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Water Quality Index and GIS-Based Technique for Assessment of Groundwater Quality in Wanaparthy Watershed, Telangana, India

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ABSTRACT

A comprehensive study of 58 groundwater samples was collected in the Wanaparthy catchment area (1600 km2), Telangana, India to assess hydrochemistry, quality, water types, and potability using hydrogeochemical characterization, WQI, and GIS techniques. The main concentrations of Na+, K+, Ca2+, Mg2+, Cl−, F−, NO3 −, and SO4 2− ions in groundwater were analysed using ion chromatography (IC). Physicochemical values of potential hydrogen (pH), total dissolved solids (TDS), and electrical conductivity (EC) were determined using portable Hanna meters, while total hardness (TH), alkalinity, and bicarbonates were estimated by titrimetric methods. The obtained results clarify the main anions and cations, which are found in the order Cl− > HCO3 − > SO4 2− > NO3 − > F− and Na+ > Ca+2 > Mg+2 > K+. Among the various ions measured were fluoride (18.97%), chloride (3.44%), nitrate (8.62%), Sulphate (5.17%), sodium (34.48%), and calcium (1.72 %) found above the acceptable limit values of the authority. Indian Standards (BIS) for drinking purposes. According to Piper's trilinear diagram, two dominant hydrochemical facies were identified, Na-Cl-SO4 and Ca-Na-HCO3 types. The Gibbs diagram conferred the dominance of samples in the area, namely the rock-water reaction and the dominance of evaporation. The WQI shows that 67.79% of the samples refer to excellent to good types of water that are suitable for drinking. The drainage diagram calculated that the concentration of the measured parameters exceeds the lower area, which may be caused by the chemical reaction of the rock-water interaction (infiltration and recharge). Since groundwater is the main source of drinking water in the study area, a proper management plan must be put in place before its quality deteriorates.

Keywords : Water quality index. Hydrochemistry. Gibbs diagram. Piper trilinear diagram. ArcGIS. Wanaparthy Basin.

I. INTRODUCTION

Groundwater is a source of water supply where there is minimal rainfall, fewer bodies of water or wetlands, and poor canal systems. Although groundwater is a recycling process, many countries in Asia and North America are facing groundwater depletion problems due to rapid urbanization and over-abstraction (Gleeson et al. 2012). It states that India's annual groundwater extraction exceeded the total consumption of the US and China combined, placing it first on the world list (NGWA 2016). In addition, according to the CGWB report (2013), about 245 × 109 m3 of groundwater is used in India to meet the demand in the agriculture sector. Groundwater property is controlled by many factors such as lithology, geological structure, soil composition and thickness, anthropogenic activities, and various minerals in the rocks (Adimalla 2019; Li and Qian 2018) of an area. Groundwater contamination is a global problem and is a composition of all physicochemical parameters consisting of toxic/heavy metals and all major ions (Tiwari et al. 2017). Natural contaminants originate from the geochemical reaction of rocks (such as fluoride, nitrate, and arsenic), decay of organic matter in the soil, precipitation of atmospheric particles and waste from agricultural fertilizers, mining, etc. (Patil et al. 2012; Adeyeye 1994). Organic and inorganic leachates from landfills also contribute significantly to the pollution of the groundwater system (Gupta et al. 2015). The increased use of various chemical fertilizers in agricultural agriculture has led to the deterioration of groundwater quality due to inadequate disposal and untreated leakage of chemicals from industries (Srinivas et al. 2015). Groundwater quality degradation will limit its use for domestic and industrial purposes (Brindha and Elango 2012). If an aquifer is polluted once, the entire aquifer is affected for thousands of years due to slow groundwater movement (Jerry 1986). The above 90% population of Indian states depend on groundwater for domestic and industrial purposes (Tiwari et al. 2015; Yadav et al. 2012). Therefore, attention was paid to the main ions of the system to check the permissible limit and avoid health risks. Subsequently, it is necessary to evaluate the quality of groundwater in terms of the chemistry of groundwater, which deciphers its suitability as a source of water for consumption by humans and animals. Therefore, water quality depends on the desired use of the water, and its standards for permissible or acceptable limits also vary according to the intended use. Water quality monitoring plays a vital role in human health and the integrity of aquatic ecosystems. In this context, the water quality index (WQI) approach is an active tool that suggests water quality information to policymakers and stakeholders in the study area (Singh 1992). ArcGIS has become a widely used tool for manipulating multidimensional values, processes, and spatial map output to aid in inference about environmental and geological scenarios (Deepesh et al. 2011). Several studies have been reported on groundwater quality and contamination due to geogenic and anthropogenic processes (Jha et al. 2020; Bashir et al. 2020; Islam et al. 2020; Vasantha Kumari Sivasankara Pillai et al. 2020; Iqbal et al. 2018; Islam et al 2018; Adimalla et al 2018; Islam et al 2017; Kim et al 2015; Kumar 2014; Magesh et al 2013; Nandimandalam 2012; Rajesh et al 2012 Ja Tatint et al 2012. Chandel 2008; Babiker et al. 2007; Simeonov et al. 2003) in the literature.

In hard rock terrain, groundwater is either in the contact zone or fracture zone, which directly adjoins the aquifer or acts as an aquifer itself. Since the granite terrain is mainly composed of an unconfined type of aquifer, the chances of contamination increase several times. Hard terrain is thus more susceptible to groundwater contamination than other geological terrains. In parts of Telangana state, most groundwaters have been found to have high fluoride concentrations above permissible limits (Mondal et al. 2009; Reddy et al. 2010) due to the natural geochemical process. In the selected research area, groundwater serves as a source of drinking water and is used directly for agriculture and daily activities without proper investigation and treatment. The Wanaparthy catchment still lacks a quality assessment hour focusing on groundwater. As there is an appalling report on the drinking groundwater quality in the selected study area except for the irrigation report in parts of Wanaparthy (Sunitha et al. 2018). This study did not focus on the catchment scale but on the administrative boundary which covers a small part of the southern part of the Wanaparthy district. Therefore, this work is the first attempt at groundwater quality to assess its suitability for drinking purposes in the Wanaparthy Basin, which may be able to communicate with policymakers and local authorities/people for their effective management. The objectives of this study are as follows: (i) to understand the hydrogeochemical process of groundwater using physicochemical parameters and major anion and cation data and (ii) to assess the groundwater quality of the Wanaparthy catchment in terms of its suitability for drinking purposes through WQI and GIS techniques. In addition, the results of these investigations provide basic data on the state of groundwater quality in the study area, which helps in the management of groundwater resources.

II. METHODS AND MATERIAL

Study Area

The study area, Wanaparthy watershed, falls under Wanaparthy and Mahbubnagar districts, Telangana, India. The selected area is bounded between latitudes 16° 19′ 1″ N and 16° 49′ 53″ N and 77° 49′21″ E and 78° 12′55″ E and covers a total area of 1600 km2 Fig. 1. Geographically, it falls in the tropical semi-arid region (hot and dry climate) with minimum and maximum temperatures ranging from 16.9 to 42 °C in winter and summer. The average annual rainfall is 596 mm, with 80% contribution from the southwest monsoon from June to September (CGWB Technical Report 2016), which originates from the Arabian Sea. They lack industrial encroachments while agriculture is a common practice which is their only source of income, rice, cotton, mango, lemon, papaya, grapes, bananas, pomegranates, sugarcane, and various types of cereals are grown here.

Geology

The current study area is predominantly dominated by granitoid terrain, where granite metamorphoses under favourable high temperatures and pressure to form coarse-grained high-grade metamorphic rocks with light and dark minerals in visible bands. The main rock types are grey biotite granite, migmatite, grey granite, pink granite, leucogranite, alkali feldspar granite, pink biotite granite, banded migmatite quartzite

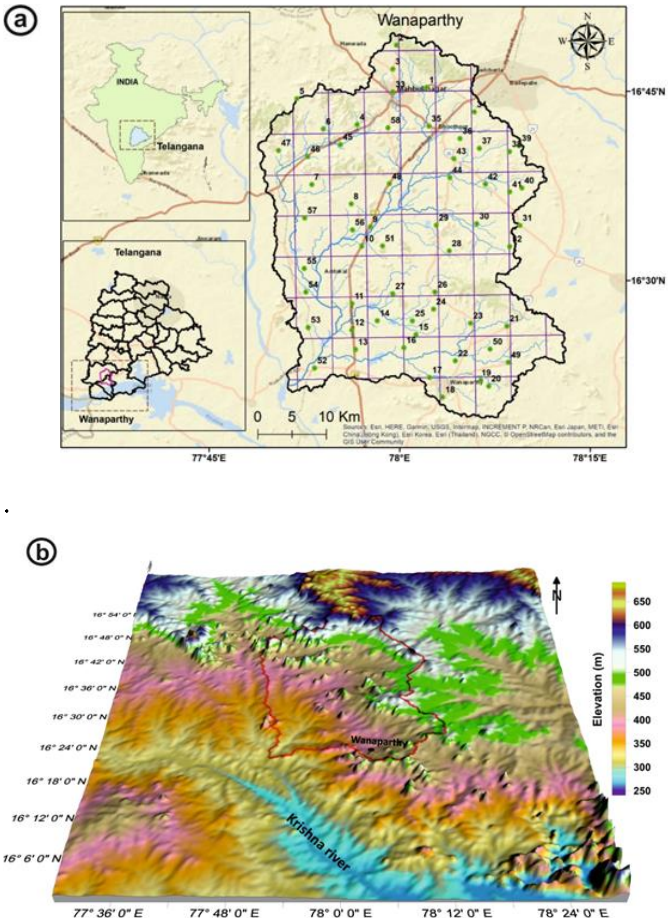


Fig. 1 Location map of Wanaparthy watershed (a) geographical location with sampling points; (b) digital elevation map in 3D view

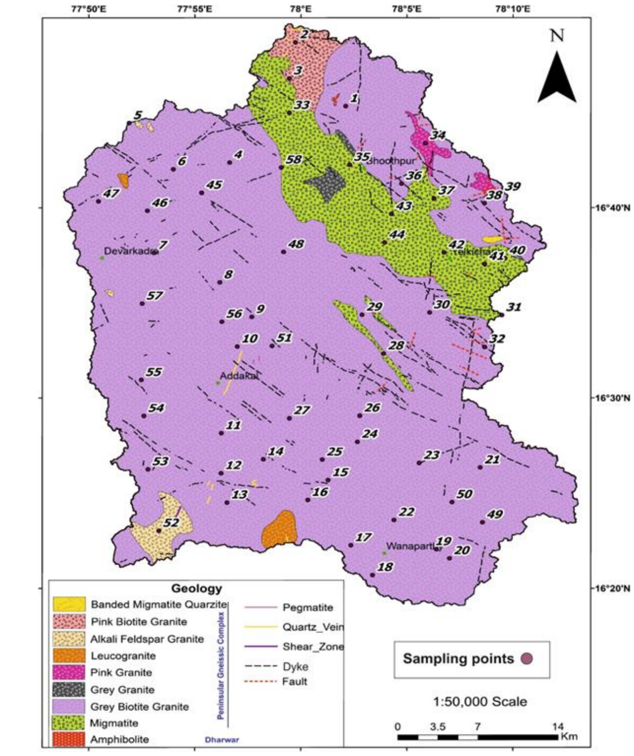


Fig. 2 Geology map of Wanaparthy watershed

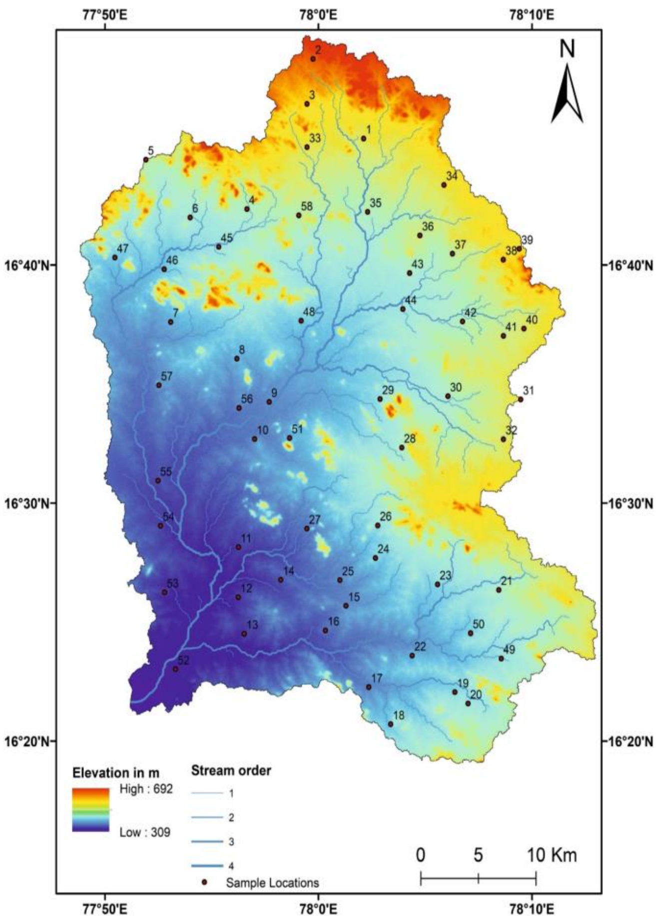


Fig. 3 2D map showing the area elevation above MSL (main sea level) and stream ordering

of peninsular gneissic complex and amphibolite of Dharwar group of Precambrian age as shown in Fig. 2 (GSI).

The geological map shows that there is a large migmatite intrusion that trends northwest to southeast. There are three soil types red soil, lateritic soil, and black cotton soil in the study area.

Hydrogeology

The study area consists mainly of two aquifer systems separated by an SZJV-trending migmatite intrusion. However, in the northern and southern parts of the region, several micro-aquifer systems have flourished according to the distribution of structural features (i.e., dike, fault, quartz vein, and pegmatite) as shown in Fig. 2. In Telangana state, groundwater is formed under the following conditions: ((a) consolidated formation, (b) semi-consolidated formation, and (c) unconsolidated formation. Since the studied area consists of hard rock terrain (granitoid), the groundwater is either in the contact zone or fracture zone, which directly connects to the aquifer or acts as an aquifer itself (consolidated formation). Depending on the main aquifer, variations in the level of different media with minimum and maximum depth (meter) are reported as basalt (1.9–69.5 m), granite (5.5–34.5 m), quartzite (6.3 –12.2 m), sandstone (–0.6–17.3 m), limestone (8.9–41.5 m), banded gneiss complex (1.6–54.8 m), gneiss (23, 5–23.5 m), shale (3.3–14.8 m) and shale (9.1–9.1 m). The maximum depth of the weathered zone reaches up to 29 m bgl (meters below ground level), with the deepest fault recorded as high as 124.5 m bgl (CGWB Technical Report 2019). The water level is reported between 2 and 40 m bgl in Telangana state. However, in the current study area, the water level above 10 m bgl is predominant, contributing an average of 49%. In addition, a water level rise of 2 to 4 m is observed in the region. The long-term trend of the water level is between 0 and 2.5 m/year. (1997–2016), according to CGWB Technical Report (2016).

Drainage system

The area is dominant with a dendritic drainage system and has an elevation ranging from 309 to 692 m above sea level. The elevation chart together with the flow order system from the first order to the higher fourth order is in Fig. 3. The area is elevated in the north-eastern and north-western parts, where the mountain ranges are visible in Fig. 1b. It gradually slopes down towards the southwest region and finally reaches the Krishna Basin where all the small streams or sporadic rivers join the Krishna River. The Krishna River is one of the major rivers in India and flows through the southern parts of Telangana state. It originates from the Western Ghats (Maharashtra) and falls into the Bay of Bengal on the east coast (Andhra Pradesh). The current study area, the Wanaparthy basin, lies in the upper basin of the Krishna River.

Field and Laboratory Setup

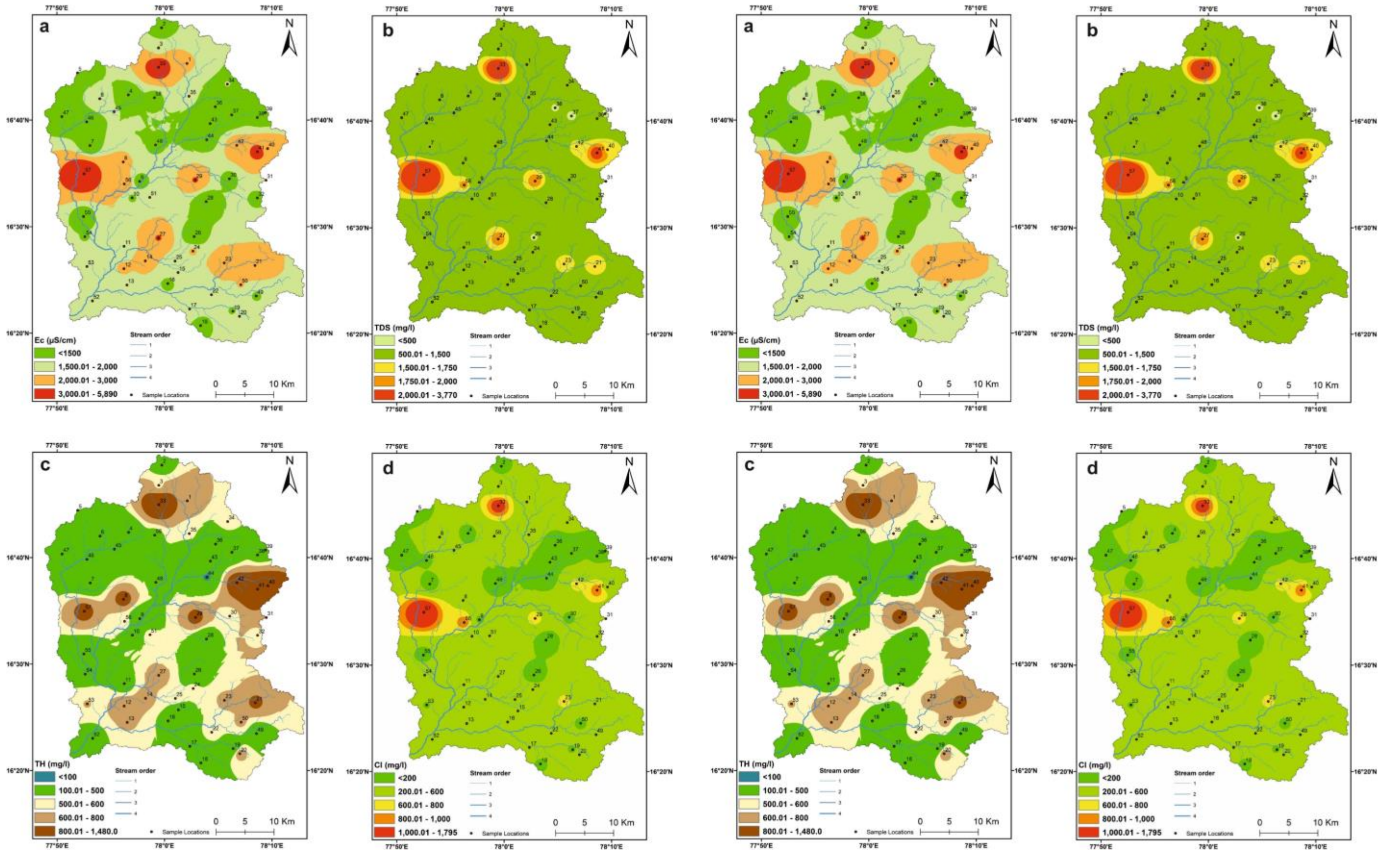
Before sampling, water was pumped from the submersible borehole and hand pump for at least 10 min to drain standing water (Brindha et al. 2011; Reddy et al. 2010). Groundwater samples were collected in pre-washed 1-liter narrow-necked HDPE bottles after rinsing the bottles 2–3 times with the water to be sampled. A total of 58 samples were collected from the Wanaparthy catchment and most preferably each sample was collected in a 5 × 6 km2 grid to have better spatial interpolation and cover the entire study area. Physio-chemical parameters such as pH, TDS, EC, and temperature were measured in situ using a Hanna portable instrument (Hanna model HI 98130, Combo pH & EC). The collected samples were transported to the CSIRNGRI Environmental Geochemistry Laboratory and were immediately analyzed within 48 hours. Total hardness, alkalinity, and bicarbonate were determined by titration (APHA 2005). Fifty milliliters of each sample was filtered using a Millipore 0.22 μm cellulose membrane filter and analyzed for major anions and cations (F–, Cl–, NO3–, SO42–, Na+, K+, Ca2+, and Mg2+) using ion chromatography (882 Compact IC plus, Metrohm) method (APHA 2017; ISO 14911 1998). Data quality control was verified by calculating the ion equilibrium error (IBE), which is obtained within ± 10%. Furthermore, the accuracy of the ion chromatography data was maintained by maintaining RSD values consistently below 10%.

Water Quality Index

Water Quality Index (WQI) is calculated to understand different classes of water using 13 water quality parameters such as pH, Total Hardness, EC, TDS, F–, Cl–, NO3 –, SO4 2–, HCO3 –, Na+, K+, Ca2+, and Mg2+. Many researchers have used WQI to differentiate water types for quality and drinking purposes (Teshome 2020; Chaurasia et al. 2018; Yadav et al. 2018; Raj and Shaji 2017; Batabyal and Chakraborty 2015; Magesh et al. 2013; Subba Rao 2006). The weight value (wi) for each parameter varies between 1 and 5, where TDS, F– and NO3 – have the highest weight, wi = 5, pH, EC, SO– 4(4), HCO3 –, Cl–, TH(3), Na+, K+, Ca2+(2) and Mg2+ have the lowest wi = 1, (Raj and Shaji 2017; Krishna Kumar.

Table 1 Relative weights (w_i) of physicochemical parameters, major anions and cations

Chemical Parameters	WHO (2011) Standards mg/L	Weight w_i	Relative weight $W_i = wi/\sum wi$
1) TDS	500–1500	5	0.116
2) NO_3^-	45	5	0.116
3) F^-	0.6–1.5	5	0.116
4) pH	6.5–8.5	4	0.093
5) EC	750–1500	4	0.093
6) SO_4^{2-}	250–400	4	0.093
7) HCO_3^-	600	3	0.07
8) Cl^-	250–600	3	0.07
9) TH	300–500	3	0.07
10) Na^+	50–200	2	0.047
11) K^+	12	2	0.047
12) Ca^{2+}	75–200	2	0.047
13) Mg^{2+}	50–150	1	0.023
		$\sum wi = 43$	$\sum W_i = 1$



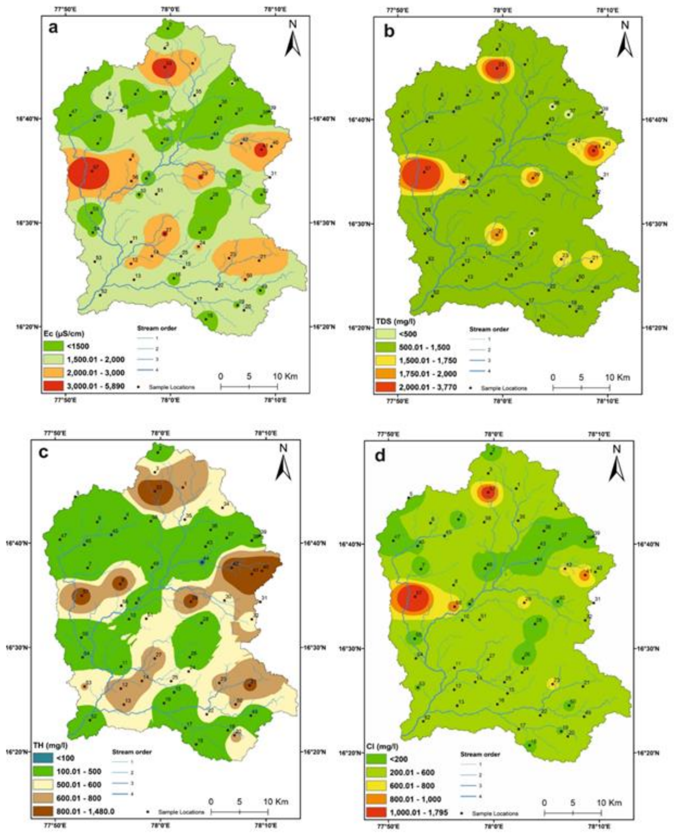


Fig. 4 Spatial distribution maps of all physicochemical parameters, major anions, and cations showing minimum to maximum ranges

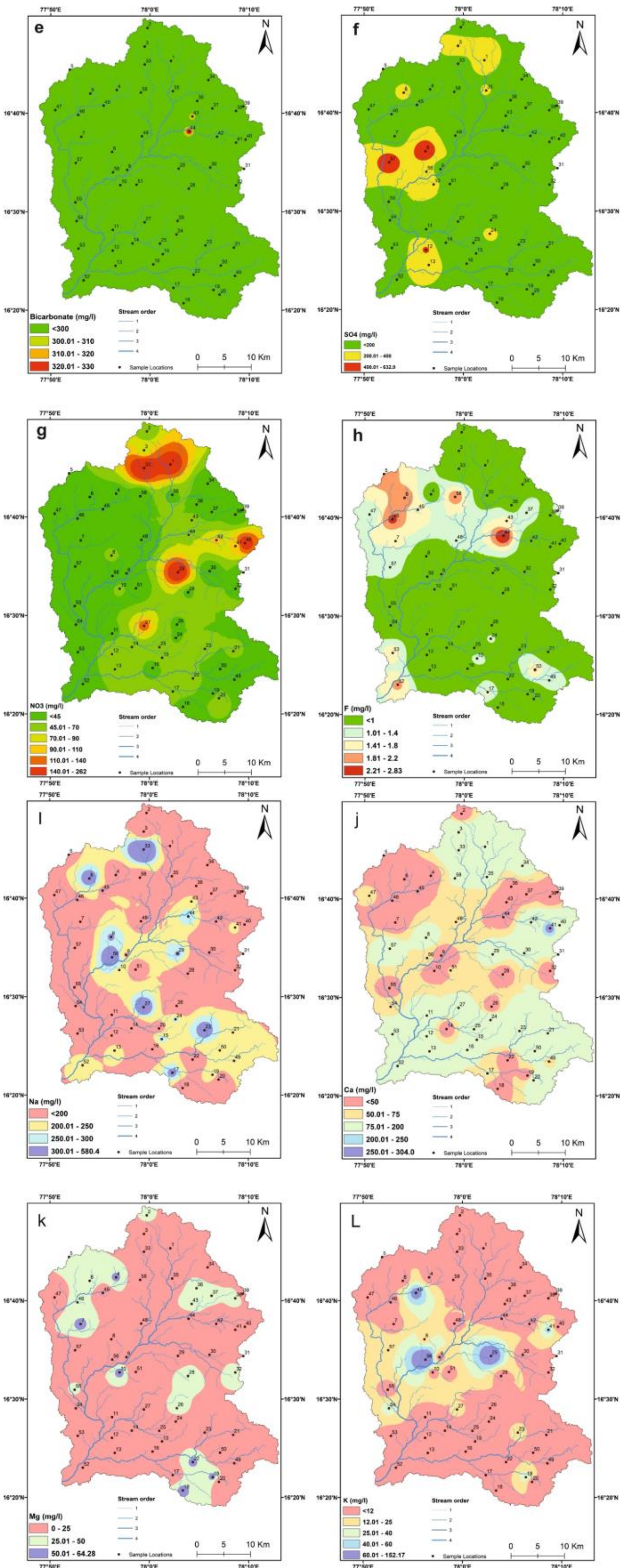


Fig. 4 (continued)

Table 2 Permissible limits of all parameters with reference to WHO (2011) and BIS (2012) standard showing minimum, maximum, average, median and standard deviation values

Parameters	Min	Max	Ave	Median	SD	WHO 2011 desire limit mg/l	BIS 2012 desire limit mg/l	Samples exceeding permissible limit BIS (2012) mg/l	
								No. of Samples	% of Samples
Physico-chemical									
pH	7.28	8.43	7.876	7.875	0.256	6.5–8.5	6.5–8.5	NIL	NIL
EC (µS/cm)	640	5890	1757.93	1540	965.48	750–1500	750–1500	32	55.17
TDS (mg/l)	409.6	3769.6	1125.07	985.6	617.91	500–1500	500–2000	3	5.17
TH (mg/l)	58.5	1480.5	526.57	474.75	303.03	300–500	200–600	18	31.03
Alk (mg/l)	60	580	251.55	230	107.29	–	200–600	NIL	NIL
Anions									
F^- (mg/l)	0.135	2.833	0.906	0.819	0.633	0.6–1.5	1–1.5	11	18.97
Cl^- (mg/l)	10.77	1794.5	349.87	288.57	329.51	250–600	250–1000	2	3.44
NO_3^- (mg/l)	0.116	261.97	48.49	37.57	54.75	45	45–100	5	8.62
SO_4^{2-} (mg/l)	0.115	632.01	119.86	68.09	142.36	250–400	200–400	3	5.17
HCO_3^- (mg/l)	30.5	329.4	142.71	128.1	62.23	600	200	–	–
Cations									
Na^+ (mg/l)	0.27	580.45	181.22	149.26	112.44	50–200	200	20	34.48
K^+ (mg/l)	0.11	152.18	11.12	2.53	25.96	12	–	NIL	NIL
Ca^{2+} (mg/l)	5.83	304	80.15	77.98	62.49	75–200	75–200	1	1.72
Mg^{2+} (mg/l)	0.52	64.28	19.74	8.91	19.51	50–150	30–150	NIL	NIL

EC (µS/cm)	Classification	No of samples exceeding allowable limits	% of samples exceeding allowable limits
< 250	Excellent	nill	nill
250–750	Good	5	8.62
750–2000	Permissible	37	63.79
2000–3000	Doubtful	11	18.97
> 3000	Unsuitable	5	8.62
	Total	58	100

Table 3 Groundwater classification based on electrical conductivity (After Todd et al. 2015; Vasanthavigar et al. 2010) as shown in Table 1.

The following equation is used for calculating WQI.

(ii) Relative weight formula Wi ¼ wi= ∑ n i¼1 wi

where Wi = relative weight, wi = parameters weight, n = number of parameters.

(iii) Quality rating formula qi ¼ Ci Si *100 ð2Þ where qi = quality rating. Ci = measure concentration for each parameter in samples in mg/L. Si = standard limit for each parameter according to WHO in mg/L.

(iv) Sub-indices are calculated by multiplying Eqs. (1) and (2). SIi ¼ Wi*qi ð3Þ

(v) Finally, after calculating SI values for every parameter, WQI (Eq. 4) is calculated by summing all SI values for a particular sample, which gives the quality classification according to their range and water types.

WQI ¼ ∑SIi

Geographic Information System

GIS analysis helps in the statistical interpolation of various experimental data to generate thematic layers and spatial maps. It limits the uncertain factors of groundwater parameters and allows for establishing a relationship in a statistical approach for summarizing the groundwater quality of the studied area in a simple image format. Inverse distance weighting, kriging, and cokriging are the most widely used and preferred methods for generating spatial distribution maps. However, in this study, spatial distribution maps of all parameters for groundwater quality from 58 samples of the study area (as shown in Fig. 4.) are generated using the inverse distance weighted (IDW) interpolation method in ArcGIS-10.7 software (GIS Lab, CSIR- NGRI). The IDW interpolation method calculates the unknown values concerning the distance, where the nearest point gets more weight, which decreases with increasing distance. This technique is further widely used by many researchers (Zolekar et al. 2020; Tiwari et al. 2016) to map the spatial distribution of various parameters. Interpolation maps help visualize a generalized view of hydrogeochemical processes along with the drainage pattern and stream sequence of the study area and provide people and decision-makers with clear information about groundwater quality. This can help with future water quality monitoring, prevention, source of contamination, and modeling for the future conservation of groundwater.

Table 4 Groundwater classification based on total dissolved solid by (Davis and Dewiest 1966)

TDS (mg/l)	Classification	No of samples exceeding allowable limits	% of samples exceeding allowable limits
< 500	Desirable for drinking	11	18.97
500–1000	Permissible for drinking	30	51.72
1000–3000	Useful for irrigation	17	29.31
> 3000	Unfit for drinking and irrigation	NIL	NIL
	Total	58	100

TDS (mg/l)	Classification	No. of samples exceeding allowable limits	% of samples exceeding allowable limits
< 1000	Fresh water type	41	70.69
1000–10,000	Brackish water type	17	29.31
10,000–100,000	Saline water type	Nil	Nil
> 1,00,000	Brine water type	Nil	Nil
Total		58	100

Overall statistical overview of physicochemical parameters and concentration of major anions and cations are given in mg/L except for pH and electrical conductivity in µS/cm as shown in Table 2. Calculated minimum, maximum, mean, median, and standard deviation values are also listed in the table above. The number of samples exceeding the permissible limit and the percentage of samples above the permissible values according to WHO and BIS standards are shown in Table 2. The details of the studied groundwater quality parameters for drinking purposes are discussed below.

Physio-chemical pH parameters

The most important and determining factor for the degree of corrosivity of water is anchored in its pH values and is the result of the reaction of water with CO2 in the subsurface to form carbonic acid. In natural water, the pH value is caused by the interplay of carbon dioxide, carbonate, and bicarbonate, and their balance. pH is the most important and determining factor for the degree of corrosivity of water. The pH values obtained in this work range between 7.28 and 8.43, which corresponds to the required limits of the BIS standard. In conclusion, it can be said that the data show that the pH value in the studied area is not inherently a corrosive property. The chemical equations below show how groundwater pH changes throughout the natural process before reaching the aquifer:

(i) Reaction of rainwater with the atmosphere to form carbonic acid

H_2O þ $CO_2 \rightarrow H_2CO_3$

(ii) Dissociation of carbonic acid into bicarbonate leaving free H^+, making water acidic $H_2CO_3 \rightarrow$ð Þ HCO_3 – þ Hþ

Electrical conductivity

Determines the property of the aqueous medium, and how much current can pass through. The maximum permissible limit for electrical conductivity is 1500 μS/cm, according to BIS (2012). The observed EC is between 640 and 5890 μS/cm. There are five main groundwater bodies classified as EC quality according to Todd (1980) as shown in Table 3. In the study area, none of the samples found an excellent type of water with EC < 250 μS/cm. However, 8.62% of samples in a good water type (EC, 250–750 μS/cm), 63.79% of samples fall into the acceptable water type (EC, 750–2000 μS/cm), 18.97% with questionable water type (EC, 2000 – 3000) and 8.62% with unsuitable water type (EC > 3000 μS/cm) as shown in Fig. 4a. Overall, it follows from this study that 27.59% of groundwater is not suitable for domestic use.

Total Dissolved Solids

TDS is a measurement of the total amount of inorganic and organic solutes present in an aqueous solution. The primary constituents of groundwater for cations are sodium, potassium, calcium, magnesium, and anions are chlorides, sulfates, carbonates, and bicarbonates. TDS is mainly regulated by natural rock formation through weathering (transport), porosity, and permeability. The anthropogenic source includes sewage disposal and fertilizer runoff. The TDS values with minimum and maximum range are 409.6- 3769.6 mg/l with the permissible limit being 2000 mg/l prescribed by BIS standard. The map of the spatial distribution of TDS of the studied area is in Fig. 4b. Referring to Davis and Dewiest's (1966), classification, 18.98% falls within desirable TDS < 500 mg/L, 51.72% falls within permissible TDS 500–1000, and 29.31% falls within undrinkable as indicated in Table 4. According to the classification based on Freeze and Cherry (1979), 70.69% of the samples are freshwater type and 29.31% of the samples are blackish water, while no samples fall into saltwater and brine water type as shown in table 5.

Table 6 Groundwater classification based on Total Hardness (TH) showing % of samples exceeding allowable limits

TH as CaCO3	Classification	No of samples exceeding allowable limits	% of samples exceeding allowable limits
< 75	Soft	NIL	NIL
75–150	Moderately high	1	1.72
150–300	Hard	6	10.34
> 300	Very hard	51	87.93
	Total	58	100

Total hardness

is one of the important factors for determining drinking water quality parameters. TH is a measurement of the concentration of calcium and magnesium ions in water. TH in the study area is between 58.5 and 1480.5 mg/l. The permissible limit of TH is 600 mg/l according to BIS standards. According to Sawyer et al. (2003), the total hardness in groundwater can be calculated using the equation below.

TH as CaCO ð Þ3 mg ¼ Ca2þ þ Mg2þ meq=L*50

It was observed that no samples were found in the soft water category with TH < 75 mg/l, 1.72% of the medium category (TH; 75–150 mg/l), 10.34% of the samples in the hard category (TH; 150– 300 mg/L) and 87.93% very hard category with TH > 30 mg/L as shown in Table 6 and the spatial distribution map (Fig. 4c). A high TH value is directly proportional to calcium concentration, limestone bed formation and soil thickness in the area, as reported in the literature (Chaurasia et al. 2018).

Alkalinity

The main primary controlling component of alkalinity in water is caused by carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions. Alkalinity is measured by the titration method, where the samples are titrated with H_2SO_4 with the addition of phenolphthalein and methyl orange indicator. Alkalinity controls the pH value of water in each area.

Alkalinity was detected in the 60–580 mg/l, where the permissible limit according to BIS standards is 600 mg/l.

Major Ion Chemistry

In this study, the anion concentration was found in the descending order of Cl^- > HCO_3^- > SO_4^{2-} > NO_3^- > F^- with a percentage of 52.93% > 21.59% > 18.13% > 7.21% > 0.14%, respectively. Chloride is the most stable, abundant ion in water. The source of Cl^- in groundwater is minerals such as halite, mica, hornblende, chlorapatite, and sodalite. Chloride in groundwater is produced by weathering, sediment and soil leaching, and urbanization (Karanth 1987). The concentration of chloride ions in the Wanaparthy watershed samples ranges from 10.77 to 1794.5 mg/L (Fig. 4d), all but two samples being above the permissible limit of the BIS standard. The concentration of bicarbonate (HCO_3^-) in water is caused by the interplay of temperature, pH, dissolved CO_2, cations, and other salts. All the samples are within the permissible limit i.e. 600 mg/L bicarbonate according to WHO standards as shown in Fig. 4e. Typically, the concentration of HCO_3^- is higher in groundwater compared to surface water with less than 200 mg/L (Kumar et al. 2015). HCO_3^- ranges from 30.5–329.4 mg/l. Sulphate is the second most abundant in the water samples with a mean of 119.86 mg/L and ranges between 0.115 and 632 mg/L (Fig. 4f), which is within the permissible limit. In general, sulfate enters groundwater through the oxidation of sulfite minerals such as pyrite (FeS_2) (Yadav et al. 2012). Nitrate concentration is within the permissible range of 45–100 mg/l (Fig. 4g), except for five samples that exceeded the limit of the BIS standard. Nitrate concentration in groundwater increases during the monsoon season due to an increase in infiltration rate in the vadose zone, causing the leaching of nitrate into the aquifer (Kumar et al. 2016). High nitrate concentrations cause health conditions such as methemoglobinemia (blue babies in infants), stomach cancer, thyroid problems, and diabetes (Dudley 1990; Majumdar and Gupta 2000). The mean fluoride value observed in the area is 0.906 mg/L, with minimum and maximum values between 0.135 and 2.833 mg/L (Fig. 4h). About 19% of the total samples in the area exceeded the permissible limit of WHO and BIS standards. The source of fluorine in groundwater is mainly orogenic processes caused by the weathering of granitic rocks with accessory F^- rich minerals such as amphiboles, apatite, fluorite, and mica (Reddy et al. 2010). A high content of fluorides in the water (i.e., above the permissible limit) causes fluorosis of the teeth and skeleton. The cation concentration is in the descending order of Na^+ > Ca^{+2} > Mg^{+2} > K^+ contributes 62.80% > 26.31% > 6.96% > 3.92%, respectively. Sodium has a maximum concentration with an average of 181.22 mg/l (Fig. 4i). It constitutes 34.48% of the total number of samples in the area above the permissible BIS limit. The source of Na^+ in groundwater is silicate minerals such as albite, nepheline, sodalite, and other minerals containing Na^+. In addition, other sources are rainwater, the dissolution of vaporized minerals, sewage, and industrial runoff (Handa 1975). According to Pillai et al. (2020) and Rajesh et al. (2012), silicate minerals such as feldspar (albite, $NaAlSi_3O_8$) can be a source of Na^+ in groundwater through a dissolution process as shown below:

2NaAlSi3O8 þ 2HþCO3 þ 9H2O↔Al2Si2O5ð Þ OH 5 þ 2Naþ þ 4H4SiO4 þ 2HCO– 3 ð Þ Albite ð Þ Silicate weathering ð Þ

The concentration of Na^+ in groundwater increases through an exchange reaction in clay minerals and zeolite (Karanth 1987). Potassium is the lowest and has an average concentration of 11.12 mg/l, ranging from 0.11 to 152.18 mg/l (Fig. 4l). In general, sodium and potassium concentrations in groundwater are high due to weathering and dissolution of silicates present in soil or rock salts through evaporation and anthropogenic sources. Sodium and potassium are also abundant in ocean water, ancient wells, industries, and discharge areas. High concentration of sodium and potassium with Cl^- ions leading to salt water and high concentration of sodium in water is not suitable for irrigation purposes. Calcium and magnesium are second and third in terms of concentration in the samples with an average concentration of 80.15 mg/L and 19.74 mg/L in the range of 5.83–304 mg/L (Fig. 4j) for calcium and 0.52–64, respectively. 28 mg/l (Fig. 4k) for magnesium. Only one sample in the area is above the permissible limit for calcium, while all other samples are below the BIS limit for magnesium. The source of calcium in groundwater is mainly igneous rocks (silicate minerals such as pyroxenes, amphiboles, and feldspars) and sedimentary rocks (such as limestone, dolomite, and gypsum). Calcium and magnesium concentrations are related to water hardness and are freely available in both surface and subsurface water as carbonates, and sources come from rocks such as limestone, gypsum, and dolomite (Domenico and Schwartz 1998). A high concentration of calcium and magnesium in water forms layers in electrical appliances and pipes and is not suitable for domestic use. Magnesium has been found to originate from all three rock types such as igneous (basalt, dunites, pyroxenites), metamorphic (amphibolite, talc, tremolite-shale), and sedimentary (dolomite, gypsum) (Karanth 1987). In general, in natural or undisturbed water, calcium concentration is higher than magnesium. Mainly, the distribution of various parameters in the percentage of concentration in groundwater samples is shown in Fig. 5. Among them, the first five highest parameters are EC in first place with 40.03%, TDS in second place with 25.79%, TH in third place with 12.07 %. , chloride in fourth with 8.02%, and sodium in fifth place with 4.08%.

Fig. 5 Pie chart showing all the physicochemical parameters and major ions percentage distribution

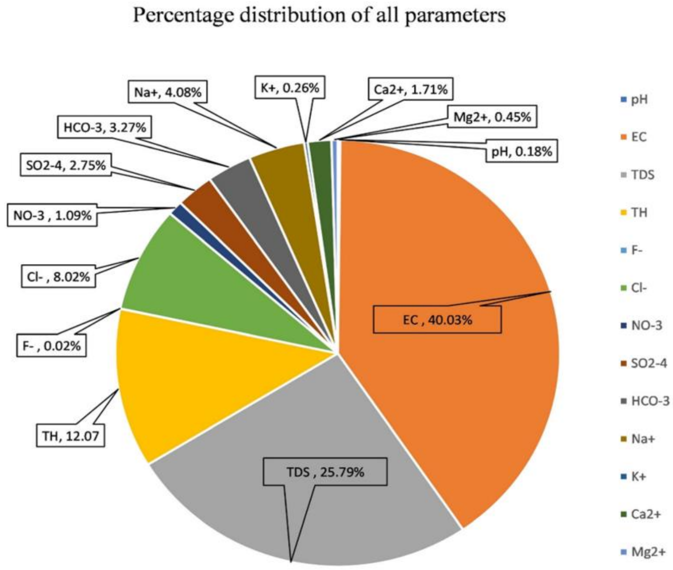


Fig. 6 Piper trilinear diagram showing different facies in groundwater

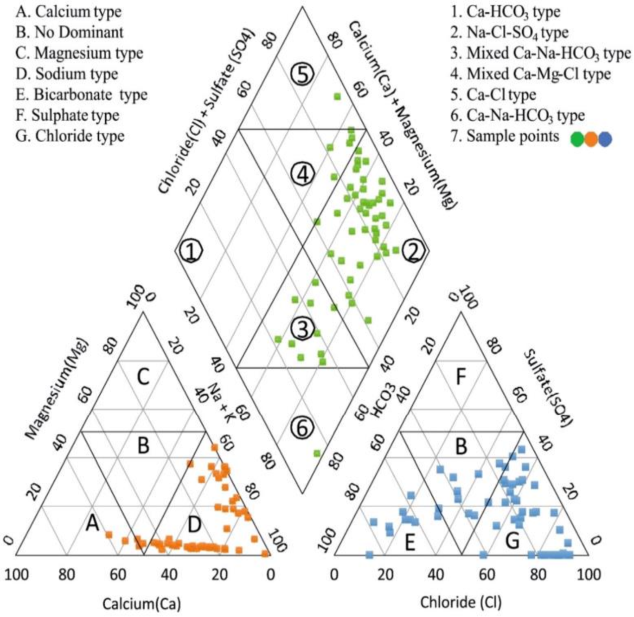


Fig. 7 Gibbs plot shows the principle controlling groundwater chemistry

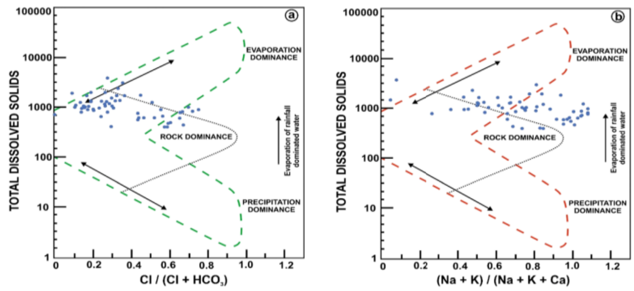


Table 7 Different types of groundwater and % distribution of samples using WQI (water quality index) range

WQI range	Type of water	No. of samples	% of samples
< 50	Excellent water	2	3.45
50.00–100	Good water	35	64.34
100.01–200	Poor water	17	29.31
200.01–300	Very poor water	4	6.90
> 300.01	Unfit for drinking purposes	NIL	NIL
	Total	58	100

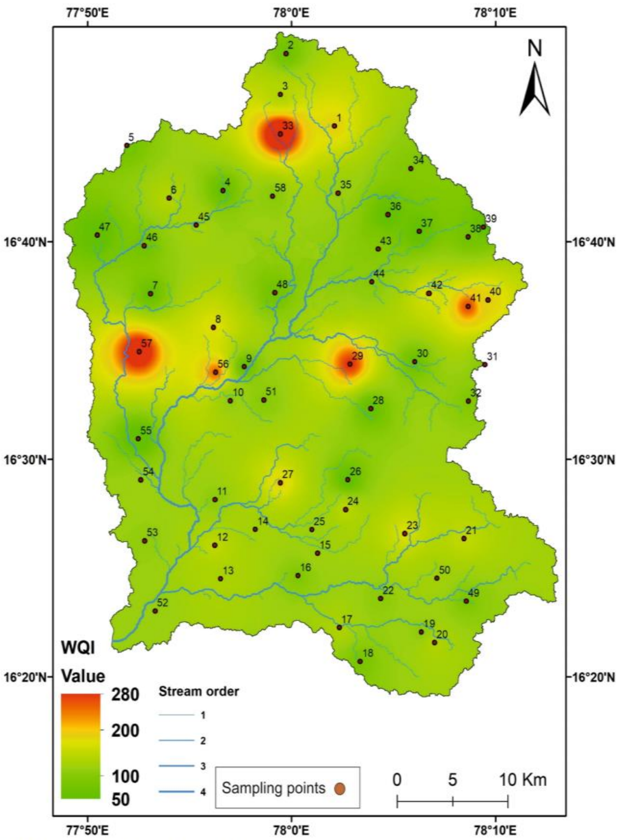


Fig. 8 Water quality index (WQI) map of Wanaparthy watershed

Table 8 Details description of groundwater point source and their respective WQI values and types of water

Sample ID	Location	GPS points latitute longitute		Source	Drinking	Colour	WQI	Type
PRM 01	Yenugonda	16.75528	78.03532	submersible	Yes	Clear	163.93	Poor
PRM 02	Parvathapuram	16.81101	77.99579	Submersible	Yes	Clear	66.22	Good
PRM 03	Kenipally	16.77956	77.99104	Submersible	Yes	Clear	115.74	Poor
PRM 04	Chowderpally	16.70595	77.94411	Submersible	Yes	Clear	60.73	Good
PRM 05	Rajunaiktanda	16.74044	77.86519	Submersible	Yes	Clear	72.79	Good
PRM 06	Ramchandrapur	16.70007	77.89989	Handpump	No	Pale yellow	127.20	Poor
PRM 07	Hajalipur	16.62681	77.88467	Handpump	Yes	Clear	63.13	Good
PRM 08	Vemula	16.6011	77.93636	Submersible	Yes	Clear	144.80	Poor
PRM 09	Komireddipally	16.57083	77.96155	Handpump	Yes	ss	62.42	Good
PRM 10	Shakapur	16.54493	77.95014	Handpump	No	Clear	90.92	Good
PRM 11	Veltoor	16.46915	77.93751	Submersible	Yes	Clear	92.52	Good
PRM 12	Kanimetta	16.43407	77.93734	Handpump	Yes	Clear	121.88	Poor
PRM 13	Palem	16.40845	77.94205	Submersible	Yes	Clear	108.71	Poor
PRM 14	Mojerla	16.44628	77.97057	Handpump	No	Pale yellow	98.62	Good
PRM 15	Peddamandaddi	16.42804	78.02144	Handpump	Yes	Clear	102.47	Poor
PRM 16	Manigilla	16.41078	78.00547	Submersible	Yes	Clear	77.35	Good
PRM 17	Vaddeda	16.3711	78.03926	Handpump	Yes	Clear	118.61	Poor
PRM 18	Srinivaspur	16.3451	78.05638	Submersible	Yes	Clear	72.57	Good
PRM 19	Appaipally	16.3676	78.1065	Handpump	No	Pale yellow	93.18	Good
PRM 20	Munnanur	16.35967	78.11681	Handpump	Yes	Clear	114.84	Poor
PRM 21	Buddaram	16.43918	78.14085	Submersible	Yes	Clear	122.20	Poor
PRM 22	Chityala	16.39324	78.07317	Submersible	Yes	Clear	84.15	Good
PRM 23	Aloor	16.44307	78.09299	Submersible	Yes	Clear	149.26	Poor
PRM 24	Chinamandaddi	16.46157	78.04445	Submersible	Yes	Clear	124.00	Poor
PRM 25	Awal	16.44603	78.01681	Submersible	Yes	Clear	95.76	Good
PRM 26	Veeraipally	16.48442	78.04633	Handpump	Yes	Clear	51.11	Good
PRM 27	Gatlakhanapur	16.48215	77.991	Handpump	No	Clear	162.31	Poor
PRM 28	Solapur thande	16.53892	78.06507	Handpump	No	Clear	59.55	Good
PRM 29	Khillaghanpur	16.5728	78.04807	Submersible	Yes	Clear	223.22	Very poor
PRM 30	Salikelapur	16.57476	78.10114	Submersible	Yes	Clear	59.78	Good
PRM 31	Manganuru	16.57252	78.15792	Submersible	No	Clear	77.43	Good
PRM 32	Latupalle	16.54469	78.14442	Submersible	Yes	Clear	75.11	Good
PRM 33	Mahabubnagar	16.7493	77.99107	Handpump	No	Pale yellow	262.97	Very poor
PRM 34	Tadparti	16.72281	78.09795	Handpump	No	Clear	74.08	Good
PRM 35	Amistapur	16.70395	78.03834	Submersible	Yes	Clear	94.15	Good
PRM 36	Botlagaddatanda	16.68746	78.07915	Submersible	Yes	Clear	54.50	Good
PRM 37	Karivena	16.67464	78.10463	Submersible	Yes	Clear	53.57	Good
PRM 38	Pullagirithanda	16.67046	78.14429	Submersible	Yes	Clear	65.63	Good
PRM 39	Pullagiri village	16.678	78.15674	Handpump	Yes	Clear	56.30	Good
PRM 40	Gorita	16.62217	78.16042	Submersible	Yes	Clear	155.91	Poor
PRM 41	Chegunta	16.61715	78.14438	Submersible	No	Clear	198.76	Poor
PRM 42	Yelkicharla	16.62718	78.11251	Submersible	Yes	Clear	137.50	Poor
PRM 43	Kothamolgara	16.66103	78.07117	Submersible	Yes	Clear	82.39	Good
PRM 44	Roadside	16.63596	78.06586	Handpump	Yes	Clear	93.83	Good
PRM 45	Kadur	16.67941	77.92212	Submersible	Yes	Clear	110.52	Poor
PRM 46	Oblaipalle	16.66376	77.87949	Submersible	Yes	Clear	71.45	Good
PRM 47	Gaddeguda	16.67193	77.84102	Submersible	Yes	Clear	49.66	Excellent
PRM 48	Janampet	16.62767	77.98649	Submersible	No	Clear	63.58	Good

Table 8 (continued)

Sample ID	Location	GPS points latitute longitute		Source	Drinking	Colour	WQI	Type
PRM 01	Yenugonda	16.75528	78.03532	submersible	Yes	Clear	163.93	Poor
PRM 49	Gopalapet	16.39119	78.14268	Submersible	Yes	Clear	77.45	Good
PRM 50	Chennur	16.4089	78.11878	Handpump	No	Clear	99.05	Good
PRM 51	Khandoor	16.54557	77.97745	Submersible	Yes	Clear	79.64	Good
PRM 52	Madanapur	16.383724	77.888394	Handpump	Yes	Clear	96.82	Good
PRM 53	Dwarakanagar	16.437511	77.879964	Submersible	No	Clear	86.64	Good
PRM 54	Perur	16.484203	77.876751	Submersible	No	Clear	98.53	Good
PRM 55	Isrampally	16.5157	77.87473	Handpump	No	Clear	47.99	Excellent
PRM 56	Ponnakal	16.56661	77.93799	Submersible	Yes	Clear	212.36	Very poor
PRM 57	Jeenugurala	16.582491	77.875398	Handpump	No	Clear	250.47	Very poor
PRM 58	Alipur	16.70156	77.9847	Submersible	No	Clear	83.95	Good

Hydrochemical Facies

The hydrochemical facies of groundwater explains the relationship between the major anions and cations and their behavior. Hydrochemical facies help determine the origin and classification of different water types (Piper 1944; Venugopal et al. 2009). Therefore, we calculated the groundwater hydrogeochemical facies using the concentration of major anions (Cl–, SO4 2– and HCO3 –) and cations

(Ca2+, Mg2+, Na+, and K+) in meq/l through their concentration plotted in a Piper diagram as shown in Fig. . 6. The mechanism of geochemical evolution is represented in six different types of water as Type I (Ca-HCO3 type), Type II (Na-Cl type), Type III (CaNa-HCO3 mixed type), Type IV (Ca-type Mg- Cl), type V (CaCl type) and type VI (Na-HCO3 type). The percentage distribution of the samples for each type of water is as follows: 70.68% Na-Cl type, 17.24% Ca-Na-HCO3 mixed type, 8.63% Ca-Mg-Cl mixed type, 1.72% each for Ca-Cl and Na Type -HCO3, but no sample falls into the Ca-HCO3 type. From the anion triangle, chloride dominates the concentration with 68.97% followed by bicarbonate with 17.24% and 13.79% of the samples have no dominance. On the other hand, for cations, the highest dominant ion is sodium with 91.38%, calcium with 5.17%, and 3.45% of non-dominant samples. Sodium is in high concentration in the area due to weathering and dissolution of silicate present in the soil or rock salts through evaporation and anthropogenic sources.

Gibbs Diagram

A Gibbs diagram explains the chemical properties of water and how they react in the subsurface with different rock lithologies. The classification is of three types (Gibbs 1970), type I evaporation dominant (due to surface/subsurface evaporation rates), type II rock dominance (due to chemical weathering of rocks by water), and type III precipitation dominance (surface/subsurface precipitation). Gibbs diagram obtained by plotting groundwater major ion data samples using two equations for anions and cations as follows: Gibbs ratio I for anions ð Þ¼ ; meq=L Cl– Cl– þ HCO– 3 ð1Þ Gibbs ratio II for cations ð Þ¼ ; meq=L Naþ þ Kþ Naþ þ Kþ þ Ca2þ ð2Þ

The concentration of all ions in meq/l. The Gibbs plot for anions and cations is shown in Fig. 7. Most samples fall into the rock-dominated type, with a few samples expected to be evaporite-dominant. The process of evaporation is rare in both surface and subsurface glasses of water as usual, but due to the hot and dry climate of the area, many samples fall into it (Selvakumar et al. 2017). However, the maximum number of rock-dominated samples indicates the chemical weathering of silicate rocks by groundwater under favourable pressure and temperature.

The WQI Groundwater

Quality Index is useful for assessing groundwater quality to determine its use for drinking purposes, which is a simple, stable, and reproducible index. Based on the WQI values, water was classified into five types such as excellent water with WQI < 50, good water (WQI between 50 and 100), poor water (WQI between 100 and 200), very poor water (WQI between 200 and 300). and unsuitable for drinking (WQI > 300). Most of the water samples in the area belong to good water, it is 64.34%, 3.45% is excellent water, 29.31% is bad water, 6.9% is very bad water, and no samples are found unfit for drinking as is described in Table 7. The WQI spatial distribution map is in Fig. 8. Of all the collected groundwater samples, 21 samples were from a hand pump and the remaining 37 were from a submersible borehole, of which 17 were not used for drinking purposes, but at most 41 points were used for both drinking and farming. To understand and know about the quality of water used for drinking, samples were collected from the villages of commonly used bore wells, which can be expected for several samples from the agricultural area. The WQI for all points along with village names, GPS points, sources, and water types are shown in Table 8. The study area has excellent to good drinking water which accounts for 67.79% and poor to very poor water quality contributes 36.21%. Water quality is poor in four sample villages namely Khillaghanpur (Sample ID: PRM 29) has a WQI value of 223.22, Mahabubnagar (Sample ID: PRM 33) has a WQI value of 262.97, Ponnakal (Sample ID: 55) has a WQI value of 212.3 and Jeenugurala (Sample ID: PRM 57) has a WQI value of 250.47 as shown in the scatter plot (Fig. 9), which are hot spots

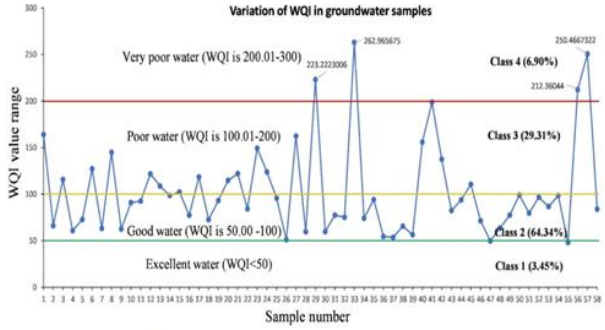


Fig. 9 Scatter plot showing water quality index (WQI) distribution in samples

Table 9 Comparing the Water Quality Index (WQI) values of Wanaparthy watershed, Telangna with similar hard rock terrain in southern region of India

S. no	Title of the research work	Study area	WQI value range		References	Publication
			Min	Max		
1	Assessing groundwater quality for drinking water supply using hybrid fuzzy-GIS-based water quality index.	Tiruchirappalli district, Tamil Nadu	65.15	89.58	Jha et al. 2020	Water Research
2	Hydrochemical characterization and geospatial analysis of groundwater for drinking and agricultural usage.	Nashik district, Maharashtra	33.00	328.00	Zolekar et al. 2020	Environ Dev Sustain
3	Groundwater quality evaluation using water quality index (WQI) for drinking purposes and human health risk (HHR) assessment in an agricultural region.	Nanganur, Siddipet district, Telangana	92.00	295.00	Adimalla and Qian (2019)	Ecotoxicol. Environ. Saf.
4	Groundwater quality for drinking and irrigation purposes and potential health risks assessment: a case study from semi-arid region of South India	Western part of Telangana	67.00	228.00	Adimalla et al. 2018	Environ Process
5	Fluoride contamination in groundwater resources of Alleppey, southern India	Alleppey town, Kerala	68.98	361.27	Raj and Shaji (2017)	Geoscience Frontiers
6	Assessment of groundwater quality for drinking and irrigation use in shallow hard rock aquifer of Pudunagaram.	Palakkad District, Kerala	16.53	837.09	Kumar et al. 2016	Appl Water Sci
7	Hydrogeochemistry and application of water quality index (WQI) for groundwater quality assessment, Anna Nagar.	Chennai City, Tamil Nadu	44.28	428.53	Kumar et al. 2015	Appl Water Sci
8	Water quality index and GIS-based technique for assessment of groundwater quality in Wanaparthy watershed, Telangana, India.	Wanaparthy watershed, Telangana	47.99	262.97	Vaiphei et al.	Present Study

lead to an impact on human health in the studied region. A comparison of the range of WQI values with other areas with similar geological hard rock terrain is shown in Table 9. It was observed that a WQI of 428.53 (i.e., unfit for potable purposes) can be seen in Anna Nagar, Chennai may be due to dense limited commercial zones such as automobiles and small to medium sizes. Additionally, Chennai is one of the largest metropolitan cities in India. While in the case of Palakkad District in Kerala, the WQI value is very high reaching up to 837.09 where the area is highly fertile and full of agriculture/farming where coconut, paddy, capsicum, etc. are grown. This may be due to the high use of fertilizers without proper drainage system waste. This study reports that the maximum WQI value is 262.97 and has the same terrain type, but the pollutant source and degree of contamination are different. It is therefore most important to note that water quality depends on the breakdown and management of liquid/solid systems.

III.CONCLUSION

The study conducted in the Wanaparthy basin covers parts of the Wanaparthy and Mahbubnagar districts for water quality assessment based on hydrogeochemical characterization, WQI, and GIS techniques. Physio-chemical parameters like EC, TDS, and TH are outside the permissible limits as per WHO and BIS standards. The concentrations of the main anions and cations in the water samples are in the descending order Cl^- > HCO_3^- > SO_4^{2-} > NO_3^- > F^- (52.93% > 21.59% > 18.13% > 7.21% > 0, 14%) and Na^+ > Ca^{+2} > Mg^{+2} > K^+ (62.80% > 26.31% > 6.96% > 3.92%). Dominant ions in groundwater samples are Cl^-, HCO_3^- for anions, and Na^+, Ca^{+2} for cations. The main anions Cl^-, SO_4^{2-}, NO_3^-, F^- and cations Na^+, and Ca^{+2} are above the permissible limit in some samples. From the Piper diagram classification, the type of groundwater is Na-Cl (70.68%) of the type with the highest dominance of sodium (91.38%) as cations. The high concentration of Na^+ in the area is due to weathering and dissolution of silicates present in the soil and rock salts through evaporation and anthropogenic sources. The Gibbs plot explains that the maximum number of samples fall into rock dominance and few samples are expected to be in evaporite dominance. The drainage system shows that the concentration of various parameters was higher at points or near the connection to the higher-order drainage system. This could be due to the chemical reaction of rock-water interaction through recharge and infiltration processes. The geological map shows that there is a large migmatite intrusion that trends northwest to southeast. This intrusion may be responsible for groundwater contamination, as several samples falling within this area were found to be above the permissible WQI classification for drinking. According to the spatial distribution maps, it was found that there was no trend or uniformity in the variation of the values; that is, the main ions are independent of the source. The Water Quality Index

(WQI) shows that 67.79% of the area has excellent to good water, while the remaining 32.21% is poor to very poor water, which are hotspots of pollution. Therefore, looking at the WQI values, most water samples are safe to drink. In addition, it concludes that groundwater contamination in the region is caused by rock-water interaction and agricultural activities. Henceforth, it is recommended to have monitoring boreholes in and around with proper management for easy access of people to drinking water in the future.

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