Hydro-geochemical evaluation of groundwater for irrigation in the Ganges river basin areas of Bangladesh

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Abstract

Groundwater is a vital source of irrigation water, and it provides over 80% of the irrigated water supply in Bangladesh. The study aimed to assess the status of irrigation water of the Ganges river basin areas in the middle-west part of Bangladesh through the hydrogeochemical characterization and classification of groundwater. The study parameters were pH, EC, TDS, Ca^{2+}, Mg^{2+}, total hardness, Na^{+}, K^{+}, B, Cl^{-}, HCO_3^{-}, SO_4^{2-}, NO_3^{-}, and PO_4^{3-} along with irrigation water quality index (IWQ_{index}), Na%, soluble sodium percentage, sodium adsorption ratio, residual sodium bicarbonate, magnesium adsorption ratio, permeability index, and Kelley's ratio. The results showed that most of the water samples were acidic in the pre-monsoon and alkaline in the post-monsoon seasons, and the water type was Ca-HCO_3. The significant geochemical process in the area determined was calcite and dolomite mineral dissolution, and there was no active cation exchange, and silicate weathering occurred. The statistical analyses showed that both the geogenic and anthropogenic sources were controlling the chemistry of the groundwater aquifers. Concerning irrigation water quality, the results revealed that all the quality parameters and IWQ_{index} (32.04 to 45.39) were within the safety ranges, except for the EC and total hardness. The study results would be useful for future groundwater monitoring and management of the Ganges basin areas of Bangladesh part.

Introduction

The Ganges River flows from the Himalayas of India and enters the middle-west parts of Bangladesh (Fig. 1). Every year, this river carrying a large amount of alluvial sediment, which washed away and finally deposited in basin areas and then make it a larger arable region in the country. The study considered the Kushtia District for its significant hydro-geologic variation and widespread irrigated land. There are 2 million people who lived in this study area, and of them, 70% are engaged in the agricultural sector. In Bangladesh, groundwater irrigation is the key factor to cultivate the high-yield crop, especially in the dry winter season. But, owing to the obstacle of trans-boundary river flow from India to Bangladesh, the watercourse in Bangladesh territory impeded significantly. Recently, the trans-boundary river, the Ganges, and three other branched rivers in the study area have become dead in the dry season, and at that time the surface water is not available for irrigation. So, people typically depend on groundwater systems for irrigation activities in that region. Throughout 1979–1980, the portion of groundwater in the total irrigation events was 11.5% when the total irrigated land grew to 1.60 million hectares (Bhuiyan 1984). At present, that portion has raised to 30% compared to the prior consumption mainly due to crop diversity and surface water shortage (BBS 2019). For that cause, it is essential to know the geochemical facies of groundwater of the local aquifer system.

Bangladesh has a great variety of physiographic sceneries, with multifaceted interactions among them that controlled the quality of groundwater and soil resources. Kushtia District is located in the upper deltaic plain (UDP), and it lies on the Ganges flood plain areas of the western region of Bangladesh. The dynamic behavior of the UDP and the negative impact of the Farakka Barrage near the Indian border makes groundwater susceptible to changes in geochemistry. In this floodplain area, groundwater degradation usually occurs due to frequent hydro-geochemical variation, excess water mining, arsenic contamination, interaction of the groundwater with saltwater, and agrochemicals deposited on the topsoil (Sanford et al. 2007; Mondal et al. 2008). Groundwater interaction with aquifer rocks significantly affects the groundwater chemistry, and this mechanism varies with season and place (Kumar et al. 2014; Ahmed et al. 2018). Different geochemical facies also foremost the chemical features of groundwater and well recognized by many researchers i.e., Park et al. (2005); Naik et al. (2009); Rajendiran et al. (2012); Xiao et al. (2012); Sivasubramanian et al. (2013); Kumar et al. (2014); Bhuiyan et al. (2016); and Islam et al. (2017c, 2018). Some studies in Bangladesh (e.g., Bhuiyan et al. 2010; Mirza et al. 2012; Islam et al. 2016, 2017a, b, c; Ahmed et al. 2018) have been carried out, exclusively in the coastal zone where salinity is a big problem. But in the upper Ganges river flood plain, where water hardness and heavy iron-loading are the main quality issues, there is no enough information on which to base geochemical investigations have been conducted. Hence, constant observation and ranking of the hydrochemical characteristics are vital to assess the water quality and protect the further worsening in the study area.

The assessment of inclusive groundwater quality is a difficult and very complicated procedure that interrelates with several physical and chemical factors accompanied by numerous regulatory variables. Horton (1965) primarily proposed a combined water quality index (WQI) for measuring water quality. Then, many irrigation water quality indexes were developed worldwide by numerous researchers (e.g., Ayers 1977; Ayers and Westcot 1985; Simsek and Gunduz 2007; Meireles et al. 2010; Bauder et al. 2011; Hussain et al. 2012; Bozdag 2015; Arslan 2017; Zaman et al. 2018). For instance, Simsek and Gunduz (2007) have established a GIS-based irrigation water quality index (IWQ_{index}) by a combination of recognized geochemical parameters (salinity hazard, ion toxicity, and others) to assess the irrigation water quality of the Simav Plain in Turkey. Meireles et al. (2010) also proposed a new technique for the evaluation of irrigation water quality. Furthermore, Ashraf et al. (2011) established an irrigation water index using GIS for computing SAR, RSC, or SSP with other parameters. Later, Romanelli et al. (2012) have evaluated the IWQ_{index} by fitting together geological features, water chemistry, and other parameters including EC, Na%, SAR, SSP, RSC, slops, hydraulic conductivity, aquifer width to evaluate groundwater appropriateness for irrigation in Wet Pampa Plain, Argentina. After then, combined with GIS, Bozdag (2015) has used an analytic hierarchy process (AHP) to measure the irrigation water suitability in central Anatolia, Turkey. Recently, many studies (Bhuiyan et al. 2015; Shammi et al. 2016; Howladar et al. 2017; Islam et al. 2017a,b,c,d; Rahman et al. 2017; Ahmed et al. 2018) were carried out in different parts of Bangladesh to judge the suitability of irrigation groundwater. A few inclusive assessments were found in that literature that combined key parameters indices including, salinity hazard, permeability hazard, specific ion toxicity, trace metal hazard, and mixed-effect to delicate crops.

The study aimed to assess the groundwater suitability for irrigation purposes in the Ganges basin in the middle-western parts of Bangladesh. The study considered the geochemical processes and classification of water established through numerous statistical approaches, multiple linear regression methods, geostatistical modeling, and using various irrigation water quality indices with IWQ_{index}. The study results would provide insightful guidelines on agricultural water management for agricultural activists, policymakers, and water managers.

Methods And Materials

Study area

Geographically the study area is positioned at 23°42' and 24°12' north latitudes and 89°20' east longitudes. The total area of sampling position is 1621 sq km and is bounded by the Ganges river (Padma river) and the other three branch rivers created a big deltaic plain (Fig. 1). The total population of that zone is around 2 million and the maximum of the people involve in agricultural activities (BBS 2018). The soil environment in the study area is good enough fertile as the District situated in the floodplain of the Ganges river, also the physiographic situation belongs to the higher Ganges flood plain. The soil surface characterizes uniform geomorphology which seems to level landscape with an elevation of around 9 m above sea-level, but in some places, it consists of shallow depression and somewhat higher ridges (DPHE 2010). The study area is covered by a subtropical humid climate with a warm and rainy monsoon and a pronounced dry season in the winter period. The maximum temperature observes in May-June and the minimum in December-January. Total rain of 1167 mm/y is received by this area. In the study area, around 95% of mining groundwater used for agricultural activities and the remaining for consumption as drinking water. So, groundwater quality should be assessed as the most efficient in terms of irrigation purposes in this zone.

Lithology and hydrogeology situated

Figure 2 shows the complete geology and hydrogeological feature of the study area. Geographically, the study area a placed under the foredeep part of the Bengal basin area. This zone is in a flood basin of the Padma river and categorized by active Ganges floodplain deposits with low relief, crossed by rivers, and enclosed by fluvial marshes and swamps. The upper lithology zone of the study area consists of sedimental sand in the southern portion and deltaic coarse sand and silt in the northern portion. The sedimental sands are part of the Ganges active floodplain and overstep the deltaic sand and slit deposition, which crop out further south part. The geology covers gravel and rough grained sand which occurs at the base, and fine grained sand and silt in the uppermost part of the investigated area. The geological cross-section of this zone shows a four-layer aquifer architecture, i.e., upper and lower shallow aquifers and upper and lower deep aquifer systems across the Ganges (BGS-DPHE 2001).

The primary aquifer of the study zone comprises unconsolidated fluvial-sediments which are spread over the surface by the impermeable silt and clayey soil. According to subsurface hydro-geological info, it appears that major good aquifers of this area occur between 20 and 150 m depth from the surface. The thickness of the local aquifer differs because of the effects of basement rock depth and the crosswise extent of the aquifer. The groundwater flow direction in the study area is typically from north to south (Fig. 2). The groundwater is recharged naturally by rainfall and floodwaters during the rainy monsoon season, resulting in groundwater table rise. After the rainy season, a portion of aquifers recharged from the river, stream, pond, and wetland. The piezometric level of groundwater drops during the dry period due to over-mining for irrigation with low definite yield and is refilled completely during the rainy season.

Sampling and analytical procedures

A total of 40 sampling spots of the Ganges basin area in the middle-western part of Bangladesh (Fig. 1) were designated for this investigation during pre-monsoon (PRM) and post-monsoon (POM) seasons. Groundwater samples were collected randomly from the selected hand pump, shallow and semi-deep tube-wells and their depths were ranges from 22 to 125 m. According to standard procedure (US-APHA 2005) samples were collected in pre-washed high-density polyethylene plastic bottles after pumping 3–5 min. to get clean water or avoid any debris. For metal analysis, the samples were preserved with AR grade HNO_3 and kept at 4°C for further analysis. The pH, EC, and TDS were measured in-situ by the moveable multimeter. Chloride (Cl^-), sulfate (SO_4^{2-}), nitrate (NO_3^-), and phosphate (PO_4^{3-}) were measured by UV-spectrophotometer using the respective standard solution. Calcium (Ca), magnesium (Mg), bicarbonate (HCO_3^-), and total hardness (TH) were determined by the titrimetric method. Sodium (Na^+) and potassium (K^+) were determined using a flame photometer. Trace elements viz. iron (Fe), manganese (Mn), boron (B), lead (Pb), chromium (Cr), cobalt (Co), copper (Cu), and zinc (Zn) were measured by the well-recognized method through Perkin-Elmer Atomic Absorption Spectrophotometer (Model 3110). The US-APHA (2005) methods were followed in every phase of all the above quantitative analyses. The quality control was kept in all metal analyses as stated by individual instruction manuals and method precision was more than 95% in confidence interval (*CI*) with the correlation coefficient, *r*=~1 of respective calibration curves. The method was recalibrated after running 10 samples and all quantitative analyses were executed in triplicate to ensure precision. Cation and anion charge balance was added proof of the accuracy of the data was determined by the following Eq. (1). Chemical and spectrometry analyses were carried out in the own laboratory of IES and Central Science Lab, University of Rajshahi, Bangladesh.

$$\text{Charge balance error, CBE} = \frac{\sum M_c|N_c| - \sum M_a|N_a|}{\sum M_c|N_c| + \sum M_a|N_a|} \times 100 - - - - - - - - (1)$$

Where M_c and N_c are molar concentration and charge of cation; similarly, M_a and N_a are the same for the anion. All calculated ionic balances error is within ± 5%. Also, $TDS_{measured}$ and $TDS_{calculated}$ ratios were computed for quality-control measures. The computed ratio varies from 1 to 1.3, which shows the accuracy of analytical data.

Irrigation water quality (IWQ) index

To establish a fast view of the inclusive irrigational water quality, two methods viz. Simsek and Gunduz (2007) and Meireles et al. (2010) are followed for the computation of IWQ_{index}. Here we followed the little modified the first one, which includes the trace metal toxicity to the crop, but the second one excluded the metal toxicity. The IWQ_{index} is prepared based on the linear correlation of five sets of irrigation water quality indices that are connected to form a single index value to evaluate the irrigation water quality in study areas. According to the guiding by Ayers and Westcot (1985), 5 (five) categories of irrigation water quality parameters, for instance, salinity threat ($w = 5$), permeability hazard ($w = 4$), definite ion toxicity ($w = 3$), trace metal toxicity ($w = 2$), and miscellaneous effects to sensitive crop ($w = 1$) are designated (Table 1). Simsek and Gunduz (2007) were selected complete standard measures for irrigation water quality indexes by the following Eq. 2:

$$IWQ_{index} = \sum_{i=1}^{5} Gi \text{ - - - - - - - - } (2)$$

Here, I = incremental index, and G = involvement of each one of the four (4) hazard groups that are vital to evaluate the quality of specific irrigation water resources; and G can be measured by the following Eq. 3:

$$G = \frac{w}{n}\sum_{k=1}^{n}(r_k) \text{ - - - - - - - - - - } (3)$$

Here, k = incremental index; n = total number of parameters for the calculation; w = weight factor of the category; and r= rating values of an individual parameter (Table 1).

Irrigation water assessment indices

For water quality assessment of irrigation, there are four most common criteria like EC or TDS, sodium adsorption ratio (SAR), magnesium adsorption ratio (MAR), the concentration of some ions like Na^+, HCO_3^-/CO_3^{2-}, and Cl^- are considered (Michael 1978; Raghunath 1987). The equations of some water quality indices for irrigation are listed in Table 2. In all the equations, the concentrations are stated as milli-equivalents per liter (mEq/L) and are calculated by dividing the aqueous concentration of the consistent ion expressed in mg/L by the product of its ionic charge and atomic weight.

Data analysis

Several multivariate statistical methods for instance, correlation matrix analysis, principal component analysis (PCA), Hierarchical cluster analysis (HCA), linear regression, several bivariate models, Piper and Gibb's plot were used to determine the classification and solutes source of the groundwater solution. Statistical analysis was done by SPSS and XLSTAT software. Pearson's correlation matrix was carried out to assess the like or unlike the source of parameters measured in the groundwater sample. The strength of a linear correlation between two variables or the degree of association was assessed by correlation coefficient matrix, r. Once the above two variables were considered concurrently, multiple linear regression analyses were used to assess their interdependence (Adhikari et al. 2009). For multiple regression, as a quantity of the degree of association, the coefficient of determination, the R^2 value is more easily explainable than correlation coefficient, r because R^2 is equivalent to the part of the total variability in the dependent variable that may be imposed the effects of the independent variables. PCA and HCA were used to categorize the groundwater samples based on their hydro-geochemical features (Wu et al. 2014). The PC analysis is one of the most common methods to regulate the geochemical dissolution/weathering measures, connected to aquifer mineralization and discriminate the key factors like anthropogenic and natural processes influencing groundwater chemistry (Bouzourra et al. 2015). The Q- and R-mode HCAs of the groundwater samples were further introduced to outline groups of samples with the content of alike hydrochemical parameters and to provide helpful statistics to the results gotten from PCA. The HCAs were computed by Ward's agglomeration method and squared Euclidean distance was measured to find the distance between clusters of analogous parameter contents (Bhuiyan et al. 2016; Chegbeleh et al. 2020). Furthermore, including Gibb's diagram, various bivariant plots are constructed to evaluate the hydro-geochemical processes in the study area. Besides, to assess the irrigation water quality, several techniques i.e., IWQ_{index}, Overall IWQ_{index} (proposed), US salinity hazard diagram, Willcox diagram, and permeability index (PI) diagram are constructed by the respective software.

Results And Discussion

Water chemistry

Natural water contains a small fraction portion of the various nutrients and minerals. The water chemistry depends on some factors such as overall geology, quality and quantity of recharging water, weathering of the different rocks, and pollution sources potentiality. The interaction of these factors creates complex water chemistry (Singh et al. 2011). The datasets of groundwater were obtained from various depths (22 to 125 m) during both the pre-monsoon (PRM) and post-monsoon (POM) seasons and it was analyzed for geochemical evaluation as well as irrigation water suitability. The descriptive statistical analyses of physical, chemical, and trace metal parameters of groundwater samples are shown in Table 3. It showed that at least 11 parameters out of a total of 22, the standard deviation (±SD) is varied noticeably, demonstrating the chemical composition of samples is impacted by various processes. The result shows that major cations and anion in the water samples are Ca^{2+}, Mg^{2+}, and HCO_3^-. The sequential order of main ions of groundwater samples is $Ca^{2+}>Mg^{2+}>Na^+>K^+$, and $HCO_3^- >> Cl^- > SO_4^{2-} > NO_3^- > PO_4^{3-}$ (Fig. 3).

pH, EC, and TDS are the driving parameters to evaluate the geochemical processes. The pH of the samples ranged from 6.65 to 7.8 with an average value of 7.01±0.154 during the PRM and 7.0 to 8.91 with an average value of 7.83±0.154 during the POM season, indicated that the water was slightly acidic and alkaline nature, respectively (Table 3). In the PRM season, the acidic nature of groundwater was mainly attributable to natural biogeochemical actions, plant-root respiration, and leachates from organic acids from the decomposition of organic matter (Sethy et al. 2016). The slightly basic nature of water in the POM was the cause of the mineralization as well as the dissolution of carbonate/bicarbonate substances through percolation and infiltration during recharge of the aquifer (Islam et al. 2017a; Mostafa et al. 2017). The higher pH values with the increased HCO_3^- concentration in the POM seasons indicated that the H^+ boned to the buffering agent HCO_3^-. All the pH values of groundwater are suitable for the irrigation water standards of DoE and FAO (Table 3). The EC values of the water samples were varied from 366 to 1035 µS/cm and 662 to 1708 µS/cm at the PRM and POM, respectively. A higher EC value was found in the POM season compared to the PRM may be the cause of mineralization of water during surface run-off and percolation in the rainy season (Helal et al. 2011). Big variations in EC values (±SD: 172.5 and 206.1) are mostly attributed to geochemical activities viz. exchange of ions, percolation and infiltration of rainwater, evaporation, and sediment dissolution (Saha et al. 2008; Mostafa et al. 2011). However, these EC ranges were much below corresponding to the waters in the coastal areas of Bangladesh (Mirza et al. 2012; Miah et al. 2015; Sukhen et al. 2017; Islam and Majumder 2020; Serder et al. 2020). The EC value mostly depends on the rich concentration of Ca, Mg, and HCO_3^-, which are the main controlling factor to evaluate the geochemical features in this study. The TDS value of water typically depends on the EC. TDS of groundwater was varied along with the EC values. The results showed a higher concentration of HCO_3^- during the POM season and Na^+ and Cl^- enrichment in the PRM season due to the intense evaporation.

Concentrations of Na^+, K^+, and Cl^- in groundwater of the study areas are very low corresponding to southern and other parts of the country (Bhuiyan et al. 2010; Islam et al. 2016, 2017a, b, c; Rahman et al. 2017; Ahmed et al. 2018; Serder et al. 2020). But the load of Ca^{2+}, Mg^{2+}, and HCO_3^- are significantly high, which accounted for more than 95% of total ions in groundwater during both seasons and these are the dominating ions of the collected samples indicating the water quality was very hard (Table 3 & Fig. 3). This might be due to the over-mining of groundwater, cation exchange, excess weathering of carbonate rock, and dissolution of carbonic acid (Mostafa et al. 2017; Islam et al. 2017b; Chegbele et al. 2020). Lower river-flow and overexploitation of groundwater are the main cause of the over-loading of the above-mentioned ions. The concentration of other anions like SO_4^{2-}, NO_3^-, and PO_4^{3-} were found within the acceptable limits for irrigation water standard. Except for the Fe, the concentration of analyzed trace metals were fall in guideline value and this would be used in IWQ_{index} calculation only. The dependence of detecting parameters concentration with water-depth is not observed at all. Based on the water chemistry of the study area, the evaluation of geochemical processes is extensively discussed in subsequent Sections.

Correlation analysis

The Pearson correlation matrix of analyzing groundwater geochemical parameters in both seasons is presented in Table 4. In some cases, the dissimilatory matrix value for the same pair of parameters was observed in both seasons. On the PRM season, EC, TDS, Ca^{2+}, Mg^{2+}, K^+, TH, and HCO_3^- of the samples are highly correlated ($r>0.5$, $p=0.01$, at 95% *CI*) to each other. But in the POM, EC was significantly correlated with TDS, Ca, TH, HCO_3^-, and SO_4^{2-}. The high value of EC mainly caused by the divalent cation and elevated concentration of HCO_3^-, but not with univalent ions such as Na^+, K^+, Cl^-, and NO_3^-. The EC value of coastal groundwater of the country was above 3000 µS/cm due to the saltwater intrusion into the ground aquifer (Serder et al. 2020). The correlation between EC and TDS ($r=$ 0.9) confirmed that the TDS ratio (Section 2), which supports the accuracy of TDS measurement in the study. TH was strongly correlated with Ca^{2+}, Mg^{2+}, HCO_3^-, and SO_4^{2-} in both the seasons, indicating its Ca-Mg-HCO_3 type temporary hardness (sulfate concentration is very low). All the parameters were not correlated with water depth because entire samples were collected from the same upper shallow aquifer. The deep aquifers started from over 150 m below the surface of the study area. This matrix Table explores important information to evaluate the hydro-geochemistry of the study areas.

Principal component analysis (PCA)

PCA is a technique that provides supplementary to classical approaches of hydro-geochemical study, which shows the correlation among different water quality variables (Morell et al. 1996). An inter-element correlation was determined among the 15 different hydrochemical variables for both PRM and POM seasons (Table 5). Results show a total variance of 74.50% and 74.49% in PRM and POM seasons with Eigenvalue >1 (Fig. 4), respectively, as determined by five PCs of R-mode. About 60% of the total variance in both seasons is displayed in the first three loadings. The positive and negative values in PCA clarified that the water samples were affected or unaffected by the presence of extracted loads on an exact constituent. EC, TDS, Ca^{2+}, SO_4^{2-}, and HCO_3^- showed a very strong association (bold type) with PC1 in PRM, but, 4 components viz. Ca, TH, EC, and HCO_3^- showed the same loading with PC1. However, only NO_3^- is strongly loaded for PC2 in the POM season, but there is no component which strongly associated. Besides, TH, K, and Mg exhibited moderately loading (italic type) for PC1 in PRM seasons. On the other hand, SO_4^{2-}, TDS, Mg, and Na showed a moderate association for the same component number in the POM season. In PRM season, the only pH for PC2 and PO_4^{3-} for PC4 are moderately associated. Similarly, TDS for PC2 and Na for PC3 is moderately loaded in the POM season. Strong with moderately strong and positive loading with Ca^{2+}, Mg^{2+}, SO_4^{2-}, and HCO_3^- recommend rock-water interaction with ion-exchange (Irabar et al. 2008; Islam et al. 2017b) during both seasons. The higher loading factors of Ca and HCO_3^- corresponds with events like carbonate-rock (calcite and dolomite) dissolution that could be revealed by elevated concentrations of Ca^{2+}, HCO_3^-, and Mg^{2+} (Kumar 2014). HCO_3^- corresponds with a dissolute carbonate environment and amphiprotic characteristics in groundwater (Rahman et al. 2017). The strong association among EC, TH, and TDS indicate the presence of huge ionic component, mainly as Ca^{2+}, Mg^{2+}, HCO_3^-, and SO_4^{2-}, which are accumulated by aquifer rock-water interaction and anthropogenic sources, like chemical manures from agricultural run-off (Kumar 2014; Bodrud-Doza et al. 2016). In both seasons, an association of Cl^- and Na^+ is too less than the groundwater of the coastal southern part of Bangladesh, where seawater intrusion has occurred. As correlation matrix, water depth association is very weak, indicating the water samples loaded by the same compositions in the study area. Substantial loading of pH and NO_3^- could be from agricultural and stationary water contaminated with fertilizers from different non-point sources. The findings of PCA are examined by cluster analysis and different bivariant linear regression models, which are discussed in the next sub-sections.

Cluster analysis (CA)

The hydro-geochemical parameters of samples in both seasons presented three (3) main cluster groups based on a dendrogram using Ward`s method (Fig. 5), with a Phenom line drawn at a linkage distance of about 3.5 in R-mode cluster analysis. Parameters the fit in the same cluster are likely to have been invented from the same rock source (Ahmed et al. 2018). Like PCA, cluster analysis seats variables (samples) into groups based on illustrious same features and associations with each other. In agglomerative schedule cluster analysis, the most similar variables are cited in one cluster and linked to a closely associated cluster(s) and further from clusters with less relative, all of which are linked to form one big cluster (Chegbeleh et al. 2020). The dendrogram demonstrates close associations between K^+, PO_4^{3-}, B, pH, NO_3^-, Na^+, SO_4^{2-}, Mg^{2+}, Cl^-, Ca^{2+}, and depth in Cluster I (Fig. 5). This designated the possible impacts of contamination of infiltrating precipitation and/or recharge, perhaps from agricultural input manures and related human-caused activities. Inorganic manures, such as NKP, urea, and TSP fertilizer may increase groundwater PO_4^{3}, K^+, and NO_3^- content, meanwhile these fertilizers are composed mainly of such chemicals, while the dissolution of K-rich feldspar rock is connected with the release of K^+ and other related ions in water. Ca^{2+}, Mg^{2+}, Na^+, and Cl^- represents a groundwater system dominated by rock-water interaction, maybe influenced by acidic groundwater conditions because of lower pH (7) of the maximum samples in the study areas (mainly in PRM season) (Subyani and Ahmadi 2010). This interaction is characterized mainly by silicate and carbonate minerals (calcite and dolomite) dissolution which releases such ions in the aquifer. But, what type of minerals is weathered in the aquifer understood by the Piper, Gibb's, and various bivariate diagrams. Similarly, SO_4^{2-} could also introduce from the oxidation of pyrite minerals, or from the dissolution of sulfate minerals, especially in recharge areas where the bedrock of the aquifer is exposed to such conditions (Miao et al. 2013; Amiri et al. 2014). The second cluster (CA-2) shows a similar association between TH and TDS proposes the domination of groundwater by precipitation and associated interaction with atmospheric CO_2. Cluster-3 includes EC and HCO_3^- which are associated with each other and the high value of EC mainly caused by HCO_3^- that confirmed through a different bivariate test.

Groundwater mineralization process

The rock-water interaction and movement of solutes are the key factors controlling the groundwater mineralization processes. Bivariate plots of major ions compared to TDS show that the geochemical facies took part in the groundwater mineralization (Selvakumar et al. 2017) (Fig. 6). The plots demonstrate that Ca^{2+} (PRM: R^2=0.971, POM: R^2=0.379), HCO_3^- (PRM: R^2=0.603, POM: R^2=0.243), and SO_4^{2-} (PRM: R^2=0.638, POM: R^2=0.325) ions of groundwater are strongly correlated with TDS in both PRM and POM seasons, representing the dominant components that contribute to the groundwater mineralization in the aquifer system. Water chemistry indicated that the Ca^{2+}, Mg^{2+}, and HCO_3^- are the most active ions in groundwater samples of the study area and these results recommend the continuous adding of these ions along the groundwater flow path that also significantly contributes to groundwater mineralization. Those ions may be originated from analogous sources. Accordingly, weathering or dissolution is the natural geochemical course controlled by the salt concentration along the groundwater flow path. Carbonate dissolution results from precipitation saturated with atmospheric CO_2 and grow rich in carbonic acid (Nayak and Sahood 2011). This acid affects the dissolution of carbonate rocks (calcite and dolomite) in the groundwater system (Nur et al. 2012). The aquifer in the study region when in interaction with groundwater undergoes calcite/dolomite rock dissolution. Similar findings were made by Bhuiyan et al. (2015); Rahman et al. (2017); Ahmed et al. (2018) in the groundwater geochemistry studies of northern and northwestern Bangladesh. Throughout weathering and water flow in rocks, chemical elements leached out and dissolved in groundwater (Naseem et al. 2010). The SO_4^{2-} concentration of the samples is comparatively higher than the other part of the country's groundwater (Rahman et al. 2017; Ahmed et al. 2018) and it is significantly correlated to TDS (Fig. 6). SO_4^{2-} loadings caused maybe by the heavy oxidation of pyrites rock at the anaerobic condition or by sulfate-rock dissolution. The molar ratio Ca^{2+}/SO_4^{2-} is very high compared to the molar concentration of SO_4^{2-} indicating an insignificant role of the pyrite oxidation process (Wu et al. 2008; Singh et al. 2018). It is assumed that SO_4^{2-} comes from the dissolution of sulfate baring Ca- or Mg-minerals. Again, plots show that along with TDS, the concentrations of Ca^{2+}, Mg^{2+}, HCO_3^-, and SO_4^{2-} increase and become more scattered from PRM to POM season. This is because of heavy rainfall and some excess agricultural activities just before the POM period. The other ions, Na^+ and Cl^- are positively correlated with TDS values but the relations are very weak and scattered. So, these ions are not the controlling components of the total geochemical processing.

Geochemical evaluation -*Source rock weathering*

The study plotted Piper's and Chadha's diagram to explore the geochemistry and water types of groundwater in the areas (Piper 1944; Chadha 1999). The piper diagram of cations Ca^{2+}, Mg^{2+}, Na^+, and K^+ and anions HCO_3^-, Cl^-, and SO_4^{2-} was used to determine water categories for both seasons (Fig. 7a). Water sample cataloging was based on the symbolic area in the piper diagram, with most water samples categorized as absolutely Ca and HCO_3 type and water class denoted as Ca-HCO_3. But for PRM season, a tittle number of samples lays in no dominant type area. These samples may classify roughly as Ca-Mg-HCO_3 type. From Chadha's classification diagram (Fig. 7b), the linear plots of HCO_3^- - ($Cl+SO_4+NO_3+PO_4$) vs (Ca+Mg)-(Na+K) shows strongly positively correlated (R^2=0.6902 in PRM and R^2=0.9714 in POM) that indicates the prevalence of Ca-HCO_3 facies and reveals the alkaline earth metals (Ca^{2+} and Mg^{2+}) significantly exceed the alkali metals (Na^+ and K^+), and strong conjugate base (HCO_3^-) dominate over a weak conjugate base (Cl^-, SO_4^{2-}, NO_3^-, and PO_4^{3-}). So, both diagrams represent the Ca-HCO_3 type of water class in the groundwater.

The Gibbs diagram is widely used to demonstrate the relationship between aquifer lithology and water chemistry (Gibbs 1970). Two plots (Fig. 8a,b) denote TDS vs Na/(Na+Ca) and TDS vs. Cl/(Cl+HCO_3), and both Figures show that all the water samples during PRM and POM seasons fall in the rock-weathering dominance region. It is noted that both the cation (a) and anion (b) plots describe the occurrence of weathering reactions in the study area. Now, it is important to find out the feature of rock-weathering and the rock-water interaction process.

Major geogenic influencing factors of weathering created from rock-water interaction and partial influencing factors from evaporation, and rock-water interaction impacted by carbonate dissolution, silicate weathering, evaporate dissolution, etc. (Kumar 2014). The feature of weathering processes was tested by the log-log scale on bivariate plots of Ca^{2+}/Na^{+} vs. $HCO3^{-}/Na^{+}$ that indicating a complete carbonate mineral dissolution during the PRM and POM seasons (Fig. 9a). Another molar ratio of Mg^{2+}/Na^{+} vs. Ca^{2+}/Na^{+} (Fig. 9b) bivariate plot demonstrates higher magnitudes of Ca^{2+}/Na^{+} and Mg^{2+}/Na^{+} ratios for groundwater (PRM: 4.0, 2.33; POM: 5.8, 2.4; respectively). The observed higher molar ratio for groundwater was ascribed to the influence of carbonate dissolution rather than silicate weathering. So, carbonate dissolution was a major process controlling the salt contents in groundwater for both seasons. This geochemical process supports the assumptions of the previous discussion on the mineralization process, PCA, and HCA test.

The results showed that the major cations and anions are largely resulting from rock-weathering rather than evaporation, crystallization, and precipitation (Fig. 8). Besides, Fig. 9 demonstrates that this rock-weathering was categorized as carbonate-based minerals (calcite and dolomite) weathering. In this Figure, a major quantity of these ions can be resulting from the weathering of crystalline calcite/dolomitic limestones and Ca-Mg silicates (Wen et al. 2005). Hence, it is important to recognize which minerals are dominating ions in the waterbody. No enough cation exchange occurred in the groundwater of the study area can be explained by the plot of (Na+K)-Cl vs. (Ca+Mg) - (HCO_3+SO_4) (Fig. 10). If effective cation exchange within Na^{+} and (Ca^{2+}+Mg^{2+}) were active in an aquifer, the slope would be negative (-1) (i.e., y = -x). The negative slope (-0.408) was found in the POM season indicated that cation exchange might have occurred (Fig. 10). But in the PRM season, the slope shows a slightly positive value, indicating no cation exchange occurred in that season. So, the metal concentrations are mostly depending on geogenic factor as mineral dissolution or weathering.

Furthermore, if Ca^{2+} and Mg^{2+} invent only from the weathering of carbonates in the aquifer ingredients and from then the HCO_3^{-} over divalent cation (Ca^{2+}+Mg^{2+}) ratio would be the bellow of 0.5 then comes from the weathering of calcite or dolomite rock (Sami 1992; Singh et al. 2017). Fig. 11a shows this ratio is lower than 0.5 i.e., below the 1:1 deons-line. So, this ratio plot indicated that these two divalent cations are mainly from the carbonate of Ca and Mg rock source. In Fig. 11d, the plot of total anions vs. (Ca^{2+}+Mg^{2+}) demonstrates that all the data falls below the 2:1 line that reflects the requirement of cations from the weathering of carbonate rocks. Moreover, the excess of alkaline earth ion indicated an additional source of Ca^{2+} and Mg^{2+} and balanced by HCO_3^{-} and SO_4^{2-} (Wen et al. 2005). This statement is supported by Fig. 11c where total cation vs (Ca^{2+}+Mg^{2+}) shows that the data is slightly below the 1:1 line, indicated a minor contribution of Na^{+} and K^{+} as the TDS increased (Rahman et al. 2011).

The bivariate plot of Na^+ vs. Cl^- is usually used to regulate the mechanism of rock-water interaction, total salinity, and saline water intrusions from external sources (Sivasubramanian et al. 2013). The values of the molar ratio of Na^+/Cl^- were less than 1 (□ 0.7 in both seasons) indicated no silicate (feldspar) weathering (Krishnaraj et al. 2011). A similar observation was found in Fig. 11e that shows most of the samples fall above the equi-line (1:1) of Cl^- vs. Na^+ and indicates no silicate weathering (Hackley 2002). However, this result does not support the ion exchange processes as stated by Singh et al. (2017). On the other hand, the molar ratio of (Na^++K^+) vs total cations (Fig. 11f) were 0.14 in PRM and 0.11 in the POM seasons and lay much below the 1:2 equi-line clearly showing the very poor dominance of alkalis (Na^++K^+) over the alkaline earth metal ions (Ca^{2+} and Mg^{2+}). Therefore, the evidence confirmed that the main source of earth metal ions and bicarbonate of the samples was earth metal carbonate rocks.

Irrigation water quality assessment

Water quality for irrigation is dependent upon both the type and quantity of the nutrients or minerals dissolved. These minerals mainly invent to water phase from the natural weathering of rocks and soil and some portion comes from domestic and industrial discharges leaching. It is usually accepted that the problems creating from irrigation water quality vary in types and severity as a function of frequent factors including the types of the soil and crop variety, the climatic conditions of the area as well as the water used. Nevertheless, there is now a general understanding that these problems can be classified as salinity hazard, permeability problems, toxicity hazards, and miscellaneous problems (Ayers and Westcot 1985). Those problems were evaluated by the various irrigation water quality parameters including IWQ_{index}.

Irrigation water quality (IWQ) index

Using Eq. 2 and 3, IWQ_{index} was computed for the collected 40 groundwater samples of both Pre-monsoon (PRM) and post-monsoon (POM) seasons. Calculated IWQ_{index} values ranged from 32.04 to 45.39 with an average of 42.85(±2.44) during the PRM and 35.83 to 38.76 with an average of 38.24 (±0.65) during the POM (Table 6). According to the suitability range (Table 5), almost 100% of the studied samples were excellent in position for irrigation uses.

Overall IWQ_{index} - a newly proposed technique

According to the concept of Richards (1954); UCCC (1974); and Ayers and Westcot (1985) the study developed Overall IWQ_{index} (Table 6) based on the various irrigation water quality parameters and pre-computed indices such as EC, TDS, TH, sodium percentage (Na%), soluble sodium percentage (SSP), sodium adsorption ratio (SAR), residual sodium bicarbonate (RSBC), permeability index (PI), magnesium absorption ratio (MAR), and Kelley’s ratio (KR). The wight of each parameter and pre-determined indices (Tab. 6) are fixed according to Simsek and Gunduz (2007), Meireles et al. (2010), and other literature. The total and lowest score of the Overall IWQindex is 127.75 and 36 respectively. The groundwater indexing values were 02.58 and 93.49 for the pre-monsoon (PRM) and post-monsoon (POM), respectively. The score of the Overall IWQ_{index} is sufficiently high and the results indicated that the groundwater of the study area was found suitable for irrigation purposes. For a more effective result, further study on this technique is needed in the future.

Irrigation water evaluation indices

Table 7 shows destructive statistics of irrigation water quality indices in groundwater during the PRM and POM and percent of suitability for irrigation uses. The EC and TDS values in the studied samples were recorded to get the salinity hazard in groundwater. The study showed that EC values in the groundwater samples were ranged from 366 to 1035 μS/cm with a mean value of 670 μS/cm in the PRM season and, 662 to 1708 μS/cm with a mean value of 956.8 μS/cm in the POM season. The results indicated that the water quality in most of the sampling areas was considered to be fair quality for irrigation purposes with respect to EC value (Table 7). But, excellent quality for irrigation purposes was assessed according to the TDS value, except for the PRM season, where only 35% was found good quality.

SAR is a quantity of Na-alkali hazard to crops since raised Na^{+} loads can decrease the soil permeability and hydraulic conductivity (Todd 1980). The Na% and SAR are usually considered a real assessment index for most water used in the irrigated agricultural activity (Ayers and Westcot 1985). The higher SAR values indicated that the alkali Na^{+} substituting Ca^{2+} or Mg^{2+} of the soil with the help of the cation exchange process. The previous findings of the hydrogeological facies showed that there was no cation exchange occurred in the aquifer of the study area. So, a lower value of the SAR was expected. The calculated Na% values varied from 3.31 to 30.97 with a mean value of 7.4 in the PRM and 2.5 to 22.03 with a mean value of 5.67 in the POM season. This indicated that the groundwater belonged to very good quality for irrigation uses in the study area (Table 7). The same as to Na%, the SAR value of all samples (□1) in both the seasons are in the excellent category. So, the presence of Ca^{2+} and/or Mg^{2+} instead of Na^{+} in irrigation water increased the permeability of the local soil (Asaduzzaman 1985). The SSP values of the samples were in the excellent irrigation water category. The box plots (Fig. 12) show that the assessment of mean, median, minimum, and maximum values of SAR, SSP, and Na% indicate similar values in the studied samples.

The water containing RSBC<5, 5–10, and <10 mEq/L is considered as safe, marginal, and risky categories, respectively (Gupta and Gupta 1987). Table 7 shows that the RSBC values ranged from -0.484 to 5.30 with an average of 2.08 in the PRM and -0.75 to 4.23 with an average of 1.64 in the POM, indicated that the water was safe for irrigation purposes. About 100% of the samples were a safe class and exhibited the same judgment. The Tables showed that SSP values of study samples in both seasons fall in the excellent category for irrigation except for one sample. The total hardness (TH) value for the groundwater samples in both seasons was in the very hard type. The results indicated that the negative impact on irrigation water of the study area. On the other hand, Kelley's ratio (KR) shows a balance between Ca^{2+}, Mg^{2+}, and Na^{+} ions in samples. Once the KR ratio is higher than 1, it indicates the extra level of Na^{+} presence in the water. Other indices MAR and PI show lower values that did not exceed the permitted limit for irrigation waters in all the sampling sites (Tab. 7). Box plot also indicates that the EC value is twice than TH value in most of the sampling sites (Fig. 12). The higher value of EC and TH in the groundwater samples pose a threat to crop production in the study area. So far, the assessment of irrigation water quality is investigated in 7 regions of Bangladesh. Investigations revealed that the irrigation water of coastal regions as Khulna (Didar-ul et al. 2017), Sathkhira (Mirza et al. 2012), Borguna (Islam et al. 2016), Lakshipur (Bhuiyan et al. 2006), etc. are highly salinity affected and those water are not fit for use. Another irrigation water of the northern and east-northern region of the country has a little salinity problem. But this present study revealed that the irrigation water of the study region (middle-west river basin flood plain) was very good in position, except for the EC and TH. The study used some diagram-based justification as the US salinity hazard diagram, Wilcox diagram, and permeability index (PI) diagram are subsequently used, except for the above-mentioned irrigation water quality indices.

The study plotted the groundwater data on the US salinity hazard diagram (Richards 1954) indicated that more than 80% of samples in the PRM season of this study fall in the categories of C2S1 (C2: medium salinity hazard; and S1: low Sodicity) for irrigation activities. Besides, almost 100% of samples in the POM season fall in the categories of C3S1 (C3: high salinity hazard), which can be utilized for all types of soil without the hazard of movable Na^+ (Fig. 13). The excess salinity of the groundwater might be occurred due to the presence of elevated bivalent cations in the study areas. However, this high salinity is not caused by Na-salt; it is caused by the Ca-Mg-salt.

The fitness of groundwater for irrigation typically depends on relative values of EC and Na^+ concerning other cations and anions (Todd 1980). Thus, Na% values were plotted on Wilcox's diagram (Wilcox 1955) demonstrated that all samples fell into the group of excellent to good categories in the PRM season (mean values of 7.8). But, in the POM season, about 75% of samples fell in the group of excellent to good and 25% were in the good to permissible category. Hence, this study observed that the groundwater quality was excellent to the permissible category for irrigation purposes (Fig. 14). A study (Rahman et al. 2017) also found the similar results in the northern region of Bangladesh.

The WHO (1998) uses the permeability index (PI) for evaluating the appropriateness of groundwater for irrigation based on permeability index (PI). The PI parameter was plotted together with the total ionic components of the water samples on Doreen's chart. There are three water categories used to describe quality. Based on the chart, class-I water type was the excellent water quality for irrigation use, class-II water type was mostly satisfactory for irrigation while, class-III water type was improper for irrigation (Doneen 1964). In this study, the PI of the groundwater samples varied from 36.91 to 71.27% with an average value of 51.16 in the PRM season. Similar results were found in the POM season. According to PI values, 100% of the samples fell under class 1 (Fig. 15), which indicated that the groundwater was of good quality and suitable for irrigation purposes in the study area.

Conclusion

Different hydro-geochemical parameters (pH, EC, TDS, and TH), and numerous irrigation water quality indices (Na%, SAR, SSP, RSBC, MAR, PI, and KR) of groundwater for both the pre-monsoon (PRM) and post-monsoon (POM) seasons were investigated to evaluate the irrigation water quality in the Ganges basin (Kushtia District) of Bangladesh.

The analysis results showed that groundwater quality was found acidic and neutral to alkaline in the PRM and POM seasons, reservedly. Besides, the study observed that the average EC (PRM: 669.95 µS/cm; POM: 956.8µS/cm) and TDS value (PRM: 413.15 mg/L; POM: 601.5 mg/L) were relatively higher than the other similar topographic part of the country may be due to the presence of an elevated concentration of earth metal and bicarbonate in the samples. The US salinity hazard diagram indicated that the groundwater type was C2S1 and C3S1 in the PRM and POM seasons, respectively. According to the Wilcox diagram, 80% of samples fell into excellent to good and the PI diagram revealed that all samples are class 1 type in both seasons. For the assessment of hydro-geochemical facies, this study reveals that the order of abundance of ions in groundwater samples are Ca^{2+}>Mg^{2+}>Na^{+}>K^{+} and major anions are HCO_3^{-}>>Cl^{-}>SO_4^{2-}>NO_3^{-}>PO_4^{3-} respectively. The Piper diagram indicated that the analyzed samples were mainly Ca-Mg-HCO_3 water type. The Gibbs diagram displayed that rock-weathering was found to be the dominant process in the analyzed samples. Several bivariate plots showed that the geochemical processes were controlling the groundwater chemistry and enrichment of mineralization in the aquifer. But, some anthropogenic activities may have influenced this process as well. The most significant geochemical feature in the study area was recognized as calcite and dolomite mineral dissolution and there was no active cation exchange process and silicate weathering occurred. The IWQ_{index} showed that almost 100% of the samples in both seasons found to be excellent for irrigation purposes. Overall IWQ index, a newly proposed technique, was recognized in the present study in which all irrigation water quality indices are used. The study results could be applied for better understanding the water quality and geochemistry of the areas and contributing to the sustainable policy-making of groundwater resources in the study region. Besides, the study findings would deliver insight for water managers for the irrigation water quality management in the present agrarian of Bangladesh.

Declarations

Conflict of Interest: The authors declare no conflict of interest.

Ethical statement:

This article does not contain any experiment with any animal or human performed by any of the authors.

The manuscript in part or in full has not been submitted or published anywhere and will not be submitted elsewhere until the editorial process is completed.

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Tables

Due to technical limitations the tables are available as a download in the Supplementary Files.

Figures

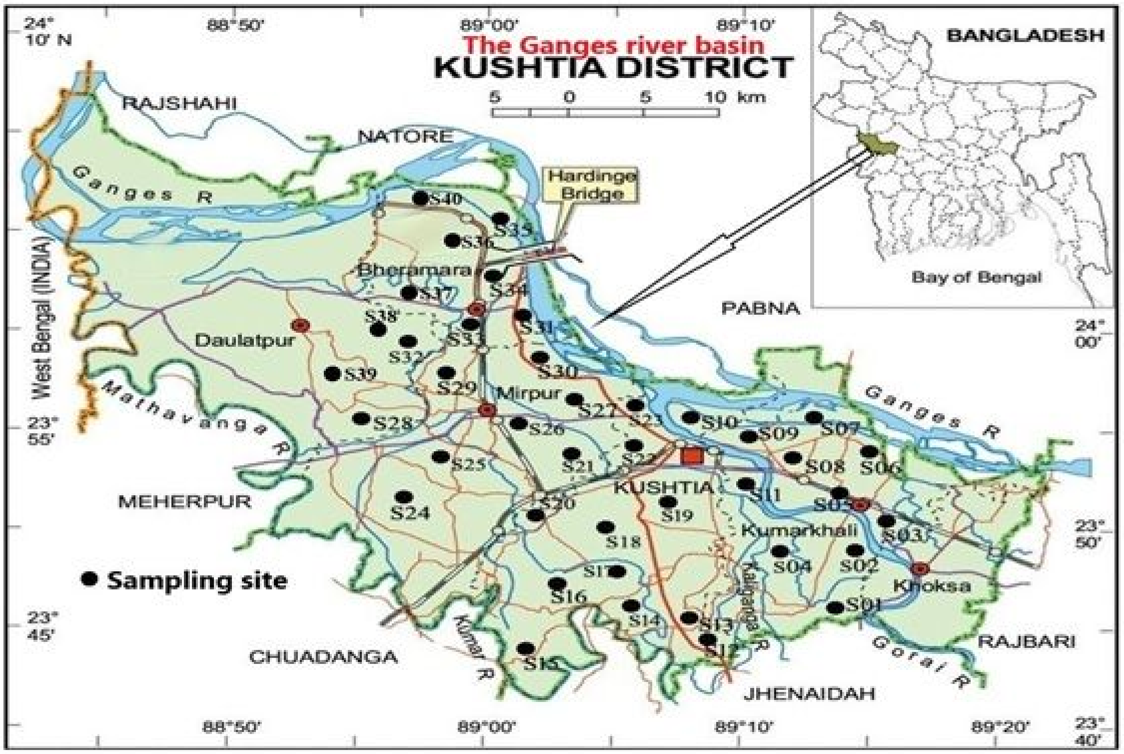

Figure 1

Location of groundwater sampling

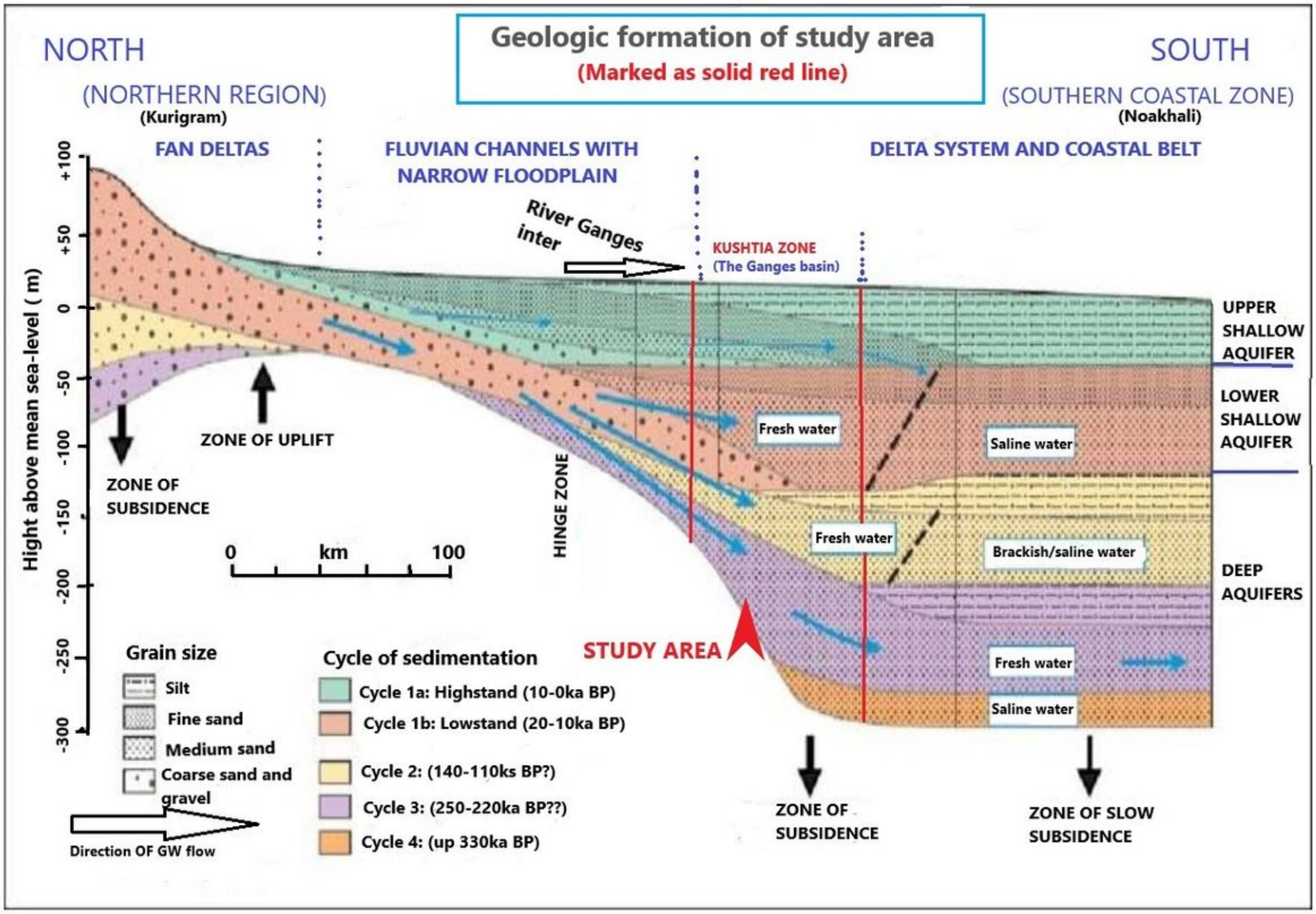

Figure 2

Hydrological setting of the study area

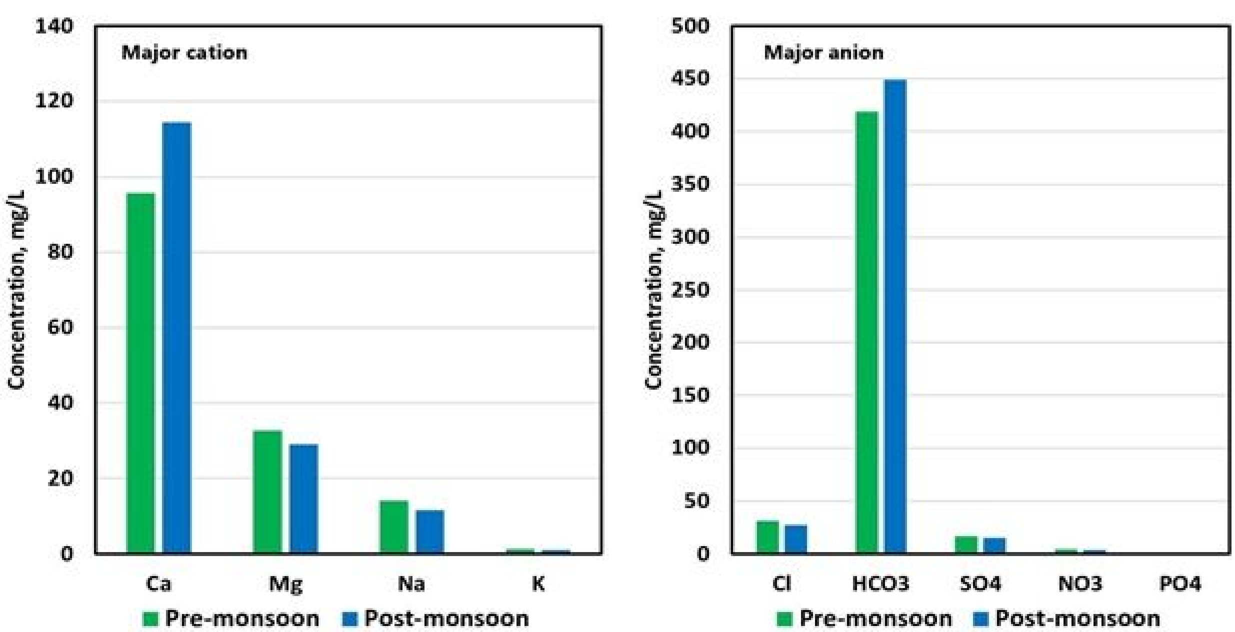

Figure 3

Concentration of major cations and anions in both seasons

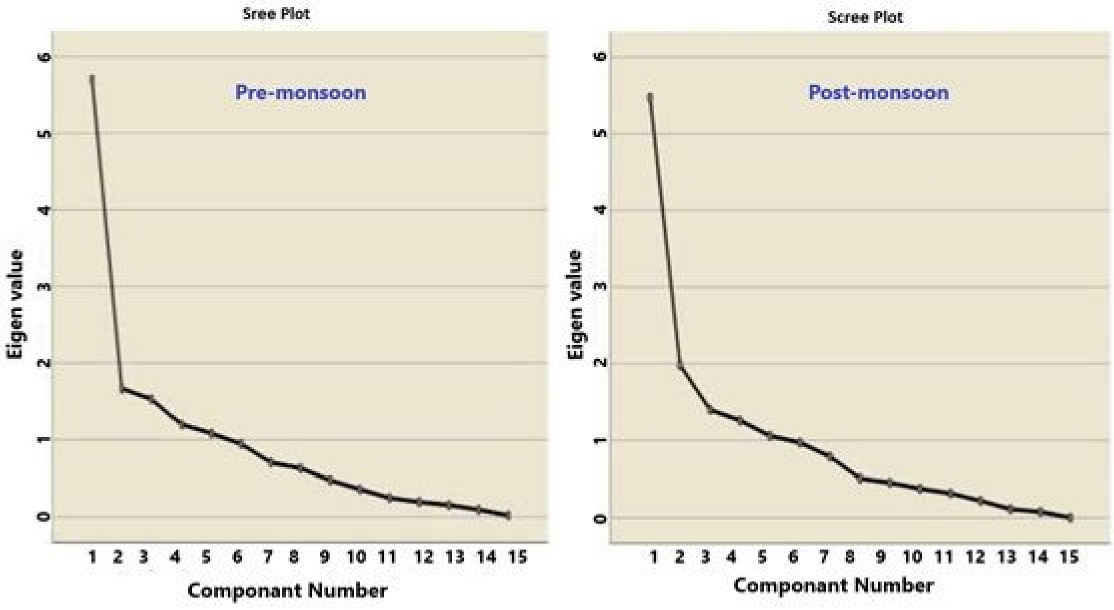

Figure 4

Eigen values for principal component analysis (PCA)

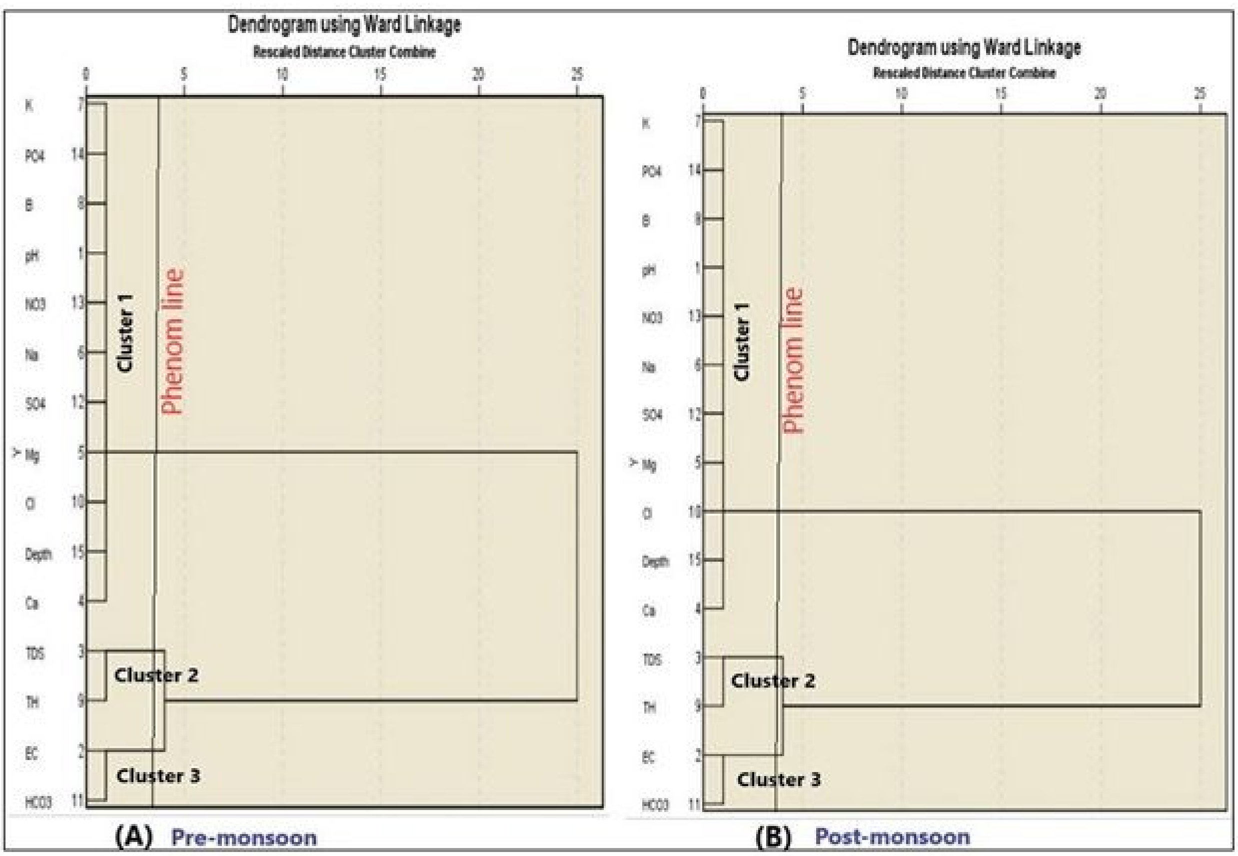

Figure 5

Dendrogram for R-mode cluster analysis (CA) of groundwater in both PRM and POM seasons.

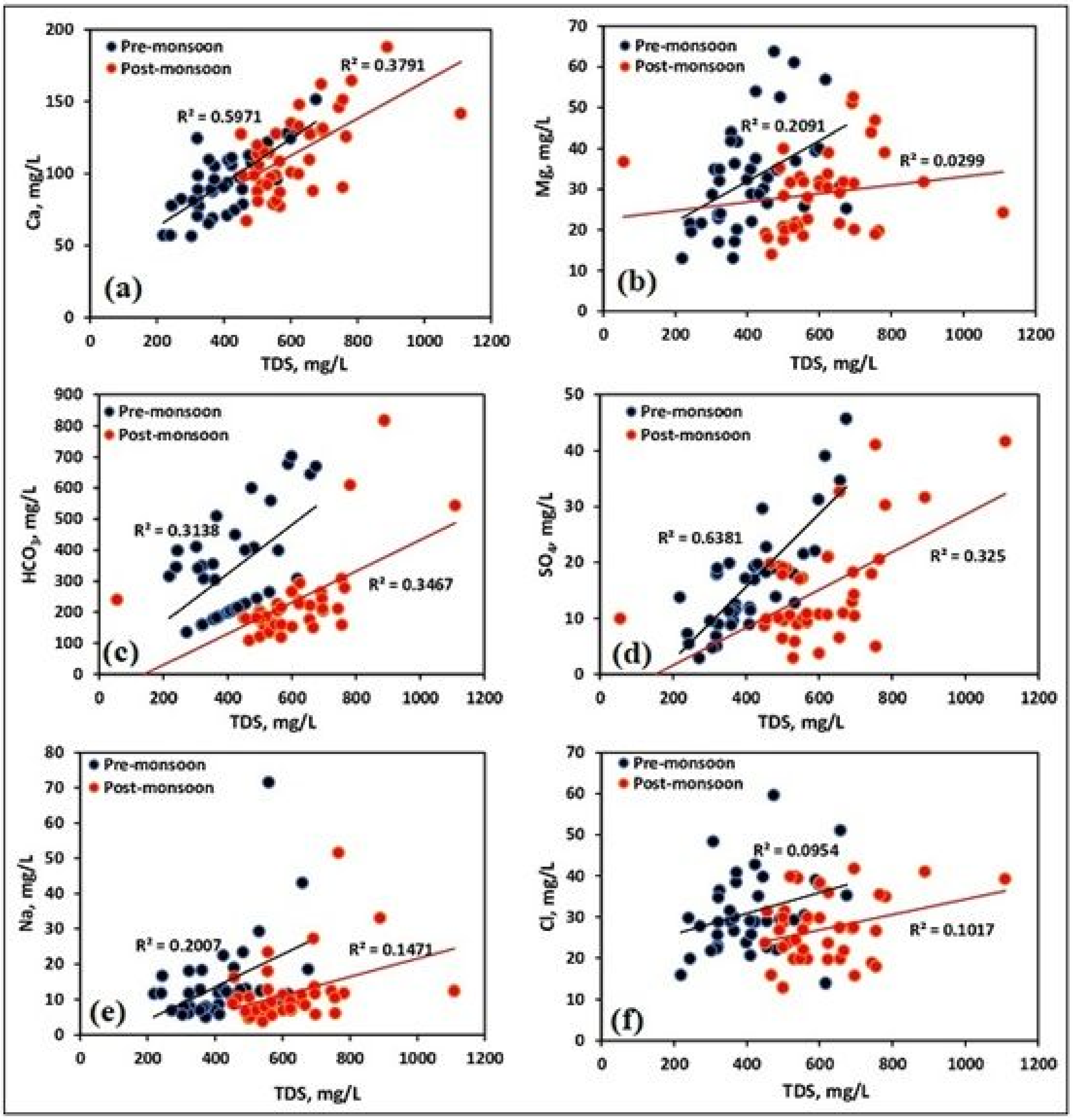

Figure 6

Bivariate plots of major ions against TDS values

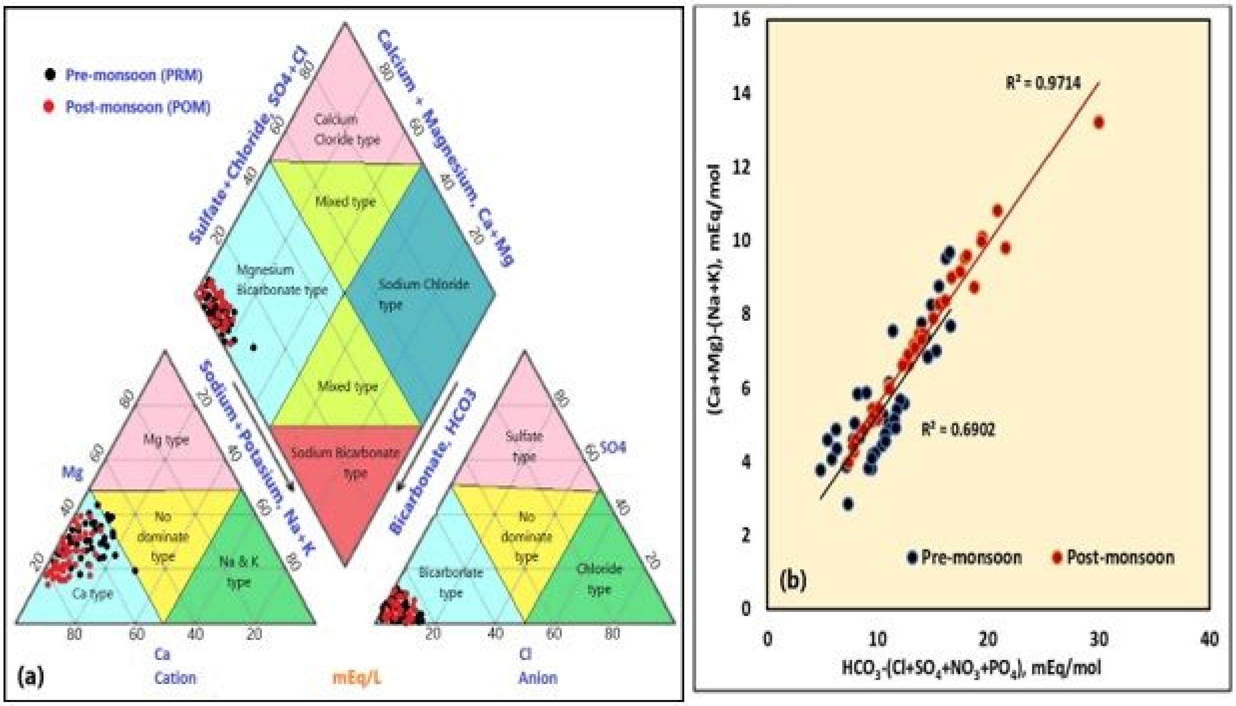

Figure 7

(a) Piper diagram and (b) Chadha’s plot for groundwater classification

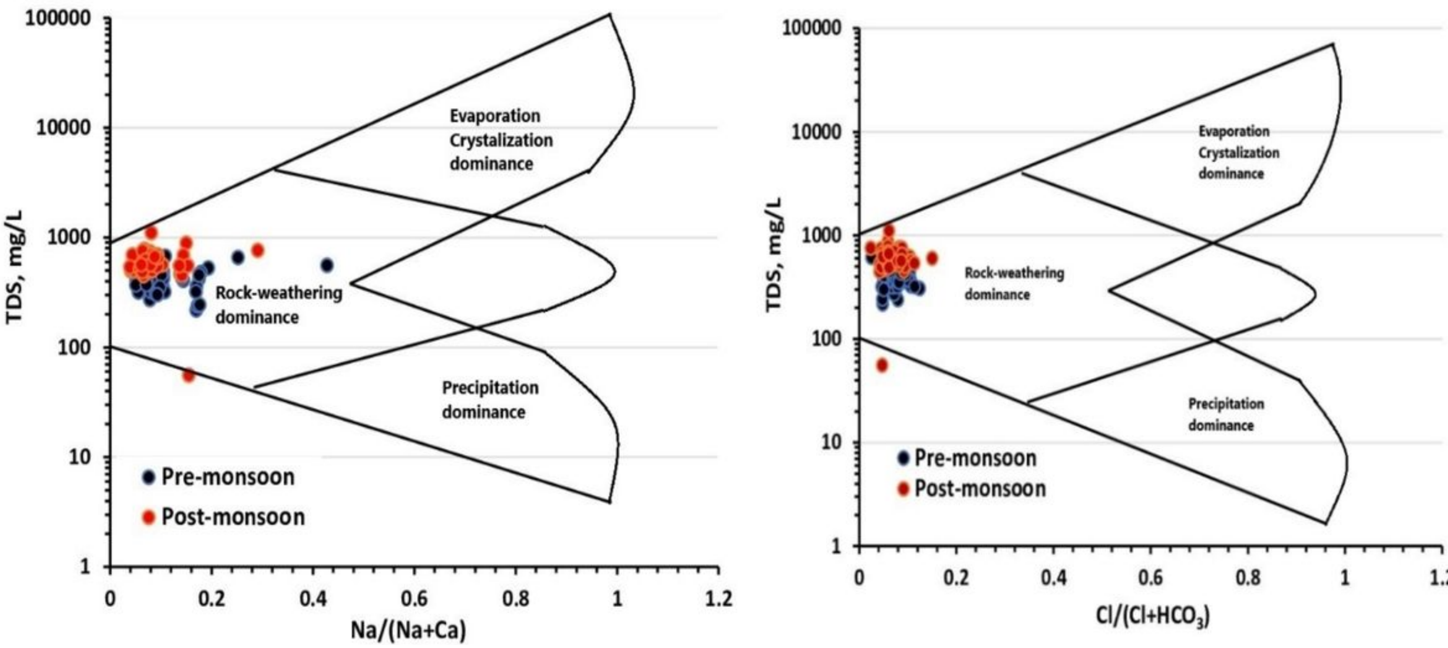

Figure 8

Gibbs’s diagrams for groundwater samples of the study area

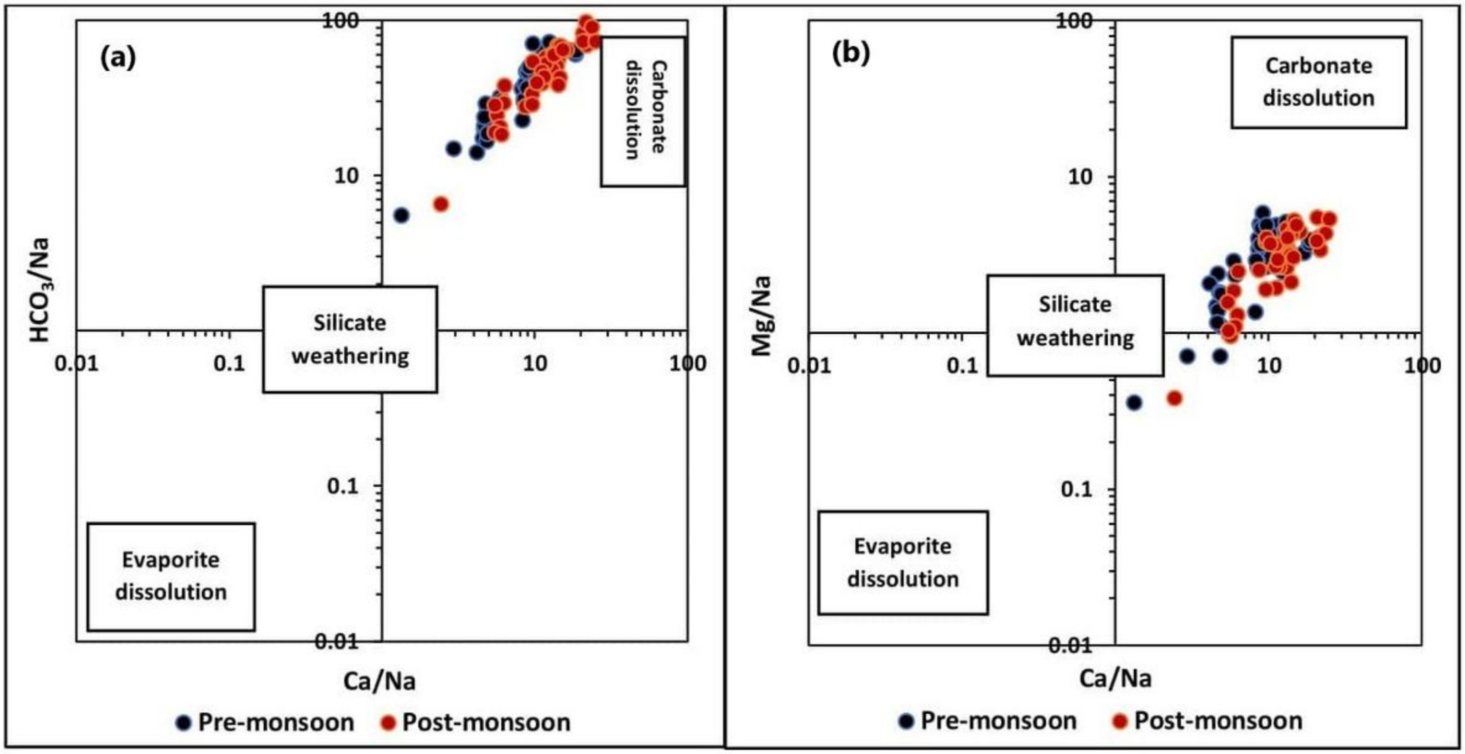

Figure 9

Bivariate plot (a) Ca/Na vs HCO3/Na, and (b) Ca/Na vs Mg/Na to classify the minerals weathering of groundwater in the study area. The boxes characterize the ranges of estimated compositions of the three main source end members (evaporate dissolution, silicate weathering, and carbonate dissolution) without any mixing

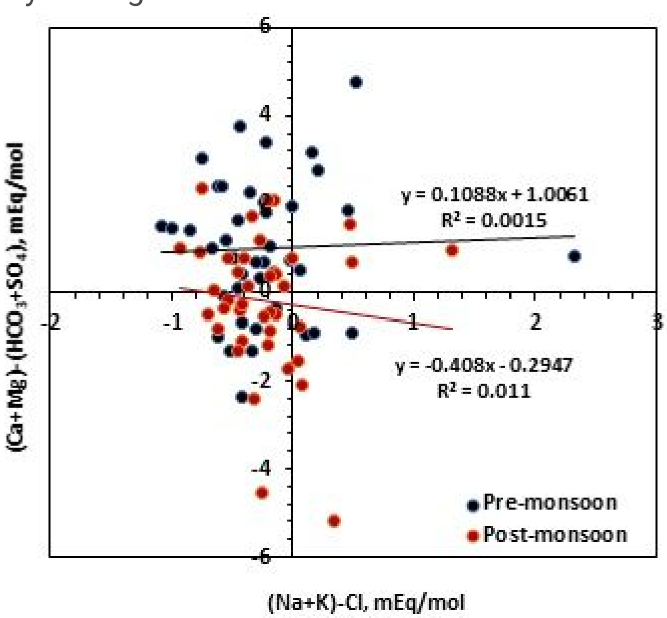

Figure 10

Bivariate plot of Cl- corrected (Na++K+), and (Ca2++Mg2+) corrected (HCO3- +SO42-) to identify the cation exchange of water in study area

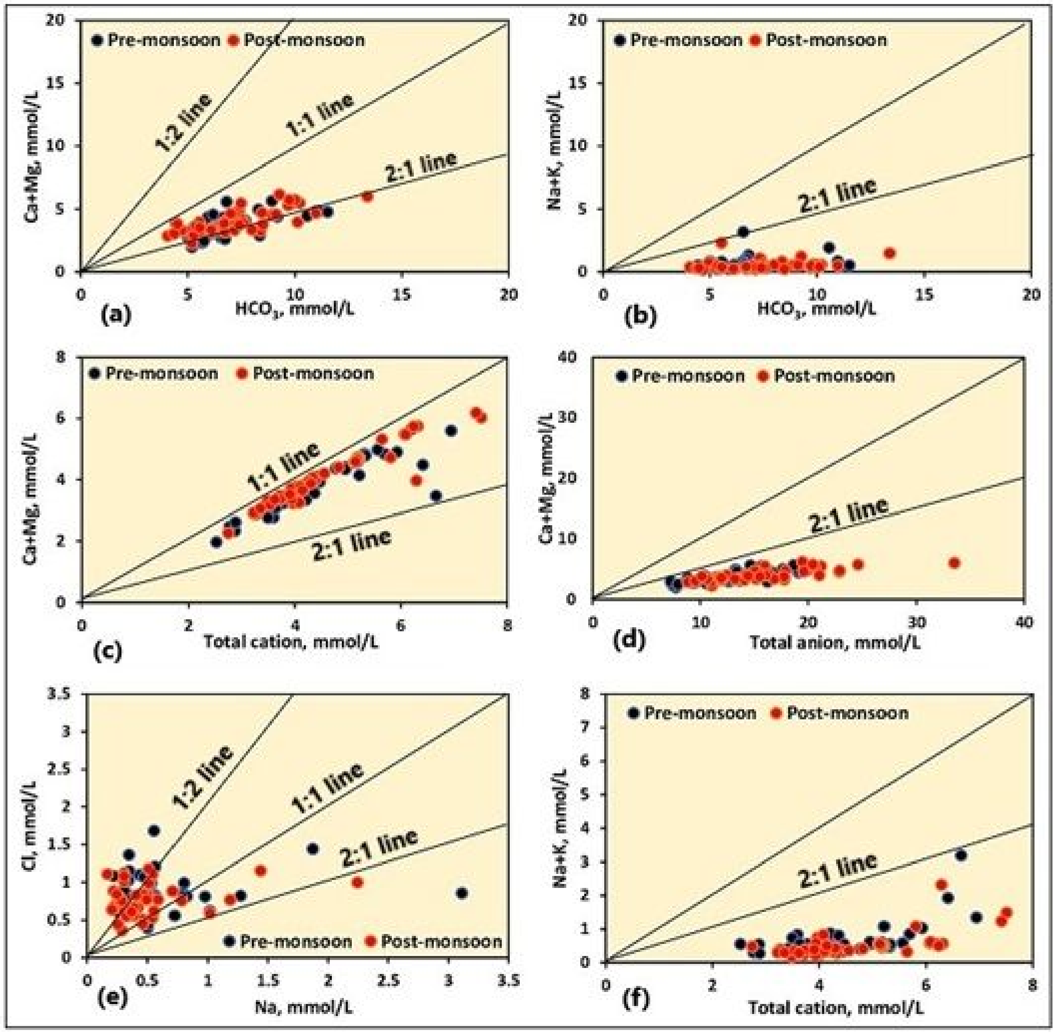

Figure 11

Bivariate plots of (a) Ca2++ Mg2+ vs. HCO3-, (b) Ca2++ Mg2+ vs. total anions, (c) Ca2++ Mg2+ vs. total cations, (d) Na++K+ vs. HCO3- (e) Na+ vs. Cl- and (f) Na++K+ vs. total cation

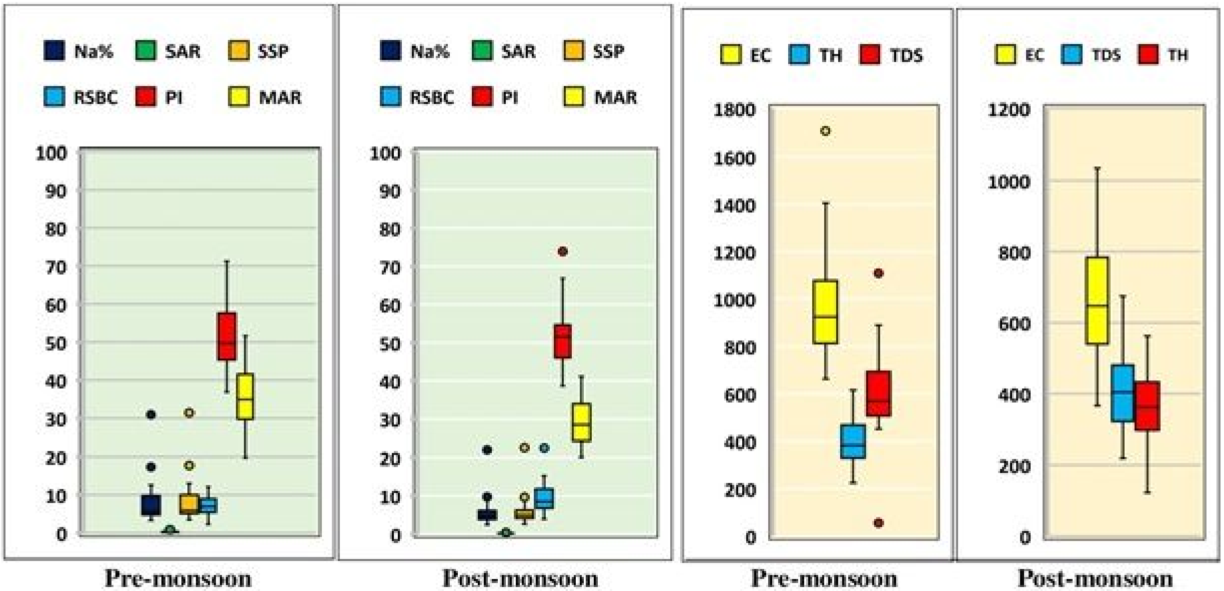

Figure 12

Box plots of irrigation water indices in study area

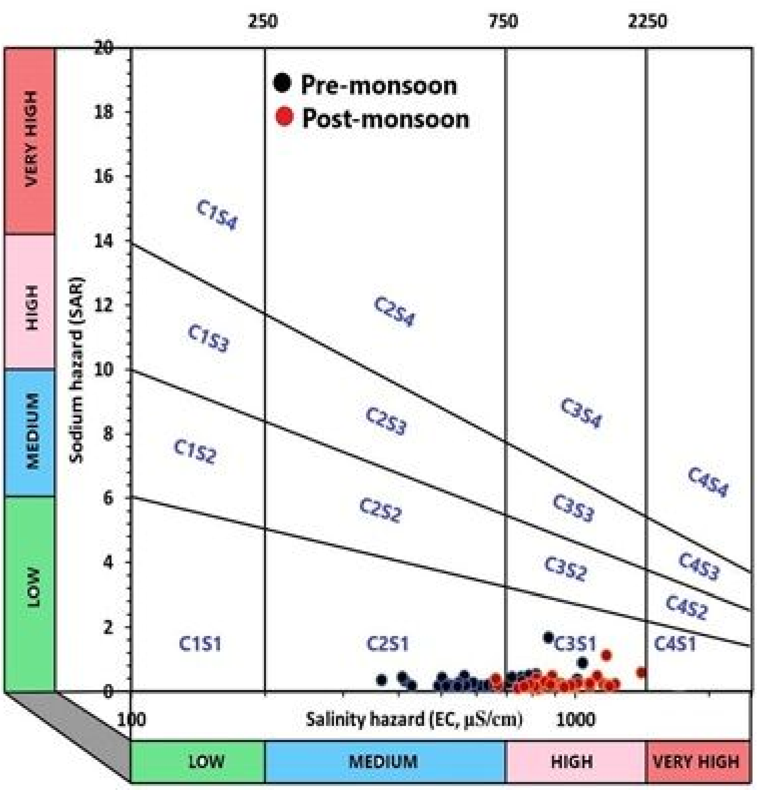

Figure 13

US salinity hazard diagram showing the suitability of water

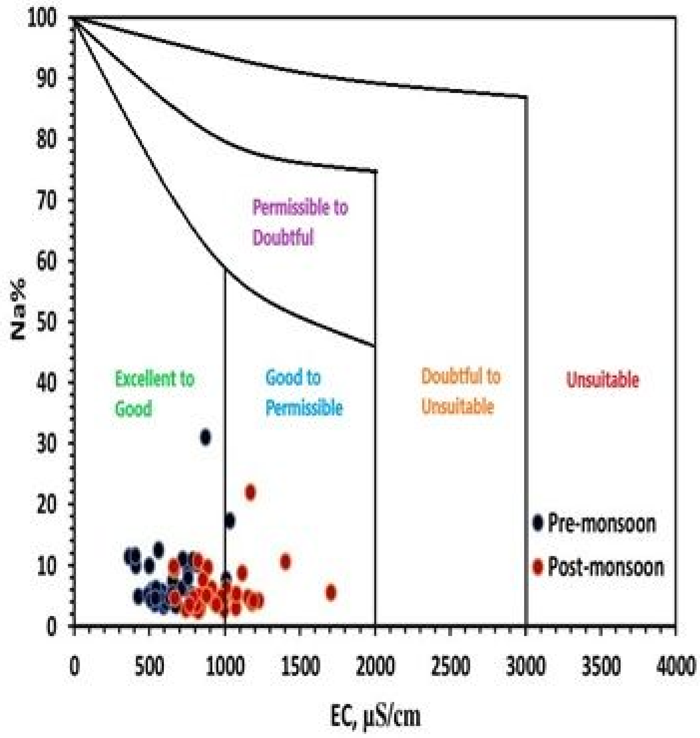

Figure 14

Wilcox diagram shows suitability water for irrigation purpose

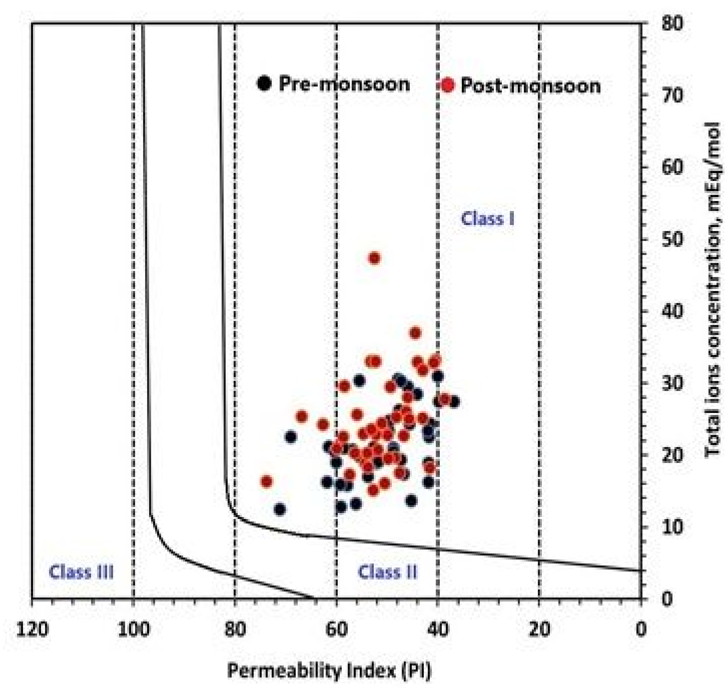

Figure 15

Permeability index (PI) diagram of the study area’s groundwater samples

Supplementary Files

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- Table.pdf