Evaluation of anthropogenic nexus on groundwater quality through integration of hydrogeochemical processes and water quality index at Nacharam watershed of greater Hyderabad, India

Rama Mohan Kurakalva (krenviron@ngri.res.in)
NATIONAL GEOPHYSICAL RESEARCH INSTITUE (CSIR) https://orcid.org/0000-0001-7199-7475
Sravya Sai Guddeti
NGRI: National Geophysical Research Institute CSIR
Anjana Nath
Kerala University of Fisheries and Ocean Studies
Eswara Venkata Ravi Kishore Vemana
NGRI: National Geophysical Research Institute CSIR

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Abstract

Anthropogenic activities such as the rapid leap of industrialization and urbanization constitute a significant concern in megacities and have become a key source of groundwater contamination. Twenty-five (25) groundwater samples were collected from tube wells and handpumps from Nacharam watershed, greater Hyderabad. The water samples were analyzed for 13 physicochemical parameters and major dissolved ions using the standard methods. WQI has been computed using a weighted arithmetic index method and integrated with GIS to identify the hotspots of contamination and their spatial distribution. The analytical data plotted on the Piper diagram showed that dominance of Ca-Mg-Cl (52%) type followed by Na-Cl type of water is dominant in 44% of samples might be resulting due to increase in anthropogenic activities such as discharge of waste water from industries. Results reveal that 96% of the samples exceed the F - concentrations compared with WHO permissible limits suggested unfit for drinking. WQI values indicate that 56% of samples fall in the poor category, 28% belong to very poor water, and 4% are unsuitable for drinking. These findings will provide valuable information to policymakers and stakeholders on the proper management and supply of potable water that reduces human health concerns .

Introduction

Contamination of groundwater resources has developed as a significant issues world wide. Groundwater is considered polluted when it contains enough foreign matter to evince it unfit for human consumption and other recreational uses (Khatri et al. 2016; Rawtani et al., 2017). Because of rapid industrialization and urbanization, numerous industries in and around the urban areas release their untreated and semi-treated effluents into nature, contaminating water bodies. Toxins, for example, substantial metals and different synthetics, which are present in the effluents dislodged through the soil, surface water, residue of the lake bed and permeated into groundwater, influencing its quality. Groundwater quality assumes significance in deciding the use of groundwater for a particular reason. Water for drinking must be free from harmful components, exorbitant minerals that may affect human well-being (Reddy et al., 2019; Vaiphe and Kurakalva, 2020). Efficient observation is profoundly required because all human health problems are straightforwardly connected with water quality. Natural and anthropogenic factors influence groundwater physical and chemical patterns in an area, thereby deteriorating the quality (Subramanian 2009; Khatri and Tyagi, 2015).

In a provincial domain, groundwater, lake water, waterway water, and channel water fill in as significant wellsprings of drinking water. Among these water resources, groundwater is the most generally utilized drinking water source in greater Hyderabad, one of the largest metropolitan cities in India (Kurakalva et al. 2021). This city has wellsprings of contamination, for example, landfills, risky sewer lines, squander lands result which leads to groundwater contamination. Inappropriately treated effluents, underground stockpiling tanks, spills, and draining of harmful synthetic compounds are the major sources of contamination and significantly influence groundwater quality (Garewal and Vasudeo, 2018; Santucci et al. 2018). It has been perceived that most of the industrial areas/towns release their effluents into the streams, and the solid waste created is discretionarily dumped on open land along lanes and lakes (Krishna and Mohan 2014; Vaiphei and Kurakalva 2021a). Groundwater has a more prominent break-up substance because of its expanded cooperation with various materials in the geologic layers (CPCB, 2007) comparatively with surface water.

Understanding hydrogeochemical processes are helpful for effective utilization, protection, and prediction of spatial and temporal variations in groundwater quality (Kadam et al. 2021; Vaiphe and Kurakalva 2021b). The WQI method is generally utilized for groundwater quality appraisal worldwide because of the capability of complete communication of the water quality data. There is insufficient knowledge about groundwater pollution at the Nacharam Watershed of greater Hyderabad, India (Bhoopathi et al. 2014; Rao et al. 2016). Besides, the watershed has various types of major industrial clusters overlapped with the habitats where groundwater is the primary source for drinking and other domestic uses. The anthropogenic activities further lead to vulnerability to impact on groundwater quality in the region. Consequently, a detailed investigation on groundwater characterization, the impact of anthropogenic activities, and their spatial distribution of contamination of great environmental and public health concerns. The present study's objective is to assess the impact of anthropogenic activity on the groundwater quality in the Nacharam watershed based on hydrogeochemical characterization and use of an integrated approach of GIS and WQI. The developed WQI distribution map can be used as tool visiualize spatially the groundwater quality of the Nacharam watershed.

Materials And Methods

2.1 About study area

Nacharam watershed is located in North-East of Hyderabad, Medchal Malkajgiri district. This watershed also includes the industrial area developed in an area of approximately 700 acres. The study area lies between latitudes $17^0 23' 30''$ N to $17^0 26' 30''$ N and longitudes $78^0 32' 30''$ E to $78^0 36' 30''$ E and falls in Survey of India toposheet No.56K/11/NW. The study area spreads about 53 Sq.km. Approximately 100 industries, including steel manufacturing, chemical manufacturing, food processing, rubber, plastic, and distilleries, are located in the study area. The watershed consists of the industrial estate is demarcated. The location map of the Nacharam watershed and sampling stations are shown in Figure 1. The study area consists of significant rock formation of medium to coarse-grained granite and presumed as part of the peninsular gneissic complex (GSI, 1995). The district is underline with various geological formations such as Archean granites and gneisses, Bhima series, and Deccan traps. The Archean crystalline rocks compressing older metamorphic rocks, peninsular gneissic complex (migmatites), and younger intrusive rocks. Intrusive dolerite dyke any common in this area (CGWB, 2015).

2.2 Groundwater sampling and analysis

Groundwater samples are collected from 25 bore wells of the Nacharam watershed according to the grid pattern (size:1 1km) in the Nacharam watershed of greater Hyderabad, Telangana. A sampling protocol is followed according to APHA (2017) standard methods and collected in polypropylene bottles. The sampling bottles were rinsed 2-3 times with sampling water and filled to avoid air-water interaction. The pH, EC, and TDS values are measured in situ immediately without filtration on the same day after collecting the samples. Bicarbonate (HCO_3^-) concentrations were determined by titration using 0.02N H_2SO_4 as titrant. Major anions and cations concentration in groundwater samples were determined using Ion chromatograph (882 Compact IC plus, Metrohm).

2.3 Water Quality Index

Water quality index (WQI) of each sample was carried out to assess the suitability of grondwater for drinking use. World Health Organization guideline values (WHO, 2017) were usedto compute WQI. The WQI has been computed using a weighted arithmetic index method as described by Brown et al. (1970) using the following equation (1).

$q_n = 100 [(V_n - V_i)/ (S_n - V_i)]$ eq. (1)

Where q_n =Water quality rating for the n^{th} parameter; V_n = Observed value of the n^{th} parameter, S_n = Standard permissible value of n^{th} parameter; V_i = Ideal value of n^{th} parameter

The unit weight (Wn) of the each parameter was an inverse proportional value to the recommended standard value of Sn and calculated as per the following equation (2)

$W_n = K/S_n$ eq. (2)

Where, Wn = Unit weight for the n^{th} parameter; Sn = Standard value of the n^{th} parameter; K = Constant for proportionality which is calculated by using equation (3)

$K = 1/\Sigma (1/S_n)$ eq. (3)

Finally, the total water quality index was calculated linearly by adding the quality rating to the unit weight according to equation (4)

$WQI = \Sigma q_n W_n / \Sigma W_n$ eq. (4)

WQI has been calculated using the relative weight for each parameter, as presented in Table 1. Groundwater quality in the Nacharam watershed, Hyderabad was used to appraise for drinking purposes from the developed WQI.

Results And Discussion

Analytical data of physicochemical parameters, major ions in all the groundwater samples are presented in Table S1. In contrast, the statistical summary of the data compared with WHO permissible limits is represented in Table 2. Hydrogeochemical processes are an effective tool for evaluating groundwater quality and establishing contamination status. Integrating WQI values in the GIS platform is the best tool to identify contamination hotspots and their distribution pattern in the study area. The detailed discussion of the data obtained is illustrated below.

3.1. Groundwater quality evaluation

3.1.1 Physicochemical properties

Physicochemical properties of groundwater have been evaluated for its suitability for drinking purposes following WHO (2017) permissible limits. pH is significant in arranging numerous sorts of geochemical balance. pH of groundwater observed in the ranges from 6.0 to 7.9, indicating alkaline nature, and their spatial distribution is shown in Fig.2 (a). pH values for all the samples are within acceptable limits. Water with a pH higher than 8.5 or lower than 6.5 can produce aesthetic effects such as staining and etching or equipment scaling. The EC values in found in ranges from 410 to 2020 µS/cm. (Table 2) and their spatial distribution is shown in Fig.2(b). The high value of TDS influences the taste, hardness, and corrosive property of the water (Devi et al., 2003). TDS varied from 262 to 1293 mg/L with a mean of 744 mg/L (Table 2). Both EC and TDS values exceed the permissible limits of WHO guideline values in 16% of the groundwater samples. The spatial distribution of TDS is presented in Fig.2(c). The acceptable limit of TH is 100 mg/L as $CaCO_3$, however, if no alternative source of water it can be used up to 500 mg/L and is given in Fig. 2(d). About 16% of the samples exceed the acceptable limits of TH as shown in Table 2.

3.1.2 Dissolved ions

The sum of all dissolved ions particles (<2 microns) in groundwater is referred to as TDS, while total hardness (TH) is mainly due to alkaline earth elements like calcium and magnesium ions. TDS and TH values obtained for groundwater of the study area have been categorized with different classifications as described (Davis and Dewiest 1966; Freeze and Cherry 1979; Sawyer et al. 2003) and presented in Table 3. The present study indicated that most of the groundwater is within permissible limits of 84% for drinking and 16% for irrigation purposes. TDS in groundwater is due to the percolation of industrial effluents observed in the eastern side of the industrial area (Fig. 2(c)). Based on the TH values (mg/L) in groundwater, classified as soft (<75), moderately high (75-150), hard (150-300), and very hard (>300) water that can be used to evaluate its suitability for drinking and other domestic purposes (Sawyer et al., 2003). The groundwater in the study area belonging to 4% is moderately high, 24% belongs to hard type, 72% of samples belongs to very hard type, and no sample is found in the soft water category. These indicate that most of the samples in the study region belonging to hard to very hard types and are not suitable for drinking. The spatial distribution of hardness in the watershed is shown in Fig.2(d).

3.1.3 Groundwater major ion chemistry

Alkali (Na^+, K^+) and alkaline earth (Ca^+ and Mg^+) elements are the most abundant in natural waters. The order of abundance of the cations was observed as Na>Ca>Mg>K. Sodium is the highest concentration among the cations ranges from 30.01 to 215.01 mg/L with a average value of 105.35 mg/L (Table 1). The WHO acceptable limit of 200 mg/L exceed in 4% of samples only. Silicate weathering is the primary source for resulting Na^+ in groundwater resources. Then, calcium is the next higher concentration found in the groundwater, varying from 12.22 to 88.67 mg/L and mean value of 47.23 mg/L (Table 1). Magnesium values varied between 6.16 and 45.11 mg/L, and the average values of 23.70 mg/L were observed (Table 2). The required, acceptable limit of magnesium in groundwater for drinking purposes is 50-150 mg/L (WHO, 2017). All the groundwater samples are within the given permissible limits. Potassium concentration of the groundwater ranging from 0.98 to 18.79 mg/L with an average value of 3.46 mg/L. The acceptable limit of potassium in drinking water is 200 mg/L. Among all the cations in groundwater, the potassium found low concentrations. The spatial distribution of cations is presented in Fig.3 (a) to 3(d).

The order of abundance of anions was observed as $HCO_3^- > SO_4 > Cl^- > F^- > NO_3^-$ in the groundwater of the study area. Bicarbonate (HCO_3^-) concentrations found ranges from 73.20 to 549 mg/L with a mean value of 264.74mg/L. Around 88% of the samples exceeded the permissible limits (WHO, 2017) as given in Table 2 and their spatial variation is presented in Fig.3(e). The source of bicarbonates in groundwater is due to the dissolution of carbonate minerals as per equations (5) and (6).

$$CaCO_3 + CO_2 + H_2O \leftrightarrow Ca^{2+} + 2HCO_3^- \quad \text{eq. (5)}$$

$$CO_2 + H_2O \leftrightarrow H^+ + HCO_3^- \quad \text{eq. (6)}$$

Sulphate is the most abundant anion next to bicarbonate in the study area, varying from 2.79 to 2374.87 mg/L with the mean value of 548.22 mg/L (Table 2), which is above the permissible limit of 250 mg/L (WHO, 2017). Around 44% of the groundwater samples exceed the allowable limits (Table 2), and their distributions spatially showed in Fig.3(i). The chloride concentration of the study area ranges from 55.26 to 1101.31 mg/L with mean of 344.95 mg/L, and spatial distribution is shown in Fig.3(g). The acceptable limit of chloride in potable water is 200-300 mg/L (WHO, 2017). Around 52% of the samples were above the acceptable limits.

Elevated fluoride concentrations were observed range from 0.58 to 7.28 mg/L with an average of 3.34 mg/L. Acceptable limit of fluoride in potable water is 0.6-1.0 mg/L (WHO, 2017). Around 96% of the samples were above the permissible limits, and their spatial variations are shown in Fig.3(f). It is well known that high concentration fluoride in drinking water originates dental decay and physiological deformation. The nitrate concentration of the groundwater samples of the study area found in all the samples are within the permissible limit (50 mg/L) of nitrate in potable water indicates there is no influence of agricultural fertilizers and domestic sewage, which are the major sources.

3.1.4 Correlation analysis

Correlation analysis of various physicochemical and major ions of the groundwater has been presented in Table 3**.** A good correlation (>0.5) was observed between EC and TDS with Cl^-, Na^+, SO_4^- and HCO_3^-. It indicates that concentrations of sodium and chloride concentration might be due to over-exploitation of groundwater resources, a common practice in urban areas (Hem,1985). It is also observed that chloride is derived from anthropogenic activity, such as releasing industrial effluents onto open drainage or land (Sunil Kumar and Ramanathan 2008).

3.2 Assessment of the impact of anthropogenic sources

Hydrochemical interactions are the best signatures to illustrates the effects of anthropogenic activities on groundwater resources. Subsequently, the major ion chemistry data plotted in Piper trilinear diagram, and Na^+/Cl^- molar ratio to interpenetrate the groundwater contamination.

3.2.1 Hydrochemical facies and groundwater types

The Piper trilinear diagram (Piper, 1953) is an effective tool in advocating sources of the dissolved constituents and modifications in the characteristics of groundwater as it passes over an area as well as related geochemical processes. The analytical values obtained for the groundwater samples are plotted on Piper trilinear diagram (Todd 1980) are presented in Fig.4. Geochemical evolution of groundwater can be elucidated from the Piper plot, which has been classified into four facies as shown in Fig.4, they are I) Ca-Mg-Cl-SO_4, II) Na-K-Cl-SO_4, III) Na-K-HCO_3, IV) Ca-Mg-HCO_3. From figure 4, it is observed that identified in the study area, 52% of the samples fall into the Ca-Mg-Cl-SO_4 category indicating that water has been changed into saline and hardness might be due to wastewater discharges from industries. Besides, 44% of samples are in Na-K-Cl-SO_4, showing the influence of sodium and chloride. Further, the Piper plot is also divided into six subcategories viz. (1) Ca-HCO_3, (2) Na-Cl, (3) mixed Ca-Na-HCO_3, (4) mixed Ca-Mg-Cl, (5) Ca-Cl type, and (6) Na- HCO_3 to know the groundwater type. In this study region, the majority of the samples are found in mixed Ca-Mg-Cl (52%) implies the predominance of reverse ion exchange such as water containing permanent hardness. Na-Cl type of water is dominant in 44% of samples might be due to an increase in industrial water pollution as the time more new ventures are installed (Eitteieb et al. 2017).

3.2.2 Sodium/chloride (Na^+/Cl^+) ratio

In natural waters presence of sodium ions is due to the atmospheric precipitation, dissolution of evaporating, weathering of silicate minerals, and ion exchange processes (Meybeck, 2004). On the other hand, chloride concentration results from the dissolution of halite (Hounslow, 1995). The Na/Cl molar ratio against EC values is plotted and presented in Fig.5. The ratio of Na/Cl should be approximately equal to 1, whereas if the ratio is greater than 1 is typically related to Na release from silicate weathering attributed due to rock water interaction (Pillai et al. 2020 and Rajesh et al. 2012), according to the equation (7) as given below;

eq. (7)

(Albite) (Silicate weathering) (Kaolinite)

In this study, 32% of samples are succeeding the above process, remaining 68% of samples are fall in Na/Cl ratio equal to or less than 1. Further, it is observed that chloride ion is beyond sodium concentration which might be due to the base exchange processes or anthropogenic pollution (Jones et al., 1999, Srinivasamoorty et al. 2014).

3.3 WQI integrated with GIS

The evaluation of the suitability of groundwater for drinking purposes obtained for each sample through estimating their respective water quality index (WQI). WQI values of groundwater samples of each sampling site are presented in Table 5. The WQI observed range from 40.231 to 393.926. Further groundwater has been classified based on WQI value is shown in Table S2. The classification indicating that 4% of samples are of excellent and 8% of samples are of good category, 56% of samples are falling in the poor category, 28% of samples belong to very poor water, and 4% of samples are of unsuitable for drinking. The sample Nos.3,6,9 and 10 falls under the classification of very poor to unsuitable for drinking type that demonstrates anthropogenic activities influences on groundwater resources. The samples from other locations are poor to very poor class that might be due to point sources of domestic effluents leached into groundwater. The generated knowledge would be helpful to the policymakers for proper management and supply of to the public to protect their health.

Conclusion

Anthropogenic activities and poor effluent management around industrial areas is one of the major cause of pollution of groundwater resources. The study was conducted at Nacharam watershed for water quality assessment based on hydrogeochemical characterization, WQI integrated with GIS techniques. The physicochemical parameters like EC and TH are beyond permissible limits, referring to WHO standards. The spatial distribution of fluoride in groundwater indicates that 96% of samples are beyond the WHO permissible limits, unfit for drinking. From the Piper diagram classification, it concluded that the dominant groundwater type is Mixed Ca^{+2}-Mg^{+2}-Cl^- followed by Na^+-Cl^-. WQI values found that only 4% of samples are excellent, and 8% are of good category, respectively. 56% of samples are of poor category, 28% of samples belong to very poor water and 4% of samples are of unsuitable for drinking. Consequently it indicated that groundwater in the study regions is not suitable for drinking purposes due to anthropogenic activities such as domestic and industrial effluents release. Proper disposal and treatment of urban sewage and effluent before releasing it to the environment should be evaluated with utmost care. The policymakers and NGOs will directly visualize the further spatial distribution of WQI values to treat and supply to the people to protect their health in the study region.

Declarations

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Authors contributions

Rama Mohan Kurakalva: Conceptulization, analysis and manuscript writing and supervison

Sravya Sai Guddeti: Fieldwork, assist in manuscript writing and interpretation of data

Anjana Nath: Fieldwork, Assist in data processing.

Eswara Venkata Ravi Kishore Vemana: Assist in data processing.

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Tables

Table 1: Relative weight assigned for each parameter to compute water quality index

Chemical Parameters	Sn	1/Sn	K	Wn = K/Sn	Ideal Value (Vi)	Observed Value (Vn)	Quality Rating (Qn)	WnQn	WQI
pH	8.5	0.117647	1.187128	0.139662	7	7.9	60.00	8.3797	39.944
EC	1500	0.000667		0.000791	0	460	30.67	0.0243	
TDS	1500	0.000667		0.000791	0	294	19.60	0.0155	
TH	500	0.002		0.002374	0	112.5	22.50	0.0534	
HCO_3^-	150	0.006667		0.007914	0	73.2	48.80	0.3862	
F^-	1.5	0.666667		0.791419	0	0.58	38.67	30.602	
Cl^-	600	0.001667		0.001979	0	76.57	12.76	0.0253	
NO_3^-	45	0.022222		0.026381	0	1.48	3.29	0.0868	
SO_4^{2-}	400	0.0025		0.002968	0	2.79	0.70	0.0021	
Na^+	200	0.005		0.005936	0	104.06	52.03	0.3088	
K^+	200	0.005		0.005936	0	4.08	2.04	0.0121	
Ca^{2+}	200	0.005		0.005936	0	62.02	31.01	0.1841	
Mg^{2+}	150	0.006667		0.007914	0	28.75	19.17	0.1517	
		0.842369		1				40.231	

Table 2: Statistical summary of physicochemical parameters, major ions compared with WHO (2017) permissible limits

Table 3: TDS and TH classification of groundwater of the study area

Water Quality Parameters	WHO permissible limits	Minimum	Maximum	Mean	Standard Deviation	CV (%)	No. of samples exceeding the permissible limit of WHO	% of samples exceeding the Permissible limit of WHO
pH	6.5-8.5	6.0	7.9	6.5	0.4	6.2	Nil	Nil
EC (µS/cm)	500-1500	410	2020	1162.8	404.17	34.8	4	16
TDS (mg/L)	500-1000	262	1293	744	259	34.8	4	Nil
TH (mg/L)	100-500	112.5	558	363.2	120.7	33.2	4	16
HCO_3^- (mg/L)	30-150	73.20	549	264.74	98.49	37.2	22	88
F^- (mg/L)	0.6-1.5	0.58	7.28	3.34	1.58	47.3	24	96
Cl^- (mg/L)	200-600	55.26	1101.31	344.95	218.17	63.2	13	52
NO_3^- (mg/L)	50	0.08	1.48	0.54	0.56	104.1	Nil	Nil
SO_4^{2-} (mg/L)	250	2.79	2374.87	548.22	642.83	117.3	11	44
Na^+ (mg/L)	50-200	30.01	215.01	105.35	50	47.5	1	4
K^+ (mg/L)	200	0.98	18.79	3.46	3.35	96.8	Nil	Nil
Ca^{2+} (mg/L)	75-200	12.22	88.67	47.23	15.69	33.2	Nil	Nil
Mg^{2+} (mg/L)	50-150	6.16	45.11	23.70	11.34	47.9	Nil	Nil

Parameter	Classification	Range(mg/L)	Number of samples	Percentage of samples	References
TDS	Desirable for drinking	<500	4	16	Davis and Dewiest 1966
	Permissible for drinking	500-1000	17	68	
	Useful for Irrigation	1000-3000	4	16	
	Unfit for drinking and irrigation	>3000	Nil	Nil	
TDS	Fresh water	<1000	21	84	Freeze and Cherry 1979
	Slightly saline	1000-10,000	4	16	
	Moderately saline	10,000-1,00,000	Nil	Nil	
	High saline	>1,00,000	Nil	Nil	
TH as $CaCO_3$	Soft	<75	Nil	Nil	Sawyer et al., (2003)
	Moderately high	75-150	1	4	
	Hard	150-300	6	24	
	Very Hard	>300	18	72	

Table 4: Correlation coefficient of physicochemical parameters and major ions

	pH	EC	TDS	HCO_3^-	F^-	Cl^-	NO_3^-	SO_4^-	Na^+	K^+	Ca^{2+}	Mg^{2+}	TH
pH	1.00												
EC	-0.565	1.00											
TDS	-0.565	**1.00**	1.00										
HCO_3^-	-0.701	**0.564**	**0.564**	1.00									
F^-	-0.27	0.193	0.193	0.239	1.00								
Cl^-	-0.324	**0.869**	**0.869**	0.23	0.198	1.00							
NO_3^-	0.401	-0.083	-0.083	-0.137	-0.03	-0.086	1.00						
SO_4^-	-0.273	**0.592**	**0.592**	0.167	-0.12	0.365	-0.023	1.00					
Na^+	-0.087	**0.734**	**0.734**	0.264	0.25	**0.726**	0.24	0.474	1.00				
K^+	0.042	0.344	0.344	-0.008	-0.24	0.289	0.086	0.618	0.451	1.00			
Ca^{2+}	0.273	-0.387	-0.387	-0.328	-0.34	-0.428	0.027	-0.06	-0.185	0.431	1.00		
Mg^{2+}	-0.039	0.19	0.19	0.382	0.247	0.078	-0.007	-0.03	0.375	-0.15	-0.36	1.00	
TH	-0.67	**0.884**	**0.884**	0.648	0.218	0.708	-0.196	0.516	0.409	0.099	-0.55	0.16	1.00

Table 5: WQI value of groundwater at individual sampling stations in Nacharam watershed

.

Figures

Sample ID	Latitude	Longitude	Location	WQI	Water Quality Status
GW01	17.43418	78.55267	Baba Nagar	40.231	Excellent
GW02	17.44317	78.57603	Mallapur	110.258	Poor Water
GW03	17.43901	78.57462	Brahma Colony	278.349	Very Poor Water
GW04	17.42937	78.57841	Devendra Nagar	61.225	Good
GW05	17.41571	78.58538	Boduppal	148.700	Poor Water
GW06	17.40795	78.58811	Mallikarjuna Nagar	243.198	Very Poor Water
GW07	17.39941	78.57285	Sathya Nagar	107.737	Poor Water
GW08	17.41855	78.56616	Hema Nagar	177.910	Poor Water
GW09	17.40903	78.5647	Kaveri Nagar	393.926	Water unsuitable for drinking
GW10	17.40728	78.55948	Uppal Prasanthi Nagar	214.874	Very Poor Water
GW11	17.41758	78.5415	Habsiguda	108.667	Poor Water
GW12	17.42559	78.54808	HMT Bhavani Nagar	142.999	Poor Water
GW13	17.43084	78.53166	Vijayapuri	116.151	Poor Water
GW14	17.43565	78.53957	Shanti Nagar	128.040	Poor Water
GW15	17.44358	78.53724	Prem Vijay Nagar Colony	297.509	Very Poor Water
GW16	17.45397	78.52922	Goutham Nagar	69.512	Good
GW17	17.4424	78.52041	Thukaram Gate	100.523	Poor Water
GW18	17.46467	78.53924	Krupa Complex	193.475	Poor Water
GW19	17.47462	78.53805	New Vidhya Nagar	235.424	Very Poor Water
GW20	17.47869	78.52488	Neredmeti	264.225	Very Poor Water
GW21	17.48761	78.52966	Vivekandapuram	189.008	Poor Water
GW22	17.48682	78.54431	Sainikpuri	182.147	Poor Water
GW23	17.47696	78.55808	A.S Rao Nagar	143.378	Poor Water
GW24	17.46308	78.55901	Eshwar Nagar Colony	262.331	Very Poor Water
GW25	17.45387	78.55421	Musi Nagar	186.521	Poor Water

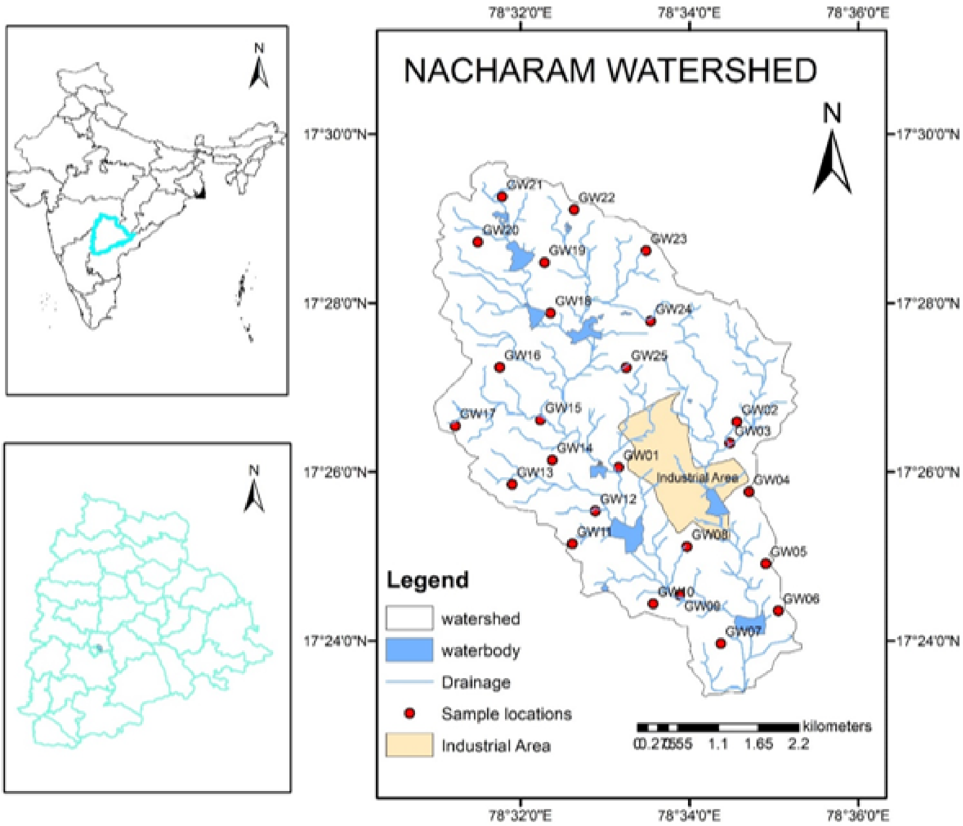


Figure 1

Location map and sampling stations of Nacharam watershed with demarcation of industrial area.

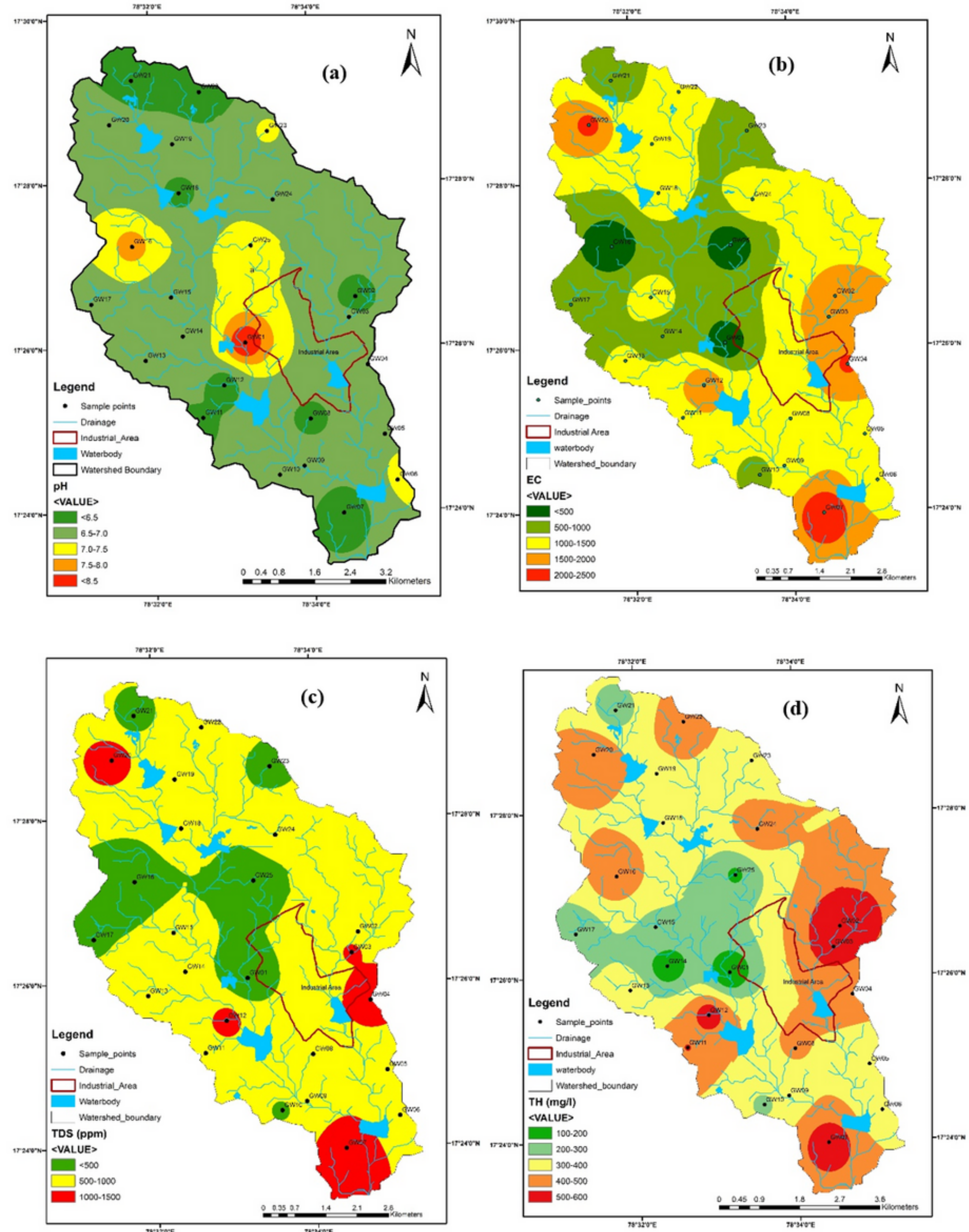


Figure 2

Spatial distribution maps of (a) pH, (b) EC, (c) TDS, and (d) TH in groundwater

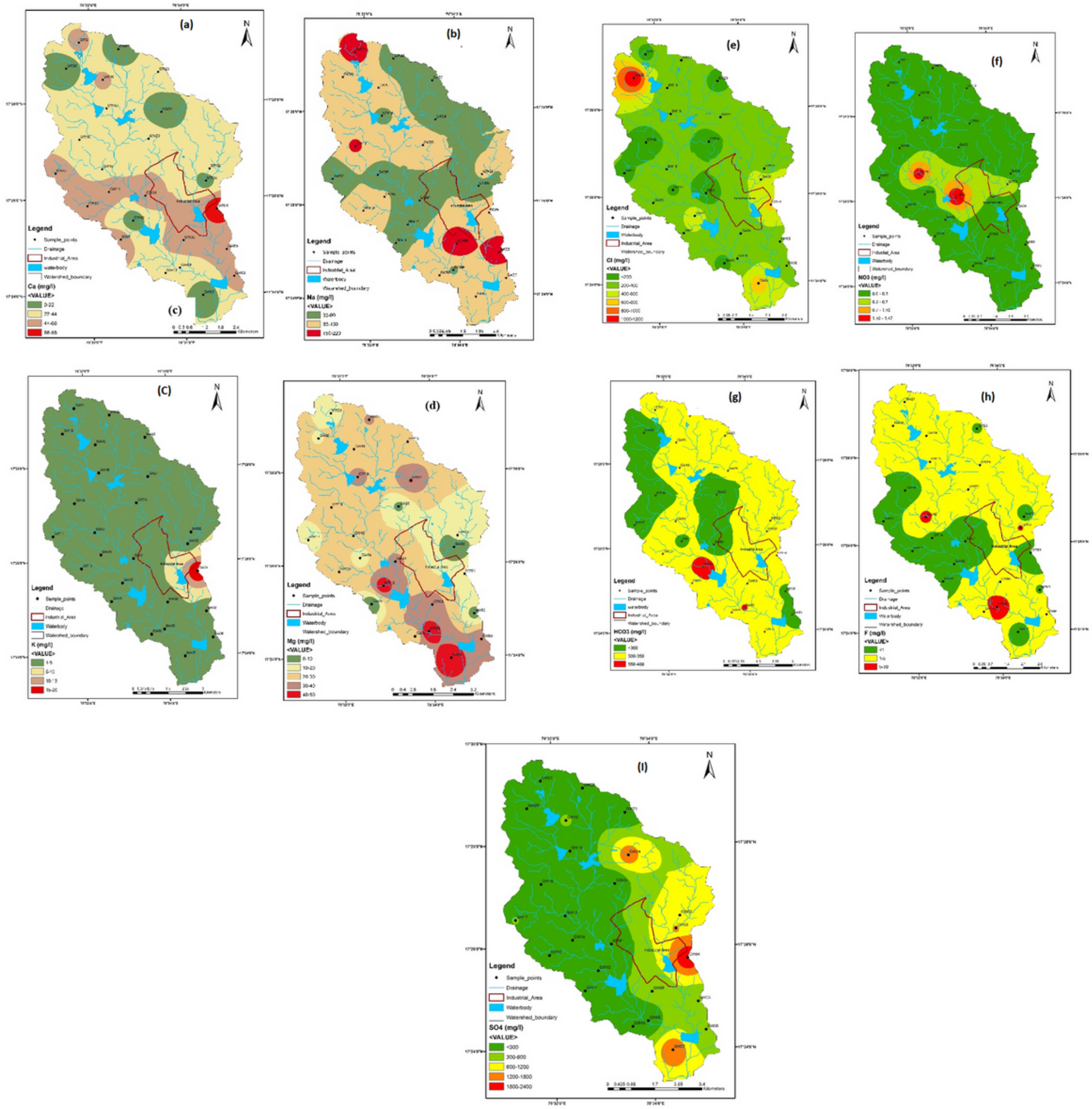


Figure 3

Spatial distribution maps of major cations (a)-(d) and anions (e) – (i) in groundwater

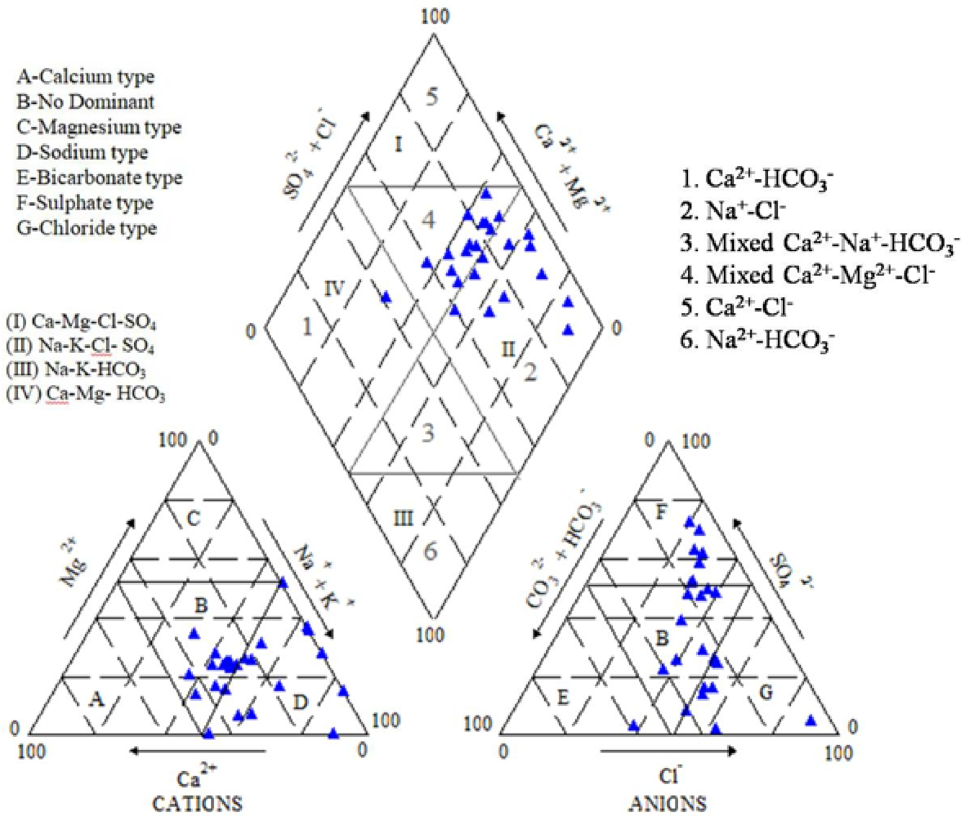
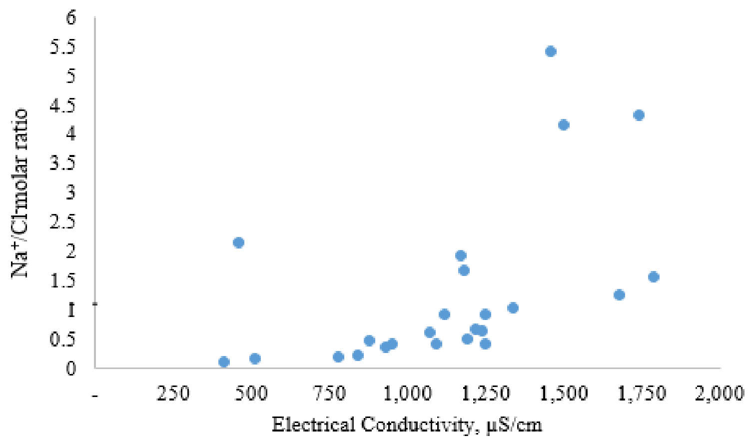


Figure 4

Piper trilinear diagram for groundwater samples from the study area

(a)



(b)

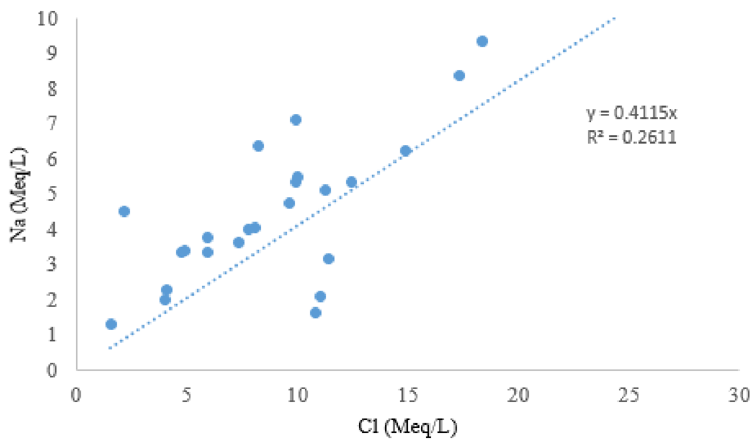
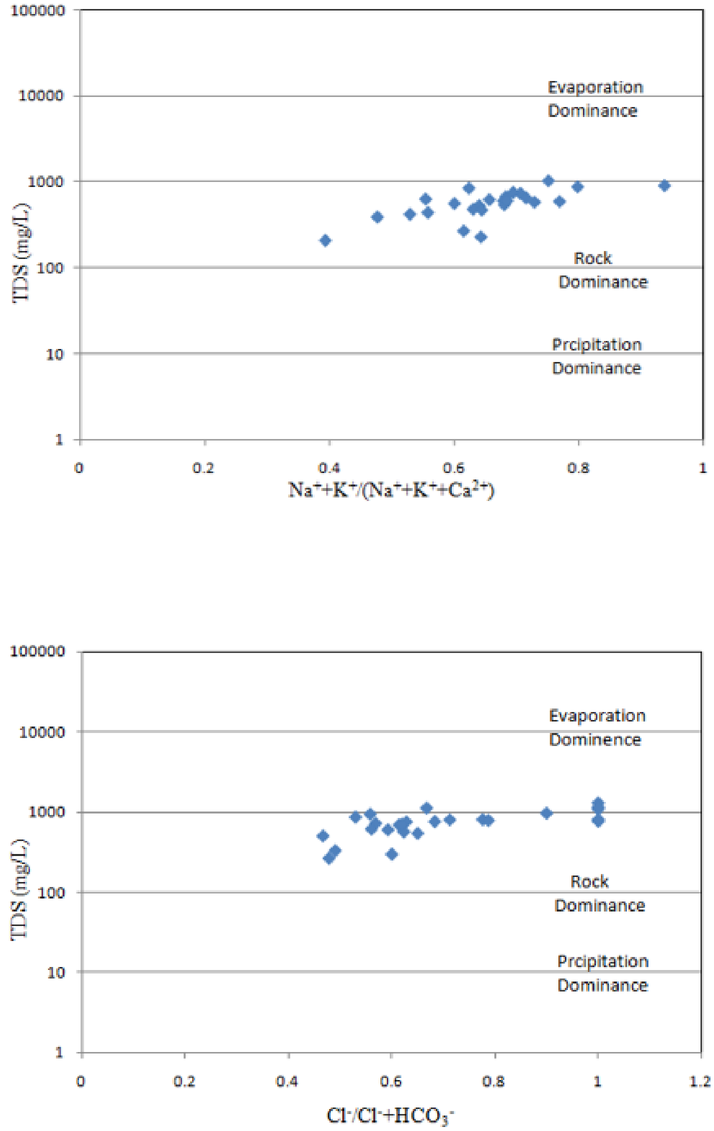


Figure 5

Na+/Cl- ratio plot of groundwater samples from Nacharam watershed

(a)



(b)

Figure 6

Mechanism controlling groundwater chemistry for study area (a) TDS vs. (Cl-)/(Cl- + HCO3-); (b) TDS vs. (Na++K+)/(Na++K++Ca2+)

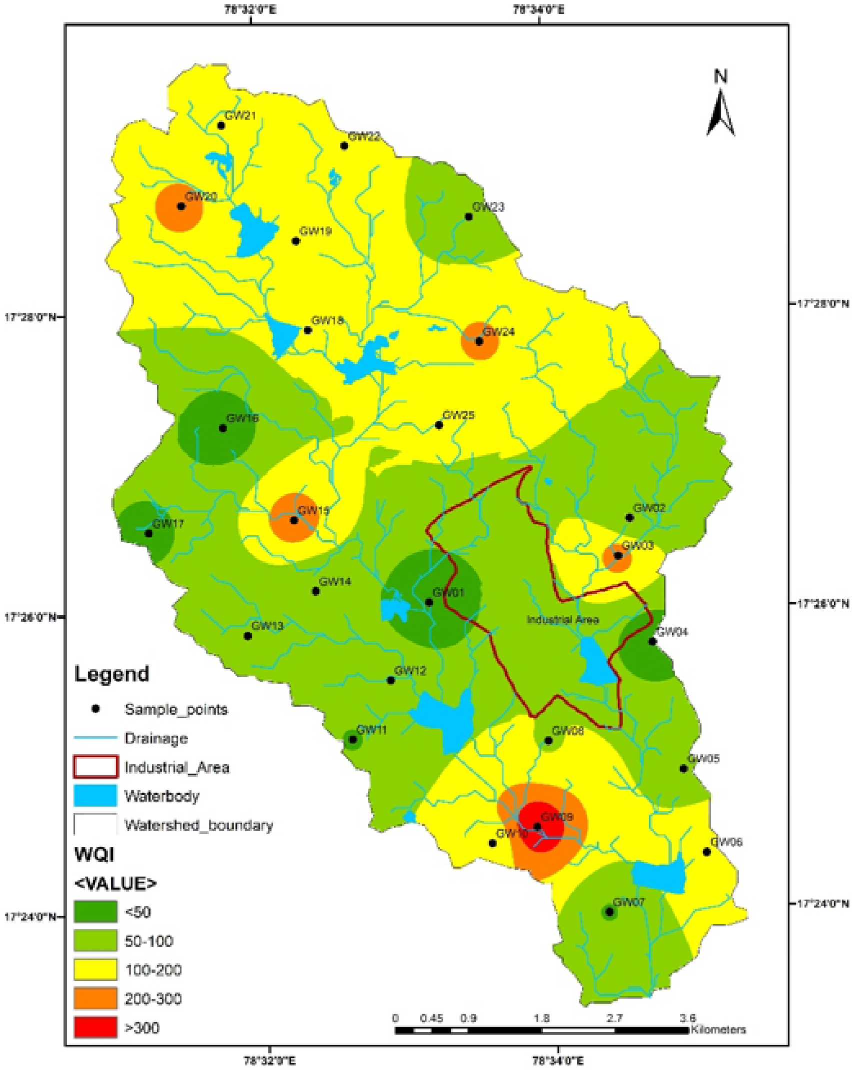


Figure 7

Distribution map of Water Quality Index (WQI) values in Nacharam watershed

Supplementary Files

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- krmsupplementarydata.docx