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Assessment of Heavy Metal Contamination and Related Human Health Risk in Groundwater in West Tripura, India

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Abstract*:* *Contamination of groundwater emerges as a concerning menace to the sustainability of ecosystem services and the preservation of natural resources. In this study, the region was examined as a case study to assess heavy metal pollution indices, and their repercussions on human health. For the research purposes, a total of 38 groundwater samples were gathered from the West Tripura district. The sequence of trace metal contaminations is as follows: Fe > Pb > Mn > Zn > Cu. In 53% of the samples, the most prevalent metal, Fe, surpasses its contamination threshold. The findings from the heavy metal indices indicate that over 57% of the samples are exposed to a high risk attributed to elevated levels of Fe and Mn contamination. The results of the health risk assessment study suggest that children are subjected to significantly higher levels of both carcinogenic and non-carcinogenic risks compared to adults due to elevated concentrations of Fe. Given the aforementioned factors, it is recommended that regular monitoring of physicochemical parameters and heavy metals be conducted to safeguard water resources. Furthermore, there should be a focus on implementing management practices aimed at upholding water quality standards. The study additionally proposes that treatment and sustainable management of groundwater resources are essential to mitigate trace metal contaminations prior to public utilization.*

Keywords: Groundwater, Heavy metal indices, Human health risks, Sustainability

I. INTRODUCTION

Sustainable groundwater resources are vital for development initiatives worldwide. In rural areas, 85% of the population, and in urban areas, 50% rely on groundwater to meet their essential needs (Roy et al. 2023). Groundwater is often more reliable than surface water due to lower levels of bacterial contamination and turbidity. The leaching process of minerals, excessive use of fertilizers, and human activities contribute to the deterioration of groundwater quality, rendering it unfit for consumption primarily due to increased contamination from heavy metals such as As, Fe, Mn, cadmium (Cd), chromium, and fluoride (F-) (Roy et al. 2021). Preserving the long-term quality of groundwater stands as one of the foremost challenges confronting the world today (Mittal et al. 2021). As a result, it is advisable to conduct long-term monitoring to assess the quality of groundwater resources through evaluations of heavy metal contamination and associated human health risks.

Heavy metal pollution, a pressing global issue, poses risks to public health when consuming contaminated groundwater. Heavy metals in a dissolved ionic state intensify the toxicity and carcinogenic effects on humans (Roy et al. 2023). Elevated levels of Fe can lead to kidney and liver malfunction. Overconsumption of arsenic can result in cardiovascular disease, central nervous system failure, skin lesions, and cancer (Li et al. 2021). Excessive chromium consumption can lead to lung damage. Metal pollution indices play a crucial role in identifying the pollution status of groundwater concerning heavy metals. Numerous researchers are focusing on these indices and studies on health risk assessment (Paul et al. 2019; Brindha et al. 2020; Li et al. 2021; Roy et al. 2023).

Published journals on groundwater quality in Tripura, a northeastern state of India, are limited. Paul et al. (2019) found that among seven heavy metals, only concentrations of Pb, Fe, and Mn exceeded the recommended water quality standards. Brindha et al. (2020) identified arsenic contamination and elevated iron levels as the primary threats assessed through health risk evaluations. Roy et al. (2021) studied that out of 38 samples, Fe concentration in 90% samples exceeded WHO standard limit of 0.3 mg/L.

Given the substantial groundwater contamination in the area and its significant ramifications on drinking water, agricultural use, health risks, and environmental concerns, the present study aims to address the following objectives:

Assessment of heavy metal pollution indices to ascertain the extent of heavy metal pollution levels.

Calculating health risk assessments for infants, children, and adults exposed to toxic heavy elements.

Additionally, an extensive review of literature highlighted the importance of comprehensively discussing the impact of iron contamination.

II. MATERIALS AND METHODS

Sampling and Analytical Methods

Tripura, situated in the southern part of northeast India, is one of the smallest states. It is characterized by a subtropical climate with high humidity and experiences a strong presence of the southwest monsoon, resulting in high rainfall in the region. The research area encompasses the west Tripura district of Tripura State, spanning between 24.14° N- 24.39° N latitude and 91.98° E- 92.17° E longitude. Approximately 38 samples were preserved in 1-liter capacity HDPE bottles following a 10-minute flush-out period for each tube-well water sample. Each sample was treated with a 1:1 solution of 7.9 N nitric acid to achieve a pH below 2. The Atomic Absorption Spectrophotometer (AAS) model AA300 by Thermo Fisher Scientific, USA, was employed for the analysis of heavy metals (Fe, Mn, Zn, Pb, and Cu). Each measurement was conducted thrice, and an average value was calculated for subsequent interpretation.

Heavy Metal Indices

To effectively manage groundwater resources, it is essential to have a deeper understanding of the impact of heavy metal pollution on groundwater.

Heavy Metal Pollution Index (HPI)

The HPI operates by assigning a weight (W_i) to each individual heavy metal using a rating scale. This rating value falls within the range of 0 to 1, taking into account the relative importance of each individual heavy metal. To compute HPI, following equations are needed:

$$W_i \propto \frac{1}{MAC} \rightarrow W_i = \frac{K}{MAC} \qquad (1)$$

$$Q_i = \sum_{i=1}^{n} \frac{M_i - I_i}{S_i - M_i} \times 100 \qquad (2)$$

$$HPI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \qquad (3)$$

Here, K represents the proportionality constant, which equals 1 for each individual heavy metal; MAC denotes the maximum admissible concentration; S_i indicates the highest permissible value of the i^{th} parameter, and I_i represents the maximum desirable value of the ith parameter (WHO 2011). M_i represents the measured value of the i^{th} parameter of heavy metals; Q_i denotes the quality rating of the i^{th} parameter, and n indicates the number of selected parameters.

Heavy Metal Evaluation Index (HEI)

The HEI can be calculated in the following equation:

$$HEI = \sum_{i=1}^{n} \frac{M_i}{MAC_i} \qquad (4)$$

Degree of Contamination (Cd)

The C_d index serves as a useful tool in evaluating the water quality of individual samples by assessing the degree of contamination through the summation of contamination factors. The computation of C_d necessitates the utilization of the following equations:

$$C_d = \sum_{i=1}^{n} C_{fi} \qquad (5)$$

$$C_{fi} = \frac{M_i}{MAC_i} - 1 \qquad (6)$$

Here, C_{fi} represents the contamination factor of the ith component.

Health Risk Assessment

The health risk assessment consists of four fundamental stages: hazard identification, dose-response assessment, exposure assessment, and risk characterization. The computation necessitates the utilization of the following equations:

$$CDI = \frac{C \times IR \times EF \times ED}{BW \times AT} \qquad (7)$$

where CDI represents the chronic daily intake (average daily dosage) in milligrams per kilogram per day (mg/kg-day), IR is the average drinking water ingestion rate in liters per day (L/day), C denotes the heavy metal concentrations in water in milligrams per liter (mg/L), BW represents body weight in kilograms (Kg), and AT stands for average time in days.

In human life, water is consumed every day throughout the average lifespan, which is typically 66.3 years. This equates to 365 days per year (EF) for exposure duration (ED), which is considered the average time (AT). Consequently, the aforementioned equation can be expressed as follows:

$$CDI = \frac{C \times IR}{BW} \qquad (8)$$

For infants, children, and adults, the values for IR are 0.25, 1.5, and 3 L/day, respectively, while BW values are 6.9, 18.7, and 57.5 kg, respectively. The non-carcinogenic risk (HQ) can be calculated as follows:

$$HQ = \frac{CDI}{RfD} \qquad (9)$$

where, HQ = hazard quotient; RfD = reference dosage (mg/kg-day). RfD values for Fe, Mn, Cu, Pb, and Zn is 0.7, 0.14, 0.005, 0.0036, and 0.3 mg/kg-day, respectively.

III. RESULTS AND DISCUSSION

The sequence of trace metal contaminations is as follows: Fe > Pb > Mn > Zn > Cu. The Fe concentration varies from 0-14.2 mg/L with an average value of 1.681 (Table 1). In 53% of samples, iron (Fe) surpasses the contaminant level set by WHO (WHO, 2011). Elevated levels of Fe in water, which manifest as reddish-brown coloration, contribute to bacterial proliferation. The primary sources of Fe in groundwater are shale from the Bokabil group and ferruginous sandstone (Roy et al. 2023). The concentration of lead (Pb) at only one sampling station (GW9) exceeds the WHO standard limit of 0.01 mg/L by 1000 times. Lead is a highly toxic and bio-accumulative element capable of causing irreversible harm to organs such as the kidneys, nervous system, and reproductive system. The manganese (Mn) concentration in four samples exceeds the WHO prescribed limit of 0.4 mg/L. Ingestion of water contaminated with manganese can lead to neurotoxic effects in both humans and animals. Maximum value of Zn is reported to be 0.947 mg/L (Table 1) which is much lower than WHO limit (3 mg/L). The metal concentrations are shown in Fig. 1 and Table 1

Table 1 Descriptive statistics of heavy metals

Parameters	Minimum	Maximum	Mean	Std. deviation	WHO, 2011 (mg/L)
Fe (mg/L)	BDL	14.2	1.681	3.048	0.3
Mn (mg/L)	BDL	2.305	0.137	0.398	0.4
Zn (mg/L)	BDL	0.947	0.034	0.160	3
Cu (mg/L)	BDL	0.086	0.002	0.014	2
Pb (mg/L)	BDL	10.049	0.264	1.630	0.01

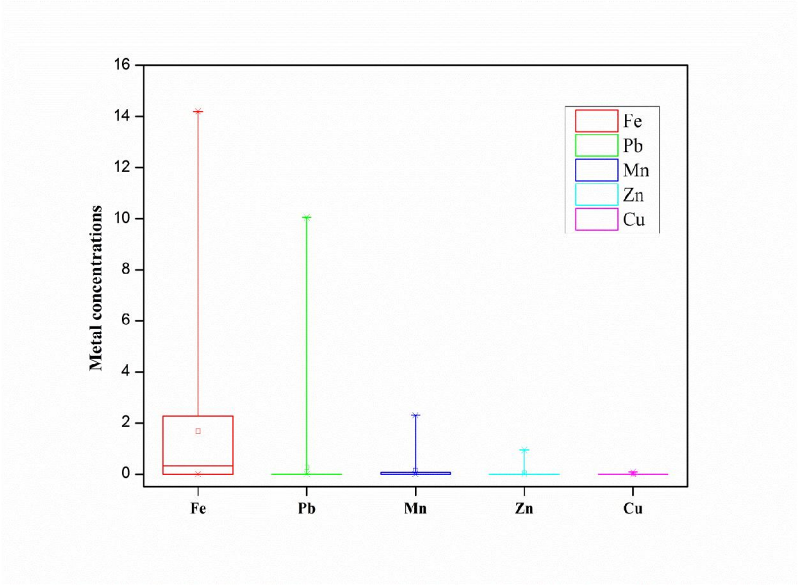

Fig. 1 Box plot showing metal concentration

HPI value ranges from 0-98.20 with a mea value of 10.82. Calculated HPI values indicate most of the samples are at low risk of pollution. Only one sample show high risk as Pb is the major contributing metal for that station. The value of HEI varies from 0-6705 with an average value of 187.69 (Table 2). Both HEI and C_d values in almost 57% samples show high risk as Fe and Mn are the major contributing metals to these indices. Table 2 provides the details value of heavy metal pollution indices.

Table 2 Results of heavy metal indices

Evaluation indices	Ranges	Degree of pollution	No of samples	Minimum	Maximum	Mean
HPI	< 40	Low	33	0	98.20	10.82
	40 - 80	Medium	4			
	> 80	High	1			
HEI	< 1	Low	13	0	6705.79	187.696
	1- 2	Medium	3			
	> 2	High	22			
C_d	< 1	Low	13	0	6704.78	186.93
	1- 3	Medium	4			
	> 3	High	21			

Since individuals consume varying amounts of water based on their age, evaluation indices fail to adequately reflect the impact of heavy metals on human health. Consequently, health risk assessment can address this limitation by analyzing Chronic Daily Intake (CDI) and Hazard Quotient (HQ) providing estimates of heavy metal ingestion severity for infants, children, and adults. A CDI value of ≤ 1 mg/kg-day indicates safety, while a value exceeding 1 mg/kg-day indicates a risk to human health (Roy et al. 2023). Computed CDI values of heavy metals in samples follow the order: Fe > Pb > Mn > Zn> Cu. Among all heavy metals, Fe is the most influencing contributor to CDI value. The health impact assessed by HQ suggests non-carcinogenic effects when its value equals 1 and indicates harm to human health when it exceeds 1. Maximum HQ values for infants, children and adults are estimated to be 2.808, 6.217 and 4.044 mg/kg-day (Table 3). Calculated HQ values follow the sequence: Pb > Fe > Mn > Zn > Cu. Pb and Fe are the most prevalent metals contributing more non-carcinogenic risk to childs than adults. According to findings of all indices, children face much non-carcinogenic risk than adults because of high contamination levels of Fe in the study area (Fig. 2).

Table 3 Results of health risk assessment of groundwater samples

Human exposure risk	Characters	Minimum	Maximum	Mean	No of samples exceeding standard limit
CDI $_{total}$ (mg/kg-day)	Infants	0	0.523	0.076	-
	Childs	0	1.159	0.170	2
	Adults	0	0.754	0.110	-
HQ $_{total}$ (mg/kg-day)	Infants	0	101.204	2.808	2
	Childs	0	224.057	6.217	4
	Adults	0	145.734	4.044	3

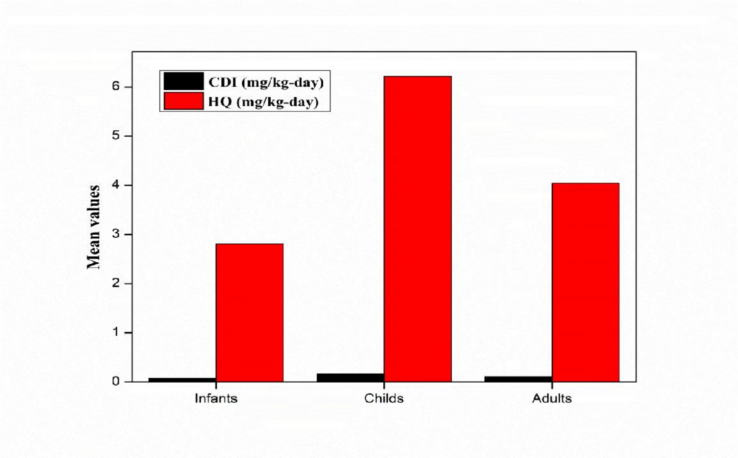

Fig. 2 Mean CDI and HQ value in groundwater

IV. CONCLUSION

This study utilized heavy metal indices and health risk assessment to understand the impact of heavy metal contamination in groundwater and their impact on human health. Fe contamination in 52% samples exceed WHO standard limit. Excessive Fe in human body can cause Parkinson's disease, Alzheimer's disease and multiple sclerosis. Heavy metal indices, particularly HEI and $C_{d,}$ show high risk in above 57% samples due to excessive Fe and Mn contaminations. Health risk assessment study implies children are facing higher non-carcinogenic risks than adults because of unsafe levels of Fe in groundwater samples. Overall, this study suggests systematic evaluation of groundwater quality followed by immediate treatment to remove harmful pollutants from water and to maintain the standard limits for drinking water. This treatment also aids in safeguarding children from both carcinogenic and non-carcinogenic symptoms by mitigating trace metal contaminations.

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