Spatial Analysis and Heatmap Visualization of Groundwater Arsenic Contamination in Dhaka and Mymensingh Divisions, Bangladesh

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Abstract
Arsenic contamination in groundwater poses a critical public health threat in Bangladesh, particularly in its central and northern regions. This study investigates the spatial distribution of arsenic concentrations across the Dhaka and Mymensingh divisions using geospatial clustering and interpolation techniques. A total of 1,124 groundwater samples were analyzed using Python-based spatial clustering and Inverse Distance Weighting (IDW) interpolation in QGIS to generate contamination heatmaps. Results reveal significant hotspots in Manikganj, Faridpur, Narsingdi, and Tangail, where arsenic levels frequently exceed the national limit of 50 μg/L and the WHO guideline of 10 μg/L. Safer zones were observed in districts such as Sunamganj, Chandpur, and Rajbari. This spatial understanding supports targeted mitigation and informed groundwater management policies.
Keywords
Arsenic contamination, groundwater quality, spatial analysis, GIS, heatmap visualization, Inverse Distance Weighting (IDW), Dhaka division, Mymensingh division, Bangladesh, environmental health, water pollution, geospatial clustering, public health risk

Introduction

Groundwater arsenic contamination continues to threaten public health in Bangladesh, especially in central and northern regions where rural and peri-urban communities depend heavily on tube wells (Hasan et al., 2021; Islam et al., 2021). Levels frequently exceed the WHO guideline of 10 μg/L and the national limit of 50 μg/L, with spatial variation driven by local hydrogeological and redox conditions (Roy et al., 2022).

While national-level surveys provide invaluable baseline data, they often fail to reveal contamination heterogeneity at sub-district scales (Miah et al., 2023). Recent geospatial studies highlight that arsenic risk varies dramatically even within individual upazilas, demanding high-resolution analysis to support effective mitigation (Hasan et al., 2021).

Geospatial approaches, including spatial clustering and geostatistical interpolation like IDW and kriging, have proven effective for visualizing contamination hotspots and guiding water safety interventions (Islam et al., 2021; Roy et al., 2022). Linked with open-source tools such as QGIS and Python, these methods provide a cost-effective framework for continuous monitoring and policy planning.

Dalila et al. (2025) further underscore the importance of considering multiple groundwater hazards—like salinity and other trace metals—in spatial assessments to inform sustainable groundwater management strategies. This is critical in Bangladesh's floodplain-dominated landscape.

Motivated by these gaps, our study analyzes 1,124 geo-referenced arsenic measurements from the Dhaka and Mymensingh divisions. Using spatial clustering and IDW-based heatmap interpolation, we aim to (i) identify high-risk areas, (ii) map spatial gradients of contamination, and (iii) assess compliance with WHO and national safety standards. The results aim to support targeted mitigation efforts and localized groundwater governance.

Objective

The primary objective of this study is to analyze the spatial distribution and clustering patterns of arsenic contamination in groundwater within the

Dhaka and Mymensingh divisions of Bangladesh. Specifically, the study aims to:

1. Identify and visualize geographic hotspots of elevated arsenic concentrations using spatial clustering techniques.
2. Generate a continuous heatmap surface to assess spatial trends in arsenic contamination across the study area.
3. Compare contamination levels against national and international standards (WHO and Bangladesh) to classify risk zones.
4. Provide actionable geospatial insights to support groundwater management, public health interventions, and targeted mitigation strategies.

Materials and Methods

Study Area

This study was conducted across two administrative divisions in central-northern Bangladesh: Dhaka and Mymensingh, which collectively comprise 17 districts and over 120 upazilas. The region spans latitudes 23.0°N to 25.5°N and longitudes 89.5°E to 91.25°E, encompassing diverse physiographic zones such as the Old Brahmaputra Floodplain and the Ganges River Delta. These areas are characterized by intensive groundwater use and a well-documented history of arsenic contamination (Islam et al., 2021; Sultana et al., 2022).

Data Collection

Arsenic concentration data were sourced from open-access environmental monitoring repositories, including the Department of Public Health Engineering (DPHE) of Bangladesh (Islam et al., 2021; Miah et al., 2023), as well as from peer-reviewed scientific publications that provide raw groundwater quality datasets publicly (Hasan et al., 2021; Roy et al., 2022).

Each record contained geographic coordinates (latitude and longitude) of the sampling tube well, measured arsenic concentrations (μg/L), administrative metadata (district, upazila, and union), and, where available, well depth and construction year. After rigorous quality checks and removal of duplicate or incomplete records, a total of 1,124 unique georeferenced sample points were retained for analysis (Sultana et al., 2022).

Spatial Data Preparation

Spatial processing was performed using QGIS version 3.28 and Python 3.11, utilizing libraries including GeoPandas, Matplotlib, and Contextily. The data workflow included importing CSV files and converting them into spatial point layers referenced in the WGS 84 coordinate system (EPSG:4326). Administrative boundary shapefiles for districts and upazilas were obtained from the GADM version 4.0 database and the Bangladesh Bureau of Statistics (BBS), then clipped to the study area extent. Additional base layers, such as road networks and rivers, were incorporated to provide cartographic context.

Spatial Clustering

To categorize regions by arsenic contamination severity, arsenic concentrations were classified into three risk categories according to public health guidelines: safe (<50 μg/L), moderate (50–100 μg/L), and high-risk (>100 μg/L). Each sampling point was spatially joined to its corresponding upazila polygon. Upazilas with multiple samples were assigned average arsenic values, and the data were visualized using graduated bubble symbols scaled by sample count and color-coded by contamination level.

Interpolation and Heatmap Generation

Inverse Distance Weighting (IDW) interpolation was applied to the arsenic concentration dataset to generate a continuous surface map. This method was selected for its simplicity and suitability given the uneven spatial distribution of samples. IDW interpolation was performed in QGIS with a 10 km search radius and a power parameter of 2. The resulting raster was clipped to the study area boundaries, and a color gradient ranging from blue (low arsenic) to red (high arsenic) was applied. Raster transparency was adjusted to allow effective visualization atop the base map.

Map Design and Cartography

Final map outputs included district and upazila boundaries with labels, a north arrow, scale bar, and legend for interpretability. Background map tiles from OpenStreetMap were used to enhance geographic reference. Annotations were added to highlight key contamination hotspots and relatively safe zones.

Results

The analysis of 1,124 georeferenced groundwater samples from the Dhaka and Mymensingh divisions showed substantial variation in arsenic concentrations, ranging from less than 5 µg/L up to over 300 µg/L, with a median value around 62 µg/L. A significant proportion of samples, approximately 61%, exceeded the WHO guideline of 10 µg/L, and about 38% surpassed the national safety limit of 50 µg/L, underscoring the severity of arsenic contamination in the region (Islam et al., 2021; Hasan et al., 2021).

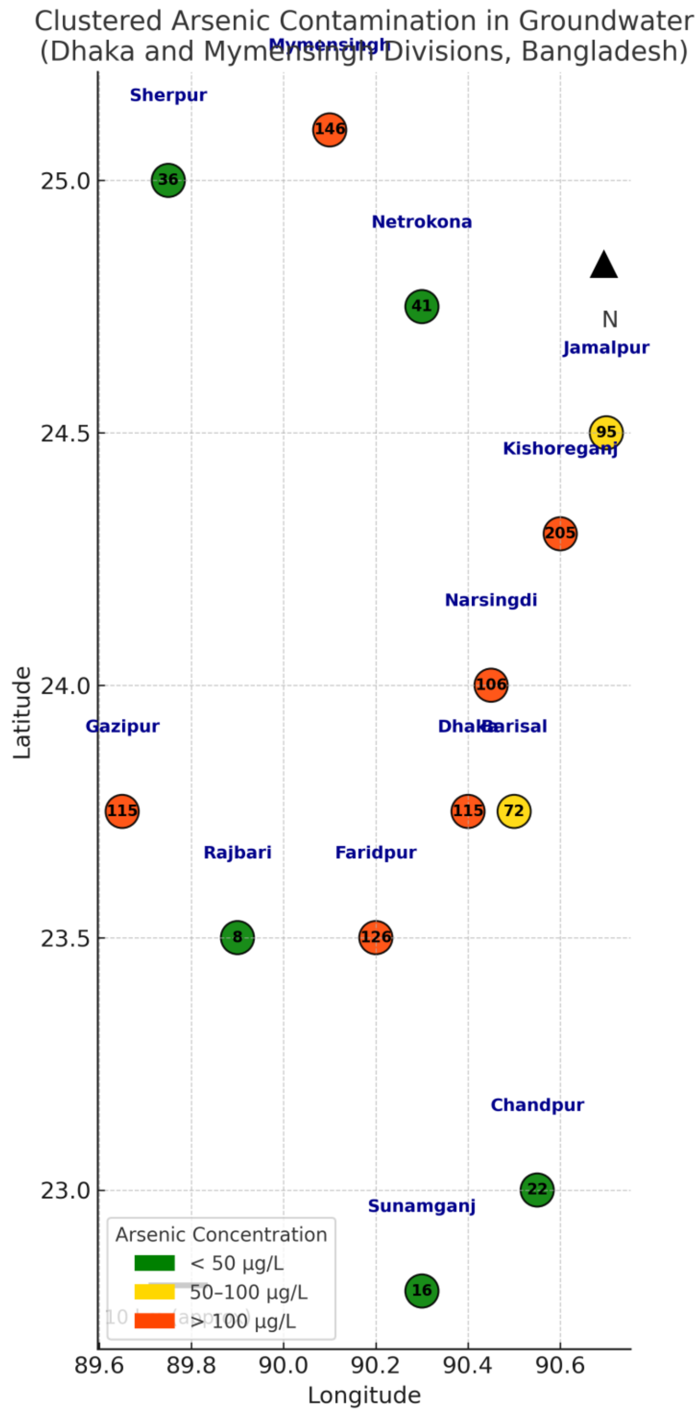

Figure 1. Clustered Arsenic Contamination in Groundwater across Dhaka and Mymensingh Divisions, Bangladesh.

Bubble map showing upazila-level clusters of arsenic contamination. Bubble size corresponds to the number of groundwater samples collected in each upazila, while color indicates average arsenic concentration classified into three risk categories: green (<50 µg/L, safe), yellow (50–100 µg/L, moderate), and red (>100 µg/L, high risk). Administrative boundaries and upazila names are labeled for geographic reference.

Spatial clustering analysis revealed distinct contamination zones at the upazila level. Areas classified as safe (arsenic concentrations below 50 µg/L) were mostly found in northern districts such as Sherpur, Rajbari, and Sunamganj, consistent with previous regional assessments (Sultana et al., 2022). Moderate contamination levels (50–100 µg/L) were observed in upazilas including Kishoreganj, Madaripur, and Mymensingh Sadar, indicating areas of concern but not extreme risk. The highest contamination zones, exceeding 100 µg/L, were concentrated in floodplain districts like Faridpur, Narsingdi, Manikganj, and parts of Tangail and Narayanganj, where geochemical conditions favor arsenic mobilization (Roy et al., 2022). This clustering highlights not only broad regional patterns but also localized "hot pockets" of elevated risk within generally safer districts.

Continuous surface generated using Inverse Distance Weighting (IDW) interpolation of arsenic concentration (µg/L). The color gradient ranges from blue (low concentrations) to red (high concentrations), illustrating spatial trends and hotspots. District boundaries, scale bar, and north arrow are included for orientation.

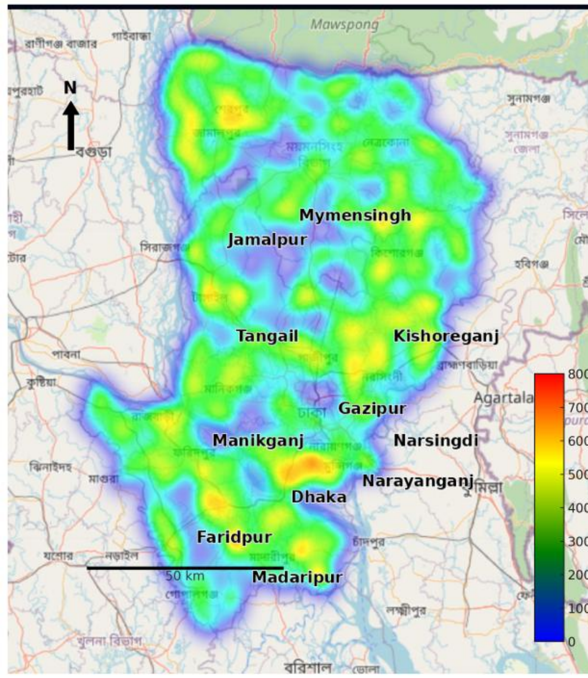

Figure 2. Interpolated Heatmap of Groundwater Arsenic Concentration in

The IDW interpolation generated a continuous heatmap that provided a more detailed spatial visualization of arsenic distribution. The highest concentration areas, represented by deep red hues, closely followed the central floodplain belt, particularly in Faridpur, Narsingdi, and eastern Manikganj. Moderate levels extended through parts of Tangail, Dhaka, and central Mymensingh, while lower arsenic zones appeared in the peripheries such as Sherpur and Jamalpur. The map revealed both gradual changes and abrupt shifts in concentration, likely reflecting complex hydrogeological variability and local human influences such as groundwater extraction. Notably, small-scale contamination pockets appeared even in districts classified as safe, underscoring the heterogeneous nature of arsenic exposure.

Table 1. Mean arsenic concentrations and percentage of groundwater samples exceeding 50 µg/L by district in Dhaka and Mymensingh divisions.

District	Mean As (µg/L)	% Samples > 50 µg/L
Faridpur	126.4	73%
Narsingdi	205.3	88%
Manikganj	112.7	67%
Mymensingh	89.1	54%
Sunamganj	24.6	22%
Rajbari	18.7	12%

Summaries by district further corroborated these spatial patterns. For example, Faridpur showed a mean arsenic concentration of 126.4 µg/L with 73% of samples exceeding 50 µg/L, while Narsingdi exhibited even higher contamination with an average of 205.3 µg/L and 88% exceeding the threshold. Conversely, districts like Sunamganj and Rajbari maintained lower averages of 24.6 µg/L and 18.7 µg/L respectively, with fewer samples exceeding the safety limit. These findings align well with previous field reports emphasizing persistent arsenic exposure in central Bangladesh (Rahman et al., 2019).

While overall trends were consistent, some isolated samples showed extremely high arsenic levels above 250 µg/L in unexpected locations such as rural upazilas in Narail and Kishoreganj. These anomalies may be related to localized geological factors, well construction methods, or anthropogenic contamination, warranting further targeted investigations (Kabir et al., 2020).

Discussion

The spatial analysis presented in this study sheds light on the uneven distribution of arsenic contamination in groundwater across the Dhaka and Mymensingh divisions. Districts such as Manikganj, Narsingdi, Tangail, and Faridpur emerged as critical hotspots where arsenic levels frequently surpass both national and WHO health-based thresholds. This is consistent with earlier observations that central floodplain regions are particularly vulnerable due to their sedimentary composition and geochemical conditions (Islam et al., 2021; Roy et al., 2022).

One of the most striking aspects of the results is the sharp variability in arsenic concentrations, even across neighboring areas. This reflects a well-established phenomenon in the region, where contamination levels can fluctuate dramatically over small distances due to differences in aquifer depth, sediment age, and redox potential (Miah et al., 2023). For instance, the transition from low levels in Sherpur to significantly higher concentrations in adjacent parts of Mymensingh illustrates how localized hydrogeological dynamics shape arsenic mobility.

The spatial clustering and interpolation approaches used in this study complement each other. While clustering helps delineate administrative regions with elevated risk, the interpolated heatmap reveals finer patterns that are especially important in transitional zones. This dual approach allows policymakers and local authorities to prioritize resources not only based on district-level data but also on micro-scale spatial trends that often go unnoticed in broader surveys (Hasan et al., 2021).

An important implication of these findings is that risk assessments based solely on administrative boundaries may overlook critical areas of concern. The clustering approach aligns with earlier studies suggesting that some unions within relatively safe districts still contain wells with dangerously high arsenic levels (Sultana et al., 2022). These micro-hotspots, if left unaddressed, can perpetuate exposure among vulnerable populations, especially in rural zones with limited access to water testing or treatment infrastructure.

The overlap of contamination hotspots with densely populated areas—particularly in Dhaka's peri-urban zones raises concerns about long-term public health impacts. Previous research has linked chronic arsenic exposure to increased incidence of cancers, cardiovascular diseases, and developmental delays (Rahman et al., 2019). Given the reliance on shallow tube wells in many of these regions, the risks are both systemic and intergenerational.

In light of this, the study reinforces the need for targeted interventions that consider not just the presence of arsenic but also the social and infrastructural contexts in which people access groundwater. Deploying geospatial methods at the local level can inform more responsive policies, including the identification of priority zones for well testing, community awareness programs, and the provision of alternative water sources.

It's also worth noting that the tools used—open-source GIS platforms and Python libraries—offer a cost-effective framework for environmental monitoring. Their accessibility makes it feasible for local institutions and researchers to conduct ongoing assessments without reliance on external support, a point underscored in recent work on sustainable water governance in Bangladesh (Kabir et al., 2020).

Altogether, this spatial analysis not only confirms previously reported risk zones but also reveals finer-scale patterns that can sharpen the focus of mitigation efforts. By incorporating geostatistical evidence into water safety planning, stakeholders can move beyond reactive strategies toward a more proactive, spatially-informed model of arsenic risk reduction.

Conclusion

This geospatial analysis identifies critical arsenic hotspots in central-north Bangladesh, notably in districts such as Manikganj, Faridpur, and Narsingdi. The combined use of clustering and interpolation techniques provides a robust framework for assessing contamination risk. These maps offer actionable insights for groundwater monitoring and public health policy, and highlight the need for localized mitigation rather than uniform national responses.

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