Evaluation of Groundwater Quality for Drinking and Irrigational Purposes in a Coastal Alluvial Aquifer using Multivariate Statistical Approach: A Case Study from West Godavari Delta, Andhra Pradesh, India

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Research Article

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Abstract

The present study investigates the groundwater quality for drinking and irrigational purposes in a coastal aquifer of the West Godavari delta region based on geochemical evaluation and multivariate statistical analysis. The study area is underlain by the Quaternary sediments with unconsolidated and semi consolidated sand, silt and clay formation. The significant hydro chemical facies of groundwater observed throughout the study is Na-Mg-Cl-HCO₃, Na-Cl- HCO₃, and Mg- Na- Cl -HCO₃⁻. The results revealed that the area occupied high salinity ground waters controlling by evaporation and also rock weathering-solubilization to some extent. The abundance of chemical parameters are Na⁺ > K⁺ > Mg²⁺ > Ca²⁺ = Cl⁻ > HCO₃⁻ > SO₄²⁻ > NO₃²⁻. The analyzed water quality parameters were compared with the Bureau of Indian Standards for their suitability for domestic usage. The chemical constituents of samples TA (85%), TDS (100%), TH (83%), Mg²⁺ (91%), Cl⁻ (81%), and SO₄²⁻ (12%) exceeded the limits, hence, are unsuitable for drinking. The irrigation suitability parameters such as Na%, SAR, RSC, PI, CAI, KR, and CCR were calculated for assessing groundwater for agriculture purposes. Most of the samples show excess values, which revealed that the ground waters was not even suitable for irrigation because of providing low productivity. However, some samples ranging between the good and moderate categories can be used for irrigation with proper management. The multivariate statistical analysis was performed to understand the relationship of chemical constituents presents in groundwater. TDS is highly correlated with EC, TH, Ca²⁺, Mg²⁺, Na⁺, K⁺, HCO₃⁻, and Cl⁻. Principal component analysis (PCA) applied to the data sets showed that the first three PCs accounted for 65% of total variance cumulatively 94.5% for a total of seven PCs. It represents the quality of groundwater deviation is possibly attributed to various anthropogenic and geogenic factors, rock-water interactions and ion-exchange processes in groundwater. The uncontrolled drawl of sub-surface waters and aqua forming at an advanced rate when compare to recharge led to the coastal aquifers in critical stage, particularly in the study region Godavari delta of Andhra Pradesh state in southern India.

Introduction

Groundwater is a vital natural resource and has a significant role in the global economy. For irrigation purposes, groundwater is a reliable source of water and can be used in a flexible manner (USGS, 2001). According to World Bank (2012), the largest consumer of groundwater in the world is India, with an estimated annual groundwater use of 230 km³. Due to the pressure created over hydrologic and hydrogeological systems about the impact of climate change the quality of groundwater will mainly degrade in coastal areas. Seawater intrusion and salinization of groundwater because of overexploitation of freshwater aquifers will establish a negative water balance in the coastal regions (Gleeson and Tom, 2012). Hydro chemical studies of groundwater have vigorously been conducted by several researchers globally to identify and interpret the human-induced impact on groundwater chemistry (Loh et al. 2019; He et al. 2019; Wagh et al., 2018; Li et al., 2016, Sarikhani et al. 2015; Brindha and Kavitha, 2015; Aly et al., 2014; Gibrilla et al. 2011; Sahu and Sikhdar, 2008; Diana et al., 2017). The multi-usage of groundwater for drinking, agricultural and industrial purposes, fisheries and energy productions depend considerably on their quality (Iscen et al. 2008). The soil structure and crop yields are adversely affected by the presence of salts in irrigation waters. Arid and semi-arid climate regions are particularly vulnerable to salinity because of variations in rainfall and temperatures, which are leading to high evaporation (Houatmia et al., 2016; Jalali, 2007). The soils of agrarian areas were created environmental problems like water resource's contaminants and health risks in human beings due to vigorous usage of fertilizers and agrochemicals (Shindo et al. 2006; Scanlon et al. 2007; Jiang et al. 2009). Zakaria et al. (2020) conducted groundwater quality studies in the Anayari catchment area which is predominantly dependent on groundwater for agricultural purposes. They found that the water containing a low percentage of Na⁺ with moderate salinization can be usually used for irrigation purposes without any prior treatment. In recent years, with an increasing number of chemical and physical variables of groundwater, a wide range of conventional tools and techniques of statistical methods applied for proper analysis and interpretation of data (Belkhiri et al. 2010; Machiwal and Jha, 2010). Multivariate statistical analysis was applied in hierarchal cluster analysis by some researchers, being a simple approach to distinguish the multivariate similarities in groundwater quality. Principal Component Analysis (PCA)/Factor Analysis (FA) and Cluster Analysis (CA) explains the data set matrixes for understanding environmental systems and quality of water influenced either by natural or anthropogenic conditions (Lee et al. 2001; Ravikumar et al. 2017; Sandeep et al. 2020; Blake et al., 2016; Dudeja et al. 2011; Guggenmos et al. 2011; Khelif and Boudoukha, 2018; Sayad et al. 2017; Paul et al., 2019; Subyani and Ahmadi, 2010). For analyzing large datasets on water quality with minimum loss of vital information can be employed using multivariate statistical techniques (Simeonov et al. 2003; Jauhir et al. 2011; Gulgundi and Shetty. 2018). The alluvial aquifer system is the dominant type of aquifer in the coastal area. The coastal alluvial aquifer is relatively vulnerable to contamination by seawater. It is hard to restore its fresh groundwater condition, which makes groundwater unsuitable for drinking as well as agriculture use (Jeen et al., 2001; Chidambaram et al., 2009; Mohapatra et al., 2011; Swarna Latha and Nageswara Rao, 2012; Guler et al., 2012; Reddy, 2013; CGWB, 2014; Sajil kumar, 2016; Alfrrah et al., 2018; Sivakarun et al., 2020). The conversion of agriculture and marshy lands into aqua farming which uses large-scale saline water from creeks, and urban-industrialization lead to the alteration of freshwater aquifers in coastal regions, thus understanding the hydro chemical characteristics of the coastal groundwater is essential to prevent saline intrusion and its associated problems (Prasanna et al., 2011; Thilagavathi et al., 2019). The residents of coastal regions in India are facing now severe drinking water

quality problems in comparison with the other regions. Keeping this in view, the present study was carried out to evaluate the hydro chemical characteristics and groundwater quality and its suitability for domestic and irrigation purposes in an alluvial coastal aquifer using multivariate statistical techniques.

Study area

The study area is located within the West Godavari delta region of coastal Andhra Pradesh (AP) in Southern India. The district West Godavari of AP is bounded by the district's East Godavari in the North and Krishna in the South, Telangana State in the West and Bay of Bengal in the East. The area is under research lying between 16° 19' N to 16° 40' N latitudes and 81° 19' E to 81° 43' E longitudes (Fig. 1). It has a 23 km coastline covered by natural vegetation, cashew, casuarina and coconut plantations on its sandy tracts. The study area receives rainfall, mostly from the south-west monsoon (June to September), and the average annual rainfall recorded is about 875 mm. The climate is maritime tropical humid noting with 20°C in December and 38°C in May. The River Godavari is a major river and its tributaries namely Tammileru, Yarrakalva and Ramileru are flowing through the West Godavari district and providing abundant water supply for vast tracts of agriculture fields and aquaculture ponds. The river Godavari bifurcates into Gautami Godavari and Vasishta Godavari in the district region. The Gautami Godavari river marks as a district boundary on the right side and drains through the present study area ultimately debouches into the Bay of Bengal at Antarvedi. The delta area is aided by the large canal system and numerous other drains. The oceanic saline water from creeks is also extensively used for aqua farming near the coastal tracts. The largest shallow freshwater lake in Asia is Kolleru Lake in the southwestern part with in the study area and designated as a wetland of worldwide importance under the international Ramsar Convention. The study area accommodates nearly 0.5 million population spreading over one major town and 79 villages. Agriculture and aquaculture are the predominant activities found throughout the study area. The area is known for the large-scale production of paddy, sugarcane, pulses, oilseeds, coconuts, etc., and it is considered to be one of the largest aqua farming regions of the country. The study area is infested by a huge number of fish and prawn ponds during the last three decades resulting in the ecological and environmental imbalance (Swarna Latha, 2018).

General Geology and Geomorphology

Geologically, the study area is underlain by the Quaternary sediments with unconsolidated to semi consolidated sand, silt and clay formations. In general, the delta sediments consist of brown, grey, gravelly sands and silty clay. The thickness of the sediments gradually increasing towards the sea and is of the order of 400 m in the Godavari delta (Raju et al., 1994; Ramesh, 2008). The quaternary sediments comprised of thick layers of alluvium, gravel and colluvial deposits, beach sand, kankar and soils of various types. Different geomorphic features such as flood plain, alluvial plain, levees, paleochannels, beach ridges, active tidal flats, mudflat, swamps, and backwater, etc. are observed. Flood plains are built up of alluvium carried by the river during floods and is deposited in the sluggish water. The flat or nearly level sloping grounds of these flood plains are yielding high groundwater potential zones. Beach ridges are low dunes formed as continuous mounds of beach materials (sand, gravel, shingle, etc.) parallel to the shoreline. Another important feature is tidal flats, which are characteristically extensive, nearly horizontal, marshy or barren stretch of lands alternately covered and uncovered by the rise and fall of the tides. It consists of unconsolidated sediments, mostly of mud and sand. Soils predominantly are in deep black clay and sandy; and some extent gravelly dark brown and silty soils. Groundwater extraction structures in the study region are mainly open, bore or tube wells. The average depth of the dug well recorded is 7 meters below the ground level (m bgl). Bore well depth varies from 10 to 65m. The average fluctuation of the water table is recorded at 0.91 m in the study area (CGWB, 2017).

Materials And Methods

A total of fifty eight (58) groundwater samples were collected with proper care from the bore wells covering the entire study area during May 2017 (Fig. 1). The 1L polyethylene bottles were used for collecting groundwater and were properly rinsed with distilled water before carrying out the sampling. At the sampling location, the bottles were rinsed several times with the same bore well water to avoid any contamination before filling. These samples were cautiously sealed and labeled and taken to the laboratory for carrying out the analysis within a week. The samples were preserved by adding appropriate reagents in the laboratory by adopting standard protocols (APHA, 1998). pH, electrical conductivity (EC), total dissolved solids (TDS) were analyzed using multi parameter digital meter. Total alkalinity (TA), total hardness (TH), calcium (Ca^{2+}), bicarbonates (HCO_3^-) and chlorides (Cl^-) were measured by titration method, sodium (Na^+) and potassium (K^+) by a flame photometer whereas sulphates (SO_4^{2-}) were analyzed by using spectrophotometry. Magnesium (Mg^{2+}) was estimated by the formulae $[\text{TH} - (2.5 \times \text{CaH})]/4.1$ (Todd and Mays 2005). The result of ionic balance shows that the error for groundwater samples was $\leq 10\%$. The analytical results of chemical parameters of groundwater are presented in Table 1. Bureau of Indian Standards (BIS, 2012) were considered for comparing chemical constituents in groundwater for its utilization both domestic and agricultural purposes.

The following selected parameters were computed for assessing the groundwater suitability for irrigation purpose.

$$\text{Percent sodium (Na\%)} = \left(\frac{\text{Na}^+ + \text{K}^+}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+} \right) \times 100$$

$$\text{Sodium adsorption ratio (SAR)} = \frac{\text{Na}^+}{\sqrt{\frac{\text{Ca}^{++} + \text{Mg}^{++}}{2}}}$$

$$\text{Residual sodium carbonate (RSC)} = (\text{CO}_3^{2-} + \text{HCO}_3^-) - (\text{Ca}^{++} + \text{Mg}^{++})$$

$$\text{Permeability index (PI)} = \left(\frac{\text{Na}^+ + \sqrt{\text{HCO}_3^-}}{\text{Ca}^{++} + \text{Mg}^{++} + \text{Na}^+} \right) \times 100$$

$$\text{Chloro alkaline indice 1 (CAI1)} = [\text{Cl}^- - (\text{Na}^+ + \text{K}^+)/\text{Cl}^-]$$

$$\text{Chloro alkaline indice 2 (CAI2)} = \frac{\left[\text{Cl}^- - \frac{(\text{Na}^+ + \text{K}^+)}{\text{Cl}^-} \right]}{(\text{SO}_4^{2-} + \text{HCO}_3^- + \text{CO}_3^{2-} + \text{NO}_3^-)}$$

$$\text{Kelly ratio (KR)} = \left(\frac{\text{Na}^+}{\text{Ca}^{++} + \text{Mg}^{++}} \right)$$

$$\text{CCR} = \frac{\left(\frac{\text{Cl}^-}{35.5} \right) + \left(\frac{\text{SO}_4^{2-}}{48} \right)}{\left(\frac{\text{CO}_3^{2-} + \text{HCO}_3^-}{50} \right)}$$

Where the concentration of ions used in the calculations is in meq/L except for KR and CR for which mg/L used. The results of all irrigation quality parameters are given in Table 2. Multivariate statistical analysis methods, including principal component analysis, factor analysis and correlation were used to analyze the groundwater chemistry characteristics. XLSTAT 2018 was utilized for preparing graphs and data table analysis. The Piper, USSL, Wilcox's diagrams were generated using Aquachem 2014 software.

Results And Discussion

Box plot helps in summarizing the distribution of a data set by the median, the variation, the skewness, outliers and extreme values in a graphical form. From Fig. 2, it is noted that TA, EC, TDS, Mg^{2+} , HCO_3^- , SO_4^{2-} are approaching normality. The data of the variables Ca^{2+} , Na^+ , Cl^- , and NO_3^{2-} depart from a normal distribution only in the skewness. There are outliers for pH, TH and K^+ but data depart from a normal distribution only in the skewness. The unexpected outliers are may be due to the usage of fertilizers in agricultural and aqua pond regions. The abundance of chemical parameters are as follows: $\text{Na}^+ > \text{K}^+ > \text{Mg}^{2+} > \text{Ca}^{2+} = \text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-} > \text{NO}_3^{2-}$.

HYDRO CHEMICAL PROCESSES

Piper (1944) plot explains the evolutionary trends of water quality parameters in order to classify the similarities and differences in the chemical composition of waters into certain water types. The ground waters were categorized into different hydro chemical facies based on major cations Ca^{2+} , Mg^{2+} , Na^+ , K^+ , and major anions HCO_3^- , Cl^- , SO_4^{2-} using Piper's trilinear diagram (Fig. 3). The prominent types shown are Na-Mg-Cl- HCO_3 , Na-Cl- HCO_3 , and Mg-Na-Cl- HCO_3 . It can be observed from the plot that the majority of groundwater samples fall in the field of 4 suggesting that strong acids exceed weak acids. The exceeding primary salinity (field 7) and alkalies exceed alkaline earths (field 2) are also found (Table 3). The samples in the Na-Mg-Cl facies indicate the leaching of primary/secondary salts and exchange of ions from the clay deposits. The mechanism controlling the geochemical process of groundwaters with respect to atmospheric precipitation, rock–water interaction and evaporation, has been presented by Gibb's plot (1970) for the present study (Fig. 4). The ratios of dominant cations $(\text{Na}^+ + \text{K}^+)/(\text{Na}^+ + \text{K}^+ + \text{Ca}^{2+})$ and anions $(\text{Cl}^-)/(\text{Cl}^- + \text{HCO}_3^-)$ were plotted against the value of TDS. It is found that the most of sampling points fall towards evaporation dominance indicating the groundwater with high salinity controlled by evaporation and also rock weathering-solubilization. Cation exchange is the influence factor controlling hydro chemical processes. The limited interaction of rock water generally includes the chemical weathering of the rocks, the precipitation dissolution of secondary carbonates and the exchange of ions between the water and the clay minerals.

IONIC GROUNDWATER USE FOR DRINKING

The chemical constituents present in the groundwater is showing a wide variation in different individual parameters (Table 1). The pH of groundwater samples ranged from 7.2 to 8.7, with a mean of 7.8, indicating the slightly alkaline nature of groundwater in the study area. pH generally varies between 6.0 and 8.5 and low pH allows to dissolve more minerals (Weiner 2000). The concentrations of physico-chemical parameters in ground waters and their effect upon human health are presented in Table 4.

The minimum and maximum values of alkalinity ranged from 124 to 466 mg/L with a standard deviation of 81.8. Above 250 mg/L concentration of total alkalinity in the water gives an unpleasant taste (BIS 2012). Nearly 85% of the water samples in the study area contain

alkalinity values higher than the desirable limits. The high alkalinity values for the study area are raised due to the action of carbonates on the basic materials on the soil which gives an unpleasant taste to water. EC fluctuated from 1675 to 3881 $\mu\text{S}/\text{cm}$, with a mean of 2800 $\mu\text{S}/\text{cm}$ while TDS ranged between 985 and 2283 mg/L with a mean of 1647 mg/L. High EC explains that the more dissolved inorganic substances in the ionized form present on the water. EC of water is considered to be an indication of the total dissolved salt content (Hem, 1985). All the groundwater samples recorded above the desirable limits of TDS (more than 500 mg/L), and 84% of samples have TDS > 2000 mg/L hence these cannot be recommended for drinking (BIS, 2012). TH as CaCO_3 varied from 114 to 688 mg/L with a mean of 386. There are ten samples that fall within the desirable limits and the remaining samples (83% of total samples > 300 mg/L) to very hard water category. The cations Ca^{2+} , Mg^{2+} , Na^+ , and K^+ ranged from 11–69 mg/L, 10–139 mg/L, 98–414 mg/L, 29–143 mg/L, respectively. The anions HCO_3^- , Cl^- , SO_4^{2-} , and NO_3^{2-} varied from 162–610 mg/L, 156–602 mg/L, 28–227 mg/L, 2–41 mg/L, respectively. Calcium bicarbonate is the prime cause of the hardness in water. Concentrations of Ca^{2+} and Mg^{2+} are well below the permissible limits. In sea waters, magnesium present in large quantities and high magnesium in the groundwater causes scaling in boilers, pipes and water heaters, and abdominal disorders, etc. and is not desirable for domestic use. Higher values of Na^+ (mean 250 mg/L) and K^+ (mean 95.2 mg/L) were found in the groundwater may be attributed to saline water intrusion, discharge of aquaculture wastewaters and domestic sewage. Normally, these ions become not toxic to humans. However, excess intake causes hypertension and vomiting, etc. Whereas K^+ is an essential element for plants and animals. Cl^- directly relates to the mineral content of water and is mostly identified by salt taste in potable water. Only 19% of groundwater samples showed less than 250 mg/L, which is acceptable for drinking as per BIS. It explains that the probable cause for the abnormal concentration of chloride is the seawater intrusion and rocks in the study region. SO_4^{2-} concentrations in seven locations showed as slightly high above limits. All the samples of NO_3^{2-} falls under permissible limits of BIS. Overall, the majority of water-quality parameters of the groundwater samples analyzed in the study area were recorded above desirable levels.

IONIC GROUNDWATER USE FOR IRRIGATION

In the study area, the groundwater samples were analyzed for monitoring the suitability of quality for irrigation purposes. It can be observed from Table 2, the groundwater recorded as high to very high salinity condition (Richards 1954). About 85% of total samples have recorded electrical conductivity very high (>2,250 $\mu\text{S}/\text{cm}$). High EC in the water proportionate to the salt content which explains that the groundwater can severely affect the plants and soils thus reducing productivity. Na^+ ranged between 41 and 87.9 meq/L with a mean of 63 meq/L. Nearly 69% of water samples were found with high percent sodium (> 60%) thereby unsuitable even for irrigation (Ramakrishna 1998, Swarna Latha and Nageswara Rao, 2012). Twenty four samples out of 58, $\text{Cl}^-/\text{HCO}_3^-$ ratio is shown above 2, which indicate the possible signatures of seawater intrusion to the land as the area is adjoining to the coast and the aqua ponds are continuously being pumped by saline water (Desai et al. 1979). High sodium content may destroy the soil structure, and affect plants growth (Wilcox 1948). Only two samples (Nos. 54 and 55) falls under the permissible to doubtful category and the remaining all the samples are in doubtful to unsuitable category (Fig. 5 and Table 5). The SAR values in the study area vary from 2.0 to 13.2 meq/L and nearly 45% of sample's exhibit increase problems as SAR > 6 meq/L (Herman Bouwer 1978).

According to the U.S. Salinity Laboratory Diagram (USDA 1955), more than 80% of the water samples comes under the fields of C4S2, C4S1, C4S3, C3S2 indicating high-very high salinity and low-high alkali water (Fig. 6 and Table 6). The groundwater is unsuitable for irrigation in the drainage restriction as it leads to low permeability and poor cultivable. RSC varied from -6.1 to 3.8 meq/L with a mean of -1.8 meq/L in the study area. More than 82% of samples shown negative values and are safe for irrigation purpose. The best irrigation practices must be adopted to use the marginal RSC water for irrigation. The high concentration of Na^+ , Ca^{2+} , Mg^{2+} and HCO_3^- in irrigation water can affect the soil's permeability condition. More than 80% of the groundwater samples unsuitable for irrigation purposes. (Donen 1964). The range of KR values is 0.7 to 8.5 mg/L, and most of the groundwater samples (91%) recorded above 1, hence, the groundwater is fit for irrigation (Kelley, 1951). The CR values (range 0.7-5.3 mg/L) recorded in the study area indicating the corrosive nature of water thus it cannot be transported through the metal pipes.

PRINCIPAL COMPONENT AND FACTOR ANALYSIS

The data set of analyzed parameters was verified for variable reduction by PCA and FA using Kaiser–Meyer–Olkin and Bartlett's sphericity tests. The results of the KMO and p were 0.58 and less than 0.001, respectively, hence the data set was used for analysis (Wang et al. 2017). The results of the principal factors, eigenvalue, explained variance and vari max–rotated loads are summarized in Table 7. EC (0.92), TDS (0.92), HCO_3^- (0.71), TA (0.69), TH (0.69), Mg^{2+} (0.6) in factor 1 while in factor 2, Na^+ (0.88) and Cl^- (0.88) were recorded. The first three PCs accounted for 65% of total variance cumulatively 94.5% for a total of 7 PCs. The scree plot showing the positive component loadings of all PCs is presented in Fig. 7. The first factor explained 33.3% of the total variance with strong positive loadings on EC, TDS, TH, HCO_3^- , TA and limited loading on NO_3^{2-} . This could be due to the influence of carbonate weathering as the main source of these minerals. Factor 2

contributed 20.3% of the total variance with high positive loadings on Na^+ and Cl^- which probably due to seawater intrusion. Factor 3 accounts for 10.8% of the total variance. The closely related parameters were SO_4^{2-} and K^+ ; this was probably due to the application of organic and inorganic fertilizers, manure and sewage. With the loading of Mg^{2+} , factor 4 contributed 9.74% to the total variance; this indicates the impact of clay minerals and rock weathering. All the hydro chemical parameters applied by Pearson's correlation indicating that TDS was significantly correlated with EC, TH, Ca^{2+} , Mg^{2+} , Na^+ , K^+ , HCO_3^- and Cl^- (Table 8). The Na^+ and Cl^- , TA and HCO_3^- are correlated highly significant. It can be observed from the Table that these chemical components are the main source of TDS.

Conclusions

The evolution of groundwater chemistry was explained through geochemical plots, ionic ratios, bivariate scatter plots, principal component and factor analysis for the coastal aquifer of Southern India. The chemical constituents in the groundwater were determined for their suitability for drinking and irrigation purposes. The average ionic concentration found in the study area is $\text{Na}^+ > \text{K}^+ > \text{Mg}^{2+} > \text{Ca}^{2+} = \text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-} > \text{NO}_3^{2-}$. The high concentrations of Na^+ , Cl^- , and SO_4^{2-} found in the groundwater may be attributed to the dissolution of mineral phases in the aquifer systems. Bivariate scatter plots strongly supported the process of reverse ion exchange and seawater intrusion. PCA and FA explained that the factors responsible for the variation in the groundwater chemistry as weathering, leaching of secondary salts, reverse ion exchange, seawater intrusion, and agricultural return flow. All the groundwater samples were compared with BIS for potability indicating the groundwater in the study area is unfit for drinking in most of the areas. The quality indices for irrigation revealed that the groundwater studied in the locations is ranging between the good and moderate category hence the water can be used for irrigational purposes with proper management. Various anthropogenic activities such as intense agricultural and aquaculture practices, aquaculture waste discharges without treatment, etc. are also the probable causes of deterioration of the quality of water. This research database provides baseline information that may be used for detecting significant trends more precisely with the help of modern tools like the Geographic Information System.

Declarations

Conflicts of interest

The author declares that there is no conflict of Interest

Data Availability Statement

All data generated or analysed during this study are included in this article.

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Tables

Table 1. The analytical results of physico-chemical parameters of groundwater samples in the study area.

Sample No.	pH	TA	EC	TDS	TH	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻	Water type
1	7.8	2421	283	1424	512	64	86	159	102	304	248	186	12	Mg-Na-Cl-HCO3
2	7.9	2482	245	1460	382	33	73	160	98	265	236	204	8	Na-Mg-Cl- HCO3
3	7.7	2468	312	1452	306	32	55	316	84	265	436	42	22	Na-Mg-Cl- HCO3
4	7.9	2460	284	1447	412	64	61	235	102	265	356	145	36	Na-Mg-Cl- HCO3
5	7.8	2185	198	1285	422	25	87	146	54	259	210	143	14	Mg-Na-Cl- HCO3
6	7.9	2332	312	1372	464	17	102	188	53	278	255	168	8	Mg-Na-Cl- HCO3
7	8.7	3451	356	2030	688	56	133	236	112	466	364	188	9	Mg-Na-Cl- HCO3
8	8.2	3222	306	1895	312	47	47	224	102	401	342	212	12	Na-Cl- HCO3-SO4
9	7.7	2766	288	1627	592	46	111	162	93	377	264	152	17	Mg-Na-Cl- HCO3
10	8.0	2691	312	1583	618	46	122	146	87	409	248	132	29	Mg-Na-Cl- HCO3
11	7.8	2587	278	1522	542	66	92	196	93	364	302	122	36	Na-Mg-Cl- HCO3
12	7.6	2470	216	1453	508	34	103	172	34	283	295	120	24	Mg-Na-Cl- HCO3
13	7.6	3024	212	1779	384	26	78	324	126	278	541	57	15	Na-Mg-Cl
14	8.1	3592	364	2113	356	62	49	302	142	477	456	112	18	Na-Cl- HCO3
15	7.2	2202	292	1295	364	33	68	143	64	383	236	42	7	Na-Mg-Cl- HCO3
16	7.6	2460	302	1447	342	36	61	202	63	396	294	56	2	Na-Mg-Cl- HCO3
17	7.6	2470	236	1453	312	42	50	321	29	309	444	123	3	Na-Mg-Cl- HCO3
18	8.0	2630	312	1547	338	26	66	181	103	409	312	33	16	Na-Mg-Cl- HCO3
19	7.9	2853	232	1678	342	64	44	268	112	304	376	164	4	Na-Cl- HCO3
20	8.4	2681	354	1577	504	69	81	110	102	464	202	112	12	Mg-Na-Ca- HCO3
21	7.8	2706	336	1592	456	42	85	98	103	440	156	156	19	Mg-Na- HCO3-Cl
22	7.7	2577	292	1516	396	42	71	294	88	383	402	88	18	Na-Mg-Cl- HCO3
23	7.9	3177	288	1869	384	64	54	316	109	377	426	212	22	Na-Cl- HCO3
24	7.8	3145	466	1850	493	26	104	326	32	610	554	113	33	Na-Mg-Cl- HCO3
25	7.8	2729	387	1605	484	42	92	178	94	507	248	98	39	Na-Mg- HCO3-Cl
26	7.7	3528	364	2075	384	56	75	304	76	477	424	126	41	Na-Mg-Cl- HCO3
27	8.1	2924	384	1720	512	16	115	212	65	503	294	108	12	Mg-Na-Cl- HCO3
28	7.8	3589	422	2111	632	24	139	306	104	553	464	88	6	Na-Mg-Cl- HCO3
29	7.9	2761	284	1624	256	25	47	201	93	372	312	126	5	Na-Mg-Cl- HCO3
30	8.0	3055	364	1797	508	64	85	303	88	477	412	103	12	Na-Mg-Cl- HCO3

31	8.0	2722	224	1601	325	22	66	223	106	293	412	58	8	Na-Mg-Cl- HCO ₃
32	7.9	2754	218	1620	322	42	53	249	143	286	372	180	26	Na-Mg-Cl- HCO ₃
33	8.1	2912	388	1713	420	16	92	144	141	508	210	143	9	Mg-Na-K- HCO ₃
34	8.0	3135	364	1844	412	36	78	312	144	477	458	188	7	Na-Mg-Cl- HCO ₃
35	7.8	3386	344	1992	399	24	82	334	121	451	532	196	12	Na-Mg-Cl- HCO ₃
36	7.8	2978	211	1752	404	16	88	223	124	276	391	227	8	Na-Mg-Cl-SO ₄
37	7.8	3208	464	1887	538	64	92	148	115	608	223	103	5	Mg-Na- HCO ₃ -Cl
38	7.8	3021	228	1777	344	25	68	323	128	299	450	144	6	Na-Mg-Cl- HCO ₃
39	7.6	3665	312	2156	444	62	36	263	113	366	584	87	14	Na-Cl- HCO ₃
40	7.9	2519	198	1482	354	26	70	181	84	259	395	120	22	Na-Mg-Cl- HCO ₃
41	7.8	3881	326	2283	412	48	71	400	122	427	573	107	37	Na-Mg-Cl- HCO ₃
42	7.8	3378	464	1987	398	46	69	323	98	608	456	126	5	Na-Mg-Cl- HCO ₃
43	7.7	2978	346	1752	354	32	67	216	112	453	302	133	9	Na-Mg-Cl- HCO ₃
44	7.6	3410	278	2006	414	64	62	346	128	364	486	214	11	Na-Mg-Cl- HCO ₃
45	7.9	3145	168	1850	312	26	60	394	94	220	536	204	8	Na-Mg-Cl
46	7.3	2200	212	1294	364	30	70	232	79	278	346	68	4	Na-Mg-Cl- HCO ₃
47	7.9	3188	146	1875	414	22	87	406	142	191	584	178	22	Na-Mg-Cl
48	7.9	3777	234	2222	424	18	92	402	124	307	574	96	38	Na-Mg-Cl
49	7.6	3653	198	2149	519	32	107	414	97	259	602	212	4	Na-Mg-Cl
50	7.9	2312	188	1360	164	46	12	312	80	246	428	83	4	Na-Cl- HCO ₃
51	7.7	2083	214	1225	217	60	33	316	46	280	592	123	13	Na-Cl- HCO ₃
52	8.0	2028	224	1193	248	22	47	173	86	293	243	86	6	Na-Mg-Cl- HCO ₃
53	8.0	2038	188	1199	114	26	12	324	94	246	594	28	18	Na-Cl
54	7.9	1675	134	985	195	22	34	192	59	176	264	68	23	Na-Mg-Cl- HCO ₃
55	7.9	1714	124	1008	188	36	24	208	67	162	282	58	36	Na-Cl
56	7.9	2540	320	1494	154	46	10	315	104	419	446	35	16	Na-Cl- HCO ₃
57	7.6	2185	202	1285	195	28	38	194	103	265	326	88	5	Na-Mg-Cl- HCO ₃
58	7.9	2317	232	1363	140	11	29	192	113	304	272	127	18	Na-Cl- HCO ₃
* All parameter concentrations are in mg/L except pH (no units) and EC (μS/cm)														

Table 2. The calculated values of chemical parameters for analyzing their suitability for irrigation.

Sample No	Na%	Cl/HCO ₃ ⁻	SAR	RSC	PI	KR	CR
1	48.2	1.4	3.1	-5.2	53.4	1.1	1.8
2	55.4	1.5	3.6	-3.3	62.0	1.5	2.1
3	72.2	2.8	7.9	-1.8	79.7	3.6	2.5
4	60.9	2.3	5.0	-3.9	66.7	1.9	2.5
5	47.8	1.4	3.1	-4.2	56.9	1.3	1.7
6	50.7	1.6	3.8	-4.7	59.1	1.6	1.9
7	48.9	1.3	3.9	-6.1	54.3	1.2	1.5
8	66.5	1.5	5.5	0.3	77.0	2.4	1.8
9	45.2	1.2	2.9	-5.3	51.6	1.0	1.4
10	41.0	1.0	2.6	-5.6	47.8	0.9	1.2
11	50.2	1.4	3.7	-4.9	56.7	1.2	1.5
12	45.1	1.8	3.3	-5.5	54.6	1.3	1.9
13	69.3	3.3	7.2	-3.1	74.6	3.1	3.0
14	70.2	1.6	7.0	0.7	78.7	2.7	1.6
15	51.9	1.1	3.3	-1.0	64.7	1.4	1.0
16	60.3	1.3	4.8	-0.3	72.6	2.1	1.2
17	70.2	2.5	7.9	-1.2	80.3	3.5	2.4
18	60.9	1.3	4.3	-0.1	71.5	2.0	1.2
19	68.0	2.1	6.3	-1.9	75.1	2.5	2.3
20	42.3	0.7	2.1	-2.5	50.8	0.7	0.9
21	43.1	0.6	2.0	-1.9	52.0	0.8	0.9
22	65.5	1.8	6.4	-1.6	73.9	2.6	1.7
23	68.3	1.9	7.0	-1.5	75.8	2.7	2.2
24	60.4	1.6	6.4	0.1	72.2	2.5	1.5
25	51.2	0.8	3.5	-1.4	61.0	1.3	0.9
26	62.8	1.5	6.2	-1.2	72.2	2.3	1.5
27	51.5	1.0	4.1	-2.0	62.2	1.6	1.0
28	55.8	1.4	5.3	-3.6	62.9	1.9	1.3
29	68.5	1.4	5.5	1.0	80.9	2.8	1.5
30	60.3	1.5	5.9	-2.3	68.5	2.0	1.4
31	65.6	2.4	5.4	-1.7	73.4	2.5	2.2
32	69.2	2.2	6.0	-1.7	75.3	2.6	2.5
33	55.5	0.7	3.1	-0.1	62.4	1.3	0.9
34	65.8	1.7	6.7	-0.4	75.1	2.7	1.8
35	68.9	2.0	7.3	-0.6	76.7	3.1	2.1
36	61.5	2.4	4.8	-3.5	66.5	2.1	2.9
37	46.6	0.6	2.8	-0.8	55.8	0.9	0.7
38	71.6	2.6	7.6	-2.0	77.7	3.5	2.6

39	70.2	2.7	6.6	-0.1	79.3	2.7	2.5
40	58.6	2.6	4.2	-2.8	66.5	1.9	2.6

41	71.4	2.3	8.6	-1.2	78.2	3.4	2.2
42	67.6	1.3	7.0	2.0	78.2	2.8	1.3
43	63.4	1.1	5.0	0.4	73.6	2.2	1.2
44	68.9	2.3	7.4	-2.3	75.0	2.8	2.5
45	75.8	4.2	9.7	-2.6	81.5	4.6	4.4
46	62.5	2.1	5.3	-2.7	70.4	2.3	2.0
47	72.0	5.3	8.7	-5.1	74.9	3.7	5.3
48	70.9	3.2	8.5	-3.4	76.0	3.7	3.0
49	66.4	4.0	7.9	-6.1	70.7	3.0	4.1
50	82.7	3.0	10.6	0.8	92.5	5.4	2.8
51	72.2	3.6	8.1	-1.1	81.6	3.4	3.4
52	66.2	1.4	4.8	-0.2	77.9	2.5	1.5
53	87.9	4.2	13.2	1.8	98.4	8.5	3.5
54	71.7	2.6	6.0	-1.0	82.1	3.4	2.5
55	74.1	3.0	6.6	-1.1	83.4	3.5	2.8
56	84.2	1.8	11.0	3.8	97.3	5.7	1.6
57	71.1	2.1	5.6	-0.2	81.4	3.0	2.1
58	79.2	1.5	6.9	2.0	93.7	4.8	1.7

Table 3. Groundwater classification based on the Piper diagram.

Sub-field	Chemical characteristics	No. of samples in different fields	Total
1	Alkaline earths (Ca + Mg) exceeds alkalies (Na + K)	1,5,6,7,9,10,11,12,14,15,20,21,25,27,33,37	16
2	Alkalies exceeds alkaline earths	2,3,4,8,13,14,16,17,18,19,22,23,24,26,28,29,30, 31,32,34,35,36,38,39,40,41,42,43,44,45,46,47, 48,49,50,51,52,53,54,55,56,57,58	43
3	Weak acids (CO ₃ + HCO ₃) exceeds strong acids (SO ₄ + Cl)	9,14,15,20,21,25,27,33,37	
4	Strong acids exceeds weak acids	1,2,3,4,5,6,7,8,10,11,12,13,14,16,17,18,19,22, 23,24,26,28,29,30,31,32,34,35,36,38,39,40, 41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58	49
5	Carbonate hardness (secondary alkalinity) exceeds 50%	-nil-	-
6	Non-carbonate hardness (secondary alkalinity) exceeds 50%	-nil-	-
7	Non-carbonate alkali (primary salinity) exceeds 50%	2,3,4,8,13,14,16,17,18,19,22,23,24,26,28,29,30, 31,32,34,35,36,38,39,40,41,42,43,44, 45,46,47,48,49,50,51,52,53,54,55,56,57,58	43
8	Carbonate alkali (primary salinity) exceeds 50%	-nil-	-
9	None of the cation or anion pairs exceed 50%	1,5,6,7,9,10,11,12,14,15,20,21,25,27,33,37	16

Table 4. The range of concentrations of chemical constituents in groundwater and their effect on human health.

Parameter	Bureau of Indian Standards (2012)		Min	Max	Mean	Std	CV	Groundwater samples exceeds the desirable limit		Effect on human health
	Desirable limit	Permissible limit						No of Samples	% of Samples	
pH	6.5-8.5	-	7.2	8.7	7.8	0.2	0.03	1	1.7	Bitter taste
EC ($\mu\text{S}/\text{cm}$)	NR	NR	1675	3881	2800.7	517.4	0.18	-	-	-
TA (mg/L)	200	600	124	466	283.3	81.1	0.29	49	84.5	Gastrointestinal issues, Nausea and skin irritations
TDS (mg/L)	500	2000	985	2283	1647.4	304.4	0.18	58	100.0	Salty and bitter taste, lung irritation, rashes, vomiting, dizziness
TH (mg/L)	300	600	114	688	386.1	123.8	0.32	48	82.8	Cardiovascular problems, diabetes, neural diseases, and renal dysfunction
Ca^{2+} (mg/L)	75	200	11	69	38.6	16.3	0.42	-	-	Hypercalcaemia and renal insufficiency
Mg^{2+} (mg/L)	30	100	10	139	70.4	28.6	0.41	53	91.4	Hypermagnesaemia, diarrhea, etc.
Na^{+} (mg/L)	NR	NR	98	414	249.8	81.2	0.32	-	-	-
K^{+} (mg/L)	NR	NR	29	143	95.6	27.8	0.29	-	-	-
HCO_3^{-} (mg/L)	NR	NR	162	610	361.7	109.1	0.30	-	-	-
Cl^{-} (mg/L)	250	1000	156	602	380.0	121.3	0.32	47	81.0	Congestive heart failure
SO_4^{2-} (mg/L)	200	400	28	227	124.3	52.5	0.42	7	12.1	Bitter taste and laxative effect
NO_3^{-} (mg/L)	45	NR	2	41	15.6	10.7	0.68	-	-	Blue baby syndrome

Table 5. Classification of groundwater based on Wilcox (1948) diagram.

Category	Sample numbers	Number of samples	Percentage of samples
Permissible to doubtful	54,55	2	3.4
Doubtful to unsuitable	1,2,3,4,5,6,9,10,11,12,15,16,17,18,19,20,21,22,25,27,29,31,32,33,36,40,43,46,50,51,52,53,56,57,58	35	60.3
Unsuitable	7,8,13,14,23,24,26,28,30,34,35,37,38,39,41,42,44,45,47,48,49	21	36.2

Table 6. Classification of groundwater based on USSS diagram (USDA 1955)

Classification	Sample numbers	Number of samples	Percentage of samples
C3S1	5,15	2	3.4
C3S2	46,51,52,54,55,57	6	10.3
C3S3	53	1	1.7
C4S1	1,2,6,9,10,12,20,21,25,33,37	11	19.0
C4S2	3,4,7,8,11,13,14,16,17,18,19,22,23,24,26,27,28,29,30,31,32,34,35,36,38,39,40,42,43,44,58	31	53.4
C4S3	41,45,47,48,49,50,56	7	12.1

Table 7. The results of principal components and factors of groundwater samples

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Eigenvalue	4.332	2.659	1.407	1.262	1.092	0.896	0.651	0.424	0.157	0.070	0.038	0.010
Variability (%)	33.323	20.456	10.825	9.711	8.397	6.891	5.011	3.264	1.210	0.540	0.291	0.080
Cumulative %	33.323	53.779	64.605	74.316	82.714	89.604	94.615	97.879	99.089	99.629	99.920	100
Variable	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
pH	0.262	-0.205	0.433	-0.518	0.074	-0.370	-0.523	-0.131	0.026	-0.002	-0.002	0.000
TA	0.706	-0.426	-0.431	-0.172	-0.214	-0.036	-0.057	0.157	-0.114	0.009	-0.131	-0.013
EC	0.917	0.332	0.008	0.017	-0.055	-0.036	0.077	0.024	0.195	-0.011	-0.009	-0.006
TDS	0.917	0.332	0.008	0.017	-0.055	-0.036	0.077	0.024	0.195	-0.011	-0.009	-0.006
TH	0.734	-0.452	0.106	0.335	0.227	0.107	0.024	-0.250	-0.031	0.024	-0.027	0.069
Ca ²⁺	0.312	-0.085	-0.137	-0.543	0.347	0.653	0.018	-0.182	-0.006	-0.016	0.014	-0.024
Mg ²⁺	0.634	-0.452	0.154	0.547	0.136	-0.118	-0.019	-0.152	-0.087	-0.028	0.034	-0.064
Na ⁺	0.301	0.878	-0.166	0.124	0.034	0.021	-0.211	-0.021	-0.134	-0.178	0.000	0.015
K ⁺	0.427	0.316	0.419	-0.415	-0.155	-0.245	0.499	-0.117	-0.156	0.004	0.004	0.001
HCO ₃ ⁻	0.717	-0.390	-0.430	-0.182	-0.252	-0.061	-0.051	0.155	-0.058	0.012	0.135	0.019
Cl ⁻	0.275	0.878	-0.208	0.126	0.039	0.012	-0.194	-0.105	-0.089	0.188	0.006	-0.009
SO ₄ ⁻	0.422	0.063	0.705	0.105	0.068	0.347	-0.104	0.410	-0.071	0.027	0.004	0.004
NO ₃ ⁻	0.079	0.042	-0.230	-0.098	0.866	-0.344	0.129	0.213	-0.011	0.006	0.002	0.002

Table 8. Correlation matrix of different parameters of groundwater samples

<i>Variable</i>	<i>pH</i>	<i>TA</i>	<i>EC</i>	<i>TDS</i>	<i>TH</i>	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^-	NO_3^-
pH	1												
TA	0.179	1											
EC	0.137	0.490	1										
TDS	0.137	0.490	1	1									
TH	0.154	0.520	0.502	0.502	1								
Ca^{2+}	0.119	0.280	0.200	0.200	0.263	1							
Mg^{2+}	0.123	0.438	0.417	0.417	0.923	-0.082	1						
Na^+	-0.133	-0.097	0.525	0.525	-0.141	0.004	-0.139	1					
K^+	0.272	0.070	0.514	0.514	0.061	0.092	-0.005	0.192	1				
HCO_3^-	0.185	0.961	0.524	0.524	0.491	0.260	0.423	-0.074	0.098	1			
Cl^-	-0.152	-0.115	0.505	0.505	-0.137	0.006	-0.159	0.926	0.177	-0.088	1		
SO_4^-	0.224	0.001	0.387	0.387	0.343	0.147	0.319	0.107	0.267	-0.009	0.033	1	
NO_3^-	0.059	0.008	0.060	0.060	0.092	0.145	0.065	0.077	-0.017	-0.013	0.078	-0.122	1

Figures

Figure 1

Location map of the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

Geomorphology of the study area.

Figure 3

Data normality of water quality parameters explaining by the Box plot

Figure 4

Classification of hydrochemical facies using the Piper plot.

Figure 5

Gibbs plot showing the geochemical process of groundwaters.

Figure 6

Wilcox diagram represents the presence of sodium content in the groundwaters

Figure 7

The suitability of groundwater for irrigation exhibiting by USSL diagram

Image not available with this version

Figure 8

Scree plot and dominance of ions in groundwaters