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Analysis of Groundwater Quality in Dhaka Division

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Abstract

Preserving groundwater quality is the key challenge for Bangladesh in recent times. The primary reason that may be identified for significant deterioration in groundwater quality parameters is the rapid change in climate and temporal variability of water supply sources. Soil characteristics are also responsible for groundwater quality transition of the particular area. Thus, a thorough understanding of numerous hydrochemical processes is required to conserve groundwater quality. This study aims to investigate the trends of groundwater quality change on a broader scale to gain a better understanding of district groundwater quality variation over time. This study correlates the 15 quality parameters of every individual location (18 stations) across the Dhaka division over a 35-year time cycle. Mann-Kendal test, Modified Mann-Kendal, and Sens Slope have been conducted to detect the diversity of the trend and the slope of the trend line. Piper Diagram was used to identify the individual hydrochemical characteristics of every station. Besides, the spatial-temporal variation of 15 groundwater quality is determined by mapping using GIS. The results indicated a significant decreasing trend in pH, Iron, sodium & magnesium of all the stations. However, the other parameters show an increasing trend which is a great concern to maintain the groundwater quality. On the other hand, the correlation matrix provides a strong correlation between Na^+ & Cl^-, $Mg^{+2,}$ and SO_4^{-2} which causes salinity and total hardness in most of the stations. Piper Diagram also illustrates that Madaripur Sadar groundwater has severe salinity problems. The findings of this study help researchers understand the current situation of groundwater quality and help them to take the necessary measures to preserve it.

Keywords: Modified Mann-Kendal Test, Sen's Slope, Correlation Matrix, Piper Diagram, GIS Mapping.

1. INTRODUCTION

The study of groundwater management is important because it provides a reliable source of fresh water, even in locations with plentiful surface water (Visser, 2009). Groundwater is one of the most important sources of fresh water in Bangladesh, mostly meeting the needs of freshwater demands for irrigation, drinking, manufacturing, agriculture, municipal water supply, and other domestic uses. There are around 0.18 crore shallow and deep tubewells across the country to meet the water demand of 12.4 crore people (Hossain et al., 2013). Dhaka Water Supply and Sewerage Authority (DWASA) responsible for the city dwellers of the Dhaka City area, drew 1.6 Mm^3 of groundwater per day in 2008 from 500 wells that were drilled both in the lower and upper Dupi Tila aquifers (Saha & Rahman, 2020). As a result, the water level in Dhaka City is declining at a rate of 3 m per year (Hoque et al., 2007). The groundwater quality in the central part of Bangladesh is deteriorating due to several variables including, inadequate water body management, changes in river direction, human activities, and climatic variability (Shamsudduha et al., 2009). In addition, the degradation of land can have an immediate effect on soil deterioration, diminishing ecosystem function and disrupting hydrological, geochemical, and biological cycles (Narany et al., 2017). The physical characteristics of soil are also impacted by water quality. Toxic or non-toxic groundwater is defined by the types and concentrations of ions it contains. Chlorine, boron, and salt are the typical toxic elements found in groundwater (Ayers et al., 1985). Extensive groundwater exploitation, dumping of municipal and industrial waste, and seepage of contaminated water coming from the surface entering aquifers that are not very deep are also contributors to the degradation of groundwater quality. Population growth, rapid industrialization, and increased use of fertilizers and pesticides in agriculture are making the problem of groundwater quality more pressing by the day (Shahidullah et al., 2000). The chemistry of water is highly reactive, and it is greatly influenced by the interaction of substances. Sulfate is mostly derived through the breakdown of gypsum and from human activity. Saline intrusions, evaporation, and the presence of silicate minerals are the primary factors that determine the salt level of groundwater. However, silicate weathering of hard rocks is the primary source of Na and K (Sajil Kumar, 2013). Calcium carbonate, which is present in rocks like dolomite and limestone, leaching from the soil, is the most prevalent mineral element that generates alkalinity. The excessive alkalinity of the water makes it taste harsh (Anwar & Vanita, 2014). NO_3 in groundwater is attributed to residential waste, organic matter, and agricultural fertilizers. Besides, groundwater's chemical composition shifts depending on the local lithology and the water's regional circulation (Jeon et al., 2020). Repeated farming and over-pumping can lead to increased mineral content in groundwater (Agoubi et al., 2013).

More than 50% of the global population today depends on groundwater for their survival, and it is estimated that 33% of the global population drinks water that comes from the ground (Moharir et al., 2022). Hence, assessing and monitoring groundwater water quality has assumed greater significance in recent years. Understanding the complex hydrochemical processes happening underneath calls for a thorough analysis of the hydrochemical facies to evaluate the water quality. The hydrochemical facies is a term used to denote the diagnostic chemical aspect of ground-water solutions occurring in hydrologic systems and reflect the response of chemical processes operating within the lithologic framework. This method is more effective to provide diagnostic information about the chemical formation of water, including its origin. The primary aims of the research are (1) to analyse the trend in groundwater quality parameters, (2) to determine the correlation of the parameters at different locations, and (3) to assist in pinpointing the origins of water's dissolved salts. The groundwater quality data for 15 parameters were collected from Bangladesh Water Development Board (BWDB) for 18 locations in the central region of Bangladesh, including Dhaka city, Gazipur, and the Gopalganj area. Modified Mann-Kendal, Mann-Kendal, and Sen's Slope tests were used for trend analysis. The Piper Diagram represents groundwater chemistry, the Pearson Test was used to identify the correlation and QGIS maps displayed spatial variation of the water quality parameters.

2. METHODOLOGY

This non-parametric test is commonly used to determine linear and non-linear time series patterns in hydrological and meteorological data sets. The test is applicable for non-normal distributions. The MK test value for the data S statistics is calculated as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\ (x_j - x_i) \quad (1)$$

Where, x_j and x_i address respectively data in the j and i years, individually, and n addresses the time length of the statistical period. In the next equation, a pair of estimation values were correlated through subtractions with growing values = +1, declining values = -1, no change = 0, and are written as:

$$sgn\ (x_j - x_i) = \begin{cases} +1, if\ (x_j - x_i) > 0 \\ 0,\ if\ (x_j - x_i) = 0 \\ -1,\ if\ (x_j - x_i) < 0 \end{cases} \quad (2)$$

Variance denotes the variance of S with a zero mean for n ≥ 8. The statistic S may be stated using the mean (E) and the variance (V), as follows:

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \quad (3)$$

The standard normal test statistic Z for the normal distribution at the 95 percent and 99 percent confidence interval levels is calculated for the data point as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(s)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{Var(s)}} & S < 0 \end{cases} \quad (4)$$

The slope of Sen is determined as follows:

$$Q = \frac{x_j - x_i}{j - i} \quad (5)$$

Where, x_j and x_i are values at periods j and i respectively. The median of Sen's slope is calculated by sorting the total N values of Q from least to largest:

$$Q_{med} = \{Q_{(N+1)/2}, If\ N\ is\ odd \quad (6)$$

$$Q_{med} = \{\frac{Q_{\left(\frac{N}{2}\right)} + Q_{\left(N+\frac{2}{2}\right)}}{2}, If\ N\ is\ even \quad (7)$$

Pearson's correlation coefficient is calculated by dividing the covariance of the two variables by the product of their standard deviations. The correlation factor is detonated by r and there is a range for this r value that can determine whether the relation between two continuous variables is strong or weak.

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}} \quad (8)$$

r = correlation coefficient, $x_i = values\ of\ the\ x - variable$ in a sample, $\bar{x}$= mean of the values of the x-variables, $y_i = values\ of\ the\ y - variable$ in a sample, $\bar{y}$= mean of the values of the y-variables.

3. RESULTS & DISCUSSIONS

From Modified Mann-Kendal test analysis (Figure 1), it was observed that for total dissolved solids (TDS), most of the stations are in positive trends except Faridpur Sadar, Gopalganj (Kashiani), Munshiganj Sreenagar, Narsingdi Sadar and Mirzapur. The reason behind this may be identified as that geology is important in the dynamics of groundwater levels in the research region. Furthermore, groundwater levels have a substantial impact on groundwater quality. Sen's Slope (Figure 2) test was used in this work to determine the sloping character (positive/negative) of trends. A positive slope indicates that over time concentration increase, and a negative trend indicate over time concentration decrease. Slope zero means no change occurs over time.

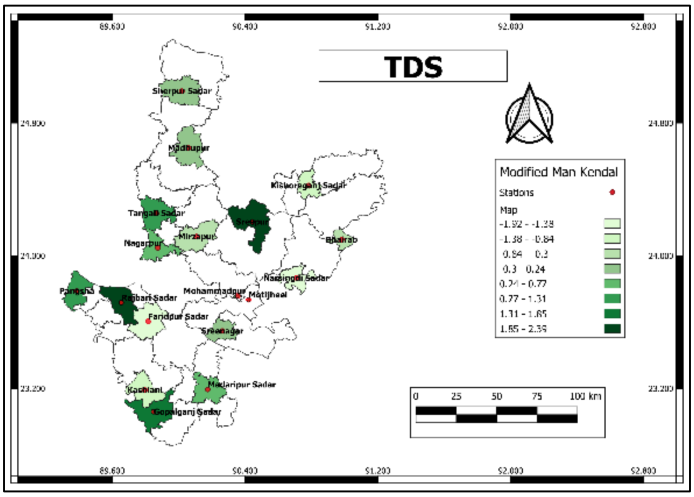

Figure 1. Modified Mann-Kendal slopes of TDS in GIS mapping.

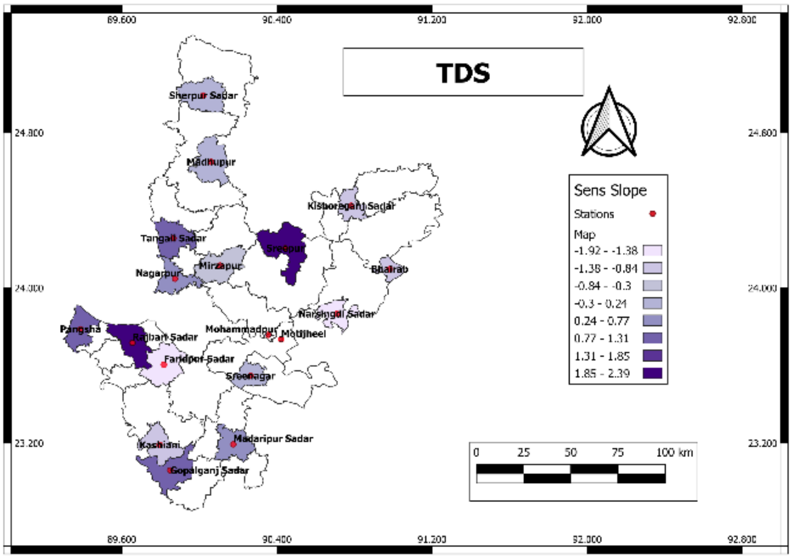

Figure 2. Sen's Slope of TDS in GIS mapping.

For TDS significant negative trend occur at Faridpur Sadar station and a positive trend at Rajbari Sadar. For Calcium, the highest decreasing trend occurs at Gopalganj Kashiani station and the positive trend is observed in Tangail, where textile mills are located. For sodium, the trend has fallen drastically at Bhairab station and increased at Tangail. Similarly, in Tangail Sadar, potassium, nitrate, and silica have shown the highest positive trend which is significant. On the other hand, chloride and sulfate have shown unusual increments of trend in Tangail. Besides, Rajbari Sadar has found a highly increasing trend in carbonate and carbon dioxide. This could be the worst-case scenario if the trend is increasing at this rate.

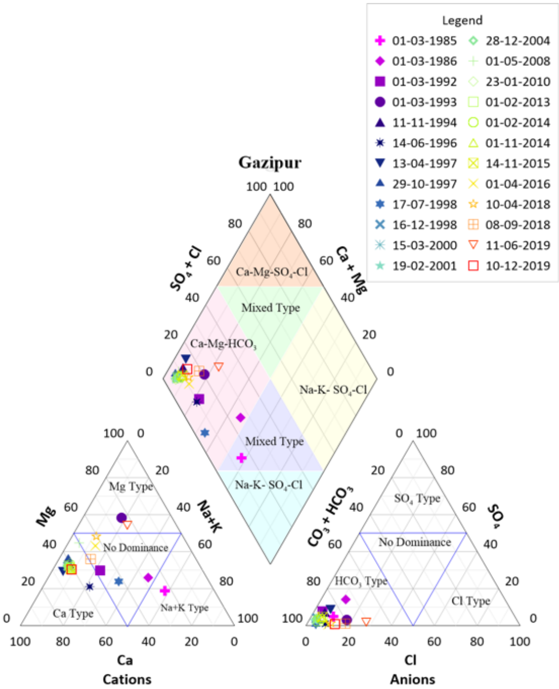

Figure 3. Piper Diagram of the water quality parameters.

From the Piper Diagram (Figure 3), it is detected that the majority of the groundwater samples of every station except Madaripur and Tangail Mirzapur were centered in the diamond's left corner, indicating that the groundwaters in the examined region were predominantly rich in Ca^{2+}, Mg^{2+}, and HCO_3^-. In Madaripur Sadar, Na^+, K^+ and Cl^- have the most influence in the middle of the periodic timeline. It identifies that the Madaripur Sadar had slightly salt constituents in water composition earlier but now it is in mixed type condition. All other 17 stations have alkali-type water which distinguishes that the hardness is present in the samples. In this study, it is observed that the most dominating anion is HCO_3^- in every station. The water contains HCO_3^- equivalent fractions among total anions of up to 0.99 from a lower value of 0.80 on average for every individual station. In Munshiganj and Madaripur Sadar, the anion becomes changed from HCO_3^- to Cl^- and in the case of Tangail Sadar, the water quality becomes changed to no dominance zone from high alkali HCO_3^-. On the other hand, Tangail (Mirzapur) contains opposite hydrochemical facies like it becomes HCO_3^- from no dominance zone. From the result, it is noticed that the Madaripur Sadar has the highest domination of Cl^- anions which are almost 80 percent of total dissolved anions.

In terms of cations, there are numerous changes in groundwater quality along with time series. Faridpur Sadar, Tangail Sadar, Rajbari Sadar, Gopalganj Sadar, Kishoregonj Sadar have the same transition of chemical composition in groundwater samples. Initially, the samples were in no dominance zone but with time, it becomes calcium type cations with a range of 60-80%. The other five samples which are collected from Motijheel, Sherpur Sadar, Tangail (Madhupur), Textile Mill Tangail, and Rajbari (Pangsha) have determined the same kind of transformation in hydrochemical facies. The chemical compositions have changed between Ca^+, $Mg^{+,}$ and no dominance zone. The rest of the samples are in different dominant zone according to periodic changes over time. The highest Mg^+ in mequ/L is observed in Motijheel which is above 80% of total cations and the highest Ca^+ is observed in Rajbari (Pangsha) (90%).

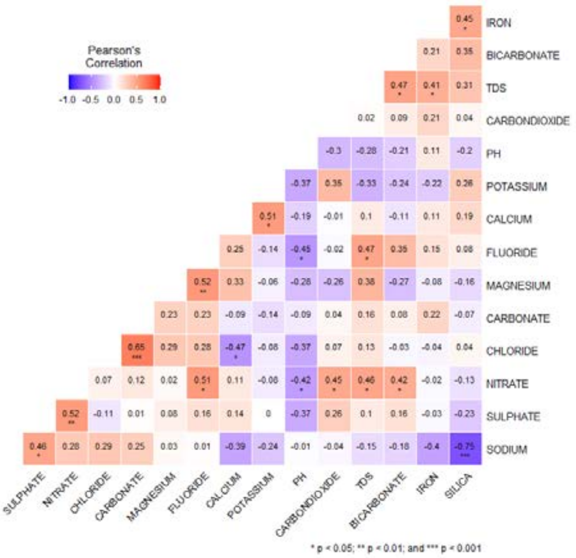

Figure 4. Pearson's correlation matrix

In addition, it is seen that all the water samples are influenced by Ca^+ cation in recent times except Madaripur Sadar and Sherpur Sadar. For Madaripur Sadar the water constituents become Na^+ and K^+ (90%) types of cations and for Sherpur, the samples came to fall in no dominance zone. Water hardness is largely induced by the presence of cations such as calcium and magnesium, as well as anions such as carbonate, bicarbonate, chloride, and sulfate in the water. The correlation between the ions have shown on Pearson's test (Figure 4)

4. CONCLUSION

Integrated methods of various multivariate statistics and hydro statistical methods are used in this work to analyse the differences in groundwater quality in the central region of Bangladesh. From the results, it is seen that in some stations the trend values have changed drastically according to time which is not totally in an acceptable range. The Mann-Kendal test and Modified Mann-Kendall test have illustrated those cases significantly. On the other hand, the Piper Diagram also demonstrates that the multiple stations have hardness in the samples which is a great concern. Pearson's correlation also defines the same result on some stations. The Mg^{+2} and SO_4^{-2} have a strong correlation that confirms the analysis results. However, in the Dhaka division, interactions with the alluvial flood plain, the breakdown of carbonates or sulfates, and the ion exchange between water molecules and clay particles are the main causes of the groundwater's quality. One of the research's drawbacks is that the data are not sufficiently consistent, and another is that more data would be required for the study region if the study were to be expanded to a broader scale. In order to define adaptive measures, researchers and policymakers can use the generated geographical distribution maps, which offer a useful and reliable visual tool. In addition, the research also gives information on prospective sources, providing baseline data on physicochemical characteristics, hazardous metals, potential sources, and spatial variation of groundwater systems in 18 distinct Bangladeshi locales.

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