Sustainability Assessment of the Groundwater Quality in the Khoyrasole Block, Birbhum District, West Bengal to Achieve Rural Water Security

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ABSTRACT

To achieve the goal of water security, particularly in rapidly expanding areas, identification of safe and sustainable water resources is an absolute necessity. The present study conducted an exploratory investigation of the hydrogeochemical characteristics of groundwater and thereby assessed the suitability of groundwater as an alternative and reliable resource for public use in the Khoyrasole block, Birbhum district, India. A total of 15 groundwater samples, collected from bore wells spread well over the Khoyrasole block have been considered.

After the hydrogeochemical analysis, the study evaluated the present state of the groundwater quality and determined the spatial distribution of groundwater quality parameters such as pH, Total Dissolved solids (TDS), Hardness, Calcium, Magnesium, Sodium, Potassium, Iron, Chloride, Carbonate, Bicarbonate, Sulphate, Nitrate and Fluoride. High to very high levels of iron and fluoride have been observed to be present in 67% and53% of the samples respectively.

Based upon the calculated parameters like SAR, MAR, PI and Chloro Alkaline Indices, groundwater of Khoyrasole block is majorly suitable for the purpose of agriculture and irrigation.

Plotting of ionic scatter plots and geochemical facies also indicate the water samples to be of 'fresh water' category, with no dominant cation or anion playing a selectively dominant role in influencing the groundwater chemistry in the region.

Keywords: Water security · Groundwater assessment · Groundwater quality · India

INTRODUCTION

The human race, for its day to day sustenance on mother Earth, makes exhaustive use of all the available vital natural resources. Over the last few decades, exponential growth in population, expansion of urban areas, discovery of cutting edge technology and above all an indifferent attitude of the human race has taken a toll on the environment. Various natural resources available in moderate quantities have already been used up and many more are on the verge of depletion. With no viable option of being able to redeem these naturally available reserves, it is high time we understand the importance of sustainable development and behave accordingly. Amongst the natural resources available, water, undoubtedly is a prime necessity for one and all and is the most sought after in almost all sectors. Water is available to us in more than one form or type such as ice, vapour and water - the last being of two types - saline and fresh water. Of the total amount of global water, only 2.4% is distributed on the main land, of which only a small portion can be utilized as fresh water. The available fresh water to man is hardly 0.3% - 0.5% of the total water available on the earth and therefore, its judicious use is imperative (Ganesh and Kale, 1995). The fresh water is a finite and limited resource (Bouwer, 2000). The utilization of water from ages has led to its over exploitation coupled with the growing population along with improved standard of living as a consequence of technological innovations (Todd, 1995; Raj, 2000). Thus contamination of groundwater is not away from the evils of modernization. As a result, quality of groundwater is deteriorating at a faster pace due to pollution ranging from septic tanks (Olaniya et al., 1977; Gilson et al.,1983), land fill leachates, domestic sewage (Eison et al, 1980; Sharma et al., 1995; Subba Rao et al., 1995) and agricultural run – off / agricultural fields (Banerji, 1983; Handa, 1986; Ramchandra et al., 1991, Datta et al., 1996; Somasekhar et al., 2006) and industrial wastes (Rengaraj et al., 1996). Contamination of groundwater also depends on the geology of the area and it is rapid in hard rock areas especially in limestone regions where extensive cavern systems are below the water table (Singh, 1982). This is a common feature, not only in developed countries but also in developing countries like India. The changes in quality of groundwater response to variation in physical, chemical and biological environments through which it passes (Singh et al., 2003). Groundwater quality is a very sensitive issue and it transcends national boundaries and the present study focuses on the quality and contamination of groundwater, the availability of which is the key to day to day livelihood. Quality of water from groundwater reserves is dynamic in nature as they are affected by various human activities, including the expansion of cultivated and irrigated lands, industrialization, urbanization and others. Due to the fact that it is the largest available source of fresh water lying beneath the ground, not only delineation of groundwater potential zones has become crucial, but also monitoring and conserving this important resource is equally prior. Groundwater is usually clear, colourless and remains relatively at constant temperature, and is therefore normally superior to surface water with regard to sanitary considerations. Utilization of groundwater as drinking water is a large scale practice especially in the semi-urban and rural parts of our country. Although India has made some progress in implementation of potable supply of water but gross disparity still exists in the country in terms of coverage area. A major part of India is comprised of semi – urban and rural areas and in these parts there still exist towns and villages, where well managed water transport systems like piped distribution of water and related infrastructures are either not available or not fully functional. Hence almost 70% of the population in India consumes groundwater for drinking on a daily basis, not by choice but by compulsion (Ek Sparsh Report, 2013).

India is heading towards a freshwater crisis (Rastogi, 1999) mainly due to improper management of water resources and environmental degradation. The outcomes of this crisis are already evident in many parts of India, varying in scale and intensity depending on the time and season of the year (Rakesh et al., 2005). Ground water has higher salt contents than surface waters because slowly moving water remains in contact with substrata for longer period thereby increasing the soluble mineral content in water until a condition of equilibrium is reached. Water being a universal solvent carries minerals in solution which, though present in small quantities, determine its suitability for various purposes. The quantity and composition of dissolved minerals in natural water depend upon the type of rock or soil with which it has been in contact or through which it has passed and the duration it has been in contact with these rocks. Quality of groundwater varies from place to place and from stratum to stratum. It also varies from season to season. The requirement of quality of water for various purposes such as drinking water, industrial water and irrigation water vary widely. In recent years it has been recognized that the quality of groundwater is of nearly equal importance as its quantity (Honarbakhsh et al. 2019 ; Khan & Jhariya 2017). In the present study quality of water w.r.t consumption has been assessed along with determination of hydrogeochemical evolution of parameters.

STUDY AREA

The community development block Khoyrasole (Fig.1) lies in the Suri Sadar sub division of

Birbhum district. The geographical area of the district is 499 sq-kms. The north-western part of the district, particularly Rampurhat - Nalhati blocks, the contours are above 110m - 140m (MSL) while it comes down to 60-70m in eastern and south eastern part around Khoyrasole – Rajnagar – Suri blocks where topography is almost flat. The Lower Gondwana Barakar Formation occurs with pronounced unconformity over the Archeans and has faulted boundaries with Archean comprising leucocratic gneisses at Rajnagar - Khoyrasole. The ground mass comprises pebbly to coarse grained white feldspathic ferrugenous sandstone, grey carbonaceous shale and coal. In Birbhum, groundwater occurs under both water table condition in the near surface aquifers and under confined condition in deeper aquifers. The western part of the district around Khoyrasole, Dubrajpur, Rajnagar and Suri, west of Rampurhat and Nalhati area is underlain by hard rocks, which vary from basaltic (Rajmahal volcanics) rocks in the north and granite, gneisses and schists in the south. The weathered zone of the hard rocks forms the main repository of ground water in the area under study. In the eastern fringe of Khoyrasole, Dubrajpur,

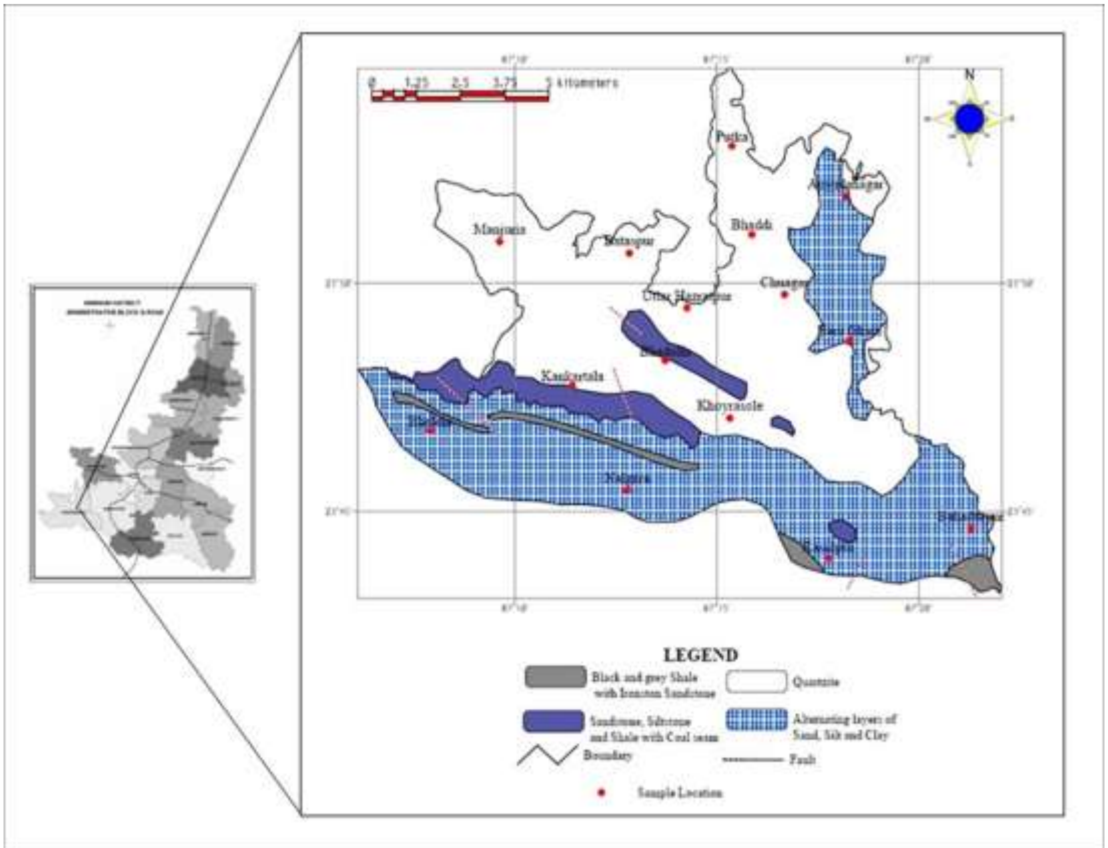


Fig.-1. Map showing study area and locations of sampling points

groundwater source in parts of Suri, Md.Bazar, and further east.

Khoyrasole lies between 23°42' and 23°54' N latitudes and 87°05' and 87°22' E longitudes. This block has been mapped on Topo Sheet nos. 73M/1, 73M/5 and 73M/6 (Fig.1). Three rivers, namely Sal, Hinglo and Ajay pass through this block. Sal flows along the northern side of Khoyrasole whereas Ajay forms the southern boundary of the block. This river also forms the boundary between Birbhum and Bardhaman districts. River Hinglo lies midway between Sal and Ajay. The climate of the area during summer is hot and dry with temperatures soaring to 40° C and above, whereas in winter temperatures fall to 10° C or below. The district, on an overall, experiences moderate to high rainfall during the monsoon season.

METHODOLOGY

The field investigation was carried out during post monsoon period in December 2018 Groundwater samples were collected from 15 bore wells spread homogeneously around the study area. Figure 1 below presents the sampling location map of the study area. The groundwater locations were selected to cover the entire area with due attention in areas expected for contamination.

Parameters like pH, Electrical Conductivity (EC) and Total Dissolved Solids (TDS) of water samples were measured *in situ* using the potable HI 98130 Combo pH / EC / TDS / Temperature meter by Hanna Instruments. Before recording the values, calibrations were done using 4.01, 7.01 and 10.01 buffer solutions for pH and 12.33 mS/cm buffer solution for electrical conductivity readings. Water samples were collected and stored at moderate temperatures before carrying out chemical analysis. Before collection, the bore wells were pumped for a few times and the bottles were rinsed well for 2 – 3 times. Each sample was collected by acid-washed polyethylene 1,000 ml bottle. The bottle was completely filled with water taking care that no air bubble was trapped within the water sample.

To prevent evaporation, the bottles were sealed with the double plastic caps. Precaution was also taken to avoid sample agitation during transfer to the laboratory. The samples were immediately transferred to the laboratory and analysed for major ions by employing standard methods (APHA 1995).

The base map showing locations of investigating points has been prepared using SoI Topo sheets 73 M/1 ,73 M/5 and 73 M/6 of 1:50,000 scale and Satellite imagery (IRS-IB, LISS-II). The GIS based image processing software TNT Mips 2012 has been used to demarcate the boundaries of geological formations and fault lines. Concentrations of cations along with fluoride in water samples were determined with an Atomic Absorption Spectrophotometer with a specific lamp for each of the particular elements. Average values of three replicates were taken for each determination. The flow chart (Fig.2) represents the entire methodology adopted.

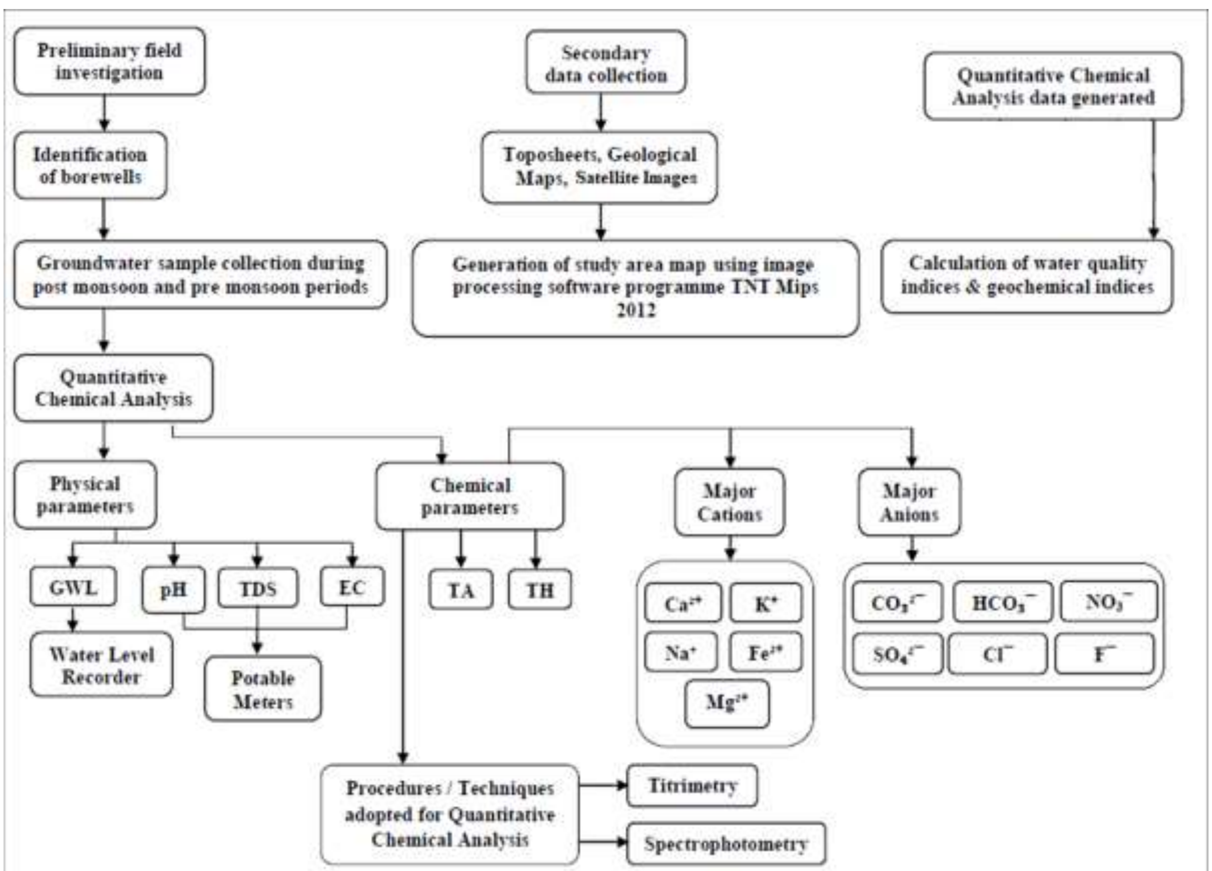


Fig.-2. Flow chart showing the entire methodology adopted.

RESULTS AND DISCUSSIONS

Groundwater Chemistry

For evaluation of the groundwater quality in general the parameters considered for study and evaluated have been presented in Table 1. Table 2 presents the permissible limits of the analysed parameters along with percentage of samples missing the mark regarding the same. Among the parameters tested *in situ* – pH, Electrical Conductivity (EC) and Total Dissolved Solids (TDS) both pH and TDS where found to have minimum, maximum and average values within the desirable/permissible guidelines of WHO. pH ranges from 6.89-7.59 with an average of 7.33 whereas TDS ranges from 221.5-896.6 mg/l with an average of 430.31 mg/l. In case of EC, 3 samples were found to have values beyond the permissible limit but the average value was contained well within the WHO guideline. The cationic abundance in the groundwater of Khoyrasole followed the pattern: $Ca^{2+}>Mg^{2+}>Na^{+}>Fe>K^{+}$. Though the abundance shows average value of iron to be behind three other major cations but almost 67% of the samples (10 out of 15) contain iron way above the permissible limit of 0.3 mg/l. The average value of iron, 3.24 mg/l in groundwater of Khoyrasole is thus almost 10 times above the prescribed limit. The highest concentration of iron in the study area has been found to be 35.8 mg/l which is 100 times the permissible limit and hence is of immense concern. The concentrations of the other cations like calcium (ranging between 18.46-112.3 mg/l with an average of 53.94 mg/l), magnesium (ranging between 10.1-141.57 mg/l with an average of 37.34 mg/l), sodium (ranging between 16.75-65.41 mg/l with an average of 36.46 mg/l) and potassium (ranging between 1-4.65 mg/l with an average of 1.94 mg/l) fall within the WHO limits.

Table 1 Statistical Summary of Physico-chemical Parameters Analysed

Parameters	Min.	Max.	Mean	Median	S D.
pH	6.89	7.59	7.33	7.36	0.22
EC	110	2200	600.67	320.0	593.77
TDS	221.5	896.6	430.31	354.5	195.06
Hardness	121.52	509.6	250.43	219.52	111.56
Ca^{2+}	18.46	112.3	53.94	50.79	28.37
Mg^{2+}	10.1	141.57	37.34	32.3	31.97
Na^{+}	16.75	65.41	36.46	37.83	14.77
K^{+}	1	4.65	1.94	1.53	1.02
Fe^{2+}	<0.02	35.8	3.24	2.8	11.09
Cl^{-}	9.7	190.12	46.82	19.4	55.78
CO_3^{2-}	12.4	28.8	20.14	17.85	4.92
HCO_3^{-}	84.84	398.9	195.9	188.98	85.84
SO_4^{2-}	0.96	24.65	10.95	9.56	7.78
NO_3^{-}	3.29	21.32	11.54	10.77	4.64
F	0.96	4.75	2.04	1.52	1.16

The anionic abundance pattern in groundwater of Khoyrasole is as follows: $HCO^{-}_{3}>Cl^{-}>CO^{2-}_{3}>NO_3^{-}>SO^{2-}_{4}>F^{-}$. In case of the anions as well all the parameters except fluoride have concentrations within the permissible limits of WHO. Bicarbonate and carbonate values, which impart alkalinity to water, range between 84.84-398.9 mg/l with average of 195.9 mg/l and 12.4-28.8 mg/l with an average of 20.14 mg/l respectively. Another vital parameter, chloride, which is also responsible for imparting salinity to groundwater ranges from 9.7-190.12 mg/l with an average of 46.82 mg/l, which is very well below the permissible guidelines of WHO as well as BIS. The sulphate and nitrate concentrations in this study area are found to be of no harm, with values ranging from 0.96-24.65 mg/l with average of 10.95 mg/l and 3.29-21.32 mg/l with an average of 11.54 mg/l respectively. The concentration of fluoride in the groundwater is although a cause of concern as almost 53% of the samples (8 out of 15) contain greater than 1.5 mg/l of fluoride with the highest value going up to 4.75 mg/l, almost thrice of the permissible level.

The various types of physiological damages that can be caused to the human body due to presence of the measured parameters in potable and drinking water beyond the permissible limits and the wide range of damages that are also caused to the piped line distribution systems put in place for supply of stored groundwater have also been shown in Table-2. In the particular study area, people consuming groundwater are thus prone to enhanced bacterial growth and dental fluorosis as both iron and fluoride are present in elevated levels in the water samples analysed.

Hydrogeochemical Evolution

For interpreting and understanding the role of the dominant cations and anions in groundwater

Table 2. WHO/BIS Standards of Analysed Parameters with % of Samples falling within the Limits along with the Physiological and Industrial Effects

Sl. No.	Parameter	WHO Standard		BIS Standard		% of Samples Beyond limit	Effects
		Des.	Per.	Des.	Perm.		
1.	pH	-	6.5-8.5	-	6.5-8.5	0	Bitter taste
2.	EC(µS/cm	500	-	500	1000	13.33	
3.	TDS(mg/l)	-	-	500	2000	0	Gastro-intestinal irritation
4.	Hardness (mg/l)	100	500	300	600	6.67	Scale formation
5.	Ca^{2+}(mg/l)	75	200	75	200	0	Scale formation
6.	Mg^{2+}(mg/l)	50	150	30	100	0	Encrustation in water supply pipelines
7.	Na^{+}(mg/l)	-	200	50	200	0	Scale formation
8.	K^{+}(mg/l)	-	200	-	200	0	Interference with nervous impulses
9.	Fe^{2+}(mg/l)	-	0.1	-	0.3	66.67	Promotes bacterial growth
10.	Cl^{-}(mg/l)	200	600	250	1000	0	Salty taste
11.	CO_3^{2-}(mg/l)	-	-	-	-	-	-
12.	HCO_3^{-}mg/l)			300	600	0	-
13.	SO_4^{2-}	250	400	200	400	0	Laxative effects
14.	NO_3^{-}	-	50	-	45	0	Methanoglobinemia/Blue Baby Syndrome
15.	F	-	1.5	-	1.5	53.33	Dental/Skeletal Fluorosis

several scatter plots have been put to use. Each scatter indicates how the ions involved affect and control the groundwater chemistry. The concentrations of all the ions have been measured in meq/l while plotting these graphs. Table 3 presents the correlation coefficient matrix, bearing the correlation coefficients generated through cross plotting of all the analysed parameters.

The scatter plots 3a and 3b have been plotted using the Ca+Mg against TZ and Na+K against TZ respectively, where TZ is the total of the concentrations of major cations in groundwater. In both plots we can see that the samples fall near the (1:1) equiline. These trends suggest that all the four cations are dominant in the groundwater samples and alter the groundwater chemistry in their own capacity. Khoyrasole

Table 3. Correlation Coefficient Matrix (Presenting the Spearman Coefficients)

	pH	**EC**	**TDS**	**Hardness**	**Ca**	**Mg**	**Na**	**K**	**Fe**	**Cl**	**CO_3**	**HCO_3**	**SO_4**	**NO_3**	**F**
pH	1.00														
EC	0.35	1.00													
TDS	0.25	0.04	1.00												
Hardness	0.12	-0.01	0.94	1.00											
Ca	0.28	0.01	0.94	0.90	1.00										
Mg	-0.60	-0.04	-0.03	0.02	-0.09	1.00									
Na	0.32	0.23	0.81	0.79	0.79	-0.14	1.00								
K	-0.26	0.34	-0.56	-0.43	-0.53	0.03	-0.11	1.00							
Fe	-0.46	-0.11	-0.30	-0.16	-0.27	-0.14	-0.34	0.07	1.00						
Cl	0.16	0.04	0.94	0.91	0.85	0.13	0.81	-0.47	-0.32	1.00					
CO_3	0.26	-0.06	0.38	0.41	0.36	0.03	0.52	0.06	-0.62	0.36	1.00				
HCO_3	0.10	0.08	0.73	0.67	0.65	-0.15	0.47	-0.35	-0.12	0.62	0.32	1.00			
SO_4	0.38	0.13	0.41	0.55	0.55	-0.12	0.39	-0.08	-0.28	0.31	0.45	0.29	1.00		
NO_3	0.07	0.36	-0.48	-0.49	-0.53	-0.17	-0.38	0.30	0.03	-0.41	-0.23	-0.19	-0.20	1.00	
F	0.44	-0.26	-0.27	-0.39	-0.40	-0.40	-0.37	-0.25	-0.13	-0.24	-0.12	-0.29	-0.37	0.24	1.00

being an agriculturally dominant area the presence and prominent dominance of K and Na

is well understood. On the other hand both Ca and Mg, which are sourced from carbonate

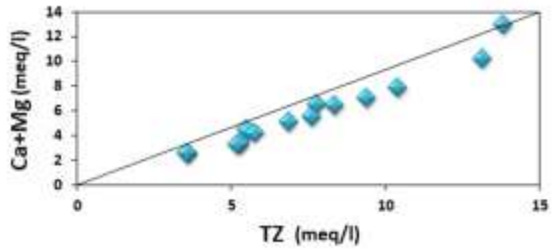
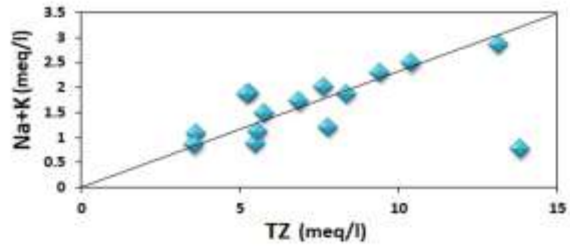


Fig. 3a



Fig, 3b

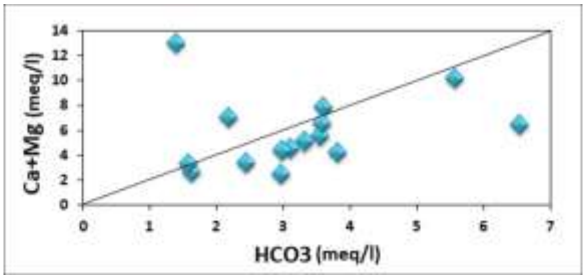
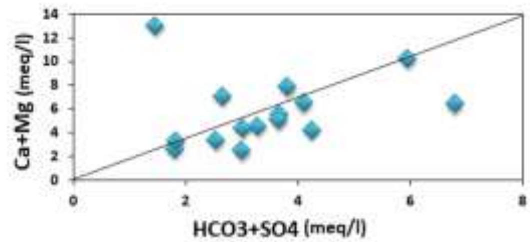


Fig. 3c



Fig, 3d

minerals weathering also, exhibit their presence quite well.

In plots 3c and 3d, HCO^{-}_3 and $HCO^{-}_3 + SO_4^{2-}$ have been plotted against Ca+Mg respectively.

In 3c, the samples fall majorly near the equiline indicating the source of these alkaline earth metals in water is majorly sourced from limestone dissolution. In case of plot 3d similar trends are shown which again reassures the fact that dissolution of Ca and Mg into groundwater is not majorly influenced by other minerals such as muscovite or calcite.

In the next series of scatter plots, both cations and anions have been plotted against each other to determine the dominant processes active in the system and sources of ions into groundwater. Plot 4a, where Na has been plotted against Cl^{-}, all the samples fall above the equiline and mostly towards Na axis indicating that salinization is not a dominant feature in the groundwater chemistry of this particular area, which has also been reflected in low values of chloride in the water samples assessed. Plot 4b, where $Cl^{-} + SO_4^{2-}$ has been plotted against Na+K, majority of the samples fall below the equiline, towards the Na+K axis – indicating that primary salinity processes – such as rainfall and gradual dissolution of minerals are the major sources imparting salinity or alkalinity to the groundwater in the region. In case of plot 4c, where Ca has been plotted against SO_4^{2-}, we can observe that the samples are scattered almost all over the plot indicating that the source of calcium in groundwater is almost equally sourced from gypsum (a common source of calcium and sulphate) as well as other minerals like limestone/calcite etc.

Plot 4d, presenting the scatter plot of TZ against HCO^{-}_3 indicates that the not geogenic and natural reasons are a dominant factor behind controlling the hydrogeochemical evolution of groundwater in the study area.

Plots 5a and 5b, where Ca+Mg and Na+K have been plotted against Cl^{-} respectively, indicate that there is no sign of increased salinity due to secondary salinity procedures in groundwater of the particular study area chosen.

Groundwater Suitability for Irrigation

For evaluation of the groundwater quality with respect to irrigational suitability parameters like SAR (Sodium Absorption Ratio), Permeability Index (PI), Magnesium Absorption Ratio (MAR), %Na, Mg/Ca Ratio and the Chloro Alkaline Indices I/II have been calculated and compared.

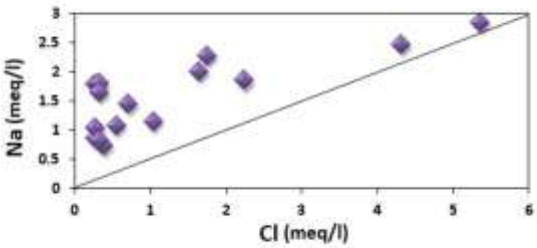


Fig. 4a

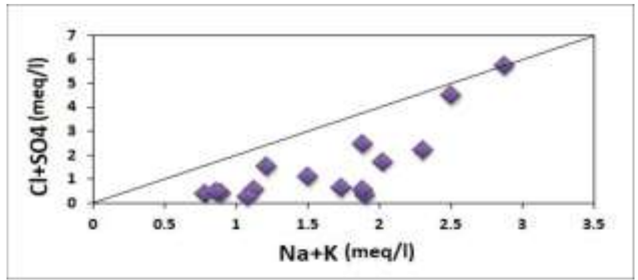


Fig. 4b

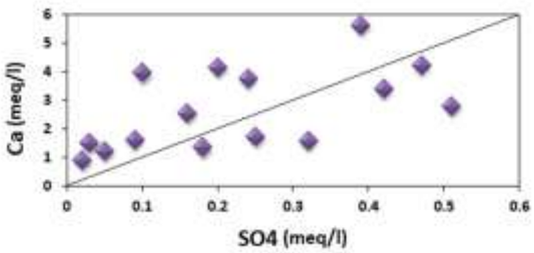


Fig. 4c

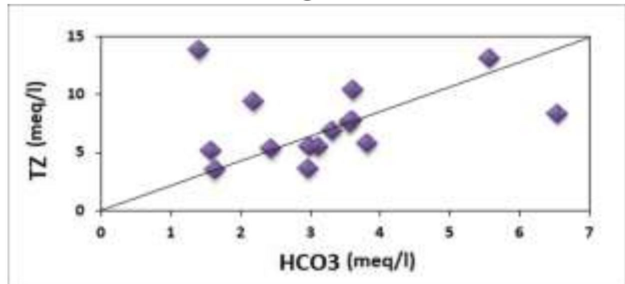


Fig. 4d

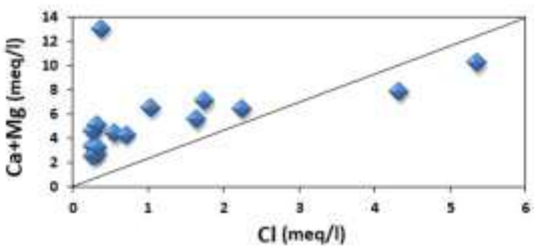


Fig. 5a

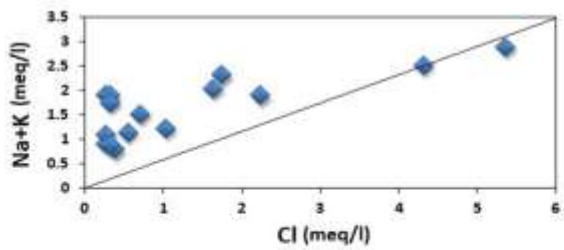


Fig. 5b

When water used for irrigation is high in sodium and low in calcium the ion-exchange complex may become saturated with sodium which destroys the soil structure, due to the dispersion of clay particles (Todd, 1980) and reduces the plant growth. Excess salinity reduces the osmotic activity of plants (Subramani et al., 2005). Sodium percentage exceeding 50% was taken as a warning of sodium hazard. However, in 1954, it was proposed that the sodium percentage is to be replaced by a significant ratio termed the Sodium Adsorption Ratio or SAR because it has a direct relation with the adsorption of sodium by soils (Richards, 1954). The salts, besides affecting the growth of the plants directly, also affect soil structure, permeability and aeration, which indirectly affect plant growth (Singh et al., 2008).

In case of calcium and magnesium, they generally maintain a state of equilibrium in most evolved based on the solubility of salts and the reaction occurring in the soil solution from cation exchange for estimating the quality of agricultural waters (Gupta and Gupta, 1987). Soil permeability is affected by long-term use of irrigation water and is influenced by - (i) Total dissolved solids, (ii) sodium contents and (iii) bicarbonate content.

Chloro – alkaline indices (CAI I and CAI II), commonly known as indices of Base Exchange (Schoeller, 1965; Schoeller, 1977) are used as indicators to determine whether ion exchange or reverse ion exchange takes place in groundwater. When there is an exchange between Na and/or K in groundwater with Mg and/or Ca in the aquifer material, both of the indices are positive, indicating direct ion exchange. When the reverse of this process occurs, the indices have a negative value, indicating reverse ion exchange (Rajmohan and Elango, 2004; Arveti et al., 2011). The equations used for the parameters explained above, have been presented in the block below, where concentrations of all ions are have been expressed in meq/l.

Table 4 presents the range of each calculated parameter in water samples and Table 5 presents their categories, classifications and percentage of samples falling in each category.

Table 4 Statistical Summary of the Calculated Parameters

	Min.	Max.	Mean	Median	S. D.
SAR	0.29	1.4	0.97	1.03	0.33
PI	13.81	76.64	49.63	50.62	14.24
MAR	19.73	90.55	50.21	47.3	18.14
Mg/Ca	0.25	9.58	1.68	0.9	2.35
%Na	5.68	36.2	23.66	24.19	7.66
CAI I	-5.94	0.46	-1.64	-1.06	2
CAI II	-0.61	0.42	-0.13	-0.16	0.26

$SAR = [Na^{+}] / \{([Ca^{2+}] + [Mg^{2+}])\}^{½}$

$PI = Na^{+} + [\{(HCO_3^{-}) / (Ca^{2+}+Mg^{2+}+Na^{+})\}*100]$

$MAR = (Mg^{2+} * 100) / (Ca^{2+} + Mg^{2+})$

$\%Na = [(Na + K) / (Ca + Mg + Na + K)] x100$

$CA1 = [Cl^{-} – (Na + K)] / Cl^{-}$
$CA2 = [Cl^{-} – (Na+K)]/(SO_4^{2-}+HCO_3^{-}+CO_3^{2-}+NO_3^{-})$

Table 5. Classification Levels of Calculated Parameters with % of Samples within Each Category

	Class	Description	% of Samples
SAR	0 – 10	Low sodium hazard – suitable for all soils	100
	10 – 18	Medium sodium hazard – suitable for coarse textured soils	0
	18 – 26	High sodium hazard – generally harmful for most soil types	0
	> 26	Very high sodium hazard – unsuitable	0
PI	<25	Class I	6.67
	25-75	Class II	86.67
	>75	Class III	6.67
MAR	≤ 50	Suitable	66.67
	> 50	Unsuitable	33.33
%Na	<20	Excellent	20
	20 – 40	Good	80
	40 – 60	Permissible	0
	60 – 80	Doubtful	0
	> 80	Unsuitable	0
CAI	Positive	Na & K from water with Ca & Mg in aquifer Matrix	20
	Negative	Ca & Mg from water with Na & K in aquifer Matrix	80

Hydrogeochemical Facies Evolution

For evaluation of the groundwater type and a lateral comparison of the major cations and anions present in the water samples two diagrams have been plotted – Piper Diagram (Fig.6) and the Schoeller Diagram (Fig.7). The Piper plot allows comparisons between a large numbers of samples and it does not portray absolute ion concentrations. The main purpose of this plot is to show clustering of samples and thus determine the major water type prevalent in the study area. In the present study the water samples fall in the Ca-Mg-HCO_3 class of the Piper diagram, thus denoting that the water samples fall in the “fresh water” category.

The Schoeller Diagram presents the concentration of the ions on a single plot using a logarithmic scale on the y-axis. This procedure enables to compare the concentration of each ion in spite of the vast disparity in quantitatively analysed values. The plot indicates that magnesium, sodium and potassium are mostly present in the samples in a similar range whereas the average concentration of calcium is higher than them. Among the anions, sulphate has the lowest values in comparison with chloride and carbonate. The Schoeller diagram pictorially

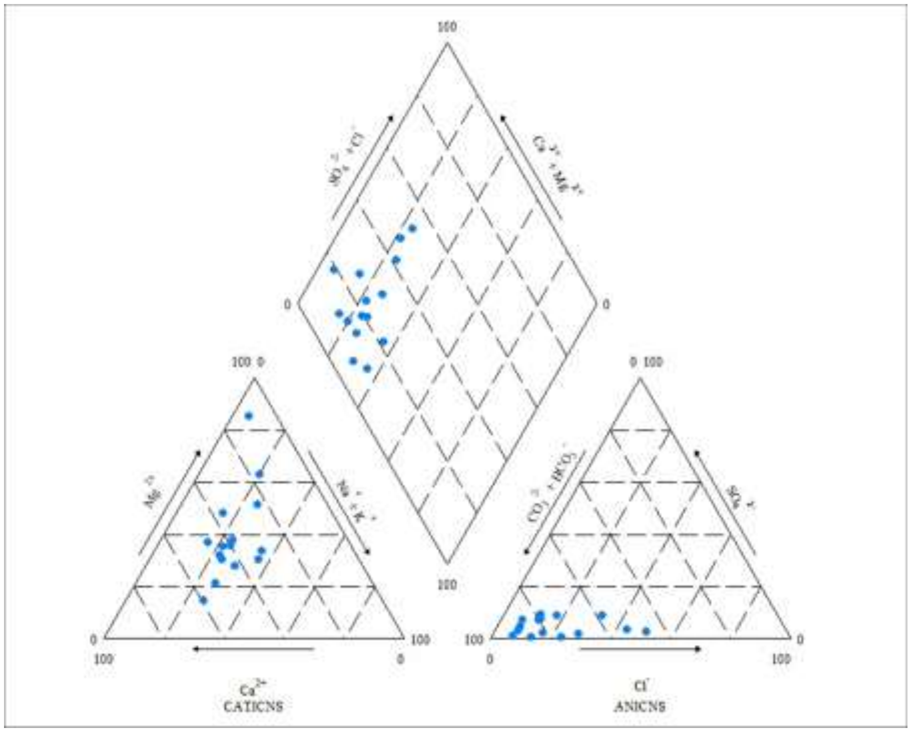


Fig.6. Piper Diagram

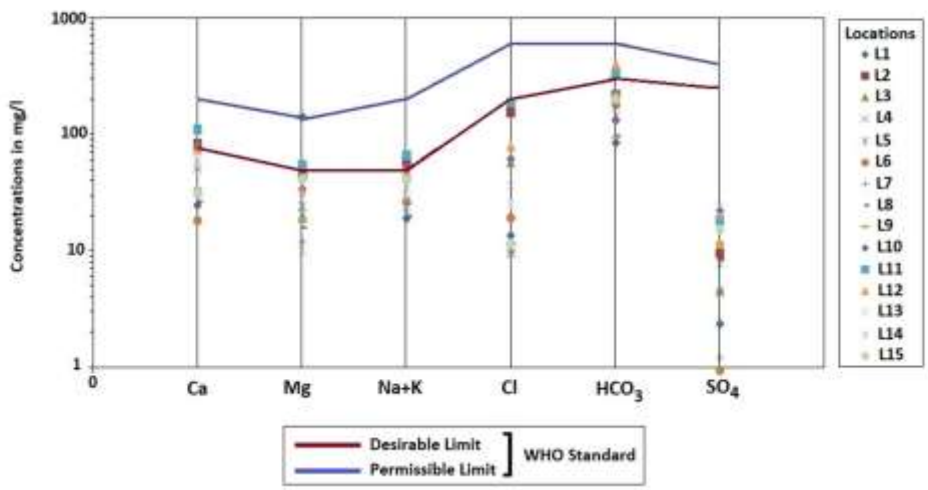


Fig.7. Schoeller Diagram

presents that the parameter concentrations in almost all samples fall within the "desired limit or guideline" set by WHO and BIS.

CONCLUSIONS

From the various parameters analysed and the several factors calculated, it can be concluded that among the ionic concentration levels, two parameters iron and fluoride pose a major and immediate threat to the physiological well being of the residents of Khoyrasole who consume the groundwater directly. Besides these parameters, all other ionic concentrations fall within the permissible limits and pose no threat. Hydrogeochemical studies indicate that nor does any particular ion dominate the groundwater chemistry in this region solely, neither are any anthropogenic and secondary sources responsible for contamination of groundwater. In terms of irrigational suitability, majority of the water samples meet all criterions to be rendered suitable for the same. Only a handful of values indicate that a couple of samples have the potential to render low permeability to the soil in contact. Thus, sustainable management of water is possible in this study area if proper measures are taken to reduce the concentrations of iron and fluoride in groundwater. For both of parameters, domestic level treatment of precipitation and filtering can be adopted. Use of alum as a precipitant in case of iron and lime in case of fluoride can be adopted as immediate mitigation measures.

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REFERENCES

APHA (American Public Health Association) (1995) Standard Methods for Examination of Water and Waste Water. American Public Health Association, American Water Works Association and Water Pollution Control Federation, Washington DC, USA

Arveti, N., Sarma, M.R.S., Aitkenhead-Peterson., J. and Sunil, K. (2011). Fluoride Incidence in groundwater: a case study in Talupula, Andhra Pradesh, India. *Environ Monit Assess*. 172:427–443.

Banerji, A. K., (1983). Importance of Evolving a Management Plan for Groundwater Development in the Calcutta Region of the Bengal Basin in Eastern India. *Proceedings of International Symposium Groundwater Resources and Planning, Koblenz, 28 August-3 September, pp. 4554.*

Bouwer, H. (2000). Integrated Water Management: Emerging Issues and Challenges. *Agricultural Water Management*, 45(3): 217-228.

Datta, N. C. and Sen Gupta, S., (1996). Effect of Artificial Aeration on the Hydrographic Regime of Pesticide Treated Aquatic System. *Journal of Pollution Research*, 15(4): 329-333.

Eison, C. and Anderson, M.P. (1980). The Effects of Urbanization on Groundwater Quality. *Aquifer Contamination and Protection, UNESCO Press*, 378 – 390.

Ek Sparsh Report, 2013, https://eksparsh.wordpress.com/tag/state-wise-groundwater-pollution-scenario/.

Ganesh, R.H. and Kale, Y.S. (1995). Quality of lentic waters of Dharwad district in north Karnataka. Indian *Journal of Environmental Health*, 37(1): 52-56.

Gilson, R.J. and Patment, C.R. (1983). Lake Phosphorous Loading from Septic System by seasonally perched groundwater. *Journal of the Water Pollution Control Federation*, 55(10): 1297 – 1304.

Gupta, S.K., Gupta, I.C. (1987). Management of Saline soils and Water. *Oxford and IBH Publishing Company*, New Delhi, India, 399.

Handa, B.K. (1986). Hydrochemical Zones of India. *Proceedings of Seminar on Groundwater Development, Roorkee*, 439 – 450.

Hem, J.D. (1985). Study and interpretation of the chemical characteristics of natural waters, 3rd edn. *USGS Water Supply Paper*, 2254: 236.

Honarbakhsh, A., Tahmoures, M., Tashayo, B., Mousazadeh, M., Ingram, B. & Ostovari, Y. 2019 GIS-based assessment of groundwater quality for drinking purpose in northern part of Fars Province, Marvdasht. J. Water Supply: Res.T-Aqua 68 (3), 187–196.

Khan, R. and Jhariya, D. 2017 Groundwater quality assessment for drinking purpose in Raipur City, Chhattisgarh using water quality index and geographic information system. J. Geol. Soc. India 90, 69–76.

Kumar, M., Kumari, K., Ramanathan, A.L. and Saxena, R. (2007). A comparative evaluation of groundwater suitability for irrigation and drinking purposes in two intensively cultivated districts of Punjab, India. *Environ Geol,* 53: 553–574.

Olaniya, M.S., and Saxena, K.L. (1977). Groundwater Pollution by Open Refuse Dumps. *Environmental Health*, 19 (3): 176-188.

Raj, I. (2000). Issues and Objectives in Groundwater Quality Monitoring Programme under Hydrology Project. *Proceedings of National Symphony Groundwater Quality Monitoring, Bangalore*, 1-7.

Rajmohan, N. and Elango L. (2004). Identification and evolution of hydrogeochemical processes in the groundwater environment in area of the Palar and Cheyyar River Basins, South India. *Environmental Geology*. 46: 47–61.

Rakesh, K., Singh, R.D. and Sharma, K.D. (2005). Water Resources of India. *Current Science*, 89: 794-811.

Ramachandra, S., Narayanan, A. and Pundarikathan, N. V. (1991). Nitrate and Pesticide Concentrations in Groundwater of Cultivated Areas in North Madras. *Indian Journal of Environmental Health*, 33(4): 421-424.

Rastogi, A.K., **(**1999). Inland Water Resources-India, Vol.-2, M.K.Durgaprasad, P. Sankara Pitchaiah (Eds.), *Discovery Publishing House*, New Delhi (India), 305.

Rengaraj, S., Elampooranan, T., Elango, L. and Ramalingam, V. (1996). Groundwater Quality in Suburban Regions of Madras City, India. *Journal of Pollution Research*, 15(4): 325 – 328.

Richards, L. A. (Ed). (1954). Diagnosis and improvement of saline and alkali soils (p. 160). *USDA Hand Book, No. 60*.

Schoeller, H. (1965). Qualitative evaluation of ground water resources. *Water Resources Series No. 33, UNESCO, Methods and techniques of groundwater investigation and development*: 44–52.

Schoeller, H. (1977). Geochemistry of groundwater. *R. H. Brown, A. A. Konoplyantsev, J. Ineson, V. S. Kovalevsky (Eds.), Paris: UNESCO, Groundwater studies—An international guide for research and practice:* 1–18.

Sharma, H. and Kaur, B.K. (1995). Environmental Chemistry. *Goel Publishing House, Meerut*.

Singh, K.P. (1982). Environmental Effects of Industrialization of Groundwater Resources: A Case Study of Ludhiana Area, Punjab, India. *Proceedings of International Symposium on Soil, Geology and Landform-Impact of Land Uses in Developing Countries, Bangkok, E6.1 – E6.7.*

Singh, M., Kaur, S. and Sooch, S. (2003). Groundwater Pollution – An Overview. *Journal of the Institute of Plumbing and Heating Engineering*, 2: 29 – 31.

Singh, A.K., Mondal, G.C., Kumar, S., Singh, T.B., Tewary, B.K. and Sinha, A. (2008). Major ion chemistry, weathering processes and water quality assessment in upper catchment of Damodar River basin, India. *Environmental Geology*, 54: 745-758.

Somasekhar, R.K., Rameshiah, V. Chethana Suvarna A. (2006). Groundwater Chemistry of Channapatna Taluk (Bangalore Rural District) – Regression and Cluster Analysis. *Journal of Environment and Pollution*, 7(2): 101 – 109.

Subba Rao, C. and Subba Rao, N.V. (1995). Groundwater Quality in a Residential Colony. *Indian Journal of Enironmental Health*, 37(4): 295 - 300.

Subramani, T., Elango, L. and Damodarasamy, S.R. (2005). Groundwater quality and its suitability for drinking and agricultural use in Chithar River Basin, Tamil Nadu, India. *Environ Geol* 47: 1099–1110. Doi:10.1007/s00254-005-1243-0.

Todd, D.K. (1980). Ground Water Hydrogeology. *Wiley International Edition, John Wiley and Sons, Inc., New York.*

Todd, D.K. (1995). Groundwater Development in an Arid Environment. Geoenvironment 2000 Conference, *American Society of Civil Engineers, Reston*, 1429-1449.