 [13, 14, 15], indicating negligible potential risk via the dermal or oral route. Several studies have found that the HI for tap water can exceed 1, indicating potential health risks [25]. Finally, none of the mountain water samples met the PWA tap water standards, which require that TCB and FCB are not detectable in tap water. Untreated water from mountain sources frequently contains total coliform bacteria (TCB) and fecal coliform bacteria (FCB) that exceed tap water standards [3, 4].

We recommend base on academic literature review the following measures: (1) establishing formal agreements or regulations to govern mountain water supply management; (2) designating the weir areas as conservation zones to prevent contamination, including restrictions on activities such as agriculture, animal husbandry, construction, and deforestation; (3) encouraging community leaders and water system administrators to acquire professional training in water supply management; (4) implementing a sediment and turbidity treatment system; (5) installing disinfection methods such as chlorination, UV, ozone, or reverse osmosis systems; and (6) developing a water quality monitoring system within the village to ensure safety and contamination control.

Conclusion

Mountain water is the main source of untreated tap water in the Akha hill tribe village. Analysis of this water showed that its quality parameters—including turbidity, pH, iron (Fe), total coliform bacteria (TCB), and fecal coliform bacteria (FCB)—are below the standards established by the Provincial Waterworks Authority (PWA). Since the hill tribe residents have been using and consuming this untreated water for a prolonged period, there is a potential risk of health issues arising from waterborne contaminants. Furthermore, the hazard index (HI) for heavy metals was low.

Therefore, it is imperative that local and national policy-makers support initiatives to provide knowledge and financial subsidies for water treatment in these remote areas. Implementing effective water treatment solutions will help mitigate health risks and ensure the provision of safe water for the hill tribe communities.

Competing Interests

The authors have declared that no competing interests exist.

Funding

The study was funded by Dr.Rozek's Lab at the School of Public Health, University of Michigan, USA, and Mae Fah Luang University.

Acknowledgements

We thank all leaders of hill tribes who allowed us to conduct the mountain water management survey. We thank The Center of Excellence for the Hill-Tribe Health Research of Mae Fah Luang University for their support via assistant researchers, and the Faculty of Tropical Medicine, Mahidol University, for heavy metal analysis.

Author contributions

CR was involved in conceptualization and original draft. SS was involved in conceptualization, laboratory analysis, project administration, and final editing. RM and NK were involved in laboratory analysis. PJ and LR are involved in final editing.

References

[1] The World Health Organization (WHO). Drinking-water. Available from: https://www.who.int/news-room/fact-sheets/detail/drinking-water.

[2] Apidechkul T. Prevalence and risk factors of intestinal parasitic infections among hill tribe schoolchildren, northern Thailand. Asian Pacific Journal of Tropical Disease. 2015; 5(9): 695-9.

[3] Sudsandee S, Fakkaew K, Keawdounglek V, Laor P, Worakhunpiset S, Apidechkul T. Drinking Water Investigation of Hill Tribes: A Case Study in Northern Thailand. Int. J. Environ. Res. Public Health. 2020; 17: 1698.

[4] Sudsandee S, Fakkaew K, Siriratruengsuk W, Worakhunpiset S, Apidechkul T. Quality of sources of drinking water and health among the hill tribe people of northern Thailand. Environ Geochem Health. 2022; 44: 873-92.

[5] The American Public Health Association (APHA). Standard Method for the Examination of water and wastewater, APHA, AWWA, WEF, 23rd Edition, 2017.

[6] The United States Environmental Protection Agency (US EPA). Risk assessment guidance for superfund - volume I - human health evaluation manual (part A). Available from: https://www.epa.gov/sites/production/files/2015-09/documents/rags_a.pdf.

[7] The United States Environmental Protection Agency (US EPA). Risk assessment guidance for superfund - volume I - human health evaluation manual (part B, development of risk-based preliminary remediation goals). Available from: http://epa-prgs.ornl.gov/radionuclides/HHEMB.pdf.

[8] Liu F, Ge J, Hu X, Fei T, Li Y, Jiang Y, et al. Risk to humans of consuming metals in anchovy (Coilia sp.) from the Yangtze River Delta. Environ Geochem Health. 2009; 31:727-40.

[9] Covello VT, Merkhoher MW. Risk assessment methods: Approaches for assessing health and environmental risks, 1st edition. 1993. DOI: 10.1007/978-1-4899-1216-9.

[10] The World Health Organization (WHO). WHO human health risk assessment toolkit: chemical hazards. Available from: https://www.who.int/ipcs/methods/harmonization/areas/ra_toolkit/en/.
[11] The Agency for Toxic Substances and Disease Registry (ASTDR). Public health assessment guidance manual, appendix g: calculating exposure doses. Available from: https://www.atsdr.cdc.gov/hac/phamanual/appg.html.
[12] The United States Environmental Protection Agency (US EPA). Guidance for superfund volume I: human health evaluation manual (part e, supplemental guidance for dermal risk assessment). Available from: https://www.epa.gov/sites/default/files/2015-09/documents/part_e_final_revision_10-03-07.pdf.
[13] Sharma SD. Risk assessment via oral and dermal pathways from heavy metal polluted water of Kolleru lake - A Ramsar wetland in Andhra Pradesh, India. Environmental Analysis, Health, and Toxicology. 2020; 35(3): e2020019.
[14] Zakir HM, Sharmin S, Akter A, Rahman MS. Assessment of health risk of heavy metals and water quality indices for irrigation and drinking suitability of waters: a case study of Jamalpur Sadar area, Bangladesh. Environmental Advances. 2020; 2: 100005.
[15] Dessie BK, Gari SR, Mihret A, Desta AF, Mehari B. Determination and health risk assessment of trace elements in the tap water of two Sub-Cities of Addis Ababa, Ethiopia. Heliyon. 2021; 7 (5): e06988.
[16] Wu B, Zhao DY, Jia HY, Zhang Y, Zhang XX, Cheng SP. Preliminary risk assessment of trace metal pollution in surface water from Yangtze River in Nanjing Section, China. Bull Environ Contam Toxicol. 2009; 82(4): 405-9.
[17] Khalili F, Mahvi AH, Nasseri S, Yunesian M, Yaseri M, Djahed B. Health risk assessment of dermal exposure to heavy metals content of chemical hair dyes. Iranian Journal of Public Health. 2019; 48(5): 902-11.
[18] Li F, Zhang J, Jiang W, Liu C, Zhang Z, Zhang C, et al. Spatial health risk assessment and hierarchical risk management for mercury in soils from a typical contaminated site, China. Environ Geochem Health. 2017; 39: 923-34.
[19] The United States Environmental Protection Agency (US EPA). Water: monitoring & assessment. Available from: https://archive.epa.gov/water/archive/web/html/vms55.html.
[20] Arndt S, LaRowe DE. Organic Matter degradation and preservation. Encyclopedia of Geochemistry. Available from: https://link.springer.com/referenceworkentry/10.1007/978-3-319-39193-9_184-1.
[21] The United States Environmental Protection Agency (US EPA). Iron and Compounds. Available from: https://cfpub.epa.gov/ncea/pprtv/documents/IronandCompounds.pdf.
[22] The Illinois Department of Public Health (IDPH). Iron in Drinking Water. Available from: https://dph.illinois.gov/topics-services/environmental-health-protection/private-water/fact-sheets/iron-drinking-water.html.
[23] The Centers for Disease Control and Prevention (CDC). Skin exposures and effects. Available from: https://www.cdc.gov/niosh/topics/skin/default.html.
[25] Zeng X, Liu Y, You S, Zeng G, Tan X, Hu X, et al. Spatial distribution, health risk assessment, and statistical source identification of the trace elements in surface water from the Xiangjiang River, China. Environ Sci Pollut Res. 2015; 22: 9400-12.