Assessment of Hydro Geochemistry and Groundwater Quality for Drinking and Irrigation purposes in Coastal Aquifer of Lakshmipur district, Bangladesh: Using Fuzzy Overlay

Md Mahedi Hasan[1*], Khondaker Emamul Haque[1], Shamim Ahmed[2], Md Nazmul Islam Hasan[1], Most. Nishat Yesmin Mim[1]

[1]Department of Geology and Mining, University of Rajshahi, Rajshahi 6205, Bangladesh
[2]Institute of Environmental Science, University of Rajshahi, Rajshahi 6205, Bangladesh

*(*Corresponding E-mail: mdmahedihasan107190@gmail.com)*

Abstract: Areas like Bangladesh's Lakshmipur District, which have limited surface water resources, rely heavily on groundwater to meet household, industrial, and agricultural needs. To determine their physical and chemical properties, forty groundwater samples from five distinct upazilas were examined, revealing that the water quality of the area is not suitable for either drinking or agricultural purposes. Statistical methods and laboratory tests were used to interpret the seasonal and regional variations in water quality. The analysis revealed that arsenic, iron, potassium, turbidity, and TDS exceeded the permissible limits of both WHO and DoE standards in the entire samples. The biggest risks to agriculture and human health were presented by the pH, EC, and salinity problems found in 60% of the samples. In the region, groundwater often contains somewhat too much arsenic (As >0.05 mg/L); in some locations, there was excessive salinity (up to 1 ppt), turbidity (up to 271 NTU), and total dissolved solids (TDS >1000 mg/L), considering it unsuitable to drink untreated. Many samples, according to hydrogeochemical facies analysis, fall into the Na^+-K^+-Cl^--SO_4^{2-} zone (Piper), the Na^+-K^+ and Cl^- zones (Durov), and the "Rock Dominance" field (Gibbs), which indicates saline impact and rock-water interaction typical of coastal aquifers. Only a small number of sites with high water quality were shown on the WQI map created using GIS-based FO analysis; the majority were poor to inappropriate. Risks to crops and soil were highlighted by irrigation indices (SAR, RSC, MH, and Kelly's Ratio), underscoring the necessity of sustainable groundwater management.

Keywords: ***Hydro geochemistry, Rock-water interaction, Water quality index, Fuzzy overlay, Costal aquifers.***

Introduction

Groundwater is a vital resource for agriculture, industry, and human use, particularly in areas where surface water is scarce. Groundwater geochemical studies help to better identify potential quality changes as development advances (Gupta et al. 2009). Groundwater quality was assessed through major anions, cations, trace elements, and key physicochemical indicators. Geochemistry is the science that uses the tools and principles of chemistry to explain the mechanisms behind major geological systems such as the Earth's crust and its oceans (Albarède and Francis, 2005). This study assesses the chemical characteristics and major influencing factors of groundwater quality in the Lakshmipur area.

Methodology

Following chart was used for this research (Figure 1).

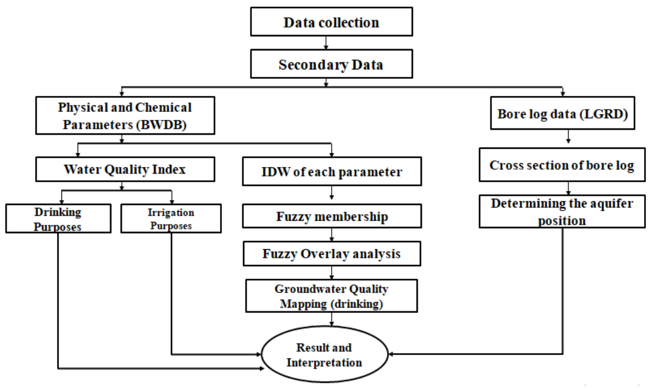


Figure 1, Methodology chart.

WQI for Drinking Water

$$WQI = \frac{\sum_{i=1}^{n} w_i q_i}{\sum_{i=1}^{n} w_i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (i)$$

$$q_i = \left(\frac{v_i - v_{id}}{s_i - v_{id}}\right) \times 100 \ldots\ldots\ldots\ldots\ldots\ldots. (ii)$$

$$w_i = \frac{K}{S_i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (iii)$$

WQI for Irrigation

$$Na\% = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100 \ldots\ldots (iv)$$

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots.......... (v)$$

$$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}).. (vi)$$

$$MH = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \ldots\ldots\ldots\ldots............ (vii)$$

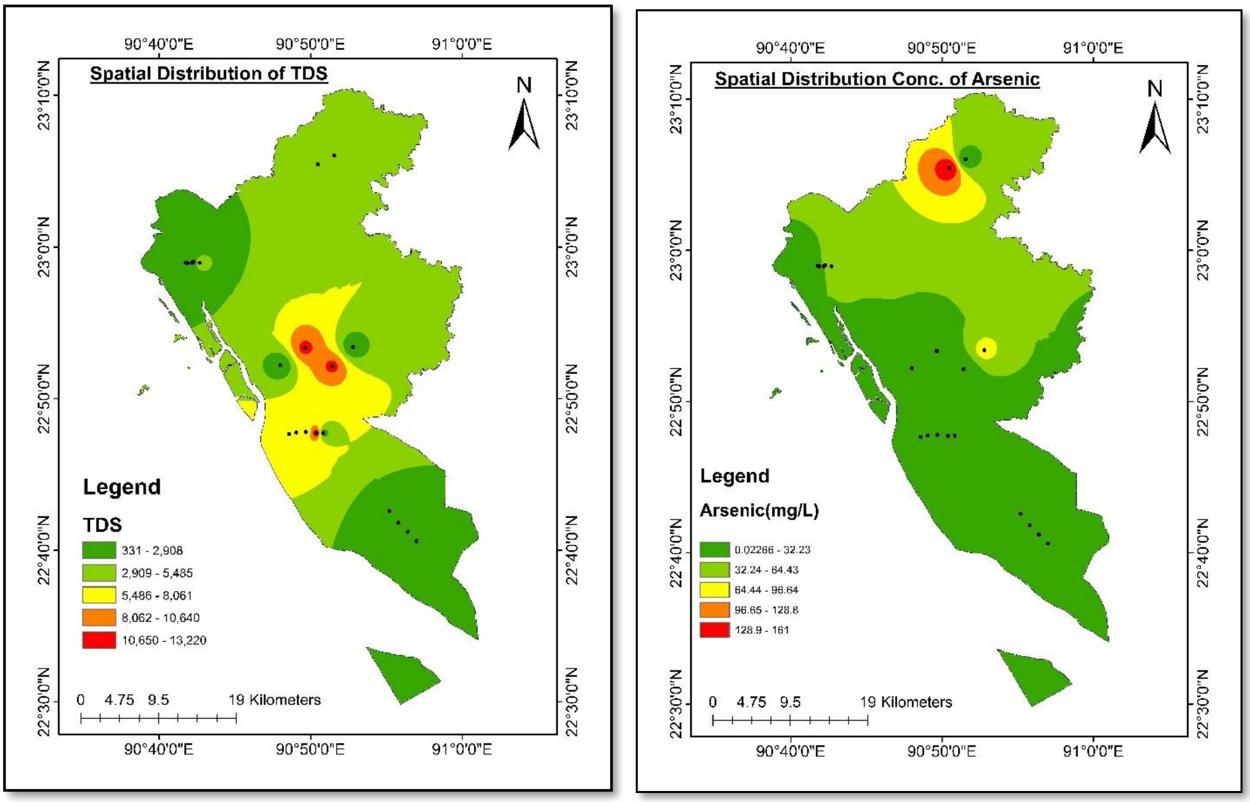
$$KR = \frac{Na^{2+}}{Ca^{2+} + Mg^{2+}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (viii)$$

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots... (ix)$$

When applying a suitable membership function, fuzzification is a crucial step to convert the crisp input into a standard input between "zero to one" (Aouragh et al., 2017). The fuzzy process was conducted using "Membership Fuzzy" and "Fuzzy Overlay" tools in ArcGIS 10.8. The "Linear" MF was used to fuzzify all water quality parameters. Every raster that has been fuzzified was superimposed using fuzzy overlay techniques. Fuzzy AND, fuzzy OR, fuzzy SUM, fuzzy PRODUCT, and fuzzy GAMMA are the five fuzzy overlay choices that are accessible in ArcGIS. For any of the input criteria, this is helpful in determining the highest membership values (Tiwari et al., 2023) and a fuzzy overlay operation is used to identify the strictly suitable water quality zones in the study area.

Results and Discussion

A total of 26 physical and chemical parameters were used for groundwater quality assessment, including 7 physical parameters and 19 chemical parameters. Several parameters, including arsenic, iron, potassium, turbidity, and TDS exceeded safe limits in most samples. Arsenic exceeded standards in 16 samples (Figure 2). Potassium surpassed limits in all 20 samples. Parameters like salinity, sodium, and chloride exceeded limits in multiple cases, indicating contamination. The piper diagram reveals water is Ca^{2+}–Mg^{2+}–Cl^{-}/SO_4^{2-} type that indicates saline intrusion and anthropogenic inputs influence the water quality.



a) (b)

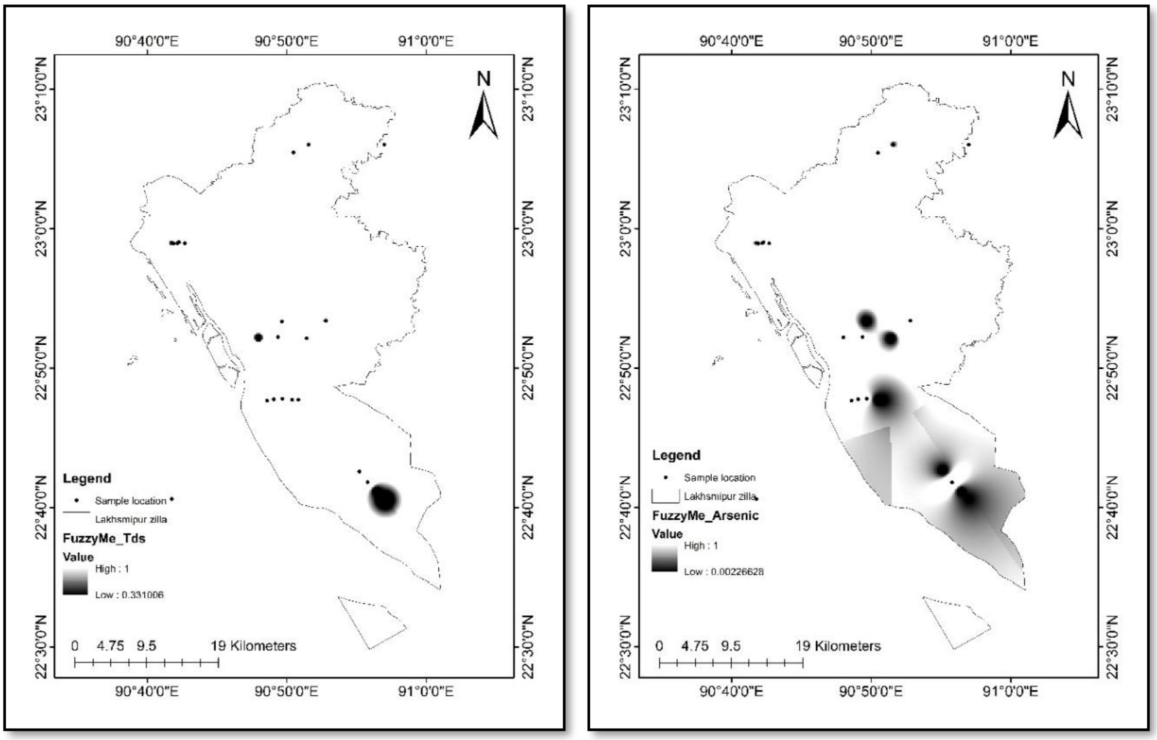
Figure 2, Spatial distribution map of (a) TDS (mg/L) and (b) Arsenic (mg/L).

Water Quality Index (WQI) values in the Lakshmipur district range from 63.51 to 1922.51, showing wide spatial variation. Most samples fall into the “unsuitable” category, highlighting severe groundwater contamination, except for a few samples that fall into good quality. Six indices were used to evaluate the quality of irrigation water. Except for few samples designated as inappropriate based on Na%, RSC, MH, and KR, many samples fall into the "permissible to good" category except SAR values of few samples are low quality.

As stated in the methodology section, the coefficient of correlation approach was used to determine the optimal fuzzy overlay technique for creating the Fuzzy-GIS based Groundwater Quality Index (FGWQI) map. The most successful technique for this was the Fuzzy-AND overlay method. Each parameter's spatial distribution map was converted into a fuzzy linear membership map based on DoE standards (Figure 3). The map (Figure 4) uses a fuzzy overlay analysis, a GIS-based technique for integrating multiple water quality parameters to assess overall quality levels.

Conclusion

Some groundwater samples exceeded permissible limits (according to WHO and DoE) for parameters such as arsenic, TDS, salinity, and certain heavy metals, making them unsuitable for drinking without treatment. The results of Water Quality Index (WQI) and fuzzy-overlay map indicate that a significant portion of the groundwater in Lakshmipur district falls unsuitable for drinking purposes. The irrigation water quality indices, including Na%, SAR, RSC, MH, KR, and PI, show varying suitability across the district. While some areas are excellent for irrigation, others are unsuitable. The findings highlight the urgent need for continuous monitoring, appropriate treatment, and sustainable groundwater management practices to ensure safe water for drinking and irrigation.



(a) *(b)*

Figure 3, Fuzzy linear membership map of (a) TDS (mg/L) and (b) Arsenic (mg/L).

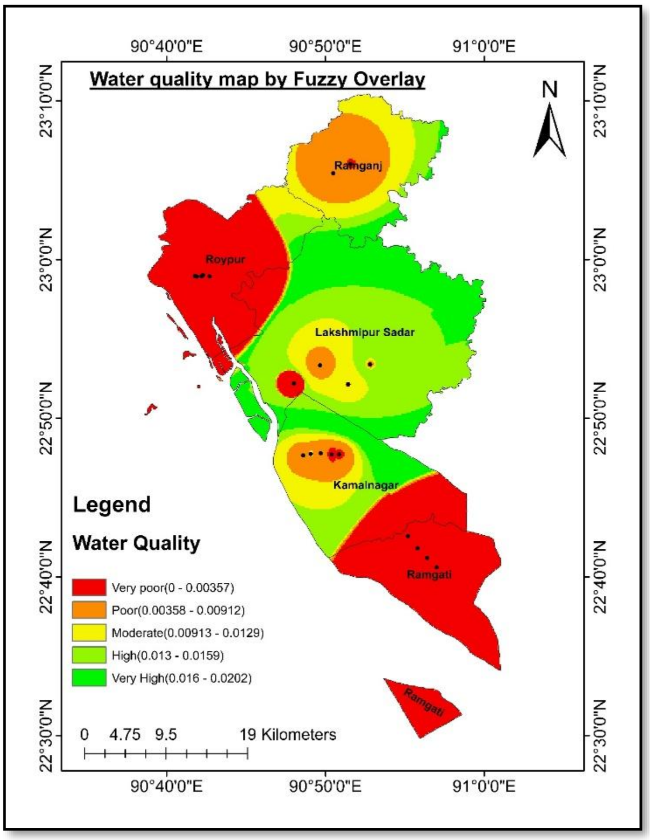


Figure 4, Groundwater Quality Index map.

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