Heliyon 10 (2024) e24011

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Hydro-chemical characteristics and groundwater quality evaluation in south-western region of Bangladesh: A GIS-based approach and multivariate analyses

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ARTICLE INFO

Keywords:
Water quality index
Geographical information system
Spatial distribution
Multivariate analyses

ABSTRACT

The study focuses on the chemistry of groundwater and if it is suitable for drinking and for use in agriculture using water quality indices, GIS mapping, and multivariate analyses in Sharsa Upazila, Jashore district, Bangladesh. In this study, the concentration of NH_4^+, K^+, Ca^{2+}, EC, Turbidity overstep BDWS drinking standards in 69 %, 14 %, 100 %, 40 % (WHO), 73 % of samples respectively. The value of Water Quality Indices (WQI) results inferred that the maximum specimen was held good quality for drinking uses, and the values distributed central eastern part to the south-eastern part were good quality water in the selected studied area. The study area's PH, EC, SAR, Na (%), TH, and NO^{3-} values were mapped using GIS tools to show their spatial distribution. The cluster and correlation matrix analyses are used to validate for Principle Component Analysis (PCA). The five PCA results exhibited that the presence of EC, turbidity, K^+, SO_4^{2-} and NO^{3-} was significant and was caused by both geogenic (rock weathering and cation exchange) and anthropogenic (agrochemicals, animal feedback) factor. According to the hydro-geochemical data, the maximum number of samples is of the Ca–Mg–HCO3–Cl type and is dominated by rocks. The irrigation water indices like MH, KR, SAR, and %Na indicate show high-quality groundwater for irrigation purposes. Most of the samples were satisfactory and compiled with WHO and Bangladeshi criteria for standard drinking water guideline values.

1. Introduction

The survival of life, ecological stability, and global economic advancement all depend on access to safe, sustainable water. In many countries worldwide, groundwater is chosen over surface water for irrigation and drinking because it is abundantly available, simple to obtain, and uncontaminated [1]. The evaluation of contaminants and the quality of groundwater has garnered significant global interest due to its direct connection to human well-being [2]. It is essential to assess the groundwater's (GW) quality to guarantee that it is suitable and to design sustainable management methods in order to meet the demands for drinking water and irrigation that exist now and in the future [3]. According to Ref. [4], groundwater is the largest source of fresh and drinkable water globally. However, countries like Bangladesh, with high population density, suffer from water scarcity and pollution, leading to uncertainty about water

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https://doi.org/10.1016/j.heliyon.2024.e24011
Received 11 July 2023; Received in revised form 19 September 2023; Accepted 2 January 2024
Available online 3 January 2024

quality, despite 97 % of the population having access to water [5]. Groundwater serves as the primary water source for over 95 % of rural and 70 % of urban residents, making it crucial to focus on its quality, availability, and sustainability, as it affects various human activities and health [6].

If groundwater is deemed suitable for drinking purposes in general, it can also be beneficial for irrigation and industrial uses [7]. The analysis and examination of water chemistry allow for a clear assessment of the sub-surface geologic conditions where the groundwater is found. As a result of the aquifer being recharged by meteoric water changing chemically, each groundwater system has a unique water chemical composition [8,9]. The question is asking about the factors that primarily determine the quality of irrigation water. The quality of irrigation water is determined by two main factors: the water composition and the concentration of dissolved solids and salts. These factors play a crucial role in determining whether the water is suitable for irrigation purposes [10]. Geochemical processes are influenced by topographical elements, flow pathways, recharge, lithology, and rock weathering brought on by the dissolution of minerals, ion exchange, and evaporation, ultimately determining groundwater quality [11]. In the southwest of Bangladesh, excess groundwater use has depleted the water table and human actions are lowering the quality of the GW [12]. Rapid industrialization and urbanization growth contribute to groundwater degradation [13].

According to previous research [14], water quality is determined by its inherent natural, physical, and chemical characteristics. For studying water quality, several researchers have tried to construct numerous groundwater quality indices (GWQIs); the selection of GWQIs is influenced by the factors associated with groundwater sources and the obtained results from analysis and assessment. Using a Geographic information system to distribute data from water sample results spatially can assist in determining water quality and preserving and managing groundwater resources [15]. Efficient and modern computer-based technologies for managing water have developed and Geographic Information System (GIS) are now very important. In order to manage water resources on a regional basis, comprehend the natural environment, avoid flooding, determine water convenience, and assess water quality, GIS may be an important tool [13]. To map the quality of groundwater, researchers employed several interpolations using GIS. For instance, the geographical distribution of physicochemical characteristics was extensively studied using the Inverse Distance Weighted (IDW) interpolation. IDW is an algorithm for estimating measurement values or spatially interpolating data. Weights are computed in the opposite direction from the observation location to the predicted point site [16]. Kriging is another types of interpolation method [17].

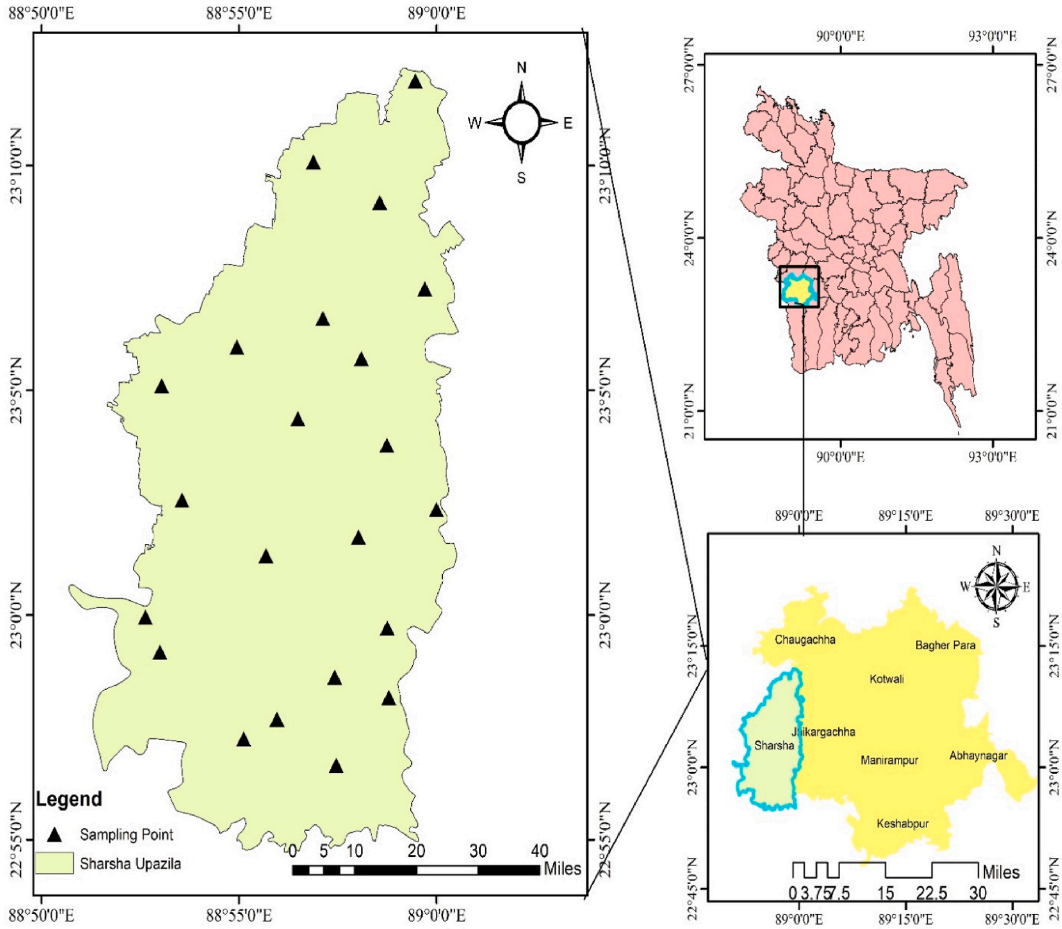

Fig. 1. Map of the sampling area is (a) Sharsha Upazila, which is under (b) Jashore District, and Jashore is one of districts of (c) Bangladesh.

They also added that Kriging provides several interpolation approaches: simple, ordinary, universal, indicator, and probability. Recently, some studies have employed conventional kriging as an analytical method for the geographical spatial variation of groundwater quality indicators [17]. The study was conducted in Sharsha upazila in the southwest part of Bangladesh located in Jashore district. In this targeted area, groundwater is used for a variety of functions such as drinking, cooking, household use and irrigation. Besides using the water for irrigation purposes, it is extensively used as potable water. Against this background, the research study's goals are to (i) analyze the hydro-chemical properties of GW and (ii) determine if GW is suitable for drinking and irrigation.

2. Materials and methods

2.1. Study area

The experiment is set up in Sharsha Upazila, Jashore, Bangladesh. Between latitudes 88°51' and 89°01' east and longitudes 22°55' and 23°12' north, it is located (Fig. 1). Pleistocene-Modhupur clay is the dominant geological feature in this region where Holocene-aged fluvial-deltaic sediment thicknesses form the primary aquifer system [1]. They also mentioned that the research area's hydro-geological condition may be divided into three layers. The three lithological indices are the topsoil, clay (or silty clay), silt, and sand. Additionally, the lithological distribution is shown as clay-fine sand-medium sand-porous medium sand. The annual rainfall was 1537 mL (60.5 inches), while the average annual temperature varied from 15.4 to 34.6 °C (59.7–94.3 °F) [18]. The main body of water in this Upazila, which has a population of 309 633 and a total area of 336.34 km^2, is the Betna River. This Upazila is made up of eleven unions. The study area's main source of revenue is agriculture (66.32 %). Tubewells account for 92.82 % of the region's drinking water sources, followed by tap water (0.93 %), pond water (0.68 %), and other sources (5.57 %), according to Banglapedia (2014).

2.2. Collection, preparation, analytical procedure of samples

This experiment collected 22 ground water samples from various tube wells in Sharsa Upazila, located in Jashore district, Bangladesh, from March to April 2022. The tube wells in the area had different installation dates, ranging from 15 to 25 years, with depths varying from 100 ft to 220 ft. and an average depth of 154.8 ft (45.72 m) as reported by the well owners. The sample collection vials were cleaned with a 1:1 HNO_3 solution and three times washed with distilled water prior to sample collection. 500 mL polystyrene bottles were used to collect samples of the GW. The tube wells were pumped for fifteen to 20 min prior to sampling, and water samples were taken in bottles that had already been cleaned for both in-house analysis and laboratory analysis. One container received conc. HNO3 (69 %, Merck, Germany) treatment for examining anions and other components, whereas the other remained untreated. The samples were thoroughly packed into containers, sealed, and maintained in a refrigerator at 4 °C until a further chemical analysis could be carried out to prevent oxidation. Approved grade standards and established drinking water analysis techniques were employed for sample analysis (Table 1) (see Table 2).

Field pH, EC, and TDS measurements were made with calibrated portable instruments. The pH meter's calibration was examined before it was put to use using buffer solutions with pH values of 4.0, 7.0, and 10.0. The electrode meter was calibrated for EC using reference solutions containing 1413 μS/cm EC, and the calibration was then confirmed after three readings. All results were reported as mg/L unit without EC, this will give in μs/cm. All studies employed deionized ultrapure water, and every piece of glassware and lab equipment was cleaned before use with 20 % HNO_3 acid and double-distilled water. Duplicate analyses, including blank, were performed for each sample to ensure quality control. For spatial distribution, we used ArcGIS (V 10.5). Data were analyzed using Microsoft Excel (V 2019), Statistical Package for Social Science SPSS (V 20), Golden Graper Software (V 21.2.338) and R Programming language (V 4.2.2).

Table 1
The name of the parameters, unit, methods, and references for the analyses of samples.

Parameters Name	Methods	References/Instruments
pH	Electrode	[19]
Turbidity	USEPA Method 180.1	USEPA Method 180.1
EC	Electrode	Hanna HI 98312 DiST
TDS	Electrode	Conductivity meter (Hach Sension- 156; multi-parameter, USA)
DO	Electrode	DO-5509, DO meter
K^+	Flame Photometer	JENWAY; Model PEP7/C
Na^+	Flame Photometer	JENWAY; Model PEP7/C
Mg^+	ICP Mass Spectrometry	[19]
Ca^{2+}	ICP Mass Spectrometry	[19]
$NH4^+$	Spectrophotometric Analysis	HACH DR 3900 Spectrophotometer, USA. Range 0.02–2.50 mg/L
HCO_3^{2-}	Titrimetric Method	[20]
CO_3^-	Titrimetric Method	[20]
Cl^-	Titrimetric Method	[20]
SO_4^{2-}	UV–visible spectrophotometer	[19]
PO_4^{3-}	UV–visible spectrophotometer	[19]
$NO3^-$	Powder Pillow Procedure	HACH DR 3900 Spectrophotometer, USA. Range: 0.02–3.00 mg/L

Table 2
WQI Value level, status and their grading [21].

WQI Value Level	Status of Water Quality	Grade
<50	Excellent	A
50–100	Good	B
101–200	Poor	C
201–300	Very poor	D
>300	Unsuitable for drinking	E

2.3. Statistical techniques

The statistical variables of the groundwater quality dataset, including maximum, minimum, mean, standard deviation, and variance, were analyzed using descriptive statistical techniques. In this study, the degree of relationship between two factors was examined using Correlation Matrix (CM) analysis. Principal component analysis (PCA) and cluster analysis (CA), two multivariate statistical techniques, were used in this work to analyze groundwater hydro-chemical data. The output of the multivariate statistical methods was analyzed using a scree plot and a dendrogram based on Ward's method. The results of the physicochemical investigation of the GW in the study area were evaluated using statistical techniques. All statistical analyses were done using the R programming language and SPSS software version 23.0. Nevertheless, different spatial interpolation methods, including the inverse distance weighted approach and others, were utilized to estimate and quantify the geographical variability of the groundwater dataset.

2.4. Geo statistical approach

For the geographical analysis, the Inverse Distance Weighted (IDW) approach was utilized, as it proved to be the most user-friendly and accurate method in comparison with other interpolation techniques, such as kriging [22]. The IDW technique is already integrated into the ArcGIS software, facilitating the creation of spatial distribution maps for the groundwater dataset (version 10.5).

2.5. Water quality analysis

The Weighted Arithmetic Water Quality Index (WAWQI) is used to determine suitability of drinking water for human consumption [1]. Using WQI in accordance with BDWS and WHO guideline, following equation was used by Ref. [23] to assess the characteristics of water.

$$\mathrm{WQI} = \sum \mathrm{SI_i} = \sum (\mathrm{W_i} \times \mathrm{qi}) = \sum \left(\left(\frac{\mathrm{wi}}{\sum_{i=1}^{n} \mathrm{wi}} \times \left(\frac{\mathrm{Ci}}{\mathrm{Si}} \times 100 \right) \right) \right) \tag{1}$$

where *qi, Ci, Sli* indicate the ground water scale of quality rating, concentration of each parameter, and sub-index of ith chemical parameters respectively.

2.6. Irrigation water indices

Equation (2) is used to compute Total Hardness (TH).

$$\mathrm{TH} = 2.497\ \mathrm{Ca}^{2+} + 4.115\ \mathrm{Mg}^{2+} \tag{2}$$

The Magnesium Hazard is determined using Equation (3).

$$\mathrm{MH} = \frac{Mg2+}{Ca2+ +Mg2+} \times 100 \tag{3}$$

The Kelley's ratio (KR) is calculated using Equation (4).

$$\mathrm{KR} = \frac{Na+}{Ca2+ +Mg2+} \tag{4}$$

By using Equation (5), SAR value is calculated

$$\mathrm{SAR} = \frac{Na+}{\sqrt{\frac{Ca2+ +Mg2+}{2}}} \tag{5}$$

Na% is determined by using the formula in Equation (6).

$$\mathrm{Na\%} = \frac{Na+}{Ca^2 + +Mg^2 + +Na^+ + K} \times 100 \tag{6}$$

By using equation (7) Permeability Index (PI) is calculated

$$PI = \frac{Na + \sqrt{HCO3}}{Ca + Mg + Na} \times 100 \quad (7)$$

[12].

An assessment was conducted to measure the sustainability of the collected water samples in the selected area by comparing its physio-chemical parameters against BDWS and WHO guidelines. This comparison helps to examine the compliance of the GW with established guidelines and regulations, thereby providing insights into its long-term viability and suitability for various purposes.

3. Results and discussion

3.1. Description of the parameter

Water samples were examined, and their physicochemical characteristics were contrasted with WHO and Bangladesh drinking water standards. From the research region, 22 samples in total were taken. This section included the outcomes of the laboratory examination of physicochemical variables to assure their suitability for drinking, irrigation, and other uses. These are explained in detail here according to parameters (Table 3).

By comparing the assessed physicochemical characteristics with the requirements established by national and international standards, the study evaluated the suitability of the water samples from the chosen location for drinking purposes. This comparison allowed for the appraisement of the groundwater characteristics and its compliance with the recommended guidelines for safe drinking water. In our study, pH values of the GW varied from 6.8 to 7.9, and its mean value is 7.29 ± 0.33, indicating a little alkaline nature. A similar study was done in Jashore region in Bangladesh and pH values of GW varied from 6.91 to 8.39 which partially agreed with current findings [24]. Electrical Conductivity (EC) is considered another important parameter in drinking water, as it indicates the levels of dissolved solids and ionic strength of the source water [14]. In Table 3, the EC value varied from 434.00 to 990.00 μS/cm, and the average value is 717.5909 ± 208.9811 μS/cm. Meanwhile, the minimum, maximum and average value of Total Dissolve Solids (TDS) in the study area is 210.00 mg/L, 611.00 mg/L and 363.5455 ± 125.3075 mg/L, respectively.

Given the classification of EC and TDS, it is reasonable to presume that the majority of GW samples belong to the freshwater group [25]. The concentrations of dissolved cations are Na^+, Mg^{2+}, K^+, Ca^{2+} ranged from 17.936 to 19.638, 2.35 to 72.65, 6.887 to 12.903, and 43.2–98.4 mg/L with the average values of 18.62164 ± 0.415805, 37.54464 ± 21.55846, 10.09264 ± 1.709392, and 79.31818 ± 13.89103 mg. L^{-1} respectively. The level of dissolved anions such as NO_3^-, HCO_3^-, Cl^-, CO_3^{2-}, and SO_4^{2-} varied from 0.1 to 1.5, 160 to 350, 56.72 to 545.93, 165 to 390 and 0.0712–1.649 mg/L with the mean concentrations of 0.609091 ± 0.36723, 268.6364 ± 160.2362, 0.241318 ± 0.23964, and 0.63055 ± 0.431085 mg/L, respectively (Table 3). The GW's physicochemical parameters were evaluated against the WHO and BDWS guidelines to determine their suitability for drinking. The pH range of the groundwater was slightly alkaline, with an average value falling within the acceptable range. The EC and TDS values were also within the freshwater category. However, the Ca2+, K^+, and NH_4^+ concentrations exceeded the recommended levels. Turbidity and DO values were within the acceptable range, indicating no major contamination. The levels of NO^{3-} and PO_4^{3-} were within acceptable ranges. At the same time, NH_4^+ exceeded the recommended threshold, possibly attributed to the degradation of natural organic matter or human-related sources like landfill leachate or agricultural practices. The greater variability in EC, Cl^-, and TDS, as indicated by the higher standard deviation, pointed to diversity in the hydrochemical composition of the groundwater.

Table 3
Descriptive statistics were performed on 22 collected groundwater samples from the study area, analyzing various parameters associated with them.

	Max	Min	Mean	SD	Standards		Exceeding (%) BDWS
					BDWS	WHO	
Turbidity	63.5	0.38	27.09	21.66274	5	5	73 %
DO	3.5	1.2	2.404545	0.666531	–	–	–
pH	7.9	6.8	7.290909	0.330813	6.5–8.5	6.5–8.5	–
EC (μS/cm)	990	434	717.5909	208.9811	2000	750	–
TDS (mg/L)	611	210	363.5455	125.3075	1000	500	–
Na (mg/L)	19.638	17.936	18.62164	0.415805	200	200	–
Mg (mg/L)	72.65	2.35	37.54464	21.55846	35	50	–
K (mg/L)	12.903	6.897	10.09264	1.709392	12	30	14 %
Ca (mg/L)	98.4	43.2	79.31818	13.89603	75	75	100 %
NH_4^+ (mg/L)	3.3	0.3	1.118182	0.811017	.5	–	68 %
NO_3^{-2} (mg/L)	1.5	0.1	0.609091	0.363723	10	45	–
HCO_3^- (mg/L)	350	160	268.6364	54.44923	100	100	–
Cl^- (mg/L)	545.93	56.72	279.2248	160.2362	600	200	–
PO_4^{-3} (mg/L)	0.956	0.008	0.241318	0.23964	6	–	–
CO_3^{-2} (mg/L)	390	165	250.0909	59.72868	–	–	–
SO_4^{-2} (mg/L)	1.649	0.0712	0.630555	0.431085	400	200	–

Table 4
Maximum minimum and average values for Irrigation water quality indices.

	MH	TH	KR	SAR	%Na	PI
Max	53.71534	516.6776	0.246736	3.05694	17.76654	39.34211
Min	3.061889	195.4471	0.112244	2.034366	9.523367	19.25117
Mean	30.24204	352.5537	0.166706	2.477418	13.13974	26.6363

MH = Magnesium Ratio.
TH = Total Hardness, KR = Kelly's Ratio, SAR= Sodium Adsorption Ratio, PI = Permeability Index.

3.2. Water quality index

The determination of water quality was conducted utilizing the Weighted Arithmetic Water Quality Index (WQI), which yielded values varying from 51.55 to 198.40, with an average of 101.6884, as shown in Fig. 2. Water with a number less than 50 is regarded to be of outstanding quality, while values between 50 and 100 indicate high-quality water. Values between 100 and 200 indicate worse water quality, while values above 200 indicate very poor-quality water that is unfit for consumption [21].

The water quality in this research region was good for drinking purposes, with the majority of water samples being high-quality 'B' grade water and 9 samples being low-quality 'C' grade water (Fig. 2).

In this study, Inverse Distance Weighted (IDW) is one type of interpolation method utilized to make spatial distribution maps of each GW parameter. Previous studies by researchers such as [26–28] investigated the geographical variation of GW quality in various places worldwide. The different colors represent the range of WQI results.

The spatial distribution maps of the WQI indicated favorable water quality values in the central-eastern to south-eastern parts, a small amount of central-western and northern parts was presented, and the poor-quality values exhibited in the western and less part was presented in the northeastern region also showed that less part of the western was very poor water quality of the study area (Fig. 3).

3.3. Irrigation indices

The suitability of irrigation water is affected by the presence of minerals in both water and soil. The quality of water also plays a crucial role in plant growth, and soil drainage is an important factor that connects water quality with plant growth. Table 5 presents the water quality indices, such as MH, TH, KR, EC, SAR, %Na, and PI, along with their classification. These indices can help farmers choose the right management practices to avoid potential salinity hazards [29].

In our studied samples the average KR and SAR values were less than 1. Without this, the other irrigation index like MH, TH, PI and % Na was 30.24, 352.55, 13.14 and 26.63 respectively Fig. 4. In case of MH, the values are classified into two categories, including class 1 (MH $<$ 50) are excellent and class 2 (MH $>$ 50) are unsuitable for irrigation uses. In the current investigation, the Magnesium Hazard (MH) values exhibited a range of 3.06–53.71, with an average value of 30.24. The maximum values corresponded to the class 1 category, indicating excellent water quality with no harmful effects on the soil when used for irrigation in the area (Table 5). Table 4 showed that Total Hardness (TH) values ranged from 195.44 to 516.67 ppm, with a mean value of 352.55 ppm of $CaCO_3$.

Kelley's ratio (KR) ranged from 0.112 to 0.246 mg/L, with a mean value of 0.166. When TH values $<$ 75, 75–100, 150–300, and $>$300, it indicates soft, moderately hard, hard, and very hard, as Table 5 shows that it indicates the research area is very hard TH values level for irrigation purposes. On the other hand, When the KR ratio is greater than 1, it signifies the presence of additional Na^+ in the samples. Conversely, KR values below 1 indicate that the water is suitable for irrigation. Since all the samples in this study had KR values less than 1, it suggests excellent irrigation water quality (Table 5). It indicates that for irrigation needs, the research area is

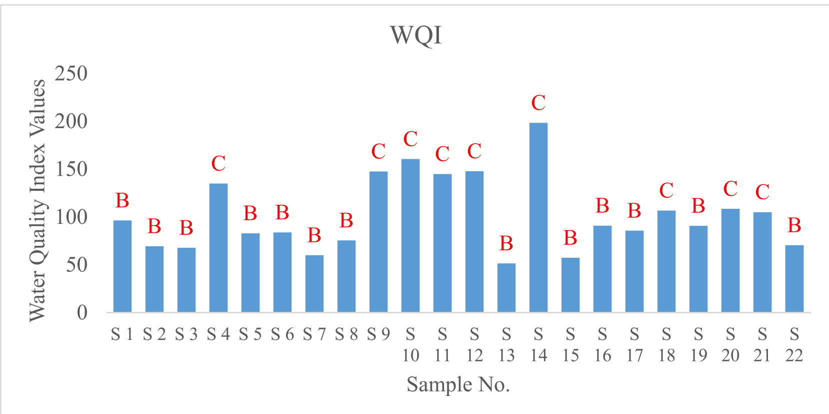

Fig. 2. Water Quality Index (WQI) value for 22 samples where symbol B indicates good water and C indicates poor water.

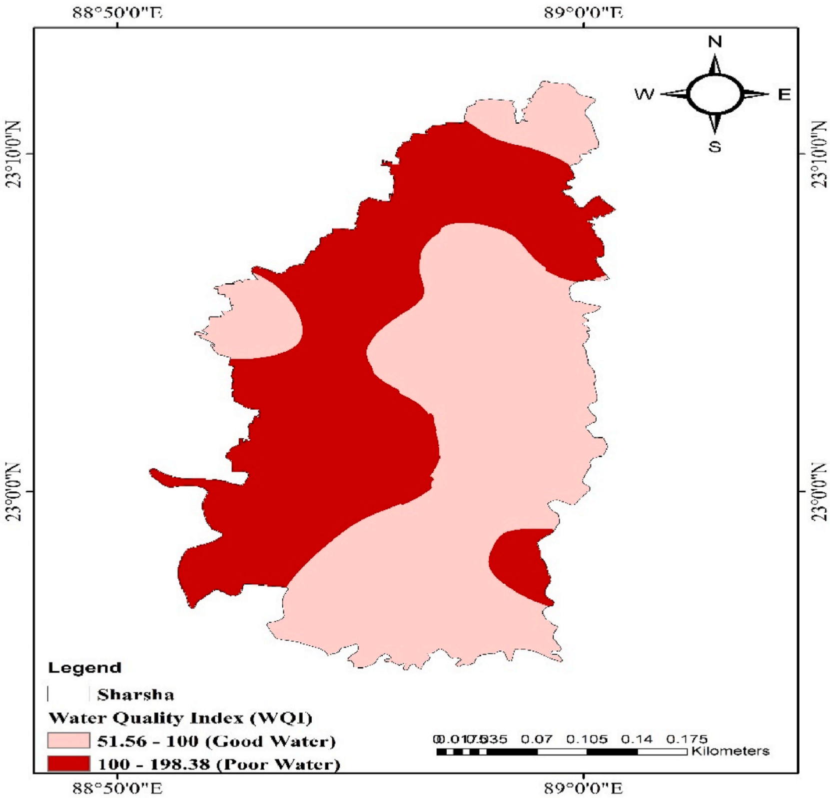

Fig. 3. The distribution of WQI of the GW samples within the targeted region is shown spatially.

Table 5
Ground water quality evaluation categories in the study area.

Index Method	Category	Water Class	Number of Samples	% of samples
EC (μS/cm)	<250	Excellent	0	0
	250–750	Good	13	59
	750–2000	Permissible	9	41
	2000–3000	Doubtful	0	0
	>3000	Unsuitable	0	0
WQI	<50	Excellent	0	0
	50–100	Good	13	59
	101–200	Poor	9	41
	201–300	Very poor	0	0
	>300	Unsuitable for drinking	0	0
TH (mg/L)	<75	Soft	0	0
	75–150	Moderately hard	0	0
	150–300	Hard	7	32
	>300	Very Hard	15	68
SAR	0–6	Good	22	100
	6–9	Doubtful	0	0
	>9	Unsuitable	0	0
KR	<1	Suitable	22	100
	>1	Unsuitable	0	0
Na%	<20	Excellent	22	100
	20–40	Good	0	0
	40–60	Permissible	0	0
	60–80	Doubtful	0	0
	>80	Unsuitable	0	0
PI	>75	Good	0	0
	25–75	Suitable	11	50
	<25	Unsuitable	11	50

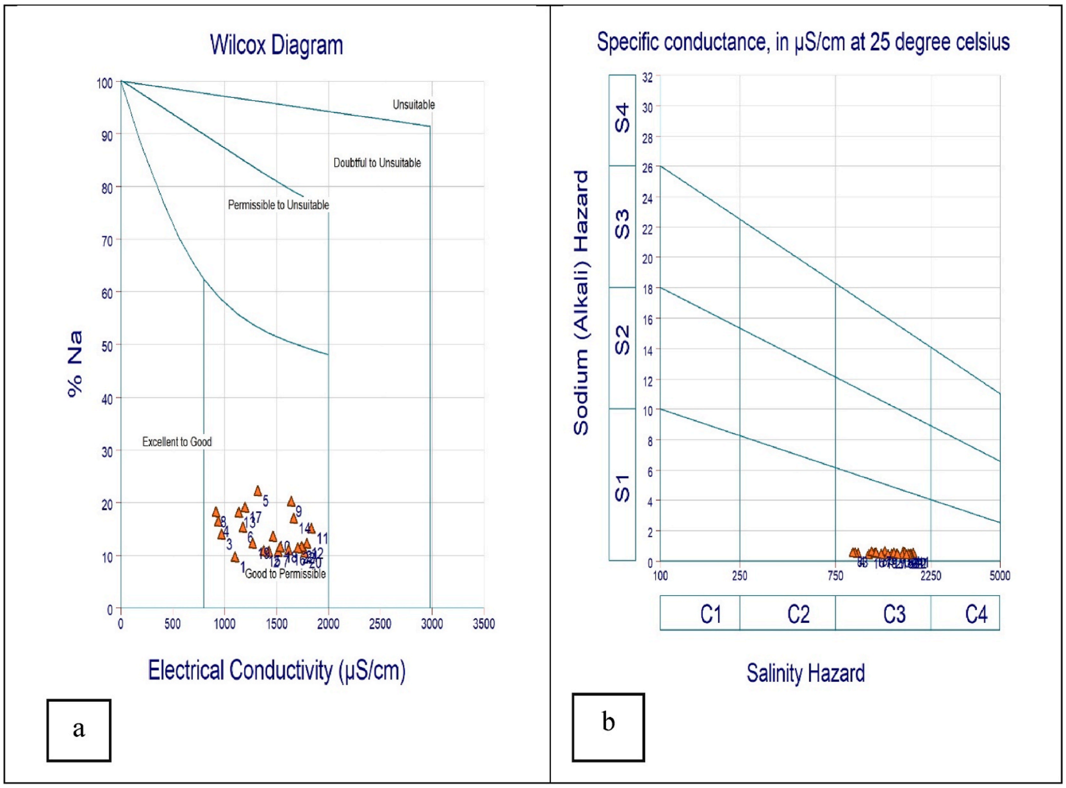

Fig. 4. (a) Wilcox diagram (b) United States Salinity Laboratory (USSL) diagram of the water samples.

suitable.

The sodium adsorption ratio (SAR) is a significant indicator used to assess the suitability of water for irrigation [30]. Generally, a higher SAR value suggests that the water is less suitable for irrigation. However, SAR is just one factor in determining the overall suitability of water for irrigation. In this study, the SAR values ranged from 2.034 to 3.056, with an average of 2.477, indicating good quality water for irrigation purposes. According to Table 5, SAR ratios between 0 and 6 indicate good irrigation water quality, ratios between 6 and 9 are questionable, and ratios above 9 are unsuitable for irrigation (Table 5).

The percentage of Na is categorized into 5 classes, including class 1 (Na< 20), which is excellent, class 2 (20–40) is good, class 3 (40–60) is permissible, class 4 (60–80) the range is undoubtful and class 5 (Na>80) is unsuitable for irrigation water quality indices (Table 5). According to a dataset or table, Na varied from 9.52 to 17.76, with an average value of 13.139.

According to the study's findings, all samples of groundwater in the study region were rated as class 1, which denotes excellent suitability for long-term irrigation needs. The World Health Organization [31] determines the suitability of water for irrigation using the permeability index (PI). Based on the [32], water is categorized into three classes based on the permeability index (PI) value (Table 5). Class I represents good quality irrigation water with a PI value greater than 75 % and low PI. Class II indicates intermediate-quality water with a 25–75 % PI value range that is suitable for irrigation. Class III denotes water with a PI value range of less than 25 %, which is considered completely unsuitable for irrigation.

The PI values in the study varied from 19.25 to 39.34, averaging 26.63 (Table 5). Based on the PI% values, the groundwater in the study area is classified into class II for 50 % of the samples and class III for the remaining 50 % of the samples. This classification suggests that half of the samples are suitable for irrigation purposes, while the other half is deemed unsuitable for irrigation.

3.3.1. Wilcox diagram

The water samples analyzed ranged in EC and TDS concentrations from 434 to 990.00 S/cm, with an average value of 717.5909 208.9811 s/cm and ranging from 210.00 to 611.00 mg/L with an average value of 363.5455 ± 125.3075 mg/L (Table 3).

The high levels of EC and TDS observed in the study area may have resulted from increased salinity, ion exchange, and prolonged water residence time. The safety of water with respect to residual sodium bicarbonate (RSBC) is categorized as safe, marginal, and unsatisfactory when RSBC is < 5, 5–10, and <10 meq/L, respectively [33]. On Wilcox's diagram, the Na^{+} % values were plotted [34], and the values ranged from 9.523 to 17.766 with an average of 13.139 indicating that the quality of the water is permissible to good (Fig. 4).

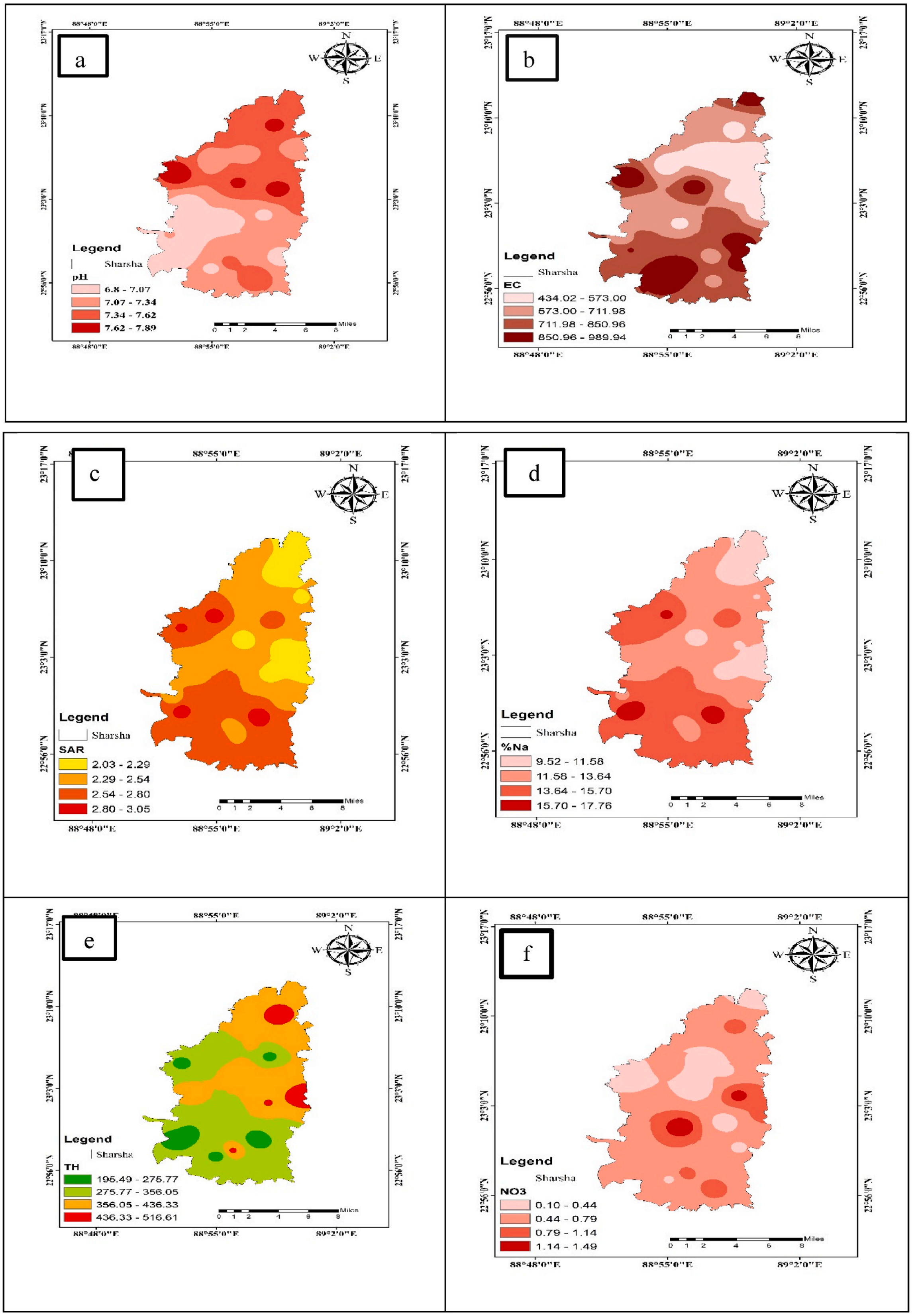

Fig. 5. Maps showing the spatial distribution of the specified areas' pH (a), EC (b), SAR (c), Na% (d), TH (e), and NO_3^- (f).

3.4. Spatial distribution maps for irrigation indices

The major portion of the groundwater in the research region is suitable for drinking and irrigation, according to the pH map (Fig. 5a), and the map reveals that the center and somewhat northern parts are more spread and have higher alkalinity.

However, for EC values, the south-eastern part shows a higher range of EC, followed by the central part, and the northern part shows a relatively lower distribution for EC prior to the southern and central parts due to increases in ion concentrations, such as significant changes found in Na^{+} and Cl^{-} in the studied area. The geographic map of SAR and Na (%) revealed that greater values were found in the southwestern and south-eastern parts of the research area, particularly in the southern region and the central western section (Fig. 5c and d). The higher TH values in the increasing trend from the central-eastern to the northern region of the study area (Fig. 5e) are most likely generated by the weathering of sedimentary rock and the leaching of lime from the soil surface to the GW aquifer on agricultural land.

The spatial distribution map (Fig. 5f) indicates a rise in NO_3^- concentration in the central and central-eastern parts of the study area. The extensive use of synthetic fertilizers to improve agricultural productivity is to blame for this rise and improper management of nitrogen sources in agriculture, which results in high leaching rates and nitrate accumulation in groundwater [35].

3.4. Hydro-geochemical facies and water type

Identifying the hydro-chemical facies is important in analyzing groundwater hydrochemistry. The trilinear Piper diagram is a commonly used technique for characterizing GW hydrochemistry based on cation and anion concentrations, first introduced by Piper [36].

Fig. 6 illustrates the significance of Mg^{2+}, Ca^{2+}, HCO_3^-, and Cl^- in characterizing the GW quality in the experimental site. These parameters play a crucial role in understanding the overall composition and characteristics of the GW. The findings of the water sample analysis indicate that the GW in the targeted region is characterized by dominant concentrations of Mg^{2+}, Ca^{2+}, HCO_3^-, and Cl^-. These elements are more prominent in the GW composition than Na^+, K^+, Ca^{2+}, and $SO_4{}^{2-}$. The existence of Mg^{2+}, Ca^{2+}, HCO_3^-, and Cl^- in

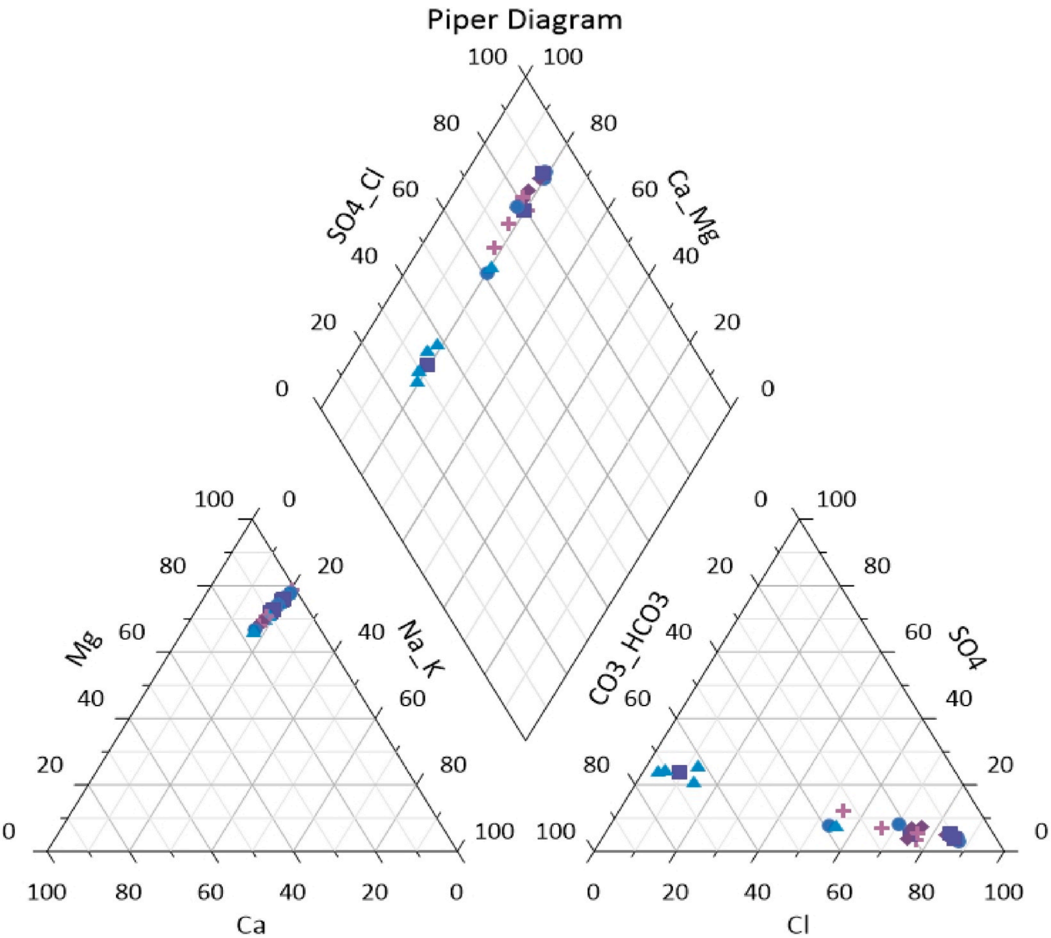

Fig. 6. Piper trilinear diagram represents the water type for the collected water samples.

the GW is primarily attributed to the base rock's and GW's interrelation. This interrelation between the base rock and GW is the main factor contributing to the variations in GW hydrochemistry observed across different hydrologic basins, as [37] suggested. Nonetheless, the existence of Mg^{2+}, Ca^{2+}, HCO_3^-, and Cl^- ions in the GW can be attributed to the dissolution of calcite, which originates from the Eocene-aged limestone present in the aquifer. This relationship between the GW's chemical facies and the dissolution process of calcite from the Eocene limestone formations was documented by Ref. [38].

In order to gain insights into the hydrogeo chemistry of GW and establish connections between its chemical constituents and their respective aquifers, a Gibbs plot is employed as a tool to examine the primary processes that govern GW chemistry. The Gibbs diagram, which Gibbs created by Ref. [39], shows the proportions of main anions and cations against total dissolved solids (TDS) values. The predominant portion of GW samples is located within the rock-dominance region (Fig. 7), indicating that the hydrochemical characteristics are primarily influenced by the dissolution of carbonate minerals within the aquifer [12]. The process of rock dissolution is a significant factor in comprehending the hydrochemistry of GW. To differentiate between the impacts of rainfall (precipitation), lithology (interactions between rock and water), and climate (evaporation) on the chemical composition of groundwater, the cation ratio and anion ratio were graphed against Total Dissolved Solids (TDS) in Gibbs diagrams [40]

3.5. Source identification

3.5.1. Pearson correlation matrix (PCM)

A study used a correlation matrix to identify the linear relationships between two sets of parameters. The findings from this analysis are illustrated in Fig. 8. A significant correlation was found among TDS-EC (0.9), TDS-HCO_3^- (0.5), EC-HCO_3^- (0.5), NH_4^-Turbidity (0.6), Cl^--NO_3^- (0.5) pair indicating their similar source of geogenic origin and mobility. Whereas pH-Turbidity (−0.7), K–HCO_3^- (−0.5), K–Ca (−0.5), Cl–HCO_3(−0.5), Cl-TDS (−0.5), Cl–Ca (−0.5), depicted negative correlation.

A moderate positive correlation exists between HCO_3^--$PO4^{3-}$ (0.4),Fe–Zn (0.34), and pH – Cu (0.33) pairs where as a moderate negative correlation was also found in the values of EC-Cu (−0.39), pH–As (−0.42) EC-Mn (−0.45) and TDS–Cu (−0.41) pairs which indicating if one parameter's value is increasing then other parameter will be decreased in Fig. 10.

3.5.2. Cluster analysis

The sampling points were compared and grouped using the hierarchical cluster analysis based on the measured parameters. The samples with similar characteristics were grouped together, indicating a common source of origin. The 22 sampling sites were divided into two clusters (Fig. 9). Cluster 1 included 9 sampling points, namely S2–S4, S7–S9, S13, S15, and S22. This could be explained by nonpoint sources and fertilizer leaching into the aquifer from the soil horizon. Cluster 2 contained thirteen samples, including S1, S5, S6, S10-12, and S16-21. Since Sarsha Upazila's primary income source is agriculture, this cluster reflects the influence of domestic and agricultural pollution and anthropogenic (mining, buring of fossile fuel) and geogenic activities such as rock weathering.

3.5.3. Principal component analysis (PCA)

A PCA was done on the GW samples obtained from 22 points in this investigation, which were analyzed for 16 physicochemical parameters. The aim was to identify the relationships between the different ions and trace metals present in the samples, and to

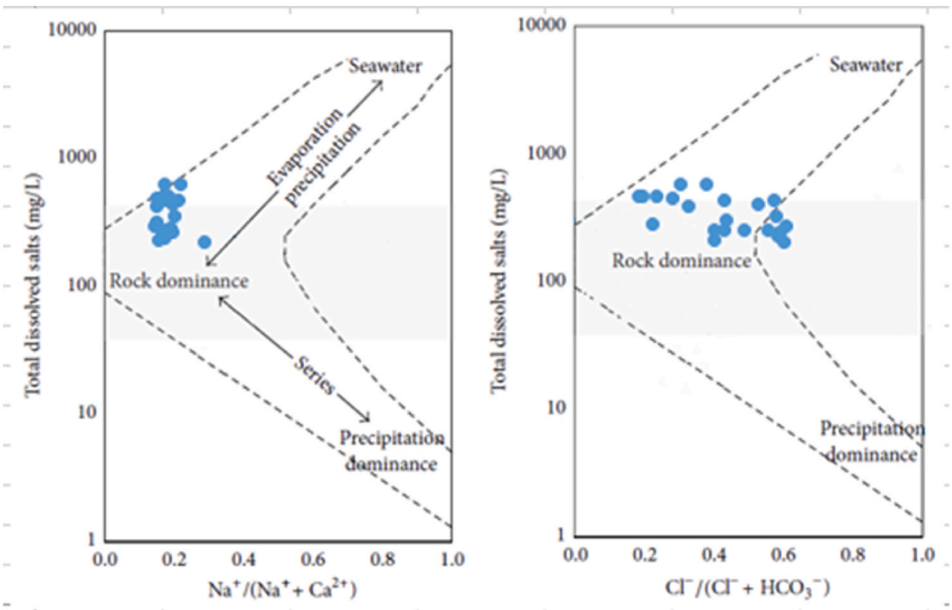

Fig. 7. Gibbs Diagram of the water samples.

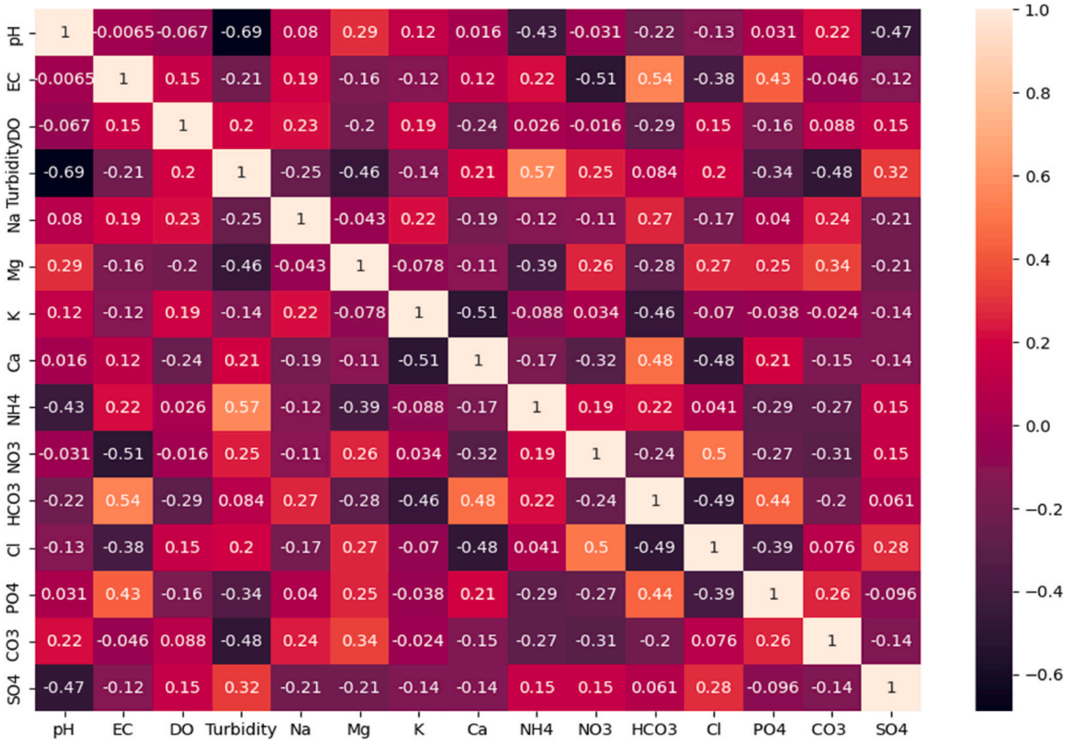

Fig. 8. Correlation matrix.

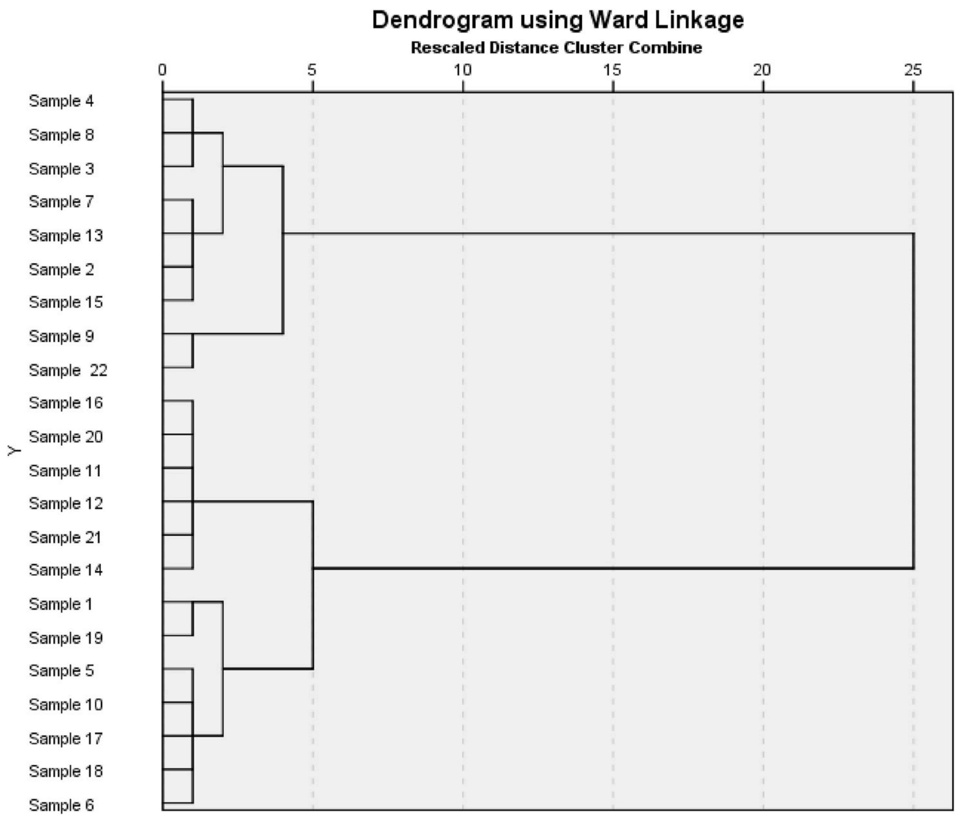

Fig. 9. Dendrogram displaying the investigated parameters' hierarchical groups.

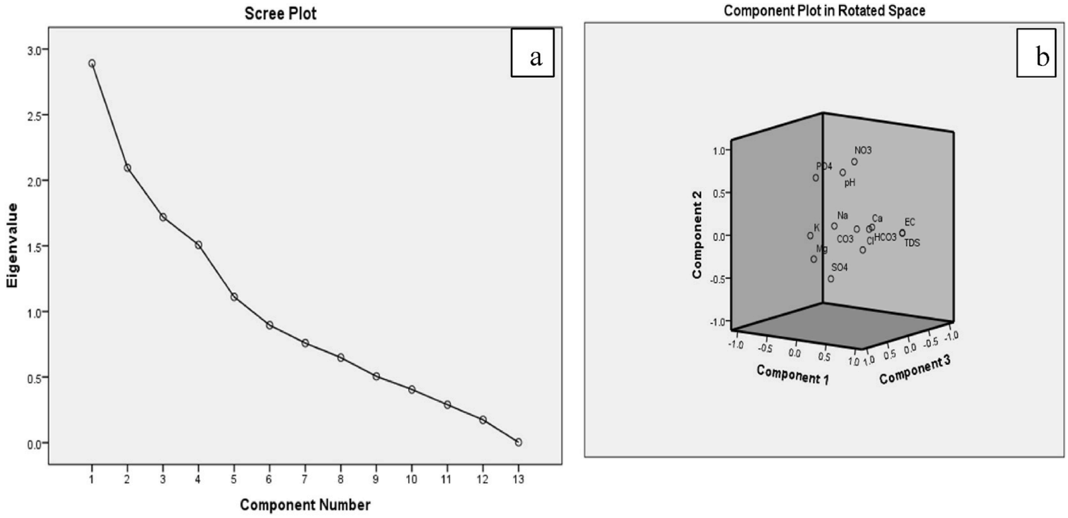

Fig. 10. The findings of the principle component analysis (PCA) are shown in this figure in two separate sections: (a) a scree plot showing the distinctive roots (eigenvalues) of the analysis; and (b) a component plot showing the distribution of variables in the PCA's rotated space.

differentiate between the sources of these contaminants, whether they are natural (geogenic) or caused by human activities (anthropogenic).

PCA of GW samples with 16 physicochemical parameters was conducted to identify the sources of ions and factors that affect GW quality. The analysis focused only on factors with eigenvalues greater than one, which provide relevant information on the datasets. This approach helped to uncover the sources and factors responsible for controlling GW quality. The five-principal component analysis (PCA), which combined explained a variation of 71.921 % of data, is found to represent all of the components adequately.

The scree plot in Fig. 10a exhibits a noticeable change in slope after the fourth eigenvalue, indicating a significant shift in the analysis. In Fig. 10 (a, b) and Table 6, the first PC (PC 1) accounted for 23.57 % of the total variation, the second PC (PC 2) accounted for 19.742 %, the third PC (PC 3) accounted for 12.663 %, the fourth PC (PC 4) accounted for 8.401 % the five PC (PC 5) accounted for 7.543 % while the PC1 was shown by strong position loading on EC. The high EC value in groundwater is attributed to geogenic processes, which cause salt accumulation in soils that eventually reach groundwater through recharge water. Therefore, EC is an indicator of water salinity. PC1 is identified as the salinity-controlled process, while PC2 is strongly associated with turbidity, which is caused by bottom sediments such as clay, silt, and organic matter. PC3 has a high positive correlation with DO and K^+. The sources of potassium are silicate minerals such as orthoclase, microcline, hornblende, muscovite, and biotite found in igneous and metamorphic rocks and evaporate deposits such as gypsum and sulphate. Agricultural practices also lead to a rise in potassium levels in GW [41]. The PC 4 exhibited with strong positively high values loaded on SO_4^{2-} that mainly cause wastes, agrochemicals, and other anthropogenic

Table 6
Total Variance explained and component matrix of the analyzed parameters in this study.

	PC1	PC2	PC3	PC4	PC5
Turbidity	−0.23191	**0.44559**	−0.02464	−0.08676	−0.11889
DO	−0.05957	0.02822	**0.46582**	0.07353	−0.33746
pH	0.12084	−0.38899	−0.03311	−0.26311	0.23199
EC	**0.40627**	0.14013	0.23512	0.19984	0.13777
TDS	0.3991	0.09574	0.28929	0.14315	0.27018
Na	0.1682	−0.10344	0.35	0.00539	−0.04565
Mg	−0.03182	−0.3677	−0.21034	0.37231	0.25708
K	−0.08031	−0.18334	**0.41455**	−0.34609	0.02202
Ca	0.21511	0.16858	−0.46486	−0.23118	−0.1996
NH4	−0.06999	0.3838	0.20166	0.06424	0.31917
NO3	−0.3372	−0.000775883	−0.03718	0.12424	**0.50441**
HCO3	0.346	0.2981	−0.14698	0.14625	0.12025
Cl	−0.38141	−0.07332	0.04596	0.3845	0.06374
PO4	0.32102	−0.08745	−0.143	0.30818	−0.05064
CO_3	0.0745	−0.32831	0.03129	0.31342	−0.41874
SO4	−0.1712	0.23588	0.02148	**0.40442**	−0.25487
Eigenvalues	3.771284	3.158769962	2.026191	1.344287	1.206887
Variance (%)	23.57052	19.74231227	12.6637	8.401796	7.543041
Percentage (%)	23.57052	43.31283519	55.97653	64.37833	71.92137

*The factor values greater than 0.4 are highlighted in bold.

factors from residential and animal wastes in the research locations. The interaction between the base rock and groundwater in the aquifer is another factor that contributes to the presence of SO4 2- ions in the groundwater, according to Ref. [42]. Previous research also suggest [43] that this interaction can increase the concentration of SO_4^{2-} ions in groundwater, indicating that it is an additional source of these ions. The PC 5 was seen high positive loading on NO_3^- values. The high NO_3^- values are mainly agricultural, runoff, animal feedback likely fertilizer, eutrophication [44].

4. Conclusions

The findings of the study showed that the pH value was higher than 7, suggesting that the water was somewhat turbid and moderately alkaline. According to the statistical results, main cations $Ca^{2+} > Mg^{2+} > K^+ >$Na were in greater abundance than major anions $HCO_3^{2-} > Cl^- > CO_3^{2-} > SO_4^{3-} > PO_4^{3-}$ in the targeted region. The Ca–Mg–HCO_3–Cl hydro-chemical facies is the most common form of groundwater. The Gibbs diagrams illustrate that the majority of the GW samples were found in the rock dominance zone. The GW chemistry in the targeted region is influenced by geogenic processes like rock weathering and ionic exchange as well as anthropogenic elements like domestic waste, indigenous fertilizers, and agrochemicals, according to the PCA of GW quality parameters, which explains 72 % of the total variance. The GW quality evaluation using the GWQI and the Wilcox diagram indicates that all sample locations provide drinkable water. However, certain samples were shown to be inappropriate for specific ions, potentially causing health and environmental issues. The irrigation water quality index findings show that the GW examined is suitable for agricultural use. Furthermore, the results revealed that 50 % of the PI values were unsatisfactory for irrigation purposes, and the TH value was extremely difficult to achieve. The study's geographical distribution maps can provide local policy makers with credible information for sustainable groundwater management. Furthermore, cost-effective water treatment facilities should be put in place to remediate polluted tube well water. This study offers critical information on physicochemical characteristics, water quality indices, possible ion sources, and contributing factors to groundwater quality and geographic variability in the study area.

Author contribution statement

Mohammed Sadid Hossain, Nazneen Nahar, Molla Rahman Shaibur: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper. Md. Tareq Bhuiyan, Abu Bakar Siddique, Abdullah Al Maruf: Performed the experiments; Analyzed and interpreted the data. Abu Shamim Khan: Contributed reagents, materials.

Data availability statement

Data will be made available on request.

Funding

This research did not receive any specific grant from any funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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