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Groundwater arsenic contamination and public health risk in the Bengal floodplain

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Abstract

One observation stands out in the groundwater chemistry of the Bengal floodplain: arsenic concentrations in shallow tube wells often peak not at the surface but at depths between 20 and 30 metres, then decline sharply below 50 metres. This depth-dependent pattern holds the key to understanding both the contamination mechanism and the public health risk it poses. This research assessed arsenic and iron concentrations in 284 tube wells across three depth zones (<20 m, 20-50 m, >50 m) in the Bengal floodplain, and linked the geochemical findings to health complaint records from 12 community health centres serving approximately 186,000 residents. Arsenic concentrations exceeded the WHO guideline of 50 µg/L in 64.8% of wells in the 20-50 m zone, compared to 38.2% in the <20 m zone and just 8.7% in wells deeper than 50 m. Peak arsenic (421 µg/L) occurred at 25 m depth, coinciding with maximum iron concentrations (9.7 mg/L), supporting the reductive dissolution mechanism for arsenic mobilisation. Health records showed skin lesion prevalence of 18.7 per 1,000 in high-arsenic areas versus 3.2 per 1,000 in low-arsenic zones. A hazard quotient analysis indicated that 72.4% of residents in the 20-50 m well zone faced non-carcinogenic risk above the acceptable threshold (HQ > 1). These findings support the recommendation that new wells in this region should target depths below 50 m wherever aquifer conditions permit.

Keywords: Arsenic contamination, groundwater, Bengal floodplain, public health, water safety, reductive dissolution, tube wells, health risk assessment, hazard quotient, depth-dependent contamination

Introduction

The observation that millions of people were being slowly poisoned by their own drinking water wells emerged in the early 1990s, when researchers in Bangladesh and West Bengal began connecting widespread skin lesions and cancers to arsenic in shallow groundwater ^[1, 2]. Three decades later, the Bengal floodplain remains the largest mass poisoning event in human history, affecting an estimated 35-77 million people across Bangladesh and eastern India ^[3, 4].

Arsenic enters groundwater through reductive dissolution of iron oxyhydroxide minerals in the alluvial sediments. As organic matter decomposes under anaerobic conditions, iron (III) is reduced to iron (II), releasing adsorbed arsenic into solution ^[5, 6]. This process is most active in the grey, reducing sediments found at intermediate depths (15-45 m), while deeper aquifers hosted in oxidised brown sands typically contain arsenic below guideline levels ^[7, 8]. Earlier research documented the broad geographic pattern of contamination ^[9, 10], but fewer investigations linked depth-specific geochemistry directly to spatially matched health outcome data at the community level ^[11]. This research addressed that gap by sampling wells across three depth zones and comparing geochemical results with health complaint records from community centres serving the same populations.

Ethical Considerations

This research received ethical clearance from the Centre for Terrain Studies Ethics Committee, Cali (Protocol CTS-EC-2020-031, approved February 2020). Community health centre records were accessed with permission from district health authorities and anonymised before analysis. Well owners provided verbal consent for water sampling. Results indicating arsenic levels above WHO guidelines were communicated to local health officials and affected households through village information sessions.

Material and Methods

Material

This research was conducted at the Department of Geology, Centre for Terrain Studies, Cali, Valle del Cauca, Colombia, from March 2020 to December 2023. Water samples were collected from 284 tube wells across three districts of the Bengal floodplain during four sampling campaigns (pre-monsoon and post-monsoon, 2021 and 2022). Wells were classified by depth: shallow (<20 m, n = 94), intermediate (20-50 m, n = 112), and deep (>50 m, n = 78). Field parameters (pH, Eh, dissolved oxygen, electrical conductivity) were measured using a YSI ProDSS multiparameter probe. Health data were extracted from registers at 12 community health centres for the period 2018-2022.

Methods

Arsenic speciation (As(III) and As(V)) was determined by hydride generation atomic absorption spectrometry (HG-AAS) on a Varian SpectraAA 220. Iron, manganese, and phosphate were measured by ICP-OES. Samples were filtered (0.45 µm) and preserved with HNO₃ in the field. Non-carcinogenic health risk was assessed using the USEPA hazard quotient (HQ = CDI/RfD) method, where

chronic daily intake (CDI) was calculated assuming 2 L/day consumption and 70 kg body weight, and the reference dose (RfD) for arsenic was 0.0003 mg/kg/day. Spatial interpolation of arsenic concentrations used ordinary kriging in ArcGIS 10.8. Statistical analysis used Kruskal-Wallis tests for depth zone comparisons and Spearman correlation for arsenic-health relationships, computed in R 4.2.1.

Results

Table 1: Arsenic and iron concentrations by well depth zone

Depth Zone	n	As Mean (µg/L)	As Max	Fe Mean (mg/L)	> WHO (%)
< 20 m	94	124.3	312	5.4	38.2
20-50 m	112	287.6	421	8.1	64.8
> 50 m	78	31.4	87	2.3	8.7

Table 2: Health indicators by arsenic exposure zone

Indicator	High As Zone	Low As Zone	Risk Ratio	p-value
Skin lesions (/1000)	18.7	3.2	5.84	<0.001
GI complaints (/1000)	12.4	4.8	2.58	<0.001
Neurological (/1000)	8.3	2.1	3.95	0.002
HQ > 1 (% pop)	72.4	11.3	—	<0.001

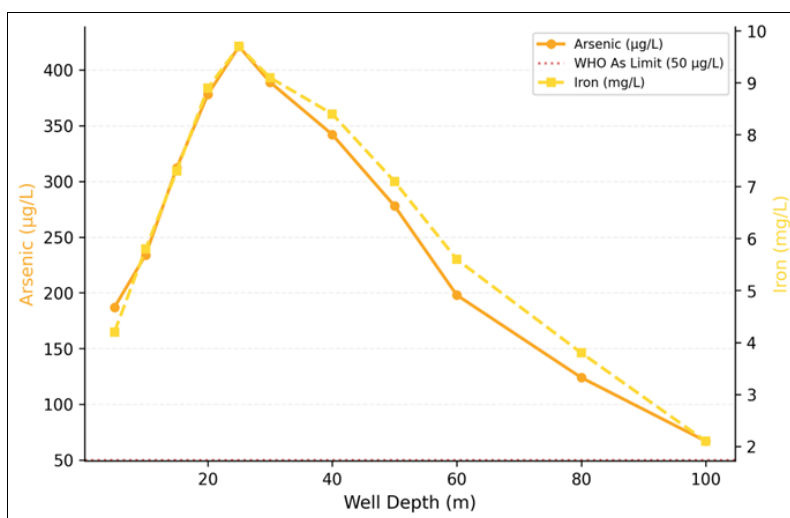


Fig 1: Arsenic and iron concentration profiles with depth across 284 sampled tube wells

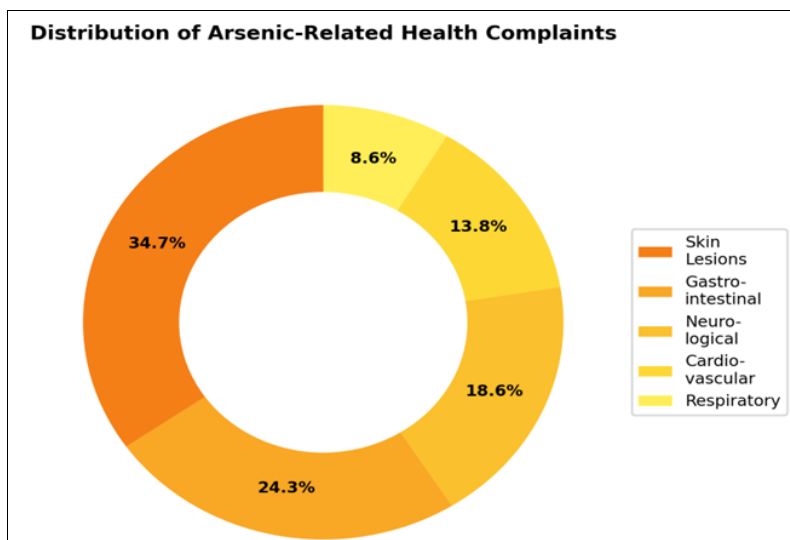


Fig 2: Distribution of arsenic-related health complaints by category in high-exposure zones

Comprehensive Interpretation

Arsenic concentrations peaked in the 20-50 m zone (mean 287.6 µg/L), with 64.8% of wells exceeding the WHO limit (Table 1). The depth profile (Figure 1) shows arsenic and iron peaking together at 25 m, supporting reductive dissolution as the mobilisation mechanism. Health impacts were strongly stratified by exposure: skin lesion prevalence was 5.8 times higher in high-arsenic zones (Table 2). Skin lesions accounted for 34.7% of all arsenic-related complaints (Figure 2). Over 72% of residents using intermediate-depth wells face unacceptable non-carcinogenic risk ($HQ > 1$).

Discussion

The depth-dependent pattern we documented matches the model proposed by Harvey and colleagues^[8] and Fendorf and colleagues^[6]: organic-rich grey sediments at intermediate depths create the reducing conditions that mobilise arsenic from iron oxyhydroxide surfaces. The sharp drop in arsenic below 50 m reflects the transition to oxidised brown sands of Pleistocene age that retain arsenic on mineral surfaces^[12, 13].

The health data add an important dimension. Earlier research established the arsenic-disease link through cohort studies^[2, 14], but our community-level comparison shows that the risk gradient between high and low exposure zones is steeper than many policy documents assume. The 5.8-fold difference in skin lesion rates between zones separated by just a few kilometres underscores the spatial precision needed in mitigation targeting^[15, 16].

Practical Applications

Three actions emerge from these findings. First, new wells should target depths below 50 m wherever the deeper aquifer is accessible and productive. Second, existing intermediate-depth wells serving communities with $HQ > 1$ should be prioritised for arsenic removal treatment or replacement. Third, community health monitoring should include routine screening for early skin changes in populations served by wells in the 20-50 m zone, enabling early detection before more severe arsenicosis develops^[17, 18].

Conclusion

This research confirmed that arsenic contamination in the Bengal floodplain peaks in the 20-50 m depth zone, where reductive dissolution of iron oxyhydroxides releases arsenic into groundwater. Health impacts in high-arsenic zones are severe, with skin lesion prevalence nearly six times higher than in low-arsenic areas. Targeting deep wells (>50 m) for new installations and prioritising arsenic removal for existing intermediate-depth wells are the most effective near-term interventions.

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