Fundamental and Applied Agriculture
Vol. 5(4), pp. 521–536: 2020
doi: 10.5455/faa.129984

Water Management | Original Article

Spatial appraisal of groundwater quality for drinking purposes: A case study of Kalihati Upazila, Bangladesh

Nusrat Jahan[1], Md Badiuzzaman Khan[1*], Muhammad Aslam Ali[1], Md Touhidul Islam[2], Md Sifat Siddik[2]

[1]Department of Environmental Science, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh
[2]Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh

Article Information

Article History
Submitted: 30 Aug 2020
Accepted: 20 Sep 2020
First online: 29 Dec 2020

Academic Editor
M Mizanur Rahman
mizaniwm@bau.edu.bd

**Corresponding Author*
Md Badiuzzaman Khan
mbkhan@bau.edu.bd

Abstract

With the aim of improving public health interventions, this study was conducted to ensure sustainable groundwater quality by adopting Geographical Information System (GIS) and Water Quality Index (WQI) for drinking purposes in Paikara Union, Kalihati Upazila of Bangladesh. Fifteen groundwater samples were randomly collected from different hand tubewells in April 2019 and analyzed for pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), major cations and anions. Almost all physicochemical parameters fell within the acceptable limit of national and international standards, though a few samples exceeded the standard limit considering As_3^+, Fe_3^+ and PO_4^{3-} concentrations. The spatial distribution of the quality parameters across the study area was depicted employing ArcGIS 10.5 software; therein it was revealed that slightly acidic water is dominant in the central and southern parts. Overall, TH–total cation, Cl–NO_3, total anion–NO_3 and total anion–Cl show a very strong correlation, and contrarily, the pairs of pH, EC, TDS are poorly correlated with most of the variables and no remarkable relationship is found between pH and TH. Furthermore, WQI of the samples ranged from 20.42 to 143.36, with 73.7, 24.1, and 2.2% of the entire study area falling under excellent, good, and poor quality categories for drinking purposes, respectively. From the results, it can be inferred that the groundwater of the study area is suitable for drinking purposes but awareness-raising on chemical contents in the water at the household level is recommended.

Keywords: Groundwater, drinking, spatial distribution, water quality index

Cite this article: Jahan N, Khan MB, Ali MA, Islam MT, Siddik MS. 2020. Spatial appraisal of groundwater quality for drinking purposes: A case study of Kalihati Upazila, Bangladesh. Fundamental and Applied Agriculture 5(4): 521–536. doi: 10.5455/faa.129984

1 Introduction

Water is regarded as one of the most fundamental resources for life on the earth, whereas a little accessible water (surface water and groundwater) is considered as consumable. In global aspects, around 33% of the total population utilizes groundwater for drinking purposes with or without treatment (Nickson et al., 2005). In Bangladesh, around 90% of drinking water originates from groundwater sources with no treatment (Shahid et al., 2006; Shariot-Ullah, 2018). Groundwater quality has become a major concern in Bangladesh as the quality of groundwater is a precursor of its usage potential for different purposes (i.e., drinking, irrigation, and domestic purposes) (Kumar et al., 2008; Subramani et al., 2005). The sustainability of groundwater quality with regards to Bangladesh is emphasized and featured with critical significance in recent literature (Raihan and Alam, 2008; Bahar and Reza, 2010; Hossain et al., 2010; Biswas et al., 2014; Bhuiyan et al., 2014; Islam et al., 2017a). The assessment of groundwater quality is not just important to know its grade but it is vital for planning any management strategy to meet the current and future demands. The quality of world water resources is being significantly influenced by the geological formation and intensified anthropogenic exploitation (Causape et al., 2004). For specific use, water quality refers to the characteristics influencing its suitability on the basis of quality parameters (i.e., physical, chemical, and microbiological), and human health is at risk if the value of the parameters exceeds acceptable limits. In many developing countries, lack of clean drinking water is adversely affecting human health including their life expectancy (Nash and McCall, 1995). As human health is directly related to the quality of consumed water, appraisal of groundwater suitability for drinking purposes is a crucial need.

Characterization and monitoring of groundwater chemistry is a critical component of management and protection, which provides the basis for defining the suitability of groundwater for its intended purpose. As groundwater moves along its path from one aquifer to another area, a variety of hydrogeochemical processes alters its chemical composition. So, appraisal of groundwater composition and its interpretation is very important for the evaluation of its suitability for drinking purposes (Jiang et al., 2009). In most cases, a large number of hydrochemical parameters are usually used to assess the water quality status, whereas some parameters might be within the guideline limits but others might be not, then the overall quality of water is ambiguous. Thus, modern approaches such as Geographical Information System (GIS) and Water Quality Index (WQI) are suggested for the appraisal of spatial variation of physicochemical parameters and effective characterization of water quality, respectively (Islam et al., 2017b; Moharir et al., 2019; Pandey et al., 2020). The WQI was first developed by Horton in 1965 to rate water quality by employing the most regularly used water parameters (Ochuko et al., 2014). The method was subsequently modified by different experts considering the weights of water quality parameters based on its respective WHO (World Health Organization) standards, and the assigned weight indicates the parameter's significance and impacts on the index. A usual WQI method follows three steps (1) parameters selection, (2) evaluation of quality function for each parameter, and (3) aggregation through mathematical equation (Tyagi et al., 2020), providing a single number that represents overall water quality at a certain location and time based on physicochemical parameters. The present study used a weighted arithmetic WQI method to deliver the water quality information to the policymakers of a resource-poor country like Bangladesh where ensuring availability and sustainable management of water is one of the challenging matters towards development.

In global aspects, some leading researchers (Elhatip et al., 2003; Lee et al., 2003; Singh et al., 2009; Jacintha et al., 2016; Javed et al., 2019; Moharir et al., 2019; Pande et al., 2019) have demonstrated that groundwater quality has been deteriorated noticeably in many countries during the past few years. Especially, in Bangladesh, a few works have been conducted on the evaluation of the quality of groundwater for domestic purposes over the past years (Islam et al., 2017a,b; Das et al., 2019; Yasmin et al., 2019; Iqbal et al., 2020), and interestingly most of the researches are concentrated in few cities, although the quality of groundwater varies with the location and habits of the population. However, to the best of our knowledge, in the Kalihati Upazila of Bangladesh, no specific research work relating to the quality of groundwater for drinking purposes has been conducted yet, and the people of this area are entirely dependent on groundwater especially for drinking purposes. Therefore, considering the risk of contaminated groundwater to public health, we aim to map the groundwater quality concentration using GIS technique and to assess the groundwater quality for drinking by employing WQI with correlation matrix analysis in our area of interest, i.e., Paikara Union, Kalihati Upazila of Bangladesh.

2 Materials and Methods

Systematic methodology involving detailed field and laboratory study has been adopted to conduct the current study, as portrayed in Fig. 1.

2.1 Study site

Fig. 2 depicts the study area named Paikara Union located at Kalihati Upazila under the Tangail District of Bangladesh. Geographically, it is positioned between 24°18′40″ N to 24°24′0″ N latitude and 89°46′40″ E to 90°5′20″ E longitude. The investigated region covers up about 18.10 km^2 area in the Kalihati Upazila, which is vulnerable to various potential threats, such as growing population, rapid urbanization, and small industries. The major river systems flowing through the Upazila are Jamuna, Dhaleshwari, and Louhajang Rivers of Bangladesh, as portrayed in Fig. 2b. The climate of Tangail District is characterized by tropical to subtropical with hot summer monsoon. The annual mean temperature of the study site is about 25.5 °C, while the annual precipitation is around 1872 mm. The targeted domain is located at a lower shallow younger Jamuna aquifer system, which is confined to semi-confined in nature occupying within the grey non-indurated alluvial sediments of the Dhamrai Formation originated in Plio-Pleistocene age. The aquifer system is divided into thick semi-consolidated to the unconsolidated formation (Zahid and Ahmed, 2006). The groundwater quality may be affected by the geology of the investigated area. The local people in the

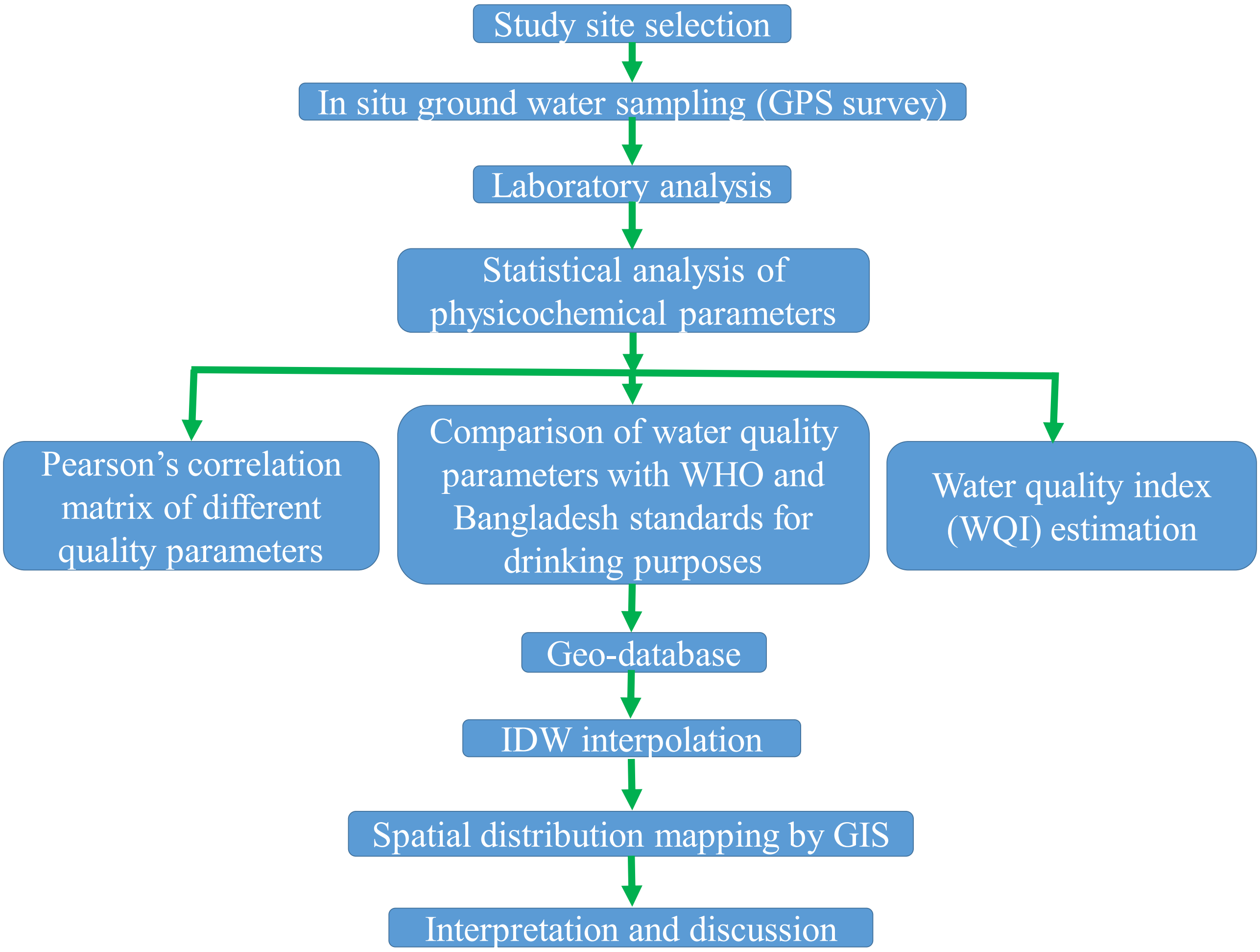

Figure 1. Flow chart on the schematic methodology adopted for the current study

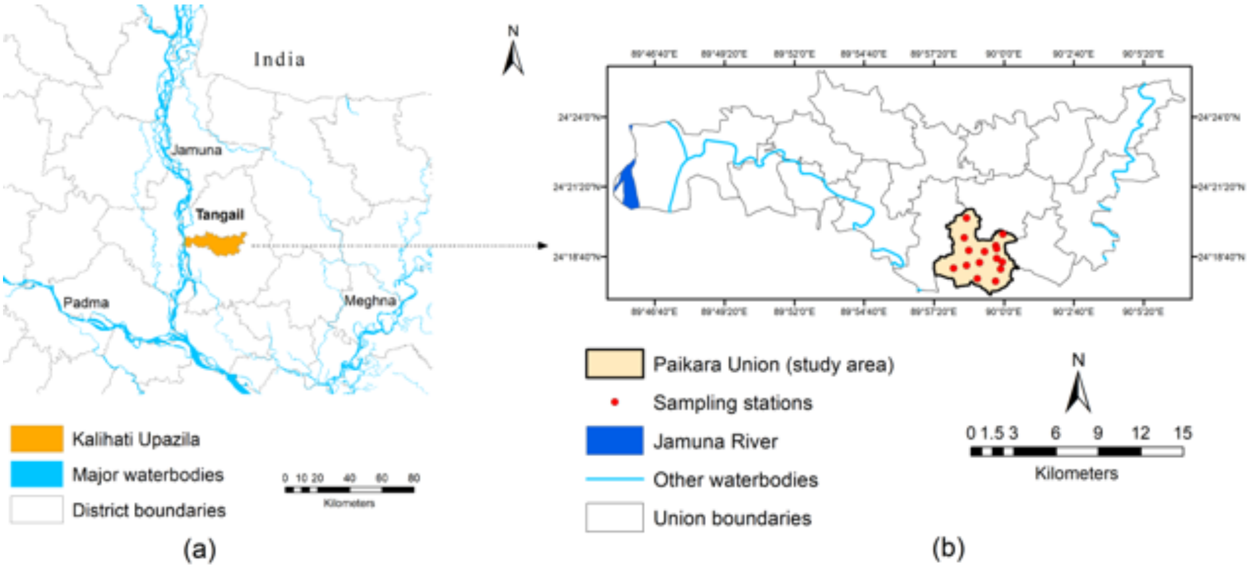

Figure 2. (a) Kalihati Upazila shown in the map of Bangladesh, (b) Study area with sampling stations elucidated in the map of Kalihati Upazila

study area are fully dependent on the groundwater for their daily life, especially for drinking purposes.

2.2 Water sample collection and analysis

Fifteen groundwater samples were randomly collected from different hand tubewells covering the entire study area in April 2019, and the location of sampling stations was taken by hand GPS (Global Positioning System). The depth of sampled wells ranged from 9 to 36 m. The samples were collected in bottles of 500 mL pre-washed with dilute HCl acid and rinsed three times with the water sample before filling and labeled accordingly. The samples were kept at a temperature below 4°C prior to examination in the laboratory, and before chemical analysis, the samples were filtered through filter paper (Whatman No. 1) to expel undesirable solids and suspended materials. The analysis of groundwater samples was performed in the laboratory of the Department of Agricultural Chemistry, and Interdisciplinary Institute for Food Security, Bangladesh Agricultural University, Bangladesh, as per standard procedures (APHA, 2005). It included the analysis of pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH) and major ionic constituents like calcium (Ca_2^+), magnesium (Mg_2^+), sodium (Na^+), potassium (K^+), arsenic (As_3^+), iron (Fe_3^+), chloride (Cl−), sulfate (SO_4^{2-}), nitrate (NO_3^-), alkalinity as bicarbonate (HCO_3^-) and phosphate (PO_4^{3-}). pH values of the samples were measured by taking 50 mL of water in a beaker and then placing the electrode of the pH meter into the samples as mentioned by Singh and Narain (1980), whereas EC was assessed by taking 100 mL of collected water in a beaker and then immersing the electrode of conductivity meter into the water sample based on the technique prescribed by Tendon (1993). The procedure as suggested by Chopra and Kanwar (1976) enabled the assessment of TDS by weighing the remaining after evaporation of 100 mL water sample to dryness. The concentration of Ca and Mg ions were analyzed by a complex metric titration method using Na_2EDTA (Disodium Ethylenediaminetetraacetic Acid) as a titrant. As and Cl concentrations were measured by performing a titration test using $AgNO_3$, whereas HCO_3^- was analyzed titrimetrically against standard HCl acid solution (0.01 N). Flame Photometer determined Na and K contents and spectrophotometer was used for analyzing Fe_3^+, $SO_4^{2-}$and NO_3^- concentrations. TH, the hardness of the mineral content of water that is irreversible by boiling, was calculated by the following equation (Sawyer and McCarty, 1967):

$$TH = (2.5 \times Ca_2^+) + (4.1 \times Mg_2^+) \tag{1}$$

where, TH and all the ions are expressed in mg L^{-1} or ppm.

2.3 Spatial distribution mapping

GIS technique is widely utilized for environmental management and monitoring (Burrough et al., 2015; Ketata et al., 2011) in an all-encompassing way considering the spatio-temporal variation which is very much essential in both the evaluation and decision-making purposes (Mtetwa and Schutte, 2002; ESRI, 1996). ArcGIS 10.5 software was used to explore the spatial distribution of different physicochemical parameters of groundwater employing the IDW technique (APHA, 2005; Robinson and Metternicht, 2006), a type of deterministic methods for multivariate interpolation used to predict a value of any unmeasured or un-sampled location employing a set of measured values. A weighted average of the values available at the known points enabled estimation of the assigned values to unknown points. The resolution of raster maps used for depicting the spatial pattern of the physicochemical parameters and WQI was 10 m × 10 m.

2.4 Correlation analysis of water samples

Pearson's correlation coefficient matrix (r) was used to assess the relationship between the physicochemical parameters of the groundwater (Javed et al., 2019). The value of r nearer to $+1$ or -1 represents the perfect linear relationship between the two variables (al hadithi, 2012), while zero reveals no connection between the parameters (Srivastava and Ramanathan, 2007). If the value of r is more than 0.7, it is considered as strongly correlated, whereas if its value extends from 0.5 to 0.7, the parameters are moderately correlated, and in case of negative value, it implies that the value of one parameter is diminishing with the expansion in another parameter (Giridharan et al., 2007).

2.5 Calculation of water quality index

Water quality index (WQI) analysis demonstrates a comprehensive picture of groundwater quality. It is defined as a rating system with a single value expression that elucidates the influences of different water quality parameters (Sahu and Sikdar, 2007) to assess groundwater quality and its suitability for drinking purpose (Tiwari and Mishra, 1985; Ramakrishnaiah et al., 2009; Pawar et al., 2014; Al-Omran et al., 2015; Boateng et al., 2016). WQI was computed following the method of Tyagi et al. (2020). In this approach, in the first step, relative weight is calculated by using the following Equation (2):

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \tag{2}$$

where, W_i is the relative weight of the ith parameter, w_i is the assigned weight of each parameter, and n is the number of parameters.

In the second step, the quality rating scale for each parameter is calculated by employing the following Equation (3):

$$q_i = \frac{c_i}{s_i} \times 100 \tag{3}$$

where, q_i is the quality rating, c_i is the concentration (ppm) or value of each parameter, and s_i the WHO (World Health Organization) standard of drinking water for each respective parameter in ppm.

In the third step, for computing the WQI, sub-index (SI) is calculated for each respective parameter using the following Equation (4) and finally, WQI is then calculated from the following Equation (5).

$$SI_i = W_i \times q_i \tag{4}$$

$$WQI = \sum SI \tag{5}$$

3 Results and Discussion

Understanding groundwater chemistry is necessary as it is one of the imperative factors in deciding its reasonableness for drinking, domestic, agricultural, and industrial purposes (Subramani et al., 2005). The insights of the physicochemical parameters of the experimented fifteen groundwater samples are statistically given in Table 1. These results are comprehensively discussed in the subsequent sections.

3.1 Drinking water quality indices

3.1.1 pH

One of the most important water parameters is pH which indicates the strength of the water to react with the acidic or alkaline material present in water. The analyzed pH value of the samples is distributed from 5.51 to 7.53 while the average value is 6.14, satisfying the range of WHO Standard (2017) and Bangladesh Standard (1997), presented in Table 1. This result of groundwater pH was partially in agreement with the findings of Yasmin et al. (2019), where they found that only 1.66% of groundwater samples in the Barishal district of Bangladesh exceeded the acceptable limit of national standard and no sample exceeded the allowable limit of WHO Standard (2017). The spatial distribution of groundwater pH across the study area is depicted in Fig. 3a, wherein it revealed that slightly acidic water was observed in the central and southern parts of the area. It might be due to the presence of low alkalinity in groundwater as a lack of alkaline substances in the groundwater system helps in the accumulation of acidity in the groundwater (Zhou et al., 2015; Das et al., 2019).

3.1.2 EC

EC is a measure of water capacity to convey electric current, which may be affected by temperature and ionic concentration present in the water. It represents the amount of total dissolved solids in groundwater. The range of EC of the experimented water samples varied from 115.70 to 458.00 µS cm^{-1} with the mean value of 266.31 µS cm^{1} (Table 1). On the basis of EC values, the study revealed that the quality of the groundwater is permissible for drinking as no sample exceeded the allowable limits of Bangladesh and international standards. The spatial distribution of groundwater EC across the study area is shown in Fig. 3b, which indicates relatively higher EC at the northeastern and southwestern parts, consistent with the findings of Islam et al. (2017a), who conducted an investigation in Joypurhat district of Bangladesh for assessing groundwater quality considering its sustainability. Overall, a moderate EC value persisted across the study area.

3.1.3 TDS

TDS in groundwater, varying considerably in different geological regions, represents the dominancy of the solubility of minerals (WHO Standard, 2017). TDS of the samples ranged from 48 to 182 ppm with an average value of 83.40 ppm and is within the prescribed limits, presented in Table 1. The classification of drinking groundwater samples based on TDS is presented in Table 2, thus indicating that the water can be used for drinking without any risk as the experimented TDS is in agreement with the prescribed classification by Davis and Dewiest (1966) and the findings of Yasmin et al. (2019). The spatial pattern of TDS is depicted in Fig. 3c, demonstrating that a low TDS signature of groundwater persisted across the study area, which could be due to the presence of lower salt contents leached from the soil. This result of the spatial distribution of TDS was in agreement with the findings of Das et al. (2019) as the almost same pattern persisted across their study area in Durgapur upazila of Bangladesh.

3.1.4 TH

Hardness of water is resulted due to the abundance of divalent cations like Ca and Mg (Todd and Mays, 2004). TH as $CaCO_3$ of the groundwater samples ranged from 33.95 to 189.66 ppm with an average value of 67.34 ppm (Table 1), revealing that only 13.33% groundwater samples exceeded the acceptable limit of WHO Standard (2017) and there was no sample that exceeded the allowable limit of Bangladesh Standard (1997). The classification of drinking groundwater samples based on TH is presented in Table 2; therein it was found that 53.33%

Table 1. Statistical analysis of physicochemical parameters with standards for groundwater samples

Parameter	Minimum	Maximum	Average	SD	WHO standard †	BD standard ‡
pH	5.51	7.53	6.14	0.59	6.5 – 8.5	6.5 – 8.5
EC (µS cm^{-1})	115.7	458	266.31	109.34	500	1000
TDS (ppm)	48	182	83.4	33.71	500	1000
Calcium (ppm)	2.41	24.05	12.77	6.15	75	75
Magnesium (ppm)	0.97	31.6	8.63	8.8	50	30–35
Sodium (ppm)	3.1	18.63	5.99	4.09	200	200
Potassium (ppm)	0.31	2.39	0.84	0.64	10	12
Arsenic (ppm)	0	0.04	0.007	0.01	<0.01	0.05
Iron (ppm)	0.1	4.2	0.98	1.18	0.3	0.3–1.0
Chloride (ppm)	5.98	65.46	24.53	16.81	250	150 - 600
Sulphate (ppm)	0.19	7.05	2.06	1.77	250	400
Nitrate (ppm)	0.87	11.09	3.36	2.97	45	10
Bicarbonate (ppm)	152.22	305.37	205.81	49.44	500	600
Phosphate (ppm)	0.02	0.52	0.19	0.16	0.5	6
TH (ppm)	33.95	189.66	67.34	42.26	100	200 - 500

† WHO standard (2017); ‡ Bangladesh standard (1997); EC = electrical conductivity, TDS = total dissolved solids, and TH = total hardness

Table 2. Classification of drinking groundwater samples based on different parameters

Range of different parameters	Water class with its developer	No. of sample	% of sample
TDS (ppm)	Davis and Dewiest (1966)		
<500	Desirable for drinking	15	100
500 – 1000	Permissible for drinking	–	–
1000 – 3000	Useful for drinking	–	–
>3000	Unfit for drinking	–	–
Hardness (ppm)	Raghunath (1987)		
0 – 50	Soft	5	33.33
51 – 100	Slightly hard	8	53.33
101 – 200	Moderately hard	2	13.33
201 – 500	Very hard	–	–
Hardness (TH as CaCO3 (ppm))	Sawyer and McCarty (1967)		
<75	Soft	13	86.67
75 – 150	Moderately hard	1	6.66
150 – 300	Hard	1	6.66
>300	Very hard	–	–

TDS = total dissolved solids, TH = total hardness of the samples fell in the slightly hard water category according to Raghunath (1987) and 86.67% of the samples were in the soft water category based on Sawyer and McCarty (1967), thus indicating that almost all the groundwater samples analyzed are potable. Fig. 3d elucidates the spatial distribution of TH across the study area revealing that the occurrence of hard groundwater was seen in the central and western parts and a decreasing trend in TH was evident towards the southern part.

3.2 Cation conc. in drinking water

Calcium (Ca) is one of the foremost abundant substances in the freshwater, which plays a significant role in physiology and biochemistry of the cell and organisms. Utilization of water which is higher in the concentration of the Ca appears negative effects on human health, such as stones in kidneys, bone weakness, and hypercalcemia, etc. (Kumar et al., 2020). The minimum concentration of Ca content in the study area is 2.4 ppm while the maximum value is 24.05 ppm with an average of 12.77 ppm, revealing that all the experimented samples fell within the allowable limit of national and international standards for drinking purpose (Table 1). The spatial pattern of Ca ion concentration across the study area is depicted in Fig. 4a revealing that a higher concentration was evident in the northern part, which might have resulted in the carbonate weathering of alluvial sediments besides agricultural waste runoff (Kumar et al., 2020), and contrarily, a comparatively lower concentration was observed in the southeastern part of the study area.

Magnesium (Mg) is a vital element for human beings which is instrumental in normal bone structure along with Ca content in the body. The presence of higher concentrations of Mg and Ca contents are regarded as hard water which is undesirable for drinking purposes (Selvam et al., 2017). Mg content of the samples ranged from 0.97 to 31.60 ppm with an average of 8.63 ppm. All the samples were within the allowable limit of national and international standards, presented in Table 1. The spatial distribution of Mg content across the study area is shown in Fig. 4b demonstrating that relatively higher concentration was observed at the central and northeastern parts and overall, a lower concentration persists across the study area. The relatively higher concentration of the Mg content in groundwater might be due to the water circulation, which makes a condition for the dissolution of Mg element from the host grey non-indurated alluvial sediments of the aquifer systems.

Groundwater is usually described by the basic appearance of sodium (Na) since soil/rock contains Na content, which is among the major cations and is moreover present in most of the natural water resources (Pandey et al., 2020). Also, without the appraisal of Na content, no specific conclusion can be drawn about the possible association among chemical components in drinking water and the occurrence of hypertension. However, concentrations of more than 200 ppm as prescribed by WHO may give rise to unacceptable taste. The concentration of Na within the study area ranges between 3.10 ppm - 18.63 ppm, and it was evident that all samples fell within the permissible limits given by WHO Standard (2017) and Bangladesh Standard (1997) with an average value of 5.99 ppm (Table 1). Fig. 4c depicts the spatial distribution of Na content across the study area exhibiting relatively higher concentration at the central part and overall, a lower concentration was found across the study area. The relatively higher concentration of Na, although within prescribed limits for drinking purposes, might have resulted from the overabundance utilization of fertilizers in the agricultural land and by the action of leached water while percolating through the sedimentary rocks.

Potassium (K) concentration determined in this work ranged from 0.31 to 2.39 ppm with an average of 0.84 ppm. The targeted zone can be expressed as low K concentrations as all samples were within the allowable limits (Table 1). The spatial pattern of K content across the study area is elucidated in Fig. 4d demonstrating that a decreasing trend was evident from northeastern towards the southwestern part.

Arsenic (As) is poisonous when its intake exceeds the limit of tolerance. People suffer from arsenicosis after consuming arsenic-contaminated water year after year. Based on the investigated As contents, it was evident that all the samples fell within the allowable limit of Bangladesh Standard (1997) with an average of 0.007 ppm, whereas on the basis of WHO Standard (2017), 33.33% of the experimented samples showed the presence of As content beyond the safe limit (<0.01 ppm), and other remaining samples were found to be As-free (Table 1). Fig. 4e illustrates the spatial distribution of As content across the study area, revealing that only one sampling site fell under the area of relatively higher concentration at the central part but within the allowable limit, and overall, a very low concentration persists across the study area.

Iron (Fe) is an essential element in human nutrition as the taste of water is not usually noticeable at Fe concentrations less than 0.3 ppm; also, laundry and sanitary ware will stain at iron concentrations higher 0.3 ppm (Vasudevan et al., 2009). The concentration of Fe content has been noted to be generally relatively higher throughout the study area, varying from 0.1 to 4.2 ppm with an average of 0.98 ppm (Table 1), wherein it was found that 40% and 66.67% of the drinking water samples were within the allowable limits. The spatial pattern of Fe content across the study area is depicted in Fig. 4f, demonstrating that a relatively higher concentration was evident in the central part, whereas a decreasing trend was found

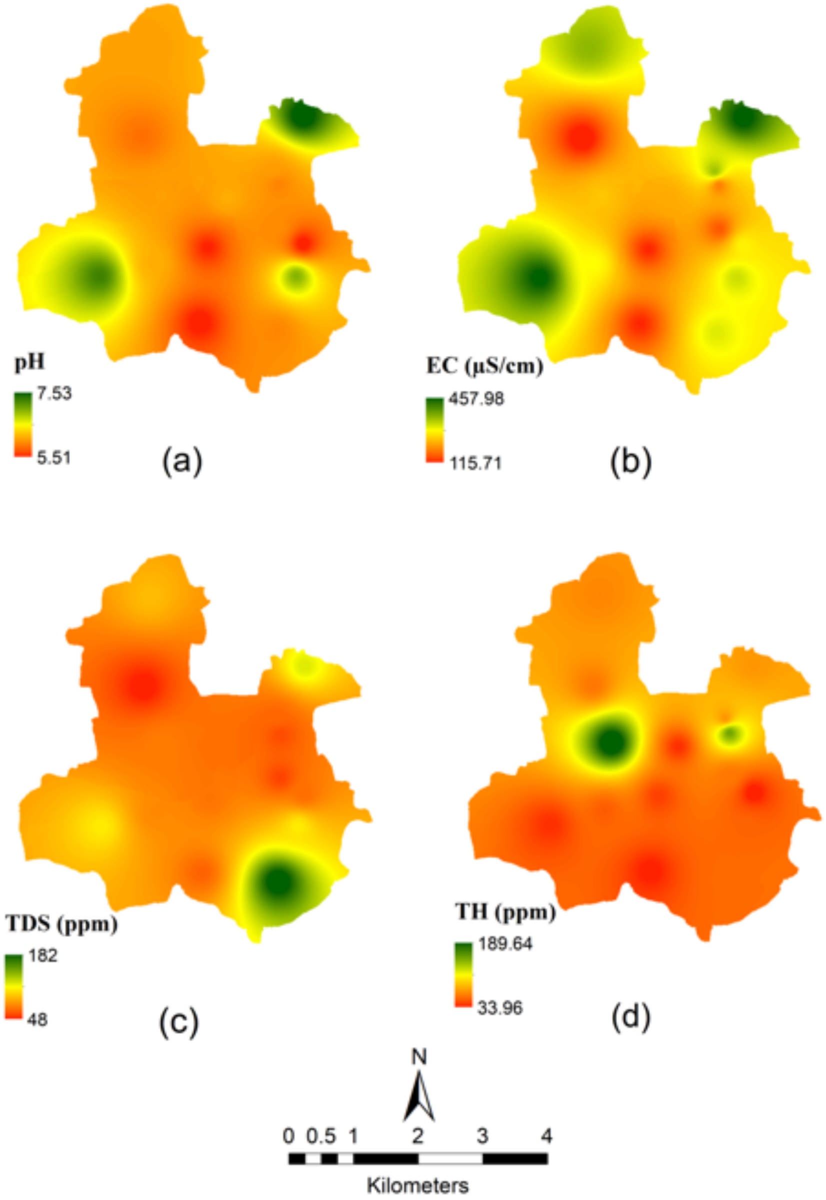

Figure 3. Spatial distribution of (a) pH (b) (EC) (µS cm^{-1}) (c) TDS (ppm), and (d) TH (ppm) of groundwater in the study area

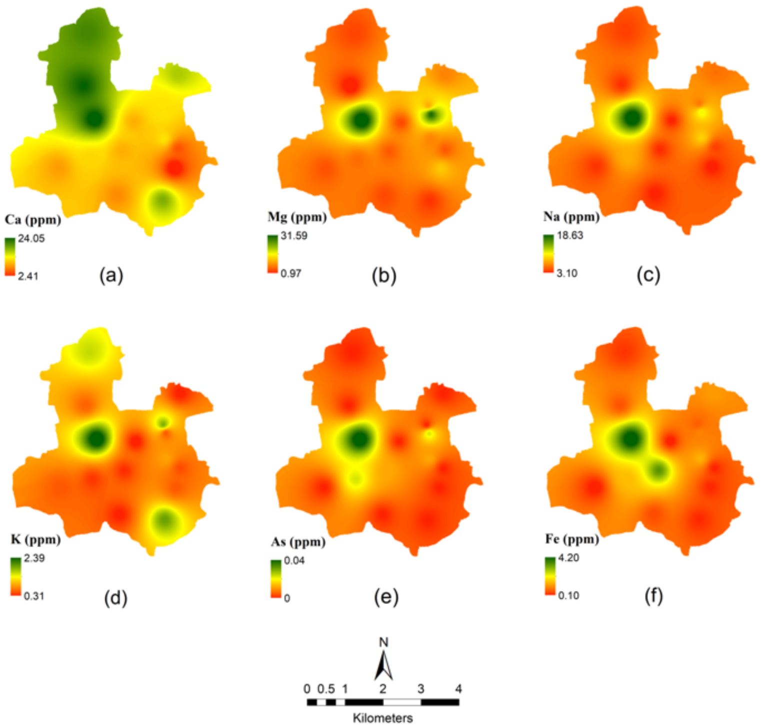

Figure 4. Spatial distribution of (a) Ca (b) Mg (c) Na (d) K (e) As, and (f) Fe contents in ppm of groundwater in the study area

from the southeastern towards the northern part. The occurrence of a higher concentration of Fe content in groundwater might be due to the natural weathering of Fe content in grey non-indurated alluvial sediments, which is geologically present in the aquifer systems of the investigated zone. The relatively higher concentration of Fe content in the groundwater may accelerate the growth of pathogenic organisms (Andrews et al., 2003).

3.3 Anion conc. in drinking water

Chloride (Cl) occurs in all the natural water sources with changing concentration. The increment of mineral content enables to increase the concentration Cl concentration in water (Sawyer and McCarty, 1967). Cl content is one of the vital parameters in assessing groundwater quality where the higher concentration of the Cl element signifies a higher grade of organic pollutants (Singh and Khan, 2011). Cl content of the investigated water samples laid within the acceptable limit of 250 ppm based on WHO Standard (2017) and allowable drinking limit of 150–600 ppm based on Bangladesh Standard (1997) with an average of 24.53 ppm (Table 1). Fig. 5a illustrates the spatial distribution of Cl content across the study area, wherein it was observed that relatively lower concentration was persisted across the targeted domain excepting the southwestern part.

The concentration of sulphate SO_4^{2-} is likely to react with human organs if the value exceeds the acceptable limit for drinking purposes. The experimented sulphate content ranged from 0.19 to 7.05 ppm with an average of 2.06 ppm (Table 1) revealing that all the sampling stations were observed within prescribed limits posing no groundwater quality problem. The spatial pattern of sulphate content across the study area is elucidated in Fig. 5b portraying that higher concentration was evident in the southwestern part but within the allowable limit, and overall, a low concentration was found across the study area and a decreasing trend was observed from the north to the southeastern part. The result is in agreement with the findings of Amadi et al. (1989), where they found comparatively lower values across the area and it could be due to the removal of sulphate from the water by bacteria.

The nitrate ion NO_3^- concentration varied from 0.87 to 11.09 ppm with an average of 3.36 ppm, presented in Table 1, revealing that none of the samples exceeded the acceptable limit of international standard for drinking but in case of national, only one sample out of the investigated fifteen groundwater samples exceeded the acceptable drinking water limit. This result is in agreement with the findings of Yasmin et al. (2019), where they found that the groundwater was fit for drinking on the basis of observed nitrate contents. Fig. 5c portrays the spatial pattern of

Table 3. Pearson's correlation matrix of different important physicochemical parameters of the drinking groundwater samples

Parameters	pH	EC	TDS	TH	As	Fe	Cl	SO_4	NO_3	TotCat	TotAnion
pH	1										
EC	0.78**	1									
TDS	0.43	0.57*	1								
TH	0	–0.07	–0.13	1							
As	–0.17	–0.24	–0.26	0.82**	1						
Fe	–0.17	–0.28	–0.22	0.63*	0.82**	1					
Cl	0.09	0.39	0.06	–0.56*	–0.36	–0.41	1				
SO_4	0.49	0.51	0.08	–0.4	–0.22	–0.32	0.60*	1			
NO_3	0.19	0.47	0.08	–0.43	–0.25	–0.36	0.94**	0.49	1		
TotCat	–0.04	–0.08	–0.12	0.98**	0.85**	0.70**	–0.56*	–0.39	–0.44	1	
TotAnion	0.33	0.61*	0.04	–0.41	–0.29	–0.32	0.91**	0.64*	0.92**	–0.41	1

TotCat = total cation, TotAnion = total anion

Table 4. Relative weight of the physicochemical parameters of the drinking groundwater samples

Parameter	WHO standard (2017) (S_i)	Weight (w_i)	Relative weight (W_i)
pH	6.5 – 8.5	4	0.077
EC (μS cm^1)	500	4	0.077
TDS (ppm)	500	5	0.096
Calcium (ppm)	75	3	0.058
Magnesium (ppm)	50	3	0.058
Sodium (ppm)	200	4	0.077
Potassium (ppm)	10	2	0.038
Arsenic (ppm)	<0.01	4	0.077
Iron (ppm)	0.3	3	0.058
Chloride (ppm)	250	5	0.096
Sulphate (ppm)	250	5	0.096
Nitrate (ppm)	45	5	0.096
Bicarbonate (ppm)	500	1	0.019
Phosphate (ppm)	0.5	1	0.019
TH (ppm)	100	3	0.058

EC = electrical conductivity, TDS = total dissolved solids, and TH = total hardness

Table 5. Calculated water quality index (WQI) classifying drinking water samples

Sampling stations	WQI	Water type for drinking purpose
1	29.49	Excellent water
2	50.08	Good water
3	35.72	Excellent water
4	57.92	Good water
5	51.74	Good water
6	27.37	Excellent water
7	26.68	Excellent water
8	26.78	Excellent water
9	143.36	Poor water
10	30.4	Excellent water
11	24.15	Excellent water
12	83.28	Good water
13	20.42	Excellent water
14	27.33	Excellent water
15	65.52	Good water

nitrate concentration demonstrating that a lower concentration was persisted across the study area. That is why routine monitoring of nitrate content is not required as it is not in the alarming condition.

The concentration of carbonates in natural water relies on the presence of soluble carbon dioxide, temperature, pH, cations, and some soluble salts. The carbonate concentration in groundwater is generally higher than that in surface water Kumar et al. (2014). The experimented bicarbonate ion HCO_3^- concentration revealed that none of the samples exceeded the standard and allowable range of WHO Standard (2017) of 500 ppm and Bangladesh Standard (1997) of 600 ppm for drinking with an average value of 205.81 ppm (Table 1). The spatial pattern of bicarbonate content across the study area is depicted in Fig. 5d revealing that a relatively higher concentration was found in the southwestern part, which might be due to the weathering of rock and dissolution of alluvial sediments (Javed et al., 2019), and contrarily, a decreasing trend was evident to the southeastern part. In the study area, the phosphate ion PO_4^{3-} concentration ranged from 0.02 to 0.52 ppm with an average of 0.19 ppm, presented in Table 1, demonstrating that based on WHO Standard (2017) standard, the phosphate content of only one sample out of the observed fifteen groundwater samples exceeded the acceptable drinking water limit, while all the samples were within Bangladesh Standard (1997). Fig. 5e depicts the spatial distribution of phosphate concentration across the study area elucidating that relatively lower concentration was persisted at the central and southeastern parts, contrarily, a comparatively higher concentration was observed at the northeastern and southwestern parts.

3.4 Chemical composition *vs* quality parameters of water

The correlation coefficient matrix (*r*) was calculated considering the significance level to find out the interrelationship and coherence pattern between chosen variables, presented in Table 3. A very strong correlation, also having a significant relationship at the 0.01 level (2-tailed test), was depicted between TH–total cation ($r = 0.98$) and Cl–NO_3 ($r = 0.94$). The total anion was also strongly and significantly correlated with NO_3 ($r = 0.92$) and Cl ($r = 0.91$). The pairs of As–total cation, As–Fe, TH-As, and pH–EC were also significantly correlated at the 0.01 level (2-tailed test) with a correlation coefficient value of greater than 0.7. Overall in the study area, the pairs of EC–TDS, EC–SO4, EC–total anion, TH–Fe, Fe–total cation and Cl–SO_4 were also significantly correlated at the 0.05 level (2-tailed) with a moderate correlation coefficient ranged from 0.5 to 0.7, whereas the pH–TDS, pH–SO_4, pH–NO_3, pH–total anion, EC–Cl, EC–NO_3, TDS–Cl, TDS–SO_4, TDS–NO_3, TDS–total anion and SO_4–NO_3 pairs were insignificantly correlated with a weak correlation coefficient value of less than 0.5. It was also evident that there was no relationship between pH and TH with a correlation coefficient of 0, and other pairs of the parameters had a negative correlation.

3.5 Drinking water quality based on WQI

WQI enables the summarization of numerous parameters to gain a better insight into overall water quality over the respective stations in the investigated area. It was estimated that a lower value of it signifies less deviation from the recommended values of parameters included and more good quality water for human consumption or vice versa. Fifteen physicochemical parameters were considered to estimate WQI assigning relative weight (Wi) concerning their perceived effects on primary health and relative importance in the overall water quality, presented in Table 4.

The parameters which have major impacts on water quality (*viz.*, TDS, Cl−, Cl, SO_4^{2-} and NO_3^- were assigned to the highest weight of 5 and a minimum of 1 was allocated to the parameters which were considered of fewer effects (*viz.*, PO_4^{3-} and HCO_3^- on the water quality, while other parameters, for example, pH, EC, TH, Ca_2^+, Mg_2^+, Na^+, K^+, As_3^+, and Fe_3^+ were allotted weight in the range of 2 and 4 relying upon their significance in the overall water quality. Estimated WQI ranged from 20.42 to 143.36 (Table 5); it was evident that 60%, 33.33% and 6.67% of the experimented samples showed excellent, good and poor categories, respectively, for drinking purpose based on prescribed classification, presented in Table 6.

Table 6. Standard water quality index (WQI) range along with classification for drinking purpose †

WQI range	Type of water
<50	Excellent water
50–100	Good water
100.1–200	Poor water
200.1–300	Very poor water
>300	Unsuitable for drinking

† Source: Ramakrishnaiah et al. (2009); Al-Omran et al. (2015); Boateng et al. (2016)

It elucidates the groundwater quality is suitable for drinking as none of the samples in the study area were unfit based on the standard classification. Besides, Fig. 6 depicts the spatial distribution of WQI along with groundwater quality across the study area demonstrating a better insight, which is in agreement with the aforementioned findings based on the physicochemical analysis. Considering a single sample set taken at a particular time in this study, this map-

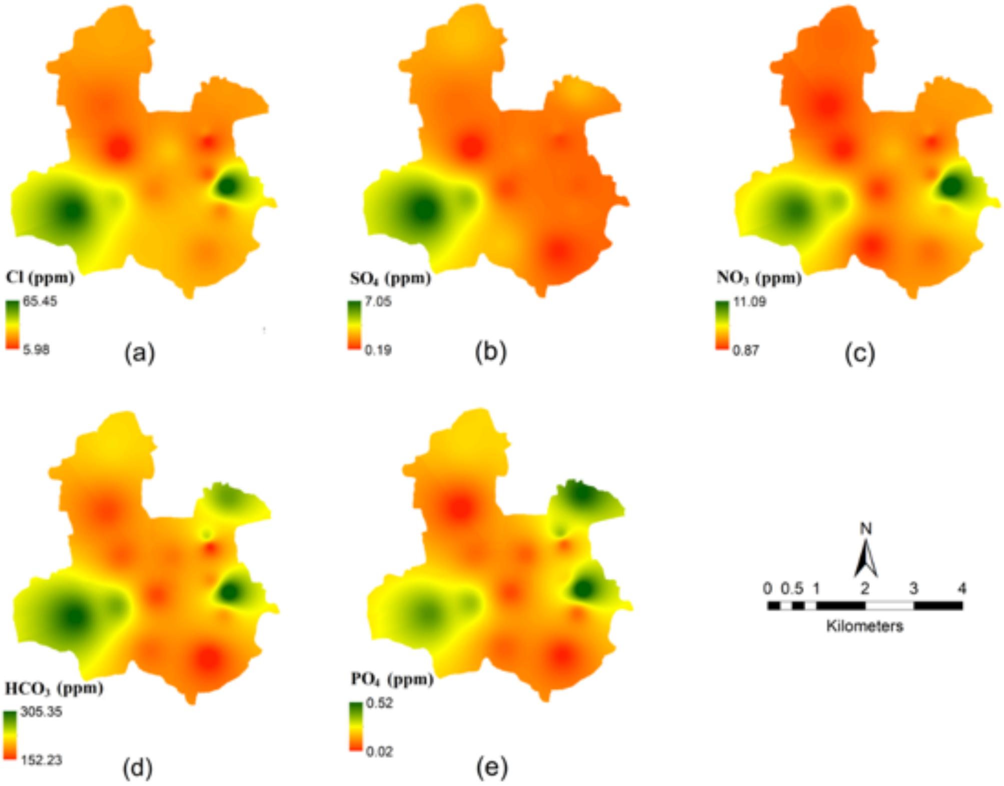

Figure 5. Spatial distribution of (a) Cl (b) SO_4 (c) NO_3 (d) HCO_3, and (e) PO_4 contents in ppm of groundwater in the study area

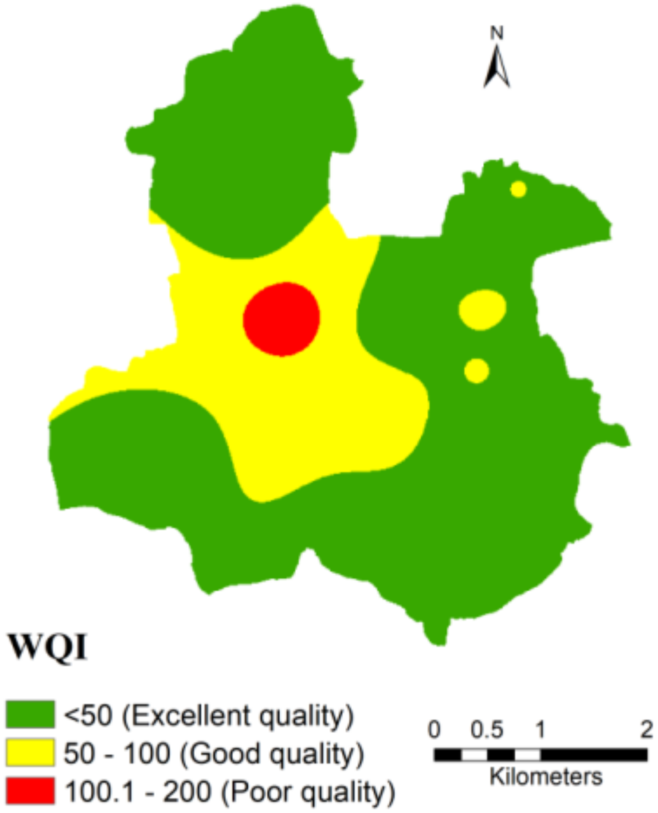

Figure 6. Spatial distribution of water quality index along with groundwater quality across the study area

ping moreover assessed that 13.35 km^2 (73.7%) area is falling under excellent quality water, and good water quality covers the area of 4.36 km^2 (24.1%), while 0.39 km^2 (2.2%) are affected with the poor category. The assertion on the area coverage might be affected in wet and dry seasons as the groundwater moves over time. The affected area under poor quality needs to be redmarked for drinking in the future and also, needs to be managed properly after assessing further chemical analysis considering heavy metals. This investigation emphasized that the single value of WQI has enough and higher affectability to order the drinking water quality than a long list of values of physicochemical parameters, previously presented in Table 1, and depicted in Figs. 3 to 5. Utilizing this approach will help decision-makers in the monitoring and appraisal of the drinking water quality in a certain area (Stigter et al., 2006; Saeedi et al., 2009). The findings of this research likewise could be applicable to similar circumstances worldwide.

4 Conclusions

This study demonstrated an interpretation of chemical analysis for groundwater quality revealing the analyzed major ions and physicochemical parameters, which were within the permissible limits for drinking with very few exceptions. It was found that the groundwater was moderately acidic and a low TDS signature persisted across the study area. The study also elucidated that most of the pairs among different chemical composition and water quality indices had a very strong correlation with a little exception considering pH, EC, and TDS pairs, weakly correlated with most of the variables. WQI mapping across the study area showed that a very small area was within the poor category for drinking. In addition, the results of the WQI and correlation matrix support the findings of the physicochemical analysis. Overall, it can be concluded that the groundwater of the study area is satisfactory for drinking purposes. It is also recommended that more samples considering other unions along with heavy metals need to be analyzed taking account of temporal variation to draw a better conclusion regarding the groundwater quality of the entire Kalihati Upazila, which would be likewise useful for proper planning and management of groundwater usage and treatment.

Acknowledgments

The authors would like to thank all the staff at the laboratory of the Department of Agricultural Chemistry, and Interdisciplinary Institute for Food Security, Bangladesh Agricultural University, Bangladesh to conduct chemical analysis for this work.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

al hadithi M. 2012. Application of water quality index to assess suitability of groundwater quality for drinking purposes in Ratmao –Pathri Rao watershed, Haridwar District, India. American Journal of Scientific and Industrial Research 3:396–402. doi: 10.5251/ajsir.2012.3.6.395.402.

Al-Omran A, Al-Barakah F, Altuquq A, Aly A, Nadeem M. 2015. Drinking water quality assessment and water quality index of Riyadh, Saudi Arabia. Water Quality Research Journal 50:287–296. doi: 10.2166/wqrjc.2015.039.

Amadi PA, Ofoegbu CO, Morrison T. 1989. Hydrogeochemical assessment of groundwater quality in parts of the niger delta, Nigeria. Environmental Geology and Water Sciences 14:195–202. doi: 10.1007/bf01705131.

Andrews SC, Robinson AK, Rodríguez-Quiñones F. 2003. Bacterial iron homeostasis. FEMS Microbiology Reviews 27:215–237. doi: 10.1016/s0168-6445(03)00055-x.

APHA. 2005. Standard methods for the examination of water and wastewater (21st ed). American Public Health Association, Washington, USA.

Bahar MM, Reza MS. 2010. Hydrochemical characteristics and quality assessment of shallow groundwater in a coastal area of Southwest Bangladesh. Environmental Earth Sciences 61:1065–1073. doi: 10.1007/s12665-009-0427-4.

Bangladesh Standard. 1997. Bangladesh Standard. The environment conservation rules 1997. Government of the People's Republic of Bangladesh, Dhaka, Bangladesh.

Bhuiyan MAH, Ganyaglo S, Suzuki S. 2014. Reconnaissance on the suitability of the available water resources for irrigation in Thakurgaon District of northwestern Bangladesh. Applied Water Science 5:229–239. doi: 10.1007/s13201-014-0184-8.

Biswas R, Roy D, Islam ARMT, Rahman M, Ali M. 2014. Assessment of drinking water related to arsenic and salinity hazard in Patuakhali district, Bangladesh. International Journal of Advanced Geosciences 2:82–85. doi: 10.14419/ijag.v2i2.3011.

Boateng TK, Opoku F, Acquaah SO, Akoto O. 2016. Groundwater quality assessment using statistical approach and water quality index in Ejisu-Juaben Municipality, Ghana. Environmental Earth Sciences 75:489–489. doi: 10.1007/s12665-015-5105-0.

Burrough PA, McDonnell R, McDonnell RA, Lloyd CD. 2015. Principles of geographical information systems. Oxford university press, UK.

Causape J, Auque L, Gimeno MJ, Mandado J, Quilez D, Aragues R. 2004. Irrigation effects on the salinity of the Arba and Riguel Rivers (Spain): present diagnosis and expected evolution using geochemical models. Environmental Geology 45:703–715. doi: 10.1007/s00254-003-0927-6.

Chopra SL, Kanwar JS. 1976. Analytical agricultural chemistry. Kalyani Publishers, India.

Das N, Rahman M, Islam M, Adham A. 2019. Assessing groundwater suitability for irrigation: a case study for Durgapur upazila, Netrokona, Bangladesh. Fundamental and Applied Agriculture 4:916–927. doi: 10.5455/faa.45057.

Davis SN, Dewiest RJ. 1966. Hydrogeology. In: Domenico PA, FW Schwartz (Eds), Physical and chemical hydrogeology. Wiley, New York, USA.

Elhatip H, Afsin M, lkay Kusu, Dirik K, Kurmac Y, Kavurmaci M. 2003. Influences of human activities and agriculture on groundwater quality of Kayseri-Incesu-Dokuzpinar springs, central Anatolian part of Turkey. Environmental Geology 44:490–494. doi: 10.1007/s00254-003-0787-0.

ESRI. 1996. ArcView Spatial Analyst. Environmental Systems Research Institute, Advanced Spatial Analysis using Raster and Vector Data, New York, USA.

Giridharan L, Venugopal T, Jayaprakash M. 2007. Evaluation of the seasonal variation on the geochemical parameters and quality assessment of the groundwater in the proximity of River Cooum, Chennai, India. Environmental Monitoring and Assessment 143:161–178. doi: 10.1007/s10661-007-9965-y.

Hossain G, Howladar MF, Nessa L, Ahmed SS, Quamruzzaman C. 2010. Hydrochemistry and Classification of Groundwater Resources of Ishwardi Municipal Area, Pabna District, Bangladesh. Geotechnical and Geological Engineering 28:671–679. doi: 10.1007/s10706-010-9326-4.

Iqbal AB, Rahman MM, Mondal DR, Khandaker NR, Khan HM, Ahsan GU, Jakariya M, Hossain MM. 2020. Assessment of bangladesh groundwater for drinking and irrigation using weighted overlay analysis. Groundwater for Sustainable Development 10:100312. doi: 10.1016/j.gsd.2019.100312.

Islam ARMT, Ahmed N, Bodrud-Doza M, Chu R. 2017a. Characterizing groundwater quality ranks for drinking purposes in Sylhet district, Bangladesh, using entropy method, spatial autocorrelation index, and geostatistics. Environmental Science and Pollution Research 24:26350–26374. doi: 10.1007/s11356-017-0254-1.

Islam ARMT, Shen S, Haque MA, Bodrud-Doza M, Maw KW, Habib MA. 2017b. Assessing groundwater quality and its sustainability in Joypurhat district of Bangladesh using GIS and multivariate statistical approaches. Environment, Development and Sustainability 20:1935–1959. doi: 10.1007/s10668-017-9971-3.

Jacintha TGA, Rawat KS, Mishra A, Singh SK. 2016. Hydrogeochemical characterization of groundwater of peninsular indian region using multivariate statistical techniques. Applied Water Science 7:3001–3013. doi: 10.1007/s13201-016-0400-9.

Javed T, Sarwar T, Ullah I, Ahmad S, Rashid S. 2019. Evaluation of groundwater quality in district Karak Khyber Pakhtunkhwa, Pakistan. Water Science 33:1–9. doi: 10.1080/11104929.2019.1626630.

Jiang Y, Wu Y, Groves C, Yuan D, Kambesis P. 2009. Natural and anthropogenic factors affecting the groundwater quality in the Nandong karst underground river system in Yunan, China. Journal of Contaminant Hydrology 109:49–61. doi: 10.1016/j.jconhyd.2009.08.001.

Ketata M, Gueddari M, Bouhlila R. 2011. Use of geographical information system and water quality index to assess groundwater quality in El Khairat deep aquifer (Enfidha, Central East Tunisia). Arabian Journal of Geosciences 5:1379–1390. doi: 10.1007/s12517-011-0292-9.

Kumar MP, Nagalakshmi K, Jayaraju N, Prasad TL, Lakshmanna B. 2020. Deciphering water quality using WQI and GIS in Tummalapalle Uranium Mining area, Cuddapah Basin, India. Water Science 34:65–74. doi: 10.1080/11104929.2020.1765450.

Kumar SK, Logeshkumaran A, Magesh NS, Godson PS, Chandrasekar N. 2014. Hydro-geochemistry and application of water quality index (WQI) for groundwater quality assessment, Anna Nagar, part of Chennai City, Tamil Nadu, India. Applied Water Science 5:335–343. doi: 10.1007/s13201-014-0196-4.

Kumar SK, Rammohan V, Sahayam JD, Jeevanandam M. 2008. Assessment of groundwater quality and hydrogeochemistry of Manimuktha River basin, Tamil Nadu, India. Environmental Monitoring and Assessment 159:341–351. doi: 10.1007/s10661-008-0633-7.

Lee SM, Min KD, Woo NC, Kim YJ, Ahn CH. 2003. Statistical models for the assessment of nitrate contamination in urban groundwater using GIS. Environmental Geology 44:210–221. doi: 10.1007/s00254-002-0747-0.

Moharir K, Pande C, Singh SK, Choudhari P, Kishan R, Jeyakumar L. 2019. Spatial interpolation approach-based appraisal of groundwater quality of arid regions. Journal of Water Supply: Research and Technology-Aqua 68:431–447. doi: 10.2166/aqua.2019.026.

Mtetwa S, Schutte C. 2002. An interactive and participative approach to water quality management in agro-rural watersheds. Water SA 28. doi: 10.4314/wsa.v28i3.4904.

Nash H, McCall GJH. 1995. Groundwater quality. In: 17th Special Report. Chapman and Hall, London, UK.

Nickson RT, McArthur JM, Shrestha B, Kyaw-Myint TO, Lowry D. 2005. Arsenic and other drinking water quality issues, Muzaffargarh District, Pakistan. Applied Geochemistry 20:55–68. doi: 10.1016/j.apgeochem.2004.06.004.

Ochuko U, Thaddeus O, Oghenero OA, John EE. 2014. A comparative assessment of water quality index (WQI) and suitability of river Ase for domestic water supply in urban and rural communities in Southern Nigeria. Int J Human Soc Sci 4:234–45.

Pande CB, Moharir KN, Singh SK, Dzwairo B. 2019. Groundwater evaluation for drinking purposes using statistical index: study of Akola and Buldhana districts of Maharashtra, India. Environment, Development and Sustainability 22:7453–7471. doi: 10.1007/s10668-019-00531-0.

Pandey HK, Tiwari V, Kumar S, Yadav A, Srivastava SK. 2020. Groundwater quality assessment of Allahabad smart city using GIS and water quality index. Sustainable Water Resources Management 6. doi: 10.1007/s40899-020-00375-x.

Pawar R, Panaskar D, Wagh V. 2014. Characterization of groundwater using water quality index of solapur industrial belt, Maharashtra, India. International Journal of Research in Engineering & Technology 2:31–36.

Raghunath HM. 1987. Groundwater (2nd edition). Wiley Eastern Ltd., New Delhi, India.

Raihan F, Alam JB. 2008. Assessment of groundwater quality in Sunamganj of Bangladesh. Iranian Journal of Environmental Health Science & Engineering 6:155–166.

Ramakrishnaiah CR, Sadashivaiah C, Ranganna G. 2009. Assessment of Water Quality Index for the Groundwater in Tumkur Taluk, Karnataka State, India. E-Journal of Chemistry 6:523–530. doi: 10.1155/2009/757424.

Robinson TP, Metternicht G. 2006. Testing the performance of spatial interpolation techniques for mapping soil properties. Computers and Electronics in Agriculture 50:97–108. doi: 10.1016/j.compag.2005.07.003.

Saeedi M, Abessi O, Sharifi F, Meraji H. 2009. Development of groundwater quality index. Environmental Monitoring and Assessment 163:327–335. doi: 10.1007/s10661-009-0837-5.

Sahu P, Sikdar PK. 2007. Hydrochemical framework of the aquifer in and around East Kolkata Wetlands, West Bengal, India. Environmental Geology 55:823–835. doi: 10.1007/s00254-007-1034-x.

Sawyer CN, McCarty PL. 1967. Chemistry of Sanitary Engineers, 2nd Edn. McGraw Hill, New York, USA.

Selvam S, Venkatramanan S, Sivasubramanian P, Chung SY, Singaraja C. 2017. Geochemical characteristics and evaluation of minor and trace elements pollution in groundwater of Tuticorin city, Tamil Nadu, India using geospatial techniques. Journal of the Geological Society of India 90:62–68. doi: 10.1007/s12594-017-0664-1.

Shahid S, Chen X, Hazarika MK. 2006. Evaluation of groundwater quality for irrigation in bangladesh using geographic information system. Journal of Hydrology and Hydromechanics 54:3–14.

Shariot-Ullah M. 2018. Impacts of sugar mill's wastewater use on physical and hydraulic properties of soil: evidence from North Bengal Sugar Mill, Natore, Bangladesh. Sustainable Water Resources Management 5:863–871. doi: 10.1007/s40899-018-0256-2.

Singh B, Narain P. 1980. Seasonal fluctuations in the quality of under-ground irrigation water in a brackish water affected tract. Agrochimica 24:169–175.

Singh P, Khan IA. 2011. Ground water quality assessment of Dhankawadi ward of Pune by using GIS. International Journal of Geomatics and Geosciences 2:688–703.

Singh S, Singh C, Kumar K, Gupta R, Mukherjee S. 2009. Spatial-Temporal Monitoring of Groundwater Using Multivariate Statistical Techniques in Bareilly District of Uttar Pradesh, India. Journal of Hydrology and Hydromechanics 57. doi: 10.2478/v10098-009-0005-1.

Srivastava SK, Ramanathan AL. 2007. Geochemical assessment of groundwater quality in vicinity of Bhalswa landfill, Delhi, India, using graphical and multivariate statistical methods. Environmental Geology 53:1509–1528. doi: 10.1007/s00254-007-0762-2.

Stigter TY, Ribeiro L, Dill AMMC. 2006. Application of a groundwater quality index as an assessment and communication tool in agro-environmental policies – Two Portuguese case studies. Journal of Hydrology 327:578–591. doi: 10.1016/j.jhydrol.2005.12.001.

Subramani T, Elango L, Damodarasamy SR. 2005. Groundwater quality and its suitability for drinking and agricultural use in Chithar River Basin, Tamil Nadu, India. Environmental Geology 47:1099–1110. doi: 10.1007/s00254-005-1243-0.

Tendon HLS. 1993. Methods of analysis of soil plants water and fertilizers. Fertilization Development and Consultation Organisation, New Delhi, India.

Tiwari TN, Mishra MA. 1985. A preliminary assignment of water quality index of major Indian rivers. Indian Journal of Environmental Protection 5:276–279.

Todd DK, Mays LW. 2004. Groundwater hydrology. John Wiley & Sons.

Tyagi S, Sharma B, Singh P, Dobhal R. 2020. Water quality assessment in terms of water quality index. American Journal of Water Resources 1:34–38. doi: 10.12691/ajwr-1-3-3.

Vasudevan S, Lakshmi J, Sozhan G. 2009. Studies on the removal of iron from drinking water by electrocoagulation - a clean process. CLEAN - Soil, Air, Water 37:45–51. doi: 10.1002/clen.200800175.

WHO Standard. 2017. Guidelines for drinking-water quality: first addendum to the fourth edition. Wold Health Organization, Geneva, Switzerland.

Yasmin G, Islam D, Islam M, ShariotUllah M, Adham A. 2019. Evaluation of groundwater quality for irrigation and drinking purposes in Barishal district of Bangladesh. Fundamental and Applied Agriculture 4:632–641. doi: 10.5455/faa.301258.

Zahid A, Ahmed SRU. 2006. Groundwater resources development in bangladesh: Contribution to irrigation for food security and constraints to sustainability. Groundwater Governance in Asia Series 1:25–46.

Zhou X, Shen Y, Zhang H, Song C, Li J, Liu Y. 2015. Hydrochemistry of the natural low pH groundwater in the coastal aquifers near Beihai, China. Journal of Ocean University of China 14:475–483. doi: 10.1007/s11802-015-2631-z.

The Official Journal of the
Farm to Fork Foundation
ISSN: 2518–2021 (print)
ISSN: 2415–4474 (electronic)
http://www.f2ffoundation.org/faa