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ORIGINAL ARTICLE

Hydrogeochemistry and multivariate statistical analysis of groundwater quality of hard rock aquifers from Deccan trap basalt in Western India

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Abstract
In the present investigation, hydrogeochemistry and multivariate statistical analysis of groundwater quality were assessed from hard rock aquifers of the Deccan trap basalt in the Jalna district of Maharashtra. Groundwater samples ($n = 105$) were collected from the study area in a systematic grid pattern to avoid biasing in sampling. Water quality parameters of all these groundwater samples were analyzed by standard BIS and APHA procedures by titrimetric and using sensors. Uranium in all samples was analyzed using an LED fluorimeter. Strict quality assurance and quality control features were adopted in all stages of the study to ensure the quality of the data. The observed sequence of the dominance of major cations and anions is $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ and $HCO^{3-} > Cl^{-} > SO_4^{2-}$ respectively. The observed uranium values were in the range of 0.1 to 16.2 µg/L with an average value of 2.04 µg/L, well below the safe limits recommended by WHO and AERB i.e. 30 and 60 µg/L, respectively. Piper trilinear diagram indicates dominant hydrochemical facies of groundwater in the study area are Mixed Ca^{2+}–Na^{+}–HCO_3^{-}, Na^{+}–Cl^{-} and Ca^{+}–HCO_3^{-} while Gibbs plot infers host rock-water interaction is the major geochemical process in these aquifers. The correlation analysis, cluster analysis, and factor analysis tests are performed. Groundwater was assessed for its suitability for irrigation purposes using multiple indices such as SAR, RSC, and Na percentage. From the estimated indices, it was found that the groundwater in hard rock aquifers of the Deccan trap basalt is suitable for irrigation purposes.

Keywords Groundwater · Hard rock aquifer · Hydrogeochemistry · Geochemical characterization

Introduction

Water, a substance that exists in all three common states of matter viz. liquid, gas, and solid on the earth, is one of the most essential compounds in any ecosystem. Water covers 71% of the earth's surface, mostly in seas and oceans. About 3.4 million people (mostly children) die per year due to water-related diseases (Osiemo et al. 2019). Groundwater is a major source of water supply for all purposes in many countries (Fienen and Arshad 2016). In the past few decades, groundwater quality awareness has increased due to impacts of industrialization, rapid urbanization, unmanaged land-use practices, expansion of population, and intensive agricultural practices that cause the risk of soil and groundwater contamination (Etikala et al. 2019; Srinivasamoorthy et al. 2014). Groundwater crisis is goverened by natural as well as human activities. The groundwater quality is affected by such natural factors as geology, topography, meteorology, hydrology, biology, and geochemical processes taking place in an aquifer (Khatri and Tyagi 2015). The hydraulic parameters like hydraulic conductivity (Werisch et al. 2014), transmissivity (Hasan et al. 2020), specific flow (Meli'i et al. 2018) are essential for the estimation of the availability of groundwater resources. The term hydrogeochemical facies are essential for describing the groundwater body in an aquifer having different chemical constituents (Ali and Ali 2018). The facies are governed by chemical processes in

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the lithological environment of an aquifer (Aghazadeh et al. 2017). Important information regarding the hydrogeochemistry of groundwater in a particular area helps understand its suitability for use. A significant correlation between water quality parameters was reported by many authors (Kale et al. 2020a, b; Kim et al. 2020; Malik and Hashmi 2017; Tiwary et al. 2018). Earlier an assessment of hydrogeochemistry was done by laboratory-based investigation only but nowadays, geospatial techniques are used for the assessment of water quality, (Hosseinifard and Mirzaei Aminiyan 2015), managing the available resource (Graham et al. 2011), and interpreting the groundwater data with ease and, accuracy in a cost-effective manner (Thakur et al. 2017). A groundwater model is also helpful in developing a geospatial decision support system using GIS-based software like ArcGIS (Hussein et al. 2017). Many researchers and decision-makers from earth sciences are using the geospatial technologies, tools and software's for (i) assessment of environmental degradations, ii) environmental impacts evaluation, (iii) environmental management, and (iv) decision-making system (Ali and Pirasteh 2005; Asadi et al. 2007; Handley 1980; Satapathy et al. 2008; Thakur et al. 2017). The study of inverse distance weighting (IDW) interpolation technique in spatial data analyst tools is used to prepare a spatial distribution map of uranium and other water quality parameters of the study area. Hence, keeping in view these influences, the main objective of current work was restricted to evaluate the chemical processes in groundwater using geochemical evaluation, multivariate statistical analysis, conventional geochemical classification, and spatial distribution modeling in hard rock aquifers of Deccan trap basalt in Western India.

Materials and methods

Study area

The designated study area, Jalna district, is an administrative district of the Marathwada region in the state of Maharashtra, (Fig. 1a). The study area is spread between 19° 10′ and 20°30′ N latitudes and 75° 40′ and 76° 40′ E longitudes and falls under Survey of India Toposheets nos. 46 P, 47 N, 55 D, and 56 A. The district covers approximately 7687.39 km^2 area with a population of 19,59,046 in 2011 (Chandramouli 2011). The study area is bound by Buldhana and Parbhani districts to the east side, north by Jalgaon district, Aurangabad district in the west, and Beed district in the south. Using the digital elevation model tool of ArcGIS 10.8 (ESRI 2019), an elevation map of the study area was prepared (Fig. 1a). Generally, the ground slope of the district is towards the east and south-east. The area is dry and very hot in summer due to the tropical climate and mild winter with slight humidity. The average annual rainfall is 725 mm (CGWB 2013). Out-off this 83% occurs during June–September, July being the rainiest month. Depth of water-table in the region varies from 3.84 to 16.20 m bgl (May 2011) and 1.05 to 14.65 m bgl (Nov. 2011) (CGWB 2013). The study area is well drained by dendritic river systems. Soil derivative of the basaltic lava flow and having a composition of regur, gravels, murum. Eastern, central, southern parts soil falls under Godavari and Dudhana basin are thicker having depth 3–6 feet (CGWB 2013).

Geology of study area

The entire study area covered by basaltic lava flows of the Deccan traps of upper cretaceous to Eocene age. The lava flows gathered on each other. The thickness of individual flow varies from 20 to 30 m (CGWB 2013; DSR 2019). The individual movement has double distinct units. The greater portion is vesicular, occupied by secondary minerals like zeolite and quartz (e.g., Moss Agate, Zebra Agate, and Green Agate) which is called a zeolitic trap. The upper zone is 30–60% vesicular basalt has limited primary porosity. The lower portion of the lava flow creates the massive basalt called a massive trap, devoid of primary porosity and permeability. The formation usually has secondary porosity and permeability acquired due to weathering, jointing, shearing, fracturing, etc. Whenever the thickness of such zones is considerable, (30–60%) the flow forms of an aquifer have moderate potential. The physical and composite characteristics mentioned above are repeated in all the lava flows of the study area and therefore they form multiple aquifer systems, which generally extend the depth from 150 to 250 m (CGWB 2013). The pediment pediplain complex is consistently distributed in the area (Fig. 1b). The majority part of the study area is under agricultural practices (Fig. 1c).

Hydrogeology

The groundwater of the study area occurs under confined environments in jointed, brecciated, or fractured and vesicular zones of lower flows. The vesicular and zeolitic basalts are highly susceptible to weathering as interconnected vesicles form channels from weathering agents. It generally appears that "Pahoehoe" flows contain uniformly distributed vesicles that have good porosity and permeability and constitute potentials aquifers. The transmissivity of the study area of shallow aquifer in basaltic range was observed form 30 to 80 m^2/day and specific capacity of good ranges was recorded and seen ranges from 75 to 200 lpm/m (CGWB 2013). The Godavari, Purna, and Dudhana are the three main rivers in the district (Fig. 1a). The occurrence of groundwater and movement in the area is prejudiced by its rock formation. Groundwater potential depended on rock formations properties like porosity and permeability. The study area is

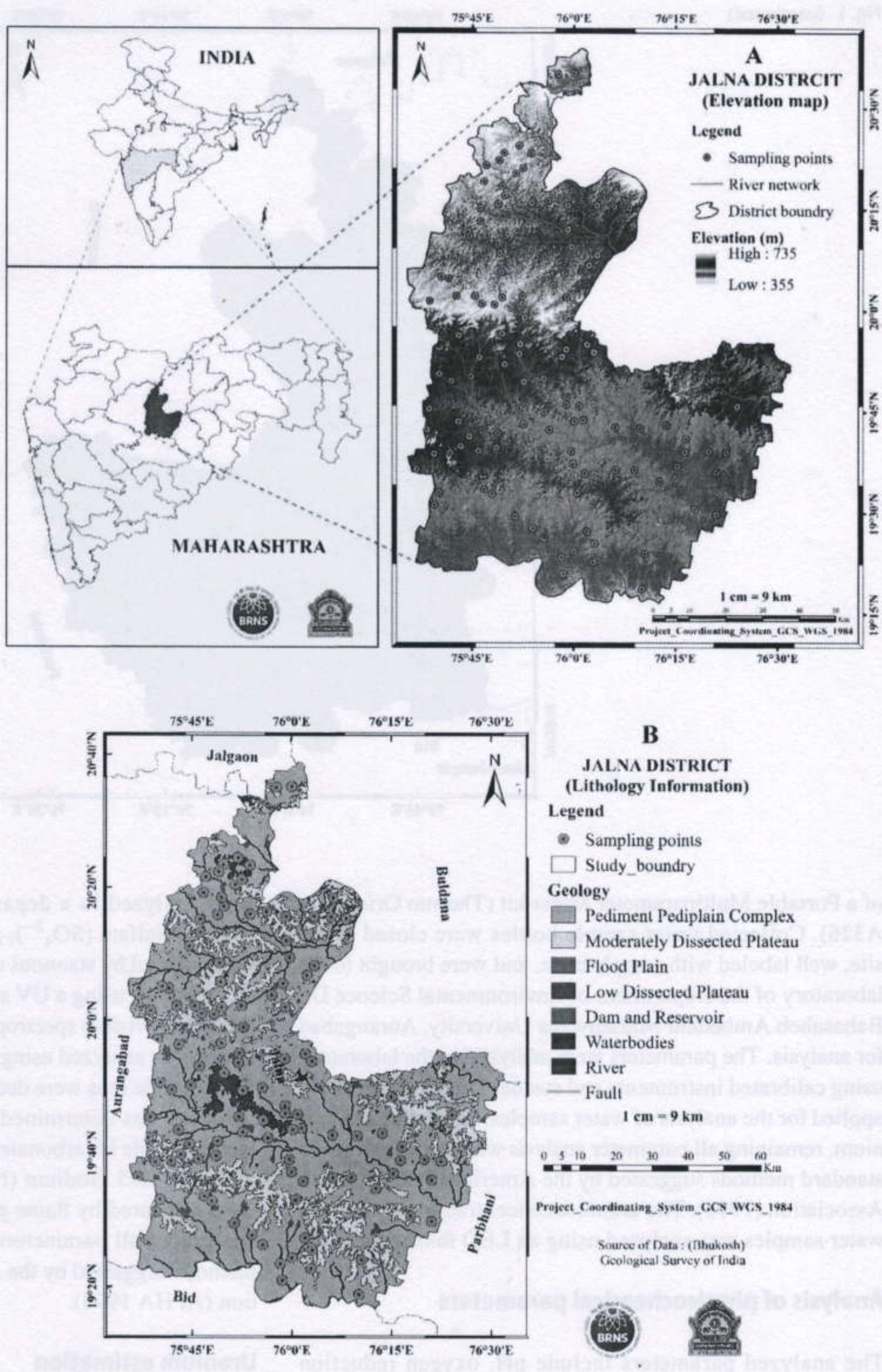


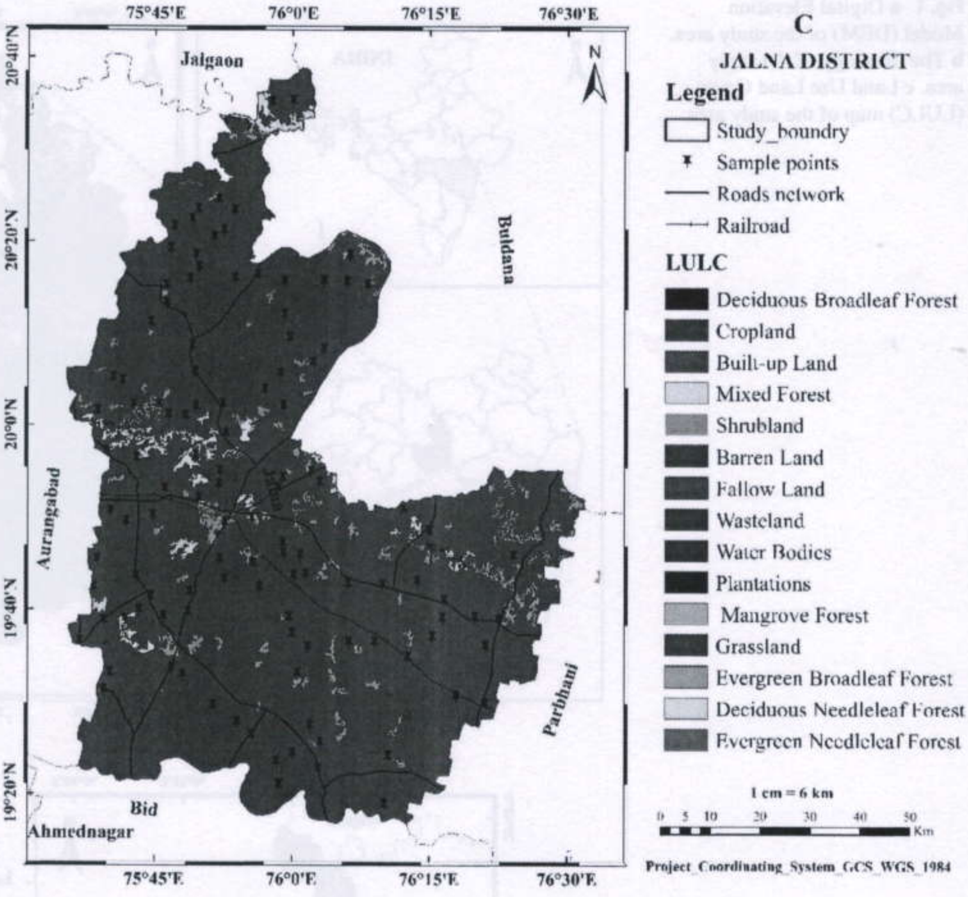
Fig. 1 **a** Digital Elevation Model (DEM) of the study area. **b** The lithology of the study area. **c** Land Use Land Cover (LULC) map of the study area

underlain by basaltic lava flows and alluvium only (CGWB 2013; Chandramouli 2011; DSR 2019).

Sampling

In the present study, a total of 105 water samples were collected at equally distributed locations to cover the entire area by making a grid of cells 6×6 km^2 area each. Geo-coordinate information (Latitude and longitude) of sample locations are recorded with the help of a GPS instrument for maintaining accuracy in spatial distribution map preparation. Water samples were collected in pre-cleaned airtight lab grade polypropylene bottles having a 1-L capacity. Some in-situ parameters were analyzed in the field with the help

Fig. 1 (continued)



of a Portable Multiparameter Meter kit (Thermo Orion Star A326). Collected water sample bottles were closed at the site, well labeled with sample code, and were brought to the laboratory of the Department of Environmental Science Dr. Babasaheb Ambedkar Marathwada University, Aurangabad for analysis. The parameters were analyzed in the laboratory using calibrated instruments and standard methods regularly applied for the analysis of water samples. Excluding the uranium, remaining all parameter analysis was carried out using standard methods suggested by the American Public Health Association (1998). The uranium concentration of collected water samples was analyzed using an LED fluorimeter.

Analysis of physicochemical parameters

The analyzed parameters include pH, oxygen reduction potential (ORP), electrical conductivity (EC), total dissolved solids (TDS), and dissolved oxygen (DO) were analyzed in-situ with the help of Portable Multiparameter Meter kit (Thermo Orion Star A326). Whereas, ex-situ parameters like anions Fluoride (F^-), Chloride (Cl^-), Nitrate (NO_3^-), Sulfate (SO_4^{2-}), Phosphate (PO_4^{3-}), bicarbonates (HCO_3^-), total hardness (TH), and important cations like calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+) were analyzed in a departmental laboratory. The nitrate (NO_3^-), Sulfate (SO_4^{2-}), phosphate (PO_4^{3-}) concentration was assessed by stannous chloride, screening, and turbidimetry methods using a UV spectrophotometer (Bio Era Single Beam UV–visible spectrophotometer). The fluoride concentration was analyzed using an Ion-Selective Electrode (ISE). The chloride ions were determined by Mohr's method. Total hardness was determined by the standard EDTA titration method while bicarbonate (HCO_3^-) was estimated by titration with HCl. Sodium (Na^+) and potassium (K^+) cations were measured by flame photometry. As mentioned earlier analysis of all parameters was carried out using standard methods suggested by the American Public Health Association (APHA 1998).

Uranium estimation

The uranium concentration of collected water samples was analyzed using an LED fluorimeter (Quantalase Enterprises Pvt. Ltd., Indore, India). This is an instrumental technique designed for the detection and measurement of trace quantities of uranium present in aqueous samples. The instrument works on the principle of measurement of fluorescence of uranium complexes in the aqueous sample. The LED fluorimeter uses a bank of pulsed LEDs to excite the fluorescence of uranyl ions at 410 nm. On excitation of uranium complexes, whenever excited ions come back to its ground state, it emits green fluorescence, which can be measured by a sensitive Photomultiplier Tube (PMT). A microcontroller is used for controlling all these processes and convert the fluorescence signals into digital form. The fluorescence yield is proportional to the intensity of the excitation source and concentration of uranium in the sample. Fluorescence measurement will give information about uranium concentration in the sample (Sahoo et al. 2009, 2010). The standard addition method was adopted for analysis of all groundwater samples due to their difference in chemical composition and to avoid any matrix effect.

Correlation analysis

In statistical methods, correlation analysis is used to measure the strength of linear association between two variables. The variables are not chosen on their characteristics of independence or dependency. In most of the research, correlation analysis was used to examine for getting the linear relationship between two variables. The statistical analysis was carried out using IBM Statistical Package for Social Sciences (2015). To calculate correlation coefficients, the correlation matrix was built by calculating the coefficient of different sets of parameters. The significance of the correlation was tested by applying p values. If p value is less than 0.05, 0.01 ($p < 0.05$ and $p < 0.01$), then the variation is significant. If $p > 0.05$, the variation is non-significant. The significance is considered at the level of 0.01 and 0.05, when if the analysis is 2-tail (Bartholomew 1995; Malik and Hashmi 2017). A lot of research work has been done on the statistical correlation between water quality parameters (Jothivenkatachalam et al. 2010; Kale et al. 2018; Sar et al. 2017; Shivanna et al. 2008; Singh et al. 2003; Tiwary et al. 2018). The following formula is used to analyzing the Pearson correlation coefficient(r).

$$r = \frac{\sum_{i=1}^{n} (x_1 - \bar{x})(y_1 - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_1 - \bar{x})^2 \sum_{i=1}^{n} (y_1 - \bar{y})^2}}.$$

Cluster analysis

To analyse and interpret the complexity of water ecology for better understanding, statistical methods like Principal Component Analysis (PCA) and Cluster Analysis (CA) is used. It is not only allowing to identify the possible factors but also offering a valuable tool for reliable water resources management (Chen et al. 2018). The multivariate statistical approach is an important modeling tool to analyze the degree of variance in different variables and is widely used in dimension reduction of huge datasets (Weng and Young 2017). The cluster analysis is a multivariate technique that is used to collect objects based on their characteristics (similarity or dissimilarity) and is presented in the form of the dendrogram (Wendler and Gröttrup 2016). In the current study, the Ward Linkage method (Squared Euclidean) method was adopted for cluster analysis. The resultant object of the cluster in the form of a dendrogram hypothetically show high homogeneity (internal) and heterogeneity (external) in the variables (Malik and Hashmi 2017).

Factor analysis

The factor analysis has been developed by Spearman in 1904, and it is the oldest one (Bartholomew 1995). Factor analysis is a data reduction method used to describe variability between observed and correlated variables. For analysis of factors, the first step is to extract different factors through PCA. Many scientists have been applied the PCA for water quality assessment and interpretation (Giri et al. 2019; Hossain et al. 2013; Kale et al. 2020b; Kuppusamy and Giridhar 2006; Park et al. 2014; Zarei and Pourreza Bilondi 2013). The main significant use of FA is considered to be a generalization of PCA which replaces a large number of variables into factors. However, FA is the path to elaborate how the patterns of relationship within different variables are arrises by a smaller number of dormant variables with common aspects that are hidden called factors (Mukherjee et al. 2018). In the current study, a factor analysis test is performed using IBM Statistical Package for Social Science (IBM 2015) software.

Spatial distribution mapping

The spatial distribution technique is useful in the interpretation of spatial data attributes over the geographical area. It is also helpful to evaluate spatial patterns, distribution trends, pattern flow, area relationship, distance, closeness, positioning, and spatial relationship (Asadi et al. 2007; Chen and Feng 2013). This particular tool monitored water quality data set, which have time and space attributes, hence the GIS is a powerful tool for interpreting and analyzing monitored data (Webley and Watson 2018). In the present study, the inverse distance weighting (IDW) interpolation method is used to interpolate the spatial data of water quality based on distance weighting. The consigned weights for interpolating locations are inverse of their distance from the interpolation location. Therefore, it is used to estimate the unknown point's data from the known measured location (Seyedmohammadi et al. 2016). Spatial distribution analysis of water quality parameters was performed using ArcGIS software, 10.8 version. The calculation of IDW is done by the following formula.

$$I(x_0) = \frac{\sum_{i=1}^{n} \frac{x_i}{h_{ij}^{\beta}}}{\sum_{i=1}^{n} \frac{1}{h_{ij}^{\beta}}},$$

where, $I(x_0)$ is the interpolated value, n denoting the total number of sample data values, x_i is the ith data value, h_{ij} is the separated distance within interpolated value and the sample data value, and β denotes the weighting power (Seyedmohammadi et al. 2016). The standard operation process flow diagram is shown in the Fig. 2.

Result

Descriptive statistical analysis of results

The descriptive statistics of water quality parameters are presented in Table 1 and Fig. 3. The pH values, varying from 6.99 to 9.04 pH with a mean value of 7.97, are denoting that, nature of groundwater is slightly alkaline. Only one sample exceeded the WHO (WHO 2011) suggested permissible limit of pH. The values of Total dissolved solids (TDS) were found in the range from 136 to 1509 mg/L with an average value of 532 mg/L. Only 7 percent sample has higher values than the allowable limit of 1000 mg/L, recommended for drinking purposes (WHO 2011). The main source for dissolved solids in the groundwater is the dissolution of soluble salts in an unsaturated zone (Sharma et al. 2017). The large variation in the electrical conductivity (EC) is indicating that the mineralization is happening in the groundwater. The EC values varied from 272 to 3079 μS/cm with an average value of 1083 μS/cm.The Oxygen Reduction Potential (ORP) is playing a crucial role in groundwater quality and affects the movement of contaminants species (Jung et al. 2015). The Oxygen Reduction Potential of collected water samples found in the range of 44–196 mV with an average value of 160 mV. The observed fluoride concentrations in groundwater are varied between 0.05 and 1.15 mg/L. According to the WHO (WHO 2004), the permissible limit is 1.5 mg/L. Higher levels of fluoride (> 1.5 mg/L) may result in dental fluorosis and skeletal fluorosis (Wang et al. 2012). However according to some reports of fluoride concentration in drinking water even if is less than the permissible limit to but more than 0.5 mg/L, can cause dental problems (Aoba and Fejerskov 2002). The chloride concentration was found to be from 15 to 1600 mg/L with a mean value of 161 mg/L. Only 11% of samples are crossed the permissible limit of 250 mg/L (WHO 2011). The large variation in the observed range is suggestive of the possibility of point source contamination or a heterogeneous groundwater chloride source. The estimated nitrate concentrations are observed in the range from 9 and 380 mg/L with an average value of 125 mg/L. Approximately half of the sample (~49%) have crossed the (WHO 2011) prescribed permissible limit of 50 mg/L for nitrates in drinking waters. These values themselves indicate the anthropogenic source of pollution that includes excessive use of chemical-based fertilizers. Many researchers reported

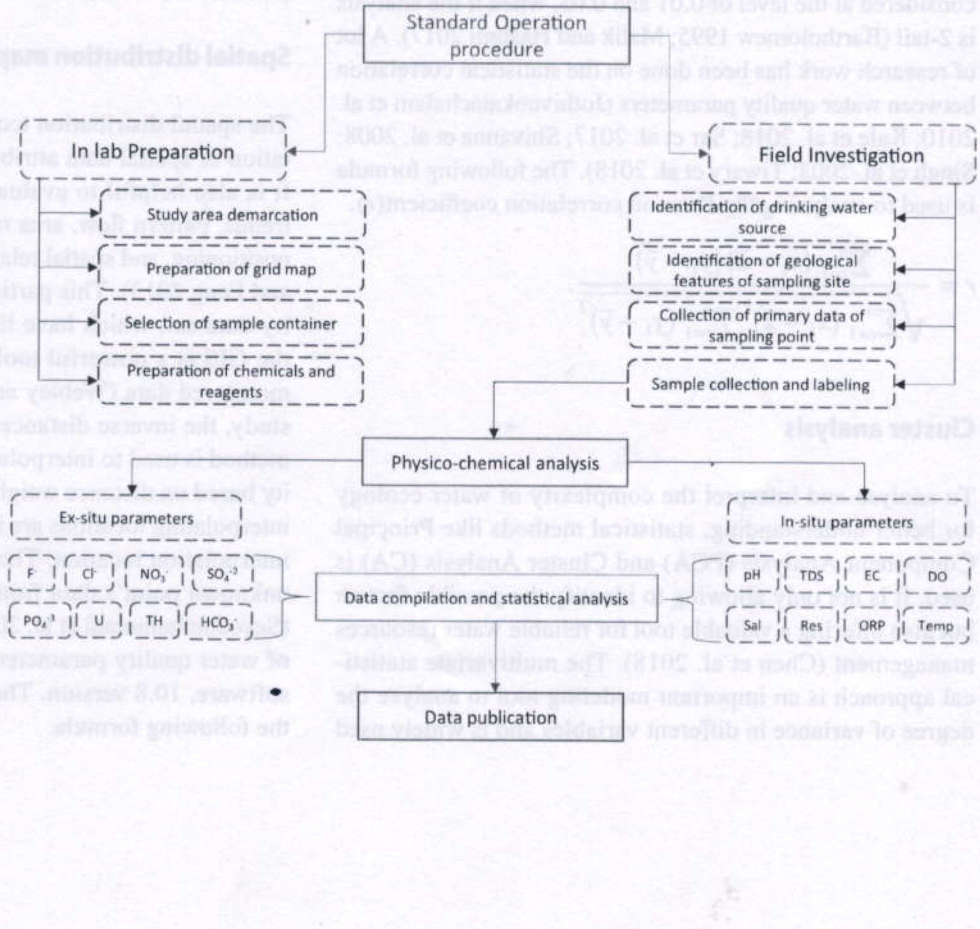


Fig. 2 Standard operation procedure adopted in the research study

Table 1 Descriptive statistics of water quality data of the study area

Parameters	Minimum	Maximum	Mean	SD	PL[a]	EPL[b] (%)
pH	6.99	9.04	7.97	0.3	6.5–8.5	1
TDS	136	1509	532	241	1000	7
EC	272	3079	1083	491	–	–
ORP	44	196	160	21	–	–
Temp	21.2	32.6	26	2.9	–	–
DO	0.99	7.29	4.24	0.7	–	–
F-	0.05	1.15	0.16	0.2	1.5	–
Cl^-	15.2	1600	161	182	250	11
NO^{3-}	9.0	380	125	68	50	48.57
SO_4^{2-}	21	400	180	71	250	16
PO_4^{2-}	2.3	53	13	6.9	–	–
U	0.1	16.3	2.04	2.8	30	–
TH	60	1090	361	196	500	17
Na^+	34	261	87	39	200	1
Ca^{2+}	5.2	54.2	24	12	200	–
Mg^{2+}	2.43	46.41	11	7.5	150	–
K +	0.2	20.7	4	3.3	–	–
HCO_3^-	182	970	510	196	–	–

All values are in mg/L except pH, EC (μS/cm) ORP (mV) and U (μg/L)

[a]Permissible limits

[b]Exceeding permissible limits (%)

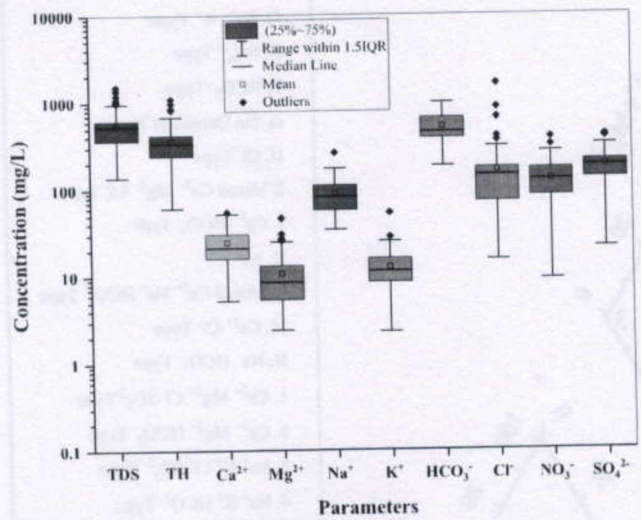


Fig. 3 Boxplot of physicochemical parameters in the study region

that most chemical-based fertilizers viz., carbamide (Urea), Di-ammonium phosphate (DAP), Single superphosphate (SSP), Ammonium Sulphate Nitrate, Nitro phosphates are generally used in the agricultural sector that leads to nitrate pollution (Almasri and Kaluarachchi 2004; Chen et al. 2017; Taneja et al. 2019). The observation of sulfate value in the study area ranges between 21 and 400 mg/L with an average of 180 mg/L. The main source for sulfate in groundwater is the dissolution of sulfate bearing rock (Rybnikova and Rybnikov 2019), oxidation of sulfide minerals (Ren et al. 2019), and human activities viz., excessive use of fertilizers and sewage disposal (Mohapatra and Kirpalani 2016), and mining activities (Singh and Singh 2018). The phosphate content varies from a minimum of 2 mg/L to a maximum of 53 mg/L. The main source of phosphate content (in trace amount) in groundwater is rock geological (Singh and Singh 2018), but excessive use of phosphate-based fertilizers may lead to phosphate pollution in groundwater (Weissengruber et al. 2018). The concentration of uranium is found in the range from 0.1 to 16.3 μg/L with an average value of 2 μg/L which is very well below the permissible limits suggested by the World Health Organization (2004). The source for uranium is geogenic in nature. The total hardness of all collected groundwater samples ranged between 60 and 1090 mg/L with an average value of 361 mg/L which is below the permissible limits of 500 mg/L as suggested by WHO (2011). In the current study, the order of ions in the groundwater is $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ for cataions and $HCO_3^- > SO_4^{2-} > Cl^- > NO_3^-$ for anions. The Na^+ ion concentrations in the study area vary from 34 to 261 mg/L with an average of 87 mg/L (Table 1). All samples are observed in the permissible limit by WHO (2011). The ionic concentration of Ca^{2+} ranges between 5.2 and 54.2 mg/L with an average value of 24 mg/L. The Mg^{2+} ions concentration is in the range between 2.43 and 46.41 mg/L with a mean value of 11 mg/L. The K^+ and HCO_3^- ionic concentration are observed in the range 0.2–20.7 mg/L and 182–970 mg/L, it is found that all the sampling locations fall under the safe category.

Groundwater classification

The modified trilinear diagram is presented by Piper (1944) and it is widely used for the presentation of groundwater composition. It is also used to observe analytical values of groundwater, which is plotted on the Piper trilinear diagram, and to understand variations in cationic and anionic concentration over the study area. The Piper trilinear diagram of the groundwater sample is presented in Fig. 4. Three main types of water have been identified based on varying ionic concentration: Mixed Ca^{2+} –Na^{+}–HCO_3^{-}, Na^{+}–Cl^{-} and Na^{+} HCO_3^{-}. The majority of water samples (60%) fall in the first category, i.e., Mixed Ca^{2+} –Na^{+}–HCO_3.. This wide variation of water types reflects that the local variation of geology and geochemistry significantly affects the groundwater compositions. The diagram itself shows the relative abundance of cations of Na^{+}–K^{+} (98%), and only two samples are fall in the no dominant type of water in first plotted on the cation triangle. In the relative abundance of $HCO_3^{-}+CO_3^{2-}$ and no dominant type of water has been found in the anion triangle.

Identification of hydrogeochemical processes

Water flows through an aquifer and as a result of interaction with the lithological framework changes in the chemical composition of groundwater occurs. The reaction between groundwaters with the lithological framework plays an important role in groundwater quality. It is helpful to understand the genesis of water (Cederstrom 1946). The hydrochemical data are presented with many conventional graphical tools to understand the hydrogeochemical reactions in the groundwater environment. Some of the possible recognized processes are explained below. The cationic ratio of Ca^{2+} and Na^{+} is used to understand the possible sources of calcium and magnesium ions in the aquifer (Mayo and

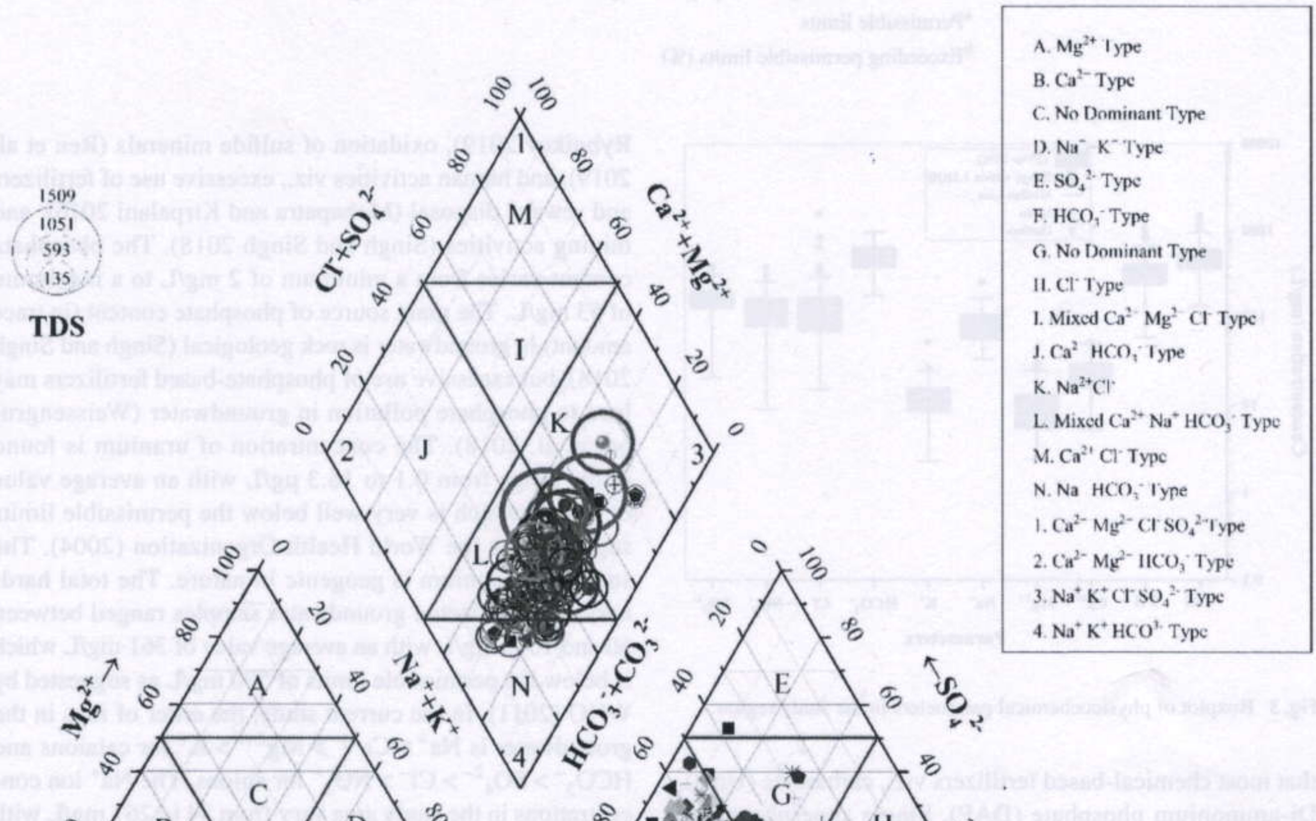


Fig. 4 Piper trilinear diagram of groundwater samples in Jalna district

Loucks 1995). The abundance of calcium and magnesium ions in the groundwater may be connected to the presence of carbonate rock in the area. The carbonate and silicate minerals weathering may contribute to the calcium and magnesium ions in the groundwater. If Ca^{2+}/Mg^{2+} molar ratio = 1, indicate the dissolution of dolomite rock (Mayo and Loucks 1995). A ratio of greater than 1 but less than 2, may indicate a more dominant contribution of calcite from the bedrock. The Ca^{2+}/Mg^{2+} ratio greater than 2 (> 2), may represent the dissolution of silicates minerals into the groundwater (Katz et al. 1997). Only six samples (5.71%) are indicating the dissolution of dolomite with a Ca^{2+}/Mg^{2+} ratio less than one (< 1) Fig. 5a. The 81 (77.14%) samples with above the 1 ratio, are indicative of the ion exchange with Na^+ with increasing Mg^{2+} ions suggesting the dissolution of calcite. The 18 (17.14%) of total samples exceed the ratio greater than 2, which presented silicate minerals dissolution that contributes to calcium and magnesium in groundwater (Mayo and Loucks 1995). The Na^+/Cl^- ratio was used to understand the plausible sources of salinity in groundwater (Fig. 5b). The molar ratio of Na^+/Cl^- will be one of the dissolutions of halite that is responsible for sodium dominance in groundwater. In case molar ratio > 1 indicate the Na^+ is released from the silicate weathering process (Meybeck 1987) due to rock water interaction via reaction:

$$2NaAlSi_3O_8 + 9H_2 + H_2CO_3 = Al_2Si_2O^5(OH)_4 + 2Na + 2HCO^{3-} + 4H_4SiO_4.$$

The majority (103) samples reflect the above process indicating release of the Na^+ from the silicate weathering associated with evaporative deposits/evaporates (Gosselin et al. 2003).

Rock–water interaction

The groundwater chemistry is control by many factors such as aquifer position, lithology of bedrock, and weathering condition. Gibbs diagram is widely used to understand the controlling mechanism of groundwater in the aquifer system (Gibbs 1970). Gibbs recommended a simple plot of TDS Vs. $Na^+/Na^+ + Ca^{2+}$ and $Cl^-/Cl^- + HCO_{3-}$ to explain the natural mechanism controlling groundwater chemistry illustrating three significant hydrogeochemical fields such as evaporation dominance, rock water interaction, and precipitation dominance. The majority of water samples are falling in the rock-water interaction dominance (Fig. 6a, b) indicating that weathering of rock in the aquifer is the main hydrogeochemicalprocess, which runs the quality of groundwater in the study area.

Ion-exchange processes

It is important to know the variations in the chemical composition of groundwater during movement. The Chloro-alkaline indices CAI-I and II are suggested by Schoeller (1977), which specifies the ion exchange among groundwater and its host atmosphere. The CAI indices used in the assessment of the Base Exchange process calculated using the formula.

$$\text{Chloro-alkaline index I} = (Cl^-(Na^+ + K^+))/Cl$$

$$\text{Chloro-alkaline index II} = (Cl^-(Na^+ + K^+))/(SO_4^{2-} + HCO_{3-} + CO_3^{2-} + NO_3^-).$$

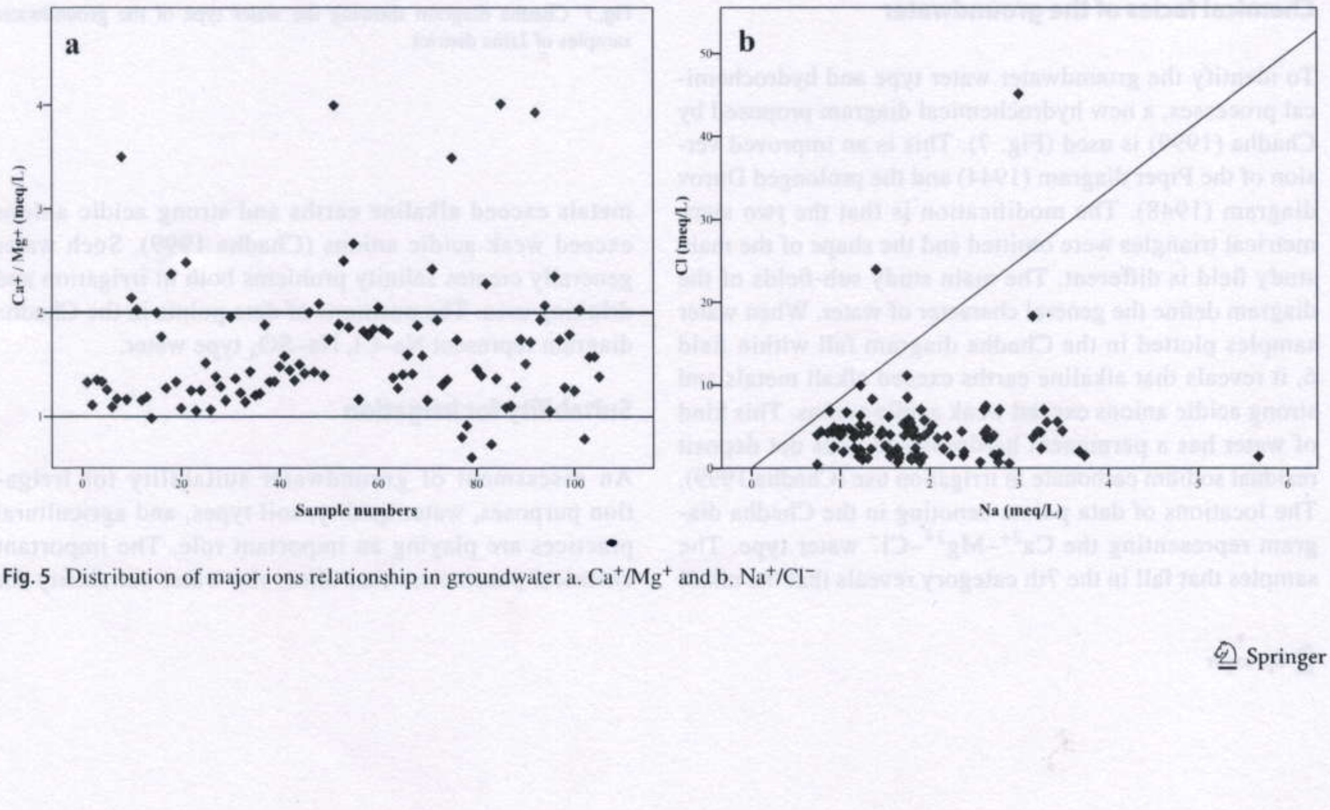


Fig. 5 Distribution of major ions relationship in groundwater a. Ca^+/Mg^+ and b. Na^+/Cl^-

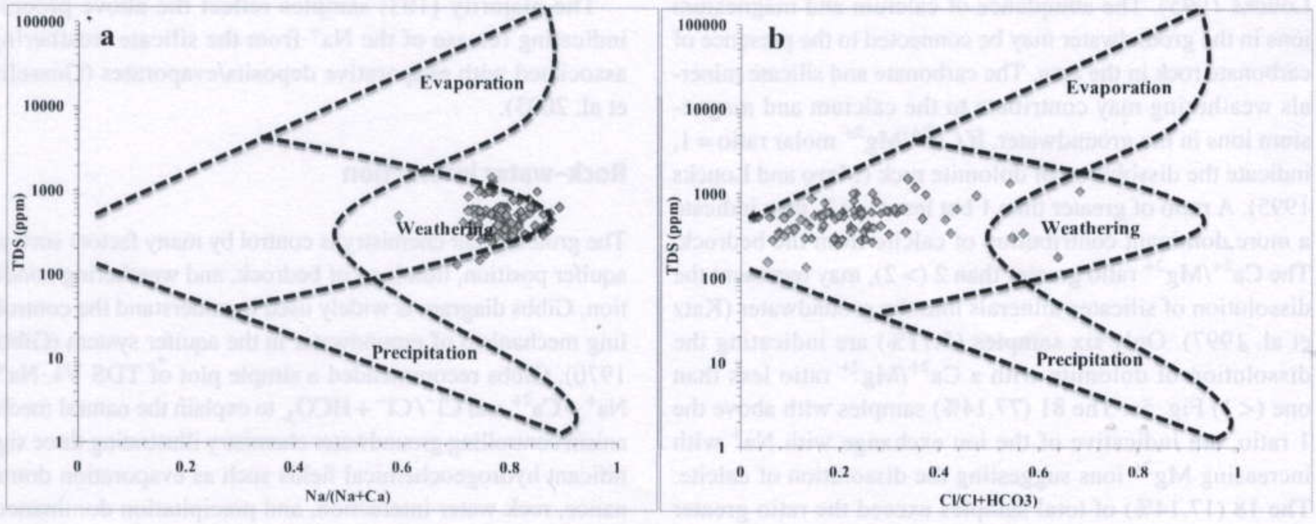


Fig. 6 **a, b** The mechanism controlling the groundwater chemistry in the study area

Whenever Na^+ and K^+ ions are exchanged with Mg^{2+} and Ca^{2+} ions, the indices value will be positive, indicating direct Base Exchange reaction or Chloro-alkaline equilibrium. While, if the process is in the opposite order then the indices are found to be negative, indicating Chloro-alkaline disequilibrium or indirect base-exchange reaction. The Chloro-alkaline indices (I and II) are calculated for the collected waters of the area (Table 1). It was observed that around 50% of samples show positive and negative ratios in CAI-I and CAI-II respectively. From the assessed Chloro-alkaline indices (CAI I and II), the principal geochemical process in this hard rock aquifer is the reverse ion exchange process that leads to higher calcium and magnesium content in groundwater.

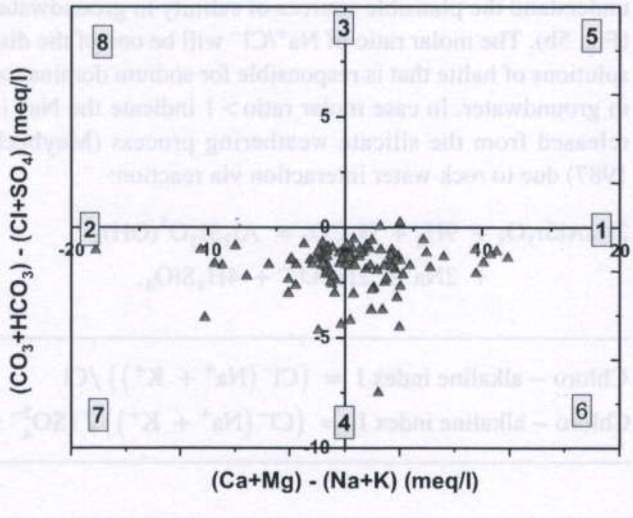


Fig. 7 Chadha diagram showing the water type of the groundwater samples of Jalna district

Chemical facies of the groundwater

To identify the groundwater water type and hydrochemical processes, a new hydrochemical diagram proposed by Chadha (1999) is used (Fig. 7). This is an improved version of the Piper diagram (1944) and the prolonged Durov diagram (1948). The modification is that the two symmetrical triangles were omitted and the shape of the main study field is different. The main study sub-fields of the diagram define the general character of water. When water samples plotted in the Chadha diagram fall within field 6, it reveals that alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions. This kind of water has a permanent hardness and does not deposit residual sodium carbonate in irrigation use (Chadha 1999). The locations of data points denoting in the Chadha diagram representing the Ca^{2+}–Mg^{2+}–Cl^- water type. The samples that fall in the 7th category reveals that the alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions (Chadha 1999). Such water generally creates salinity problems both in irrigation and drinking uses. The positions of data points in the Chadha diagram represent Na–Cl, Na–SO_4 type water.

Suitability for irrigation

An assessment of groundwater suitability for irrigation purposes, water quality, soil types, and agricultural practices are playing an important role. The important chemical parameters that affect the water suitability for irrigation are the total dissolved salts, relative proportion of bicarbonate to calcium and magnesium, sodium to calcium. The salinity indices like sodium percentage (Na%), sodium absorption ratio (SAR), and permeability index (PI) are important factors for determining the groundwater suitability for agricultural practices.

Sodium adsorption ratio

Excessive sodium concentration can reduce the permeability and soil structure, which inhibits the supply of water needed for the crops (Todd and Mays 2004). The excess sodium (SAR) was estimated using the following formula (HEM 1985).

$$\mathrm{SAR} = \frac{\mathrm{Na}^+}{\sqrt{\frac{\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+}}{2}}}.$$

All the concentrations in this equation are expressed in meq/L. The classification of water samples of the study area based on SAR is given in Table 2. All water samples of the area fell under the excellent category concerning SAR, and hence, there is no hazard due to sodium.

Table 2 Classification of groundwater quality based on the suitability of water for irrigation purposes

Parameters	Range	Water class	Number of samples (%)
EC	< 250	Excellent	0
	250–750	Good	28
	750–2000	Permissible	65
	2000–3000	Doubtful	07
	> 3000	Unsuitable	01
SAR	< 10	Excellent (S1)	100
	10–18	Good (S2)	0
	18–26	Doubtful (S3)	0
	> 26	Unsuitable (S4)	0
% Na	< 20	Excellent	0
	20–40	Good	0
	40–60	Permissible	21
	60–80	Doubtful	79
	> 80	Unsuitable	01
KI	< 1	Suitable	0
	1–2	Marginal	01
	> 2	Unsuitable	99
RSC	< 1.25	Good	2
	1.25–2.50	Doubtful	8
	> 2.5	Unsuitable	90
MR	< 50	Suitable	94.28
	> 50	unsuitable	5.71

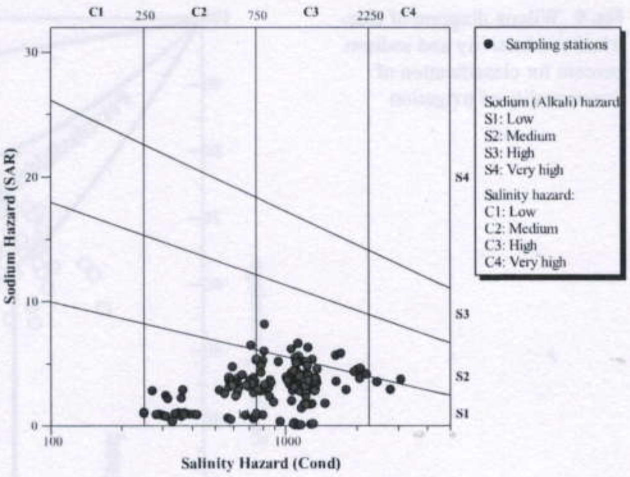


Fig. 8 Grouping of irrigation water quality based on salinity hazard vs. sodium adsorption ratio

For rating irrigation water, the US salinity diagram was used, in which the SAR is plotted against EC. The USSL plot representing that, 34% of groundwater samples fall in C2S1 (Medium salinity–low sodium type) is suggesting that the water type in the study region has medium salinity with low sodium content and it can be used for irrigation on all types of soil (Fig. 8) and 60% of the samples fall in the C3S1 category indicating high salinity-low sodium type. Only 6% falls in the medium salinity too high sodium category (C3S2). This type of water can be used to irrigate salt-tolerant and semi tolerant crops under favorable drainage conditions.

Sodium percentage (Na %)

It is significant to the estimation of sodium percentage in the water classification for irrigation use due to its ability to react with soil that decreases its permeability, which affects both soil and crop. It is important to calculate sodium percentage with SAR to determine the effect of sodium. The percent Na is calculated using the formula:

$$\text{Sodium percentage(Na\%)} = \frac{(\mathrm{Na}^+ + \mathrm{K}^+)}{\mathrm{Ca}^+ + \mathrm{Mg}^+ + \mathrm{Na}^+ + \mathrm{K}^+} \times 100,$$

where all concentrations are in meq/L. The classification of water samples based on % Na is given in Table 2. As per the (Wilcox 1955) classification for irrigation, 22 samples fall under the permissible category, 82 samples (Table 2) were found in the doubtful category and only 1 sample falls under the unsuitable category (Fig. 9).

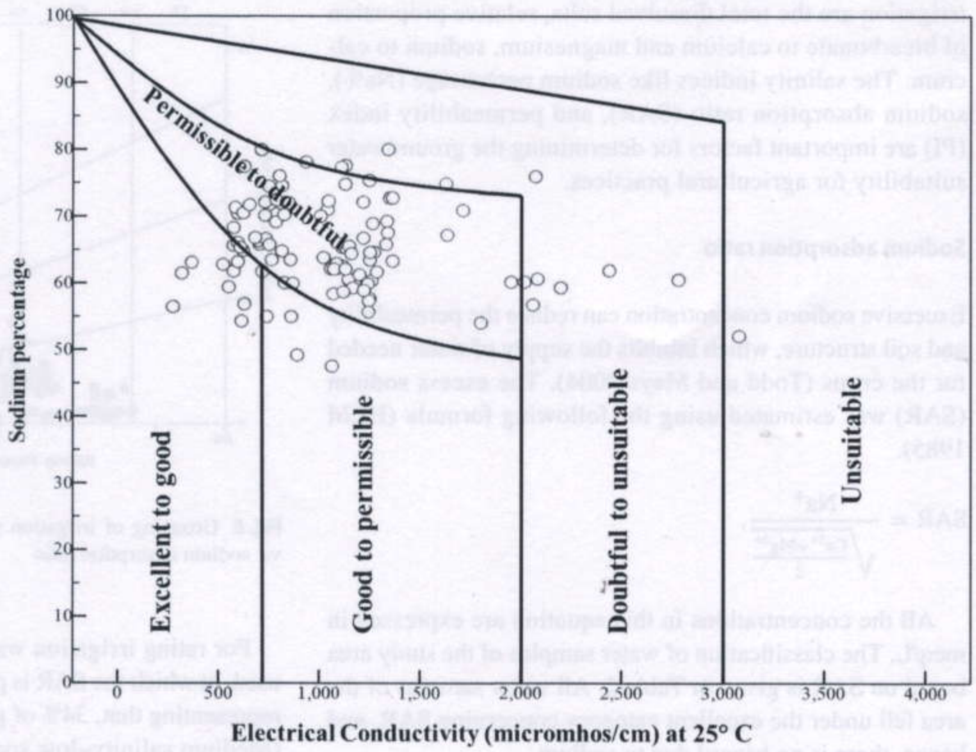


Fig. 9 Wilcox diagram of electrical conductivity and sodium percent for classification of water quality of irrigation

Kelly's index

The KI is based on the ratio of the concentration of sodium to calcium and magnesium. The KI was calculated using the following formula (Kelly 1963). According to this index, if the value of KI is less than one (< 1) suggests that the water is suitable for irrigation while those with a greater ratio are unsuitable. Where all ions are expressed in meq/L. KI calculated by the formula;

$$\text{Kelly's index (KI)} = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}}.$$

The classification of the quality of irrigation water based on KI is presented in Table 2. Only one sample falls in the marginal category and the rest falls above the unsuitable limit, indicating a higher percentage derived from weathering of lithological units of the study area.

Residual sodium carbonate (RSC)

The calculation of RSC is essential to determine the harmful effect of $CO_3{}^{2-}$ and HCO_3 on the quality of water for cultivation usage. The RSC value was calculated, using the relation, where ionic concentration is expressed in meq/L.

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

While RSC < 1.25 is safe for irrigation, it is considered unsuitable if it is greater than 2.5 (USEPA 1999). The groundwater of the study area is classified based on RSC and the results are presented in Table 2. From the total sample, only 02% of the samples fall in good, 08% fall in Doubtful and 90% of samples are fall in the unsuitable category for irrigation use (Table 2). High RSC in the irrigation water is due to fine-textured soil that will result in the development of alkali soil.

Magnesium hazard

To maintain a state of equilibrium in waters, magnesium ions are playing an important role. Paliwal (1972) introduced a ratio formula that calculates the magnesium hazard. This formula was suggesting that the ratio value of magnesium hazard crossing high (> 50), results in declining the crop yield as soil develops alkaline nature. The magnesium ratio is calculated by the following formula.

$$\text{Magnesium ratio (MR)} = \frac{Mg^{+}}{Ca^{+} + Mg^{+}} \times 100.$$

In the current study, out of a total of 99 samples (Table 2) 93 fall under the suitable for irrigation category i.e. MR < 50. The remaining 06 samples fall in the unsuitable category with magnesium hazard > 50 suggesting that the samples can affect the agricultural yield.

Table 3 Extracted output for correlation of water quality parameters of Jalna district

	pH	TDS (mg/L)	EC (µS/cm)	ORP (mV)	Temp. (°C)	DO (mg/L)	F^- (mg/L)	Cl^- (mg/L)	NO_3^- (mg/L)	SO_4^{2-} (mg/L)	PO_4^{3-} (mg/L)	U (µg/L)	TH (mg/L)	Na^+ (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	K^+ (mg/L)	HCO_3^- (mg/L)
pH	1																	
TDS (mg/L)	− 0.171	1																
EC (µS/cm)	− 0.172	**1.000**[b]	1															
ORP (mV)	**− 0.931**[b]	**0.197**[a]	**0.198**[a]	1														
Temp. (°C)	− 0.278[b]	− 0.022	− 0.021	**0.295**[b]	1													
DO (mg/L)	0.159	− 0.082	− 0.082	− 0.118	0.106	1												
F^- (mg/L)	0.171	**0.217**[a]	**0.215**[a]	**− 0.260**[b]	− 0.13	− 0.039	1											
Cl^- (mg/L)	− 0.138	**0.341**[b]	**0.341**[b]	0.155	− 0.062	− 0.114	− 0.058	1										
NO_3^- (mg/L)	− 0.019	0.126	0.126	− 0.047	− 0.037	− 0.028	0.083	0.111	1									
SO_4^{2-} (mg/L)	0.003	0.076	0.074	− 0.032	0.039	0.007	0.05	0.175	**0.283**[b]	1								
PO_4^{3-} (mg/L)	0.068	0.032	0.031	− 0.08	− 0.059	0.08	0.063	**0.279**[b]	0.099	0.074	1							
U (µg/L)	− 0.177	**0.576**[b]	**0.576**[b]	**0.193**[a]	0.079	0.013	0.187	0.053	0.017	− 0.105	0.069	1						
TH (mg/L)	− 0.059	**0.263**[b]	**0.262**[b]	− 0.005	0.014	− 0.043	**0.206**[a]	**0.261**[b]	**0.266**[b]	0.069	**0.212**[a]	0.073	1					
Na^+ (mg/L)	**0.264**[b]	**0.329**[b]	**0.328**[b]	**− 0.306**[b]	**− 0.210**[a]	− 0.06	**0.620**[b]	− 0.039	0.155	0.086	0.156	0.164	**0.259**[b]	1				
Ca^{2+} (mg/L)	**0.193**[a]	**0.304**[b]	**0.305**[b]	**− 0.210**[a]	**− 0.284**[b]	− 0.106	**0.515**[b]	− 0.024	0.139	− 0.027	0.118	**0.241**[a]	0.183	**0.819**[b]	1			
Mg^{2+} (mg/L)	0.182	**0.247**[a]	**0.247**[a]	**− 0.222**[a]	**− 0.213**[a]	− 0.058	**0.453**[b]	− 0.014	0.159	− 0.032	0.122	**0.218**[a]	0.165	**0.712**[b]	**0.839**[b]	1		
K^+ (mg/L)	0.175	0.089	0.088	− 0.172	**− 0.235**[a]	0.065	− 0.171	0.015	0.022	0.033	− 0.09	− 0.019	0.014	0.092	0.079	0.075	1	
HCO_3^- (mg/L)	− 0.143	**0.259**[b]	**0.260**[b]	0.091	− 0.018	− 0.073	0.144	0.058	**0.399**[b]	0.174	0.103	**0.248**[a]	**0.287**[b]	0.178	**0.195**[a]	**0.255**[b]	-0.164	1

Bold values represent the significantly corrected with 0.05 and 0.01 level of confidence

U uranium, *TH* total hardness

[a]Correlation is significant at the 0.05 level (2-tailed)

[b]Correlation is significant at the 0.01 level (2-tailed)

Statistical correlation

The Spearman correlation matrix was built to evaluate the strength of a linear association between two variables of water quality parameters from the study area. The statistical software Statistical Package for Social Sciences (SPSS) version 23 (IBM 2015) is used to perform the correlation operation. The extracted output of correlation from water quality parameters is presented in the tabular form in Table 3. Significant correlations were observed between water quality parameters. A strong negative correlation of pH with ORP (− 0.931) and a weak negative with sodium and calcium (0.264 and 0.193) correlation has been observed. The strong positive correlation has been found between TDS with EC (1.00), chloride (0.341), uranium (0.576), hardness (0.263) sodium (0.239), calcium (0.304), magnesium (0.247) and bicarbonate (0.259). Whereas a week correlation has been noted in TDS to fluoride and nitrate. The ORP is significantly correlated with temperature, fluoride, uranium, sodium, calcium, and magnesium. It is suggesting that OPR is playing a significant role in groundwater quality and affect the movement of contaminant species. The temperature and fluoride are positively correlated to cations such as uranium, sodium, calcium, and magnesium. A strong positive correlation coefficient (0.576) was observed between uranium to TDS and EC. A week positive correlation was observed in uranium to ORP, calcium, magnesium, and bicarbonate ions. This finding itself suggesting that the existence of uranium may be due to the soluble mineral salts as well as an anthropogenic source like excessive use of phosphate-containing fertilizers, the same finding is reported by many researchers (Sharma and Singh 2016). Based on the result, it is very important to minimize the use of chemical-based fertilizer and discharge the radioactive waste in water bodies. The calcium and magnesium ions also positively correlated with each other. It is suggesting that the weathering of bedrock is the main source of the cations.

Custer analysis

In this study, the Cluster Analysis (CA) classified the water quality data in different groups and presented it in the form of a dendrogram represented in Fig. 10 and extracted cluster variables in Table 4. The Ward Linkage method (Squared Euclidean) method was implemented for the analysis of clusters. The CA joined the groundwater samples of the study region into three types of cluster groups. For the water quality parameters, the First cluster contains pH, dissolved oxygen, phosphate, uranium, and potassium, whereas cluster two including TDS, EC, pH, ORP, temperature, chloride, nitrate, sulfate, total hardness and bicarbonate, and total hardness which indicating that input from the dissolution of soluble salt. The fluoride, sodium calcium and magnesium are the only parameter,

Table 4 Final Partition of water quality parameters of the study area

	Variables
Cluster 1	pH, DO, PO_4^{3-}, U, and K^+
Cluster 2	TDS, EC, ORP, Temperature, Cl^-, NO_3^-, SO_4^{2-}, TH, and HCO_3^-
Cluster 3	F^-, Na^+, Ca^{2+}, Mg^{2+}

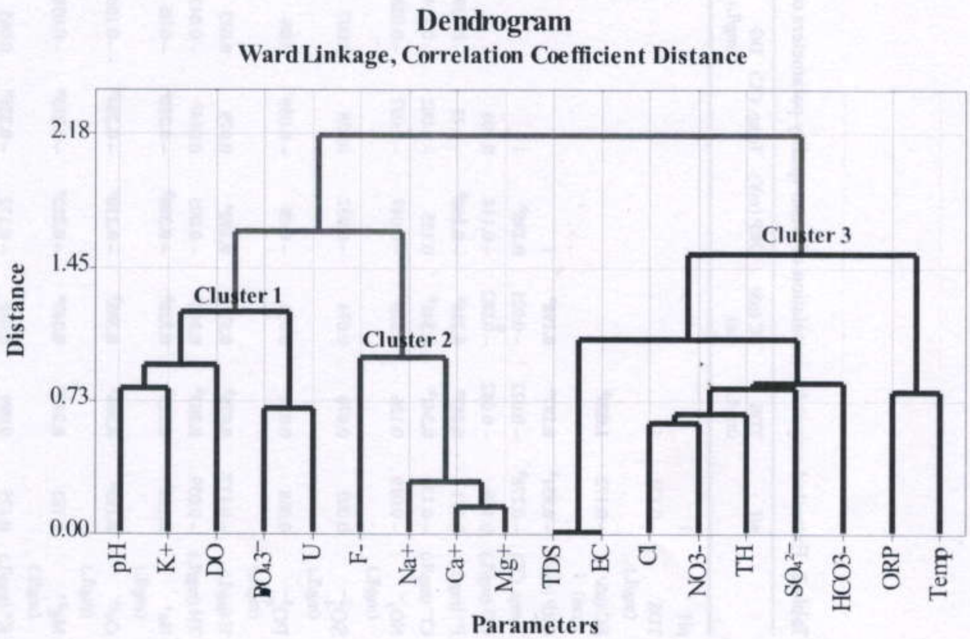


Fig. 10 Clustering dendrogram of water quality parameters from the study area

which falls under cluster 3. The CA groups are mostly resulting from the dissimilar dissolution of minerals from rock and the high calcium and magnesium content in soil are mainly deep black cotton types of soils occurs and it percolates due to rainfall (Rajesh et al. 2012). The results indicate that CA is useful to classify water quality parameters in an ideal way and offer a reliable arrangement of water quality parameters in the groups of the study area.

Factor analysis

In the present investigation, the factors are extracted using the Varimax rotation of principal component method in the factor analysis test. It helps to compare compositional patterns of analyzed data of water quality parameters. The rotated loading matrix, the total eigenvalue of different factors, variance percentage with cumulative percentage are presented in Table 5 and presented in scree plot (Fig. 11). The FA of the water quality parameters were extracted above the criterion eigenvalue one (> 1). The 18 variables are loaded for extraction, out of, five factors were extracted is presented in (scree plot) Fig. 10. The total variance is contributed for F1 is 3.22%, for F2, 2.88%, F3, 2.21%, 1.60% for F4 and 1.40% for F5, respectively. The cumulative percentages are 17.9%, 16%, 12.30%, 8.90% and 7.80% for F1, F2, F3, F4 and F5 correspondingly. The Communality percent variance of all factors is 62.83%. Factor one having 17.9% of the total variance is showing strong positive loading of fluoride, sodium, calcium, and magnesium suggesting that the groundwater environment is dominant by fluoride-bearing minerals like sellaite, villianmite, and fluorite (Jha et al. 2013) which controlling geochemical mechanism leads to leach the fluoride content in the groundwater (Adimalla et al. 2018; Ayoob and Gupta 2006; Li et al. 2019). A significant correlation was also noticed between fluoride, sodium, calcium, and magnesium.

The second factor loaded with TDS, EC, chloride, nitrate, sulfate total hardness which indicating that input from the dissolution of soluble salt. Chloride is mobilized mainly through the weathering of rocks (Fernández-Turiel et al. 2003). The presence of Cl^- can be attributed to natural and anthropogenic sources. The significant load of nitrate and sulfate indicating that the anthropogenic source of chemical-based fertilizers. This factor may be termed as eutrophication factor as the sign of the loadings of nitrate and sulfate concentration leads to the eutrophication process. In factor,

Table 5 Extracted values of various factors of water quality parameters for the study area

Rotated Factor Loadings and Communalities

Varimax Rotation

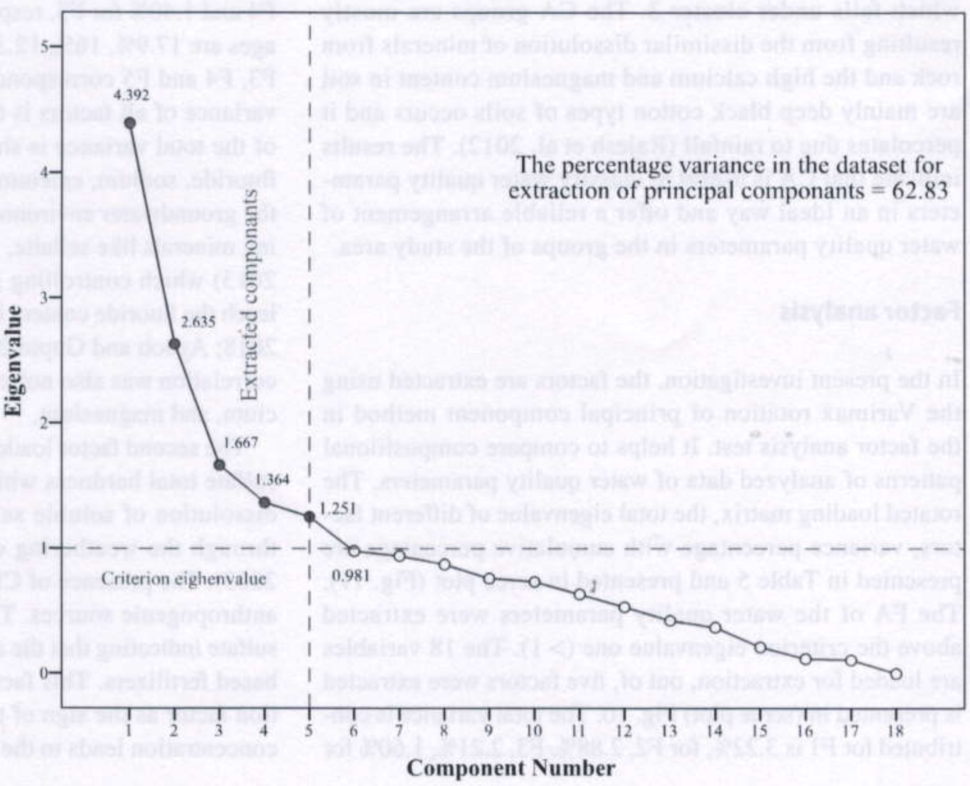
Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
pH	0.15	0.07	**0.87**	− 0.07	0.19	**0.83**
TDS	0.42	**− 0.63**	− 0.38	− 0.27	0.26	**0.86**
EC	0.42	**− 0.63**	− 0.38	− 0.27	0.26	**0.86**
ORP	− 0.21	0.01	**− 0.85**	0.03	− 0.17	**0.80**
Temp	− 0.28	− 0.14	− 0.24	0.00	− 0.43	0.33
DO	− 0.30	− 0.02	0.27	− 0.37	0.13	0.32
F-	**0.52**	0.00	− 0.03	0.24	0.13	0.35
Cl	− 0.02	**− 0.73**	− 0.10	− 0.09	0.13	**0.57**
NO_3-	0.11	**− 0.76**	0.10	0.12	− 0.18	**0.65**
SO_4^{2-}	− 0.18	**− 0.63**	0.26	0.13	− 0.20	**0.55**
PO_4^{3-}	0.06	− 0.07	0.20	**− 0.72**	− 0.07	**0.56**
U	0.19	− 0.02	− 0.22	**− 0.76**	− 0.01	**0.66**
TH	0.31	**− 0.53**	− 0.10	− 0.16	0.02	0.41
Na +	**0.82**	− 0.13	0.29	− 0.05	− 0.02	**0.77**
Ca +	**0.88**	− 0.12	0.13	− 0.16	− 0.03	**0.83**
Mg +	**0.83**	− 0.17	0.06	− 0.26	0.01	**0.79**
K +	0.03	− 0.24	0.16	− 0.01	**0.77**	**0.67**
HCO_3-	0.24	− 0.39	− 0.06	− 0.11	**− 0.55**	**0.53**
Variance	**3.22**	**2.88**	**2.21**	**1.60**	**1.40**	**11.31**
% Variance	**17.9**	**16**	**12.3**	**8.9**	**7.8**	**62.80**

Bold values represent the significantly loaded parameters in that factor

Extraction Method: Principal Component Analysis

a. 5 components extracted

Fig. 11 Scree plot of extracted factors of water quality parameters from the study area



F2 contributes 16% of the total variance with an eigenvalue of 2.635. The pH and ORP are inversely loaded to each other in factor three and suggesting that it may be termed as a heavy-metal removal factor. An increase in the oxygen reduction potential of water will disturb the contact between metal ions from the solution. Same work is reported that ORP monitoring may apply to track the conditions and periodic deviations of heavy metal pollution in groundwater and also give the response for more effective metal removal process from the groundwater (Bose and Sharma 2002; Kale et al. 2020b; Racys et al. 2017). Factor four represented 8.90% of the total variance and the uranium and phosphate are significant positively loaded. This factor suggesting that there is the same source for phosphate and uranium. Anthropogenic sources like excessive use of phosphatic fertilizer in agricultural practices can cause the dissolution of phosphate in groundwater. The same finding was also reported by my research workers (Loganathan et al. 2006; Shekhar et al. 2017; Singaraja et al. 2014). Factor five contributes 7.8% of the total variance (eigenvalue 1.251) is inversely loaded with potassium and bicarbonate. The source may be for potassium bicarbonate is a fungicide used to control the powdery mildew (Sawant and Sawant 2008; Wenneker and Kanne 2010) which percolates from the surface to groundwater aquifer.

Spatial distribution mapping

Spatial distribution analysis of uranium concentration and other water quality parameters was performed using ArcGIS 10.3 software. The inverse distance weighted (IDW) interpolation method is used for the preparation of distribution maps. IDW is an algorithm to interpolate the spatial data based on weighted average values of surrounding sample points. The interpolation method is assuming the values are nearer to one another are more alike than those which are farther away. The spatial distribution map of pH, ORP, TDS, EC, DO, fluoride, chloride, nitrate, sulfate, phosphate, uranium, total hardness, and bicarbonate are presented in Fig. 12a–m. These figures are practically visualizing how water quality parameters are distributed over a study area. The pH is not uniformly distributed, which is the east side is of the study area elevated in the pH values, i.e., 8–9 pH. The main reason for this is the use of alkaline chemical-based fertilizer. The OPR is inversely proportional to pH (Fig. 11a, b) which is showing inverse distribution over the study area. The spatial distribution of the TDS and EC of the study area is showing scatter distribution. In the distribution map, the red-colored point's heights which are crossed the permissible limit suggested by the health agency. The main source for dissolved solids is the dissolution of soluble salts in an unsaturated zone (Sharma et al. 2017). The dissolved oxygen and fluoride content are well below the permissible limits. In the case

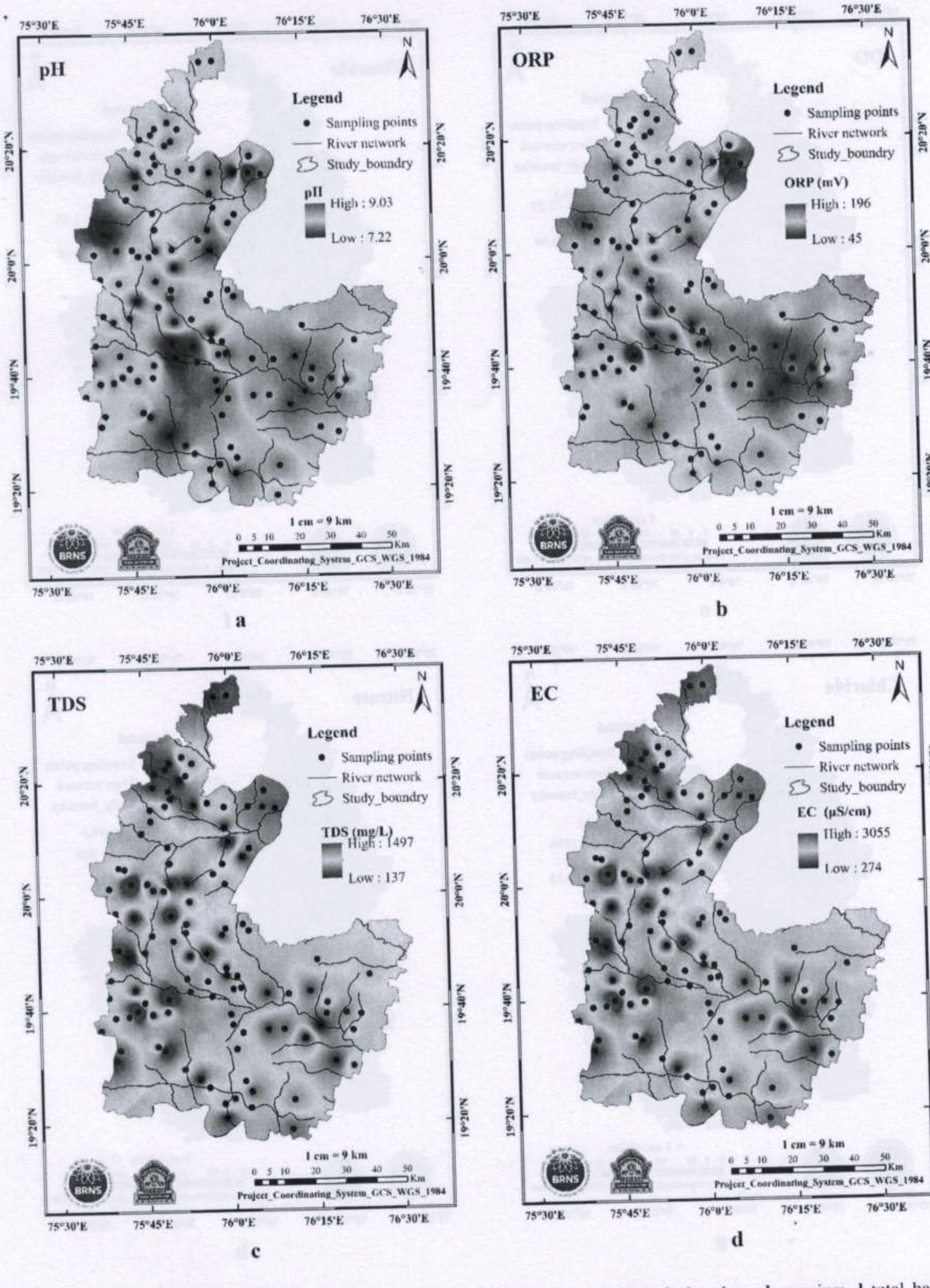
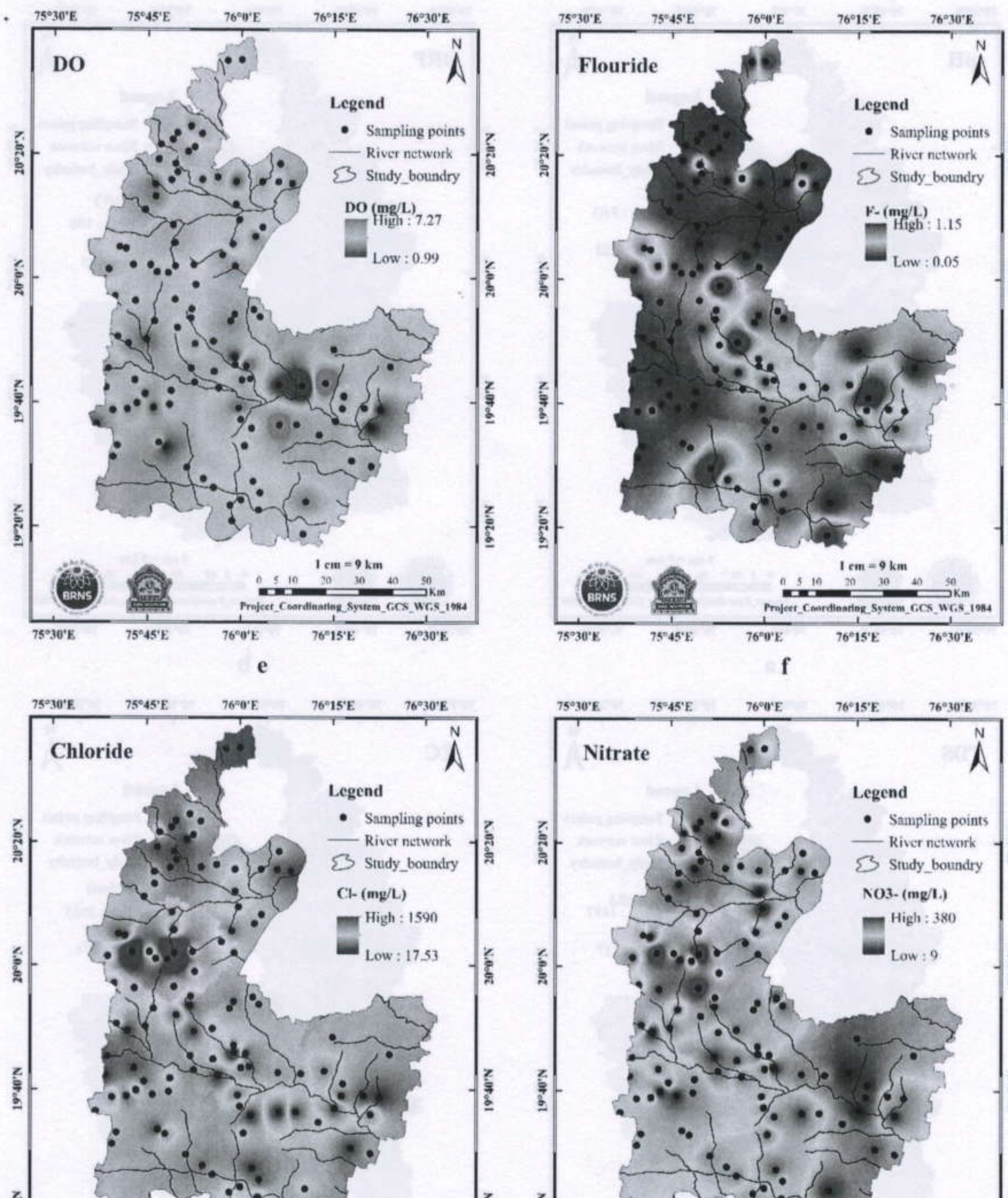


Fig. 12 Spatial distribution of water quality parameters from Jalna district. **a** pH, **b** oxygen reduction potential, **c** total dissolved solids, **d** electrical conductivity, **e** dissolved oxygen, **f** flouride, **g** chloride, **h** nitrate, **i** sulfate, **j** phosphate, **k** uranium, **l** total hardness and **m** sodium, **n** calcium, **o** magnesium, **p** potassium, and **q** bicarbonate



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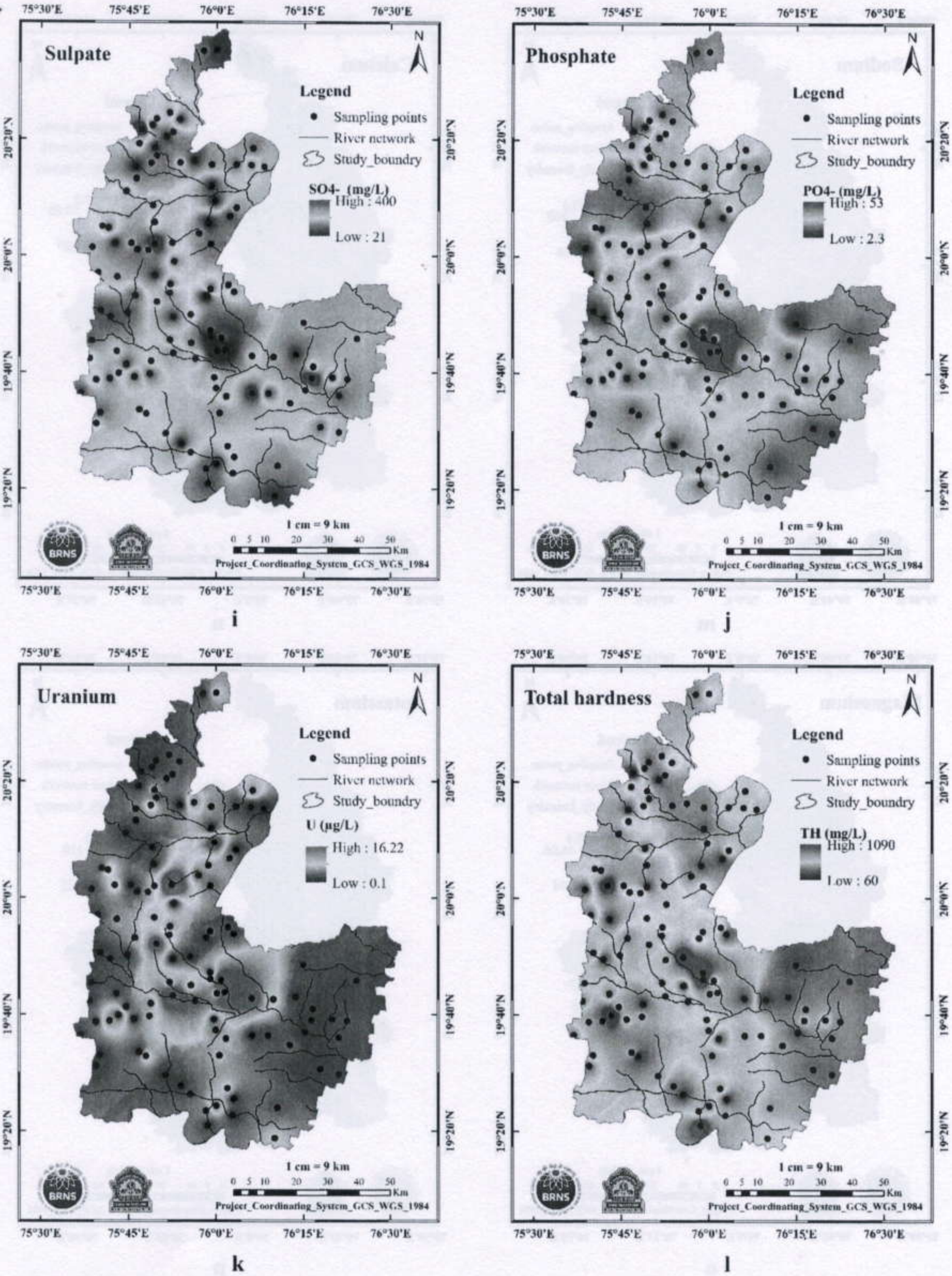

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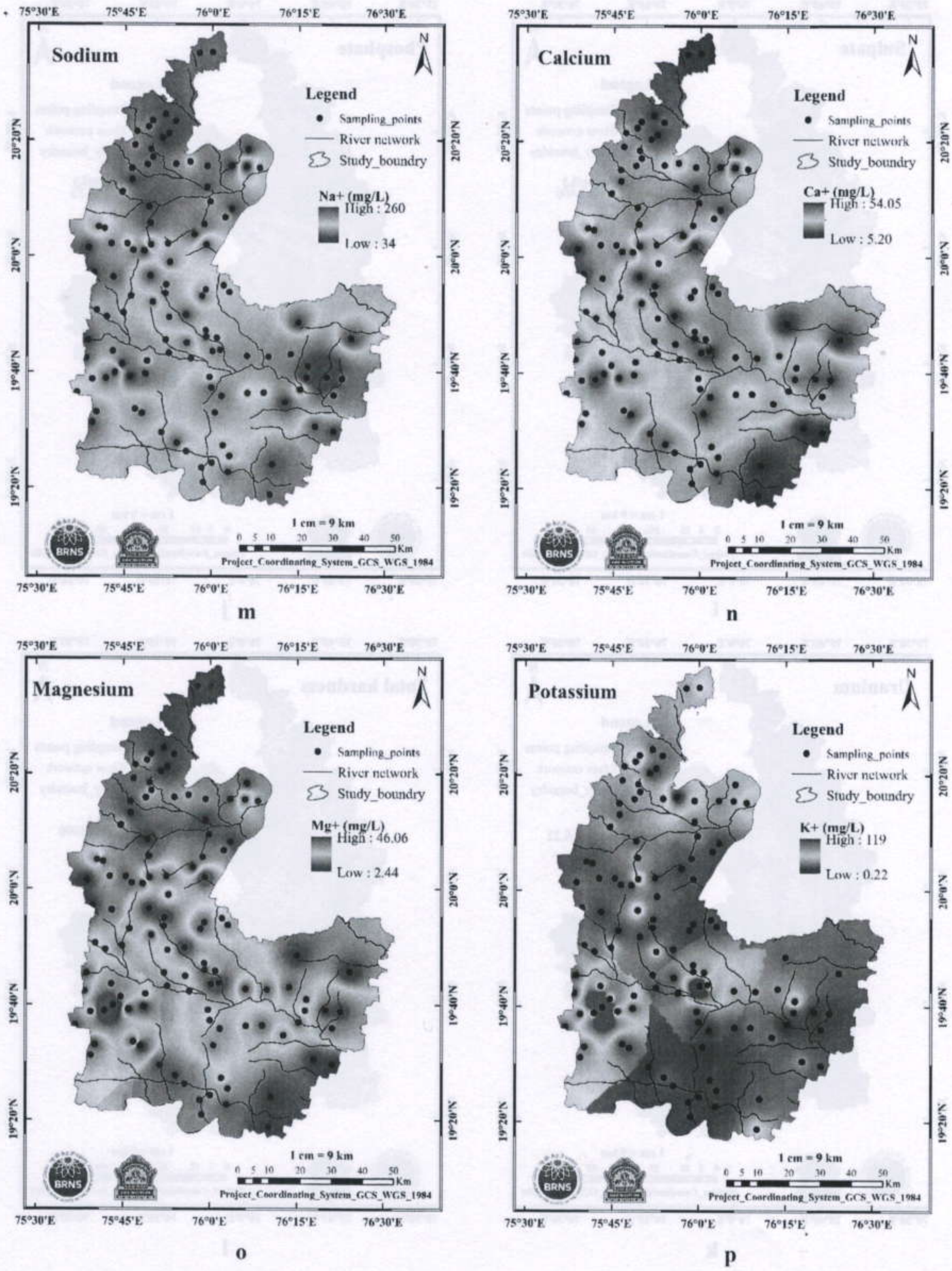

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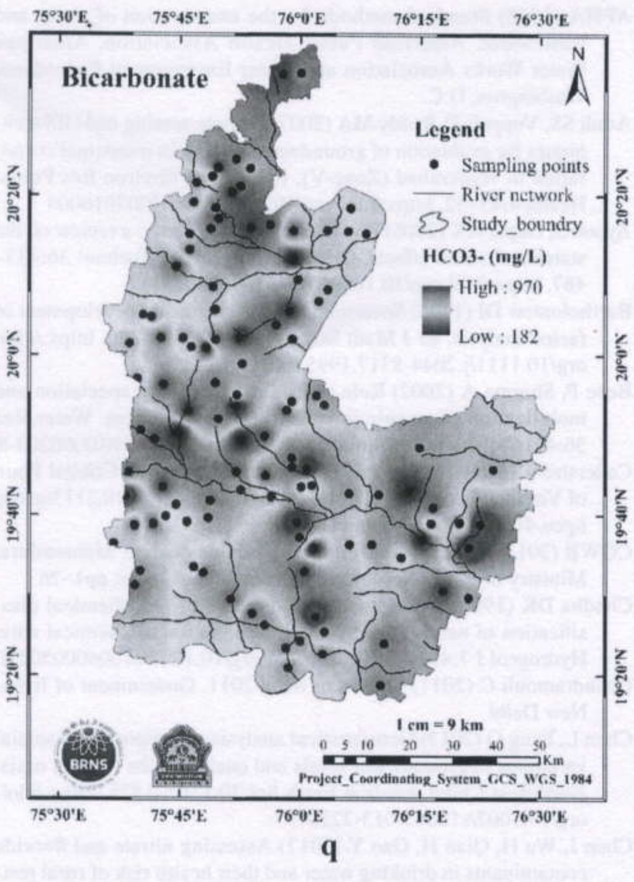

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Fig. 12 (continued)

of chloride and nitrate, there are 5–6 sampling points which show the same pattern of distribution denoting there is any constitutional pattern of that particular location. The possibility of point source contamination or maybe heterogeneous groundwater chloride and nitrate. The values themselves indicating the anthropogenic source of pollution like excessive use of chemical-based fertilizers. The sulfate distribution pattern is showing the same pattern as TDS. The sources for sulfate in groundwater are the dissolution of sulfate bearing rocks (Fig. 11i). The uranium is showing well below the permissible limit. The main source for the uranium in the study area is geogenic in nature. The hardness, sodium, calcium, and magnesium distribution pattern are elaborating the same pattern.

Conclusion

Efforts are made in the present study to understand the hydrogeochemical processes in the hard rock aquifers of Deccan trap basalt in Western India and multivariate statistics employed to delineate the sources of major ions in groundwater. The major observations are found in the study are given below.

1. The water quality parameter exceeded the recommended safe limit for drinking purposes for most parameters at very few locations.
2. The concentration of uranium is found in the range from 0.1 to 16.3 µg/L with an average value of 2 µg/L that is well below the guideline value recommended by the World Health Organization.
3. The sequence of the dominant major cations and anions is $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ and $HCO_3^{-} > Cl^{-} > SO_4^{2-}$ respectively.
4. Piper trilinear diagram indicates, dominant hydrochemical facies of groundwater in the study area are Mixed Ca^{2+}–Na^{+}–HCO_3^{-}, Na^{+}–Cl^{-} and Na^{+}–HCO_3^{-}. Also, similar observations were observed from the Chadha diagram.
5. The Ca/Mg ratio in the majority of samples observed above the 1, indicating the ion exchange with Na^{+} with increasing Mg^{2+} ions suggesting that the dissolution of calcite, also some samples indicating the dissolution of silicate minerals that contribute calcium and magnesium in groundwater.
6. Based on Gibbs's classification, the majority of water samples fall in the rock-water interaction dominance indicating that weathering of the host rock in the aquifer is the main hydrogeochemical process in the study area.
7. Based on the ion-exchange processes of the study area, it was observed that around 50% and 84% of samples show positive and negative ratios in CAI-I and CAI-II, respectively.
8. Evaluation of chemical facies of the groundwater using Chadha classification, the samples are fall within the field 6, revealing a Ca^{2+}–Mg^{2+}–Cl^{-} water type. In this field, that alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions and field 7 represent Na-Cl, Na-SO4 type water reveals that the alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions
9. The groundwater suitability was assessed for irrigation. All water samples of the area fall under the excellent category for SAR and hence, there is no hazard due to sodium. The USSL plot indicating that 34% of the groundwater samples fall in C2S1 (Medium salinity–low sodium type), suggesting that study area water has medium salinity with low sodium content and it can be used for irrigation. Around 60% of the samples fall in the C3S1 category indicating a high salinity-low sodium type. This type of water can be used to irrigate salt-tolerant and semi tolerant crops under favorable drainage conditions.

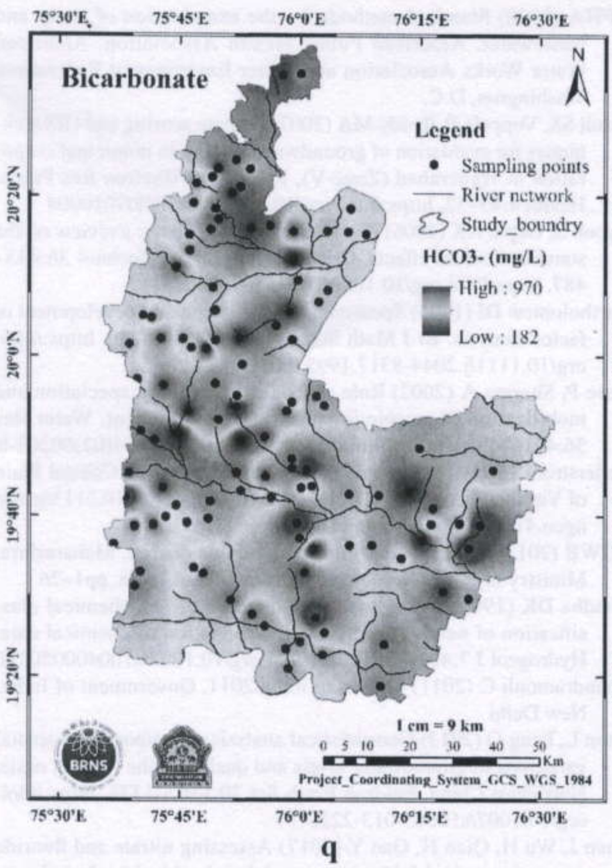

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Fig. 12 (continued)

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2. The concentration of uranium is found in the range from 0.1 to 16.3 µg/L with an average value of 2 µg/L that is well below the guideline value recommended by the World Health Organization.
3. The sequence of the dominant major cations and anions is $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ and $HCO_3^{-} > Cl^{-} > SO_4^{2-}$ respectively.
4. Piper trilinear diagram indicates, dominant hydrochemical facies of groundwater in the study area are Mixed Ca^{2+}–Na^{+}–HCO_3^{-}, Na^{+}–Cl^{-} and Na^{+}–HCO_3^{-}. Also, similar observations were observed from the Chadha diagram.
5. The Ca/Mg ratio in the majority of samples observed above the 1, indicating the ion exchange with Na^{+} with increasing Mg^{2+} ions suggesting that the dissolution of calcite, also some samples indicating the dissolution of silicate minerals that contribute calcium and magnesium in groundwater.
6. Based on Gibbs's classification, the majority of water samples fall in the rock-water interaction dominance indicating that weathering of the host rock in the aquifer is the main hydrogeochemical process in the study area.
7. Based on the ion-exchange processes of the study area, it was observed that around 50% and 84% of samples show positive and negative ratios in CAI-I and CAI-II, respectively.
8. Evaluation of chemical facies of the groundwater using Chadha classification, the samples are fall within the field 6, revealing a Ca^{2+}–Mg^{2+}–Cl^{-} water type. In this field, that alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions and field 7 represent Na-Cl, Na-SO4 type water reveals that the alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions
9. The groundwater suitability was assessed for irrigation. All water samples of the area fall under the excellent category for SAR and hence, there is no hazard due to sodium. The USSL plot indicating that 34% of the groundwater samples fall in C2S1 (Medium salinity–low sodium type), suggesting that study area water has medium salinity with low sodium content and it can be used for irrigation. Around 60% of the samples fall in the C3S1 category indicating a high salinity-low sodium type. This type of water can be used to irrigate salt-tolerant and semi tolerant crops under favorable drainage conditions.

10. The Spearman correlation matrix was built to check the correlational pattern in the water quality data. From this, significant correlations were observed between water quality parameters. The cluster analysis test was performed to classify the water quality data in different groups. From the data, three clusters are extracted. The factor analysis was performed for 18 variables, out of which 5 factors were extracted. The multivariate statistical analysis helps to evaluate the origin of pollutants, dependent variables, and factors that affect the quality of water. The spatial distribution maps are created for visualization of pollutants over the study area.
11. The limitations of this particular study are; the author has to consider other geological parameters for the comprehensive to make it more insightful, but due to resource limitations and lack of instrumentation facilities, therefore the other parameters could not be taken up. Therefore the current parameters are analyzed as per the facilitates are available at the university lab.

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Declarations

Conflict of interest The authors declare that there are no conflicts of interest regarding the publication of this paper.

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