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Hydrogeochemical Assessment, Spatial and Temporal Distribution of Groundwater Quality in Handri river basin, Southern India

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ABSTRACT

Groundwater is the most efficient and effective tool in the world for consumptive purposes. The present study was conducted to assess the water quality and the spatial distribution of physicochemical parameters and hydrogeochemical characteristics of groundwater in Kurnool district's Handri river basin. Groundwater samples from 41 sites were collected during pre and post monsoon seasons are analyzed for their physicochemical constituents like pH, EC, TH, TDS, major ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, F^-, Cl^-, HCO_3^-, NO_3^-, SO_4^{2-}). The analytical findings were matched with water standards as approved through the World Health Organization for domestic usage and irrigation suitability. In the study area the groundwater pH is slightly alkaline. The Electrical conductivity, TDS, TH, chloride and concentration of nitrates were beyond the maximum allowable limits where as sodium, potassium and calcium concentrations in most of the groundwater samples are within the desirable limits for the both the seasons. The major hydrochemical facies were identified using Piper's trilinear diagram. This plot showed that most of the samples fall in the field of NaCl, $CaCl_2$ type for both seasons. Parameters like percent sodium (%Na), residual sodium carbonate (RSC), sodium adsorption ratio (SAR), permeability index (PI), and kelly's ratio (KI) implies that majority of samples of groundwater were not ideal for irrigation purpose. The USSL and Wilcox diagrams proposed that most part of groundwater samples belongs to C3-S4, C4-S4 and C3-S1, C4-S1 class, signifying high salinity, low alkali hazards and high salinity, high alkalinity hazard water, mostly unsuitable for irrigation for pre and post monsoon seasons respectively. The present study presumes that greater part of the samples in the study area is unsuitable for domestic and agriculture purposes.

High Lights:

- The predominant hydrochemical facies of groundwater was observed as NaCl, CaCl2 type.
- Groundwater is unsuitable drinking purpose as fluoride and nitrate concentration were exceeded the WHO Limits.
- Various indices calculated for groundwater showed that groundwater is unsuitable for irrigation purposes in both the seasons.

Keywords: Hydrochemistry, Spatial distribution, Groundwater quality, Handri basin, South India.

INTRODUCTION

Groundwater is a very important and valuable natural resource. Out of 2.8% fresh water available on the earth 2% occurs in ice bodies and the remaining 0.8% occurs as surface and ground water. Within it 2/3 occurs as groundwater and remaining 1/3 as surface water [1]. Based upon its availability, use and utilization the resource can be either a reusable or non reusable. It is shows that around 75% ground water is being used for irrigation, 20% for industry and 5% used for domestic purpose [2]. The main source of water supply for domestic, urban and rural areas in India is groundwater due to the scant availability of surface water resources. The major source for supply of surface water is through river, lakes, channels, with its availability limited to particular season, which when available is not safer for drinking due to contamination and other related activities. A general conception is that the groundwater is cleaner and securer from contaminants due soil purification capabilities [3, 4]. Infact the groundwater quality is frequently verified by indication to stipulated drinking water standards set by WHO [5]. The groundwater quality is the result of procedures and their actions that takes place for instance the vapour condenses to water in the atmosphere and released into the aquifer through the soil or ground. Hence, it is important to observe and determine quality and suitability of groundwater for a particular use. The groundwater quality is more discriminating in the areas that are thickly populated and densely industrialized resulting in problems related to groundwater in shallow tube wells[6].

As development progress, geochemical studies give a proper knowledge about viable variations in quality of groundwater [7-9]. The availability of the groundwater for irrigation and domestic purposes is decided by its groundwater geochemistry [10]. For better understanding, the process of controlling factors of groundwater quality, there is need of key technical interventions for groundwater management. This includes control of groundwater pumping to sustainable levels control of discharges to groundwater and managing aquifer recharge in some areas. Especially this is more needful due to the intense effect of groundwater contaminants on were to be evaluated. Therefore it is important to include the information on baseline groundwater quality, pollution trends spatially and temporally and impact on aquifer can be evaluated with suitable degree of confidence [11]. The management of water quality must be useful due to high cost for the treatment of effluent and intricateness to bring awareness among the public to achieve within a short period [12]. Therefore it is proposed to investigate the hydrogeochemical characteristics and groundwater quality factors in and around Handri river basin of Kurnool district Andhra Pradesh.

MATERIALS AND METHODS

Geology of the study area: The study area (i.e Handri river basin) is located between latitudes 15°14'1"N and 15°53'40"N and longitudes 77°20'13" E and 78°9'25"E. The study site areal extent is approximately 3398.54 km^2 and is situated at about 2 km west of Kurnool city, Andhra Pradesh (Fig.1). Kurnool urban agglomeration is the fifth most crowded city in the Kurnool district of Indian state, Andhra Pradesh. The city is located on the banks of the river Tungabhadra. The Handri and Neeva rivers flow through the city. Granite gneisses dominate the majority of the district in the west, while quartzites, shales, and lime stones of the Kadapa and Kurnool group underlie the eastern portion. The new alluvium is limited to large courses in the streams and rivers such as Krishna, Tungabhadra, Gundlakamma and Kuderu.

Climate and rainfall: The atmosphere in this region is tropical with seasonal rainfall. The temperature of this region in sweltering summer is as above as 42°C with minimum temperature being 15°C. In this zone wide variation in contour, substantial greenery, little rainfall and with assortment variety in meteorological parameters were observed. The Kurnool district has an average annual rainfall of about 665 mm which ranges from zero rainfall in the months of January and December to 139.6 mm in September. The year’s wettest months are August and September.

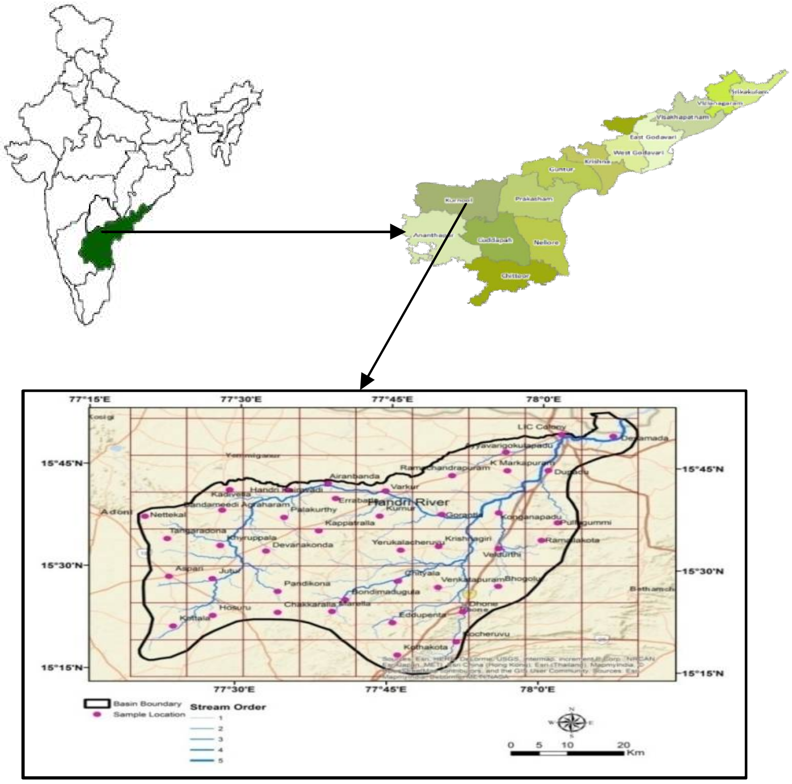


Figure 1. Location map of study area.

The distribution of mean seasonal rainfall is 455.9 mm in south-west monsoon (June-September) and in north-east monsoon (October-December) this is about 133.7 mm. The percentage distribution of rainfall is about 69% in south-west monsoon and 20.1% in north-east [13].

Hydrogeology: The groundwater appears in most of the Kurnool district geological formations. The water exists under confined situations below semi-restricted conditions with shallow weathered zones in joints, fractures and fissures. The occurred joints and fissures stretch up to the depth extending from 20 to 100 mbgl. In Panyam Quartizes arise under confined and semi confined conditions in sheared zones, joint planes and bedding contacts of the weathered area. The intensity of the dug rightly varied from 7-13 mbgl with bores extending down to outmost depth of 15m. The nature of water is and fits for both consumption and irrigation uses [14].

Methodology: In and around the Handri river basin 41 groundwater samples have been collected in the month of July 2017. Using a portable GPS device sampling locations were recorded and they were shown in figure 1. The samples of water are collected in one liter and 100 mL polypropylene (PP) bottles after pumping hand pumps for 10 min. Before the samples collection; the bottle was rinsed with twice and filled totally with water to evade air bubbling. In the same day the collected water samples were delivered to the laboratory. The water samples collected in the field were analyzed for Electric conductivity (EC), Total dissolved solid (TDS), important cations such as sodium, potassium, calcium and magnesium, anions like carbonate, bicarbonate, fluoride, chloride and sulphate implementing the standard methods [15, 16]. As per the ideas of the investigation and the geology the sampling methods were chosen. To determine the strength of the linear relationship between these parameters, various techniques and diagrams were used to calculate the Pearson coefficient to analyze and elucidate the water structure.

Preparation of spatial distribution maps: The base map of the study area was prepared from topographic sheet 56 03 of Survey of India and digitized using software ArcGIS 10.5 (Figure 1). GPS (Garman eTrex 30) was used to show the positions defined for the sampling points, and the appropriate latitudes and longitudes of sampling points were imported into the GIS database for further analysis. The spatial distribution map with the study area's chemical parameters was prepared using extensions of the spatial analyst method to interpolate the weighted (IDB) inverse distance algorithm. The spatial distribution maps were drawn up for different purposes using the global IDW technique.

RESULTS AND DISCUSSION

Physicochemical parameters: Chemistry of groundwater helps to understand the nature of ground water, it is the main factor that decides its suitability for domestic, agricultural and industrial uses [17]. Table 1 was set out physico-chemical parameters with statistical quantities such as minimum, maximum, average, median and mode. The EC values ranged from 750 to 8430 µS cm^{-1} (Avg: 2631 µS cm^{-1}) and 100 to 6010µS cm^{-1} (Avg: 2578 µS cm^{-1}), respectively, during pre and post-monsoon times. At the sampling sites (sample no: K2, K3, K8, K20, K22, K32, K33, K37) the higher EC values in both seasons could be attributed to high mineral content and high salinity. It also dependent upon concentration, temperature, and nature of ions present in groundwater and also on the TDS concentration. The pH values for groundwater ranged from 6.85-8.25 (Avg: 7.35) and 6.9-8.7 (Avg: 7.64) in pre- and post-monsoon periods, indicating that groundwater is alkaline in nature, respectively. TDS values ranged from 487- 5479 mg L^{-1} (Avg: 3672 mg L^{-1}) and 390-3010 mg L^{-1} (Avg: 1343 mg L^{-1}), respectively, for pre- and post-monsoon seasons. The greater differences in TDS between two seasons can be attributed to geochemical process variation and anthropogenic activities [18, 19].

Table 1. Statistical Summary of the analytical data

Water quality constituents	Premonsoon					Postmonsoon				
	Min Conc.	Max Conc.	Avg	Median	Mode	Min Conc.	Max Conc.	Avg	Median	Mode
pH	6.9	8.7	7.6	7.7	7.8	6.85	8.1	7.3	7.24	7.24
EC (µS cm^{-1})	750	8430	2536	1870	1760	100	6010	2601.2	2495	#N/A
TDS (mg L^{-1})	487.5	5479.5	1648.4	1215.5	1144	390	3010	1338.7	1300	580
F^- (mg L^{-1})	0.15	3.8	1.2	1.1	0.65	4.56	0.1	1.1	1.0	1.216
Cl^- (mg L^{-1})	20.9	2488.5	527.1	358.1	#N/A	30.75	2327.9	651.4	545.9	#N/A
NO_3^- (mg L^{-1})	1.4	1609.7	312.9	197.4	#N/A	0.17	754.9	270.7	166.0	#N/A
SO_4^{2-} (mg L^{-1})	0.0	1.5	0.1	0.0	0.0	0.00	13.2	0.3	0.0	0.0
HCO_3^- (mg L^{-1})	20	635.0	365.4	325.0	325	157.50	1354.5	425.0	388.5	388
Na^+ (mg L^{-1})	0.0	296.2	59.6	13.4	0.0	0.00	258.0	58.0	0.00	0
K^+ (mg L^{-1})	0.0	168.3	21.5	4.7	0.0	0.00	493.6	82.9	13.6	#NA
Ca^{2+} (mg L^{-1})	0.0	235.9	40.4	0.0	0.0	0.00	76.1	21.0	0.0	0.0
Mg^{2+} (mg L^{-1})	0.0	24.6	1.05	0.0	0.0	0.00	40.2	12.3	0.0	0.0
TH (mg L^{-1})	80	1830	610.9	540.0	350	175	1550	770.7	710	1470
TA (mg L^{-1})	20	635	370.3	325	325	173.2	1501.5	468.5	451.5	619.5
SAR(meq)	0.0	12.5	2.64	0.0	0.0	0.00	10.01	5.852	0.0	0.0
RSC(meq)	-3.6	9.4	4.1	4.5	6.9	-2.311	22.5	5.66	5.0	#NA
PI(%)	15.62	946.	596	50.0	#NA	0.645	1.95	1.10	1.0	#NA
Kellys ratio	0	5.10	0.86	0.0	0.0	0.0	6.4	1.08	0.04	0.0

Not applicable

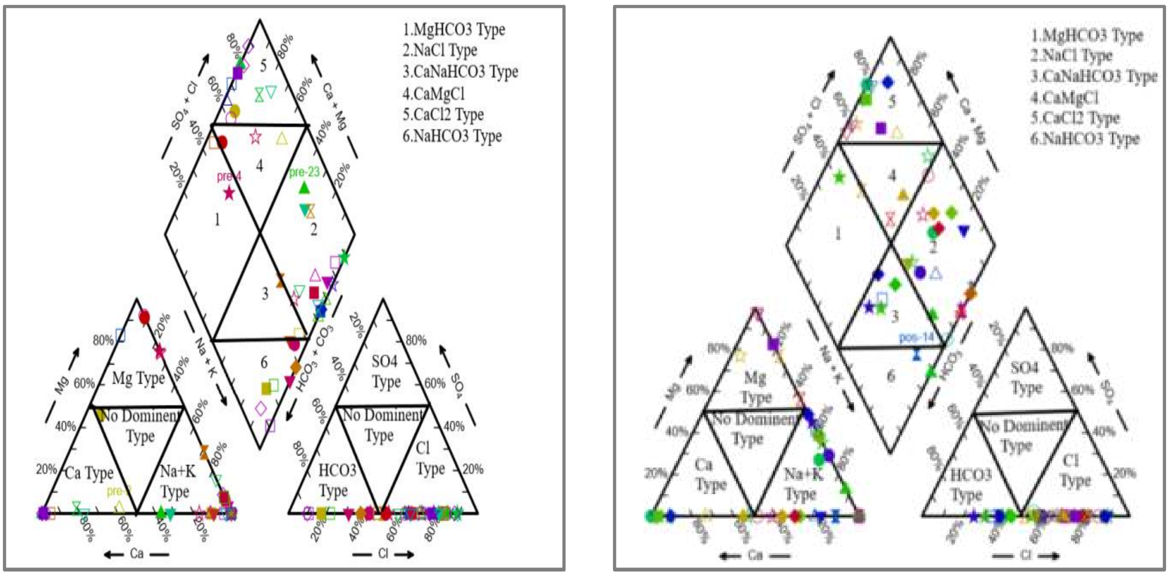
Hydrogeochemical process

Hydrochemical facies: Piper diagrams are generally used by plotting concentrations of cations and anions in groundwater on a trilinear diagram to analyze the geochemical evolution and hydrochemical characteristics. It was originally planned by Hill (1940) and later developed by piper (1944) [20-22]. The concentrations of major cations and anions in percent milli-equivalents are plotted in triangular plots of piper diagram. Further the concentrations of cations and anions for each sample are assigned into the central diamond shaped plot from which conclusions are drawn based on hydrochemical facies concept. The groundwater is divided into 6 facies based on the chemical analytical study (Figure 2). From the pre- and postmonsoon season plots (Figure 2) it shows that monovalent cations

(Na^+ and K^+) dominate over divalent cations (Ca^{2+} and Mg^{2+}). Among anions Cl^- shows dominance over other anions HCO_3^- and SO_4^{2}. The plot for the two seasons imply that groundwater is largely of NaCl (41.4%), $CaCl_2$(24.3%) and $NaHCO_3$ (19.5%) type for pre-monsoon and NaCl(53.6%), $CaCl_2$(21.9%) and $CaNaHCO_3$(9.7%)type for period of post monsoon respectively. In the study area the identification NaCl water type in both the season may be due to high concentration of total dissolved solids and electrical conductance. It water type is represented as the brackish. The higher concentrations of sodium (Na^+) and chloride (Cl^-) has derived from different sources such as deposits evaporated, highly enriched salts in the study area.

Table 2. Groundwater Hydrogeochemical facies

S. No	Facies	Premonsoon			Postmonsoon		
		Sample numbers	**No of samples**	**% of samples**	**Sample numbers**	**No of samples**	**% of samples**
1	$MgHCO_3$	1, 4	2	4.87	21, 28, 31	3	7.30
2	NaCl	5, 6, 11, 15, 19, 20, 23, 24, 25, 26, 28, 31, 33, 36, 39, 40, 41	17	41.46	1, 3, 5, 6, 7, 8, 9, 11, 13, 15, 19, 20, 22, 24, 26, 29, 32, 33, 34, 36, 40, 41	22	53.65
3	$CaNaHCO_3$	5	1	2.43	12, 16, 35, 38	4	9.75
4	CaMgCl	2, 13, 30	3	7.30	4	1	2.43
5	$CaCl_2$	3, 8, 10, 14, 17, 18, 21, 22, 32, 37	10	24.39	2, 10, 17, 18, 23, 25, 30, 37, 39	9	21.95
6	$NaHCO_3$	7, 9, 12, 16, 27, 34, 35, 38	8	19.51	14, 27	2	4.87
	Total		41			41	



Pre-monsoon Post-monsoon

Figure 2. Piper diagram showing hydro-geochemical characteristics of groundwater collected during pre and post-monsoon seasons from Handri river basin.

Correlation matrix: Correlation among the different parameters of groundwater of Handri river basin illustrated the positive and negative relationship involving the various parameters, a few somewhat correlated and a few were not correlated (Table 3). It has been observed the highest positive correlation. between these parameters: EC and TDS (1.00); TH and TDS (0.81); TH and EC (0.81); Cl and TDS (0.93); Cl and EC (0.93); Cl and TH (0.89), CO3 and TDS (0.65), CO3 and EC

(0.65), Ca and TDS (0.65); Ca and EC (0.65); Ca and Cl (0.60); NO3 and TH(0.67) respectively for pre-monsoon and EC and TDS (0.97); Cl and TDS (0.83); Cl and EC (0.84); Ca and TH (0.73); Ca and Cl (0.68) respectively for post-monsoon period. The strong differences between those parameters suggest that the primary water-rock interaction occurring in the aquifer may be the dissolution of carbonates. The high EC and TDS values suggest the significant penetration of salt into groundwater. Generally, the principal chemical elements present in the handri basin system's groundwater are linked to the study area's dolomitic rocks.

Table. 3. Correlation coefficient between different soluble ions in groundwater

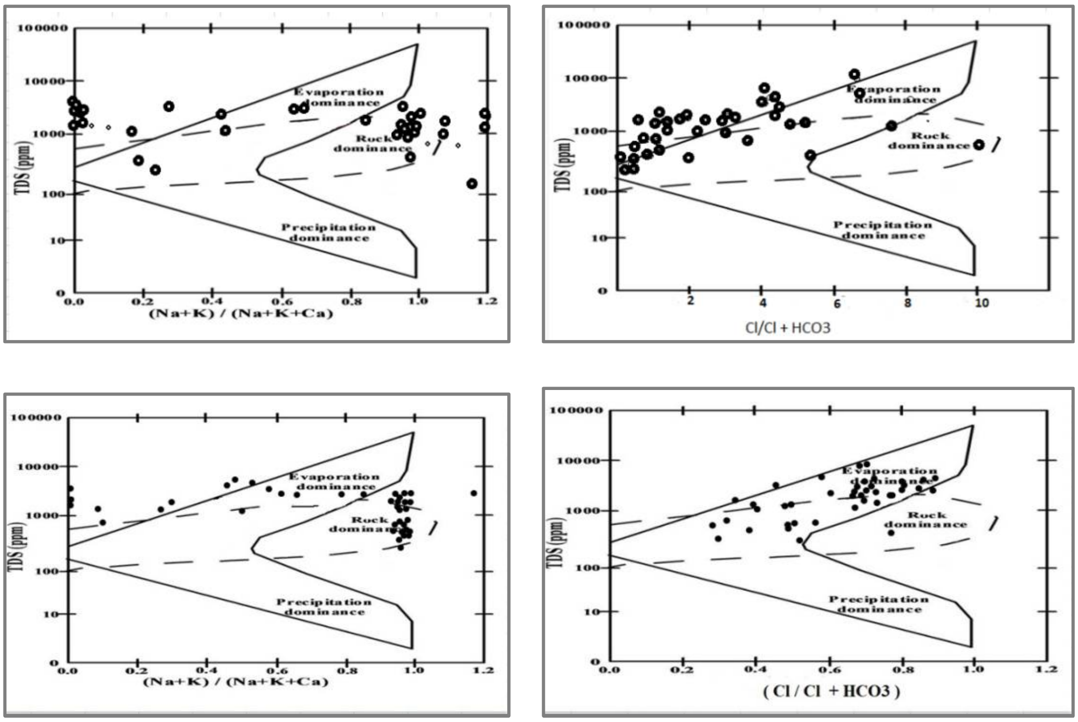
Parameters	pH	TDS	EC	TH	F-	Cl-	NO_3^-	SO_4^{2-}	HCO^{3-}	CO_3^-	Na^+	K^+	Ca^{2+}	Mg^{2+}
						Pre-monsoon								
pH	1.00													
TDS	-0.12	1.00												
EC	-0.12	1.00	1.00											
TH	-0.29	0.81	0.81	1.00										
F-	0.04	0.22	0.22	0.11	1.00									
Cl-	-0.21	0.93	0.93	0.89	0.26	1.00								
NO3-	-0.22	0.57	0.57	0.67	0.20	0.67	1.00							
SO42-	-0.35	0.40	0.40	0.36	-0.12	0.37	0.04	1.00						
HCO3-	0.39	0.03	0.03	-0.06	0.13	-0.08	-0.16	-0.11	1.00					
CO3-	-0.26	0.65	0.65	0.48	0.43	0.64	0.47	0.19	-0.05	1.00				
Na+	0.18	-0.23	-0.23	-0.16	-0.42	-0.26	-0.02	-0.22	-0.17	-0.42	1.00			
K+	-0.18	0.23	0.23	0.19	-0.06	0.29	-0.16	0.34	-0.13	0.23	0.08	1.00		
Ca2+	-0.04	0.65	0.65	0.66	0.18	0.60	0.32	0.21	0.38	0.40	-0.10	0.09	1.00	
Mg2+	-0.16	-0.19	-0.19	-0.24	-0.20	-0.17	-0.14	0.00	-0.07	-0.25	0.07	-0.10	-0.12	1.00
						Post-monsoon								
pH	1.00													
TDS	-0.36	1.00												
EC	-0.38	0.97	1.00											
TH	-0.41	0.63	0.64	1.00										
F-	0.18	0.23	0.21	0.03	1.00									
Cl-	-0.32	0.83	0.84	0.61	0.03	1.00								
NO3-	-0.13	0.05	0.08	0.23	-0.06	0.01	1.00							
SO42-	0.40	-0.12	-0.12	0.01	0.01	-0.13	0.09	1.00						
HCO3-	-0.27	0.37	0.39	0.23	0.21	0.26	-0.02	-0.09	1.00					
CO3-	0.34	-0.03	-0.07	-0.44	0.33	-0.01	0.10	-0.11	0.10	1.00				
Na+	-0.15	-0.40	-0.36	-0.09	-0.33	-0.37	-0.09	-0.01	0.09	-0.21	1.00			
K+	-0.22	0.38	0.40	-0.04	-0.12	0.36	0.13	-0.09	0.27	0.32	0.08	1.00		
Ca2+	-0.28	0.56	0.58	0.73	0.09	0.68	0.27	-0.13	0.38	-0.12	-0.28	0.08	1.00	
Mg2+	0.52	-0.44	-0.48	-0.60	0.20	-0.53	-0.30	-0.12	-0.33	0.28	-0.06	-0.26	-0.56	1.00

Gibbs Diagram: Gibbs diagram is a significant way for explaining the methods managing the groundwater composition and aquifer lithological physiognomies (Gibbs, 1970) [**23, 24**]. The Gibbs ratio 1 and ratio 2 are determined using the equation as follows:

$$\text{Gibbs ratio 1(Cations)} = \frac{Na^{+} + K^{+}}{Na^{+} + K^{+} + Ca^{2+}}$$

$$\text{Gibbs ratio 2(Anions)} = \frac{Cl^{-}}{Cl^{-} + HCO3^{-}}$$

In Gibbs diagram, ratio for cations (Gibbs ratio 1) and anions (Gibbs ratio 2) of groundwater samples are discretely plotted against TDS values (Figure 3). In the Gibbs diagrams three types of distinctive fields are predicted, i.e. precipitation dominance, evaporation dominance and rock dominance. The Gibbs ratio 1 and 2 varied from 0.00-1.20 (avg: 0.36) and 0.09 - 0.89 (avg: 0.39) for pre-monsoon and 0.00-1.00 (avg: 0.75) and 0.25-0.89 (avg: 0.63) for post monsoon periods respectively. The plotting outlines indicate that rock weathering is the main motivating factor affecting groundwater chemistry in Handri basin region with marginal atmospheric precipitation influence. The rock weathering is the product of chemistry between the groundwater and aquifer material [**25**].



Pre-monsoon Post-monsoon

Figure 3. Gibbs plots showing different mechanisms which control the groundwater composition in Handri basin for pre and post-monsoon

Drinking water quality: The findings obtained from physico-chemical analyses of groundwater samples for pre- and post-monsoon seasons were compared with normal values recommended for drinking and public health purposes by WHO standards (1993) (Table 4). The table reveals the most suitable and highest allowable ranges with various parameters are .The cationic concentration (i.e., K+, Na+, Ca^{2+}) for pre and post monsoon season specifies that 29.2%, 7.3%, 9.7% and 48.7%, 7.3% of samples are beyond the WHO allowable limits. The anionic concentration (i.e., F^-, Cl^-, NO_3^-, SO_4^{2-}) for pre and post monsoon periods indicates that 26.8%, 31.7%, 85.3 % ,19.5 and 48.7%,75.6%,0% of samples exceeds the WHO permissible limits.

Table 4. standards of drinking water quality

Water quality parameters	WHO(1993)		Pre monsoon		Post monsoon		Undesirable effects
	Maximum desirable limits	Maximum allowable limits	No of samples exceeding allowable limits	% of samples exceeding allowable limits	No of samples exceeding allowable limits	% of samples exceeding allowable limits	
pH	6.5-8.5	9.2	NIL	NIL	NIL	NIL	Taste
EC(μS cm^{-1})	750	1500	27	65.85	13	31.71	-
TDS (mg L^{-1})	500	1500	17	41.46	15	36.58	Gastrointestinal irritation
TH (mg L^{-1})	100	500	22	53.65	38	92.68	
Ca^{2+} (mg L^{-1})	75	200	4	9.76	NIL	NIL	Scale formation
Mg^{2+} (mg L^{-1})	50	150	NIL	NIL	NIL	NIL	
K^+ (mg L^{-1})	-	12	12	29.26	20	48.78	Bitter taste
Na^+ (mg L^{-1})	-	200	3	7.32	3	7.32	
Cl^- (mg L^{-1})	200	600	13	31.71	20	48.78	Salty taste
NO_3^- (mg L^{-1})	45	-	35	85.36	31	75.61	Bluebaby syndrome
SO_4^{2-} (mg L^{-1})	200	400	NIL	NIL	NIL	NIL	Laxative effect
F^- (mg L^{-1})	-	1.5	11	26.82	8	19.51	Fluorosis

Electrical conductivity: The classification of groundwater samples for pre- and post-monsoon periods based on electrical conductivity is given in table 5. The samples with 36% and 29% are within the permissible limits, where as 41.4% and 31.71% samples are not within the permissible limits for pre and post monsoon respectively. It signifies poor in quality. Only 10 and 36.5% of samples are classified as hazardous according WHO prescribed standards. The hazardous quality could be due to leaching in the study area from municipal landfill, effluent from private and municipal septic systems and chemicals used in agriculture. EC 's spatial distribution map in the study area is shown in figure 4 (c, d).

Table 5. Classification of groundwater based on electrical conductivity

Electrical conductivity	Classification	Pre monsoon			Post monsoon		
		Sample numbers	No of samples	% of samples	Sample numbers	No of samples	%of samples
<1,500	Permissible	4, 7, 9, 12, 16, 19, 26, 27, 29, 30, 34, 35, 36, 38	14	34.14	4, 6, 12, 16, 19, 26, 27, 29, 30, 31, 35, 36, 38	13	31.71
1500-3000	Not permissible	1, 5, 6, 10, 11, 13, 15, 17, 18, 21, 23, 24, 25, 28, 31, 40, 41	17	41.46	1, 5, 9, 14, 15, 18, 21, 24, 28, 34, 39 ,40, 41	13	31.71
>3000	Hazardous	2, 3, 8, 14, 20, 22, 32, 33, 37, 39	10	24.40	2, 3, 7, 8, 10, 11, 13, 17, 20, 22, 23, 25, 32, 33, 37	15	36.58
Total			41	100		41	100

Total dissolved solids: In order to determine the suitability of groundwater for different purposes, it is important to classify groundwater based on its hydrochemical properties in relation to the TDS values [26, 27] as shown in table 6 and 7 respectively. 36.5 and 34.1 per cent of groundwater samples are saline types and the remaining samples belong to pre and post monsoon brackish water types based on freezing and cherry classification(1979) respectively for pre and post monsoon period. The study indicates that only 9.7 and 14.6 percent of samples are below 500 mg L^{-1} of TDS for the pre- and post-monsoon seasons, which enables them to be used for drinking purposes without any treatment. The spatial distribution map of TDS for the groundwater sample area is given in figure 4(e, f).

Table 6. Groundwater classification based on Total dissolved solids (Davis and Dewiest 1966)

Total dissolved solids(mg L^{-1})	Classification	Pre monsoon			Post monsoon		
		Sample numbers	No of samples	% of samples	Sample numbers	No of samples	% of samples
<500	Desirables for drinking	4, 7, 34, 38	4	9.76	4, 16, 31, 35, 36, 38	6	14.63
500-1000	Permissible for drinking	9, 12, 13, 16, 19, 26, 27, 29, 30, 35, 36	11	26.83	6, 12, 19, 21, 27, 28, 29, 34, 40	9	21.95
1000-3000	Useful for irrigation	1, 2, 5, 6, 8, 10, 11, 14, 15, 17, 18, 20, 21, 23, 24, 25, 28, 31, 39 ,40, 41	21	51.22	1, 2, 3, 5, 7, 8, 9, 10, 11, 13, 14, 15, 17, 18, 22, 23, 24, 25, 30, 32, 33, 37, 39, 41	25	60.98
>3000	Unfit for drinking and irrigation	3, 22, 32, 33, 37	5	12.19	20	1	2.44
Total			41	100		41	100

Table 7. Classification of groundwater based on Total dissolved solids (Freeze and Cherry 1979)

Total dissolved solids(mg L^{-1})	Classification	Pre-monsoon			Post-monsoon		
		Sample number	No of samples	% of samples	Sample number	No. of samples	% of samples
<1000	Fresh water type	4, 7, 9, 12, 13, 16, 19, 26, 27, 29, 30, 34, 35, 36, 38	15	36.58	4,6,12,16,19,21, 26,27,28,29,31, 34,35,36,38	15	36.58
1000-10,000	Brackish water type	1, 2, 3, 5, 6, 8, 10, 11, 14, 15, 17, 18, 20, 21, 22, 23, 24, 25, 28, 31, 32, 33, 37, 39, 40	26	63.42	1, 2, 3, 5, 7, 8, 9, 10, 11, 13, 14, 15, 17, 18, 20, 22, 23, 24, 25, 30, 32, 33, 37, 39, 40, 41	26	63.42
10,000-1,00,000	Saline water type	--	--	--	NIL	NIL	NIL
>1,00,000	Brine water type	--	--	--	NIL	NIL	NIL
Total	--	--	41	100	--	41	100

Total hardness: The classification of groundwater samples for the pre and post monsoon period on the basis of total hardness is shown in table 8. The majority of the groundwater sample falls under the category of very hard water. The formula used to calculate hardness 0f water is given below
TH (as $CaCO_3$) mg L^{-1} = (Ca^{2+} + Mg^{2+}) meq L^{-1} x 50

The values of hardness ranged from 80-1830 mg L^{-1} (avg. 610 mg L^{-1}) and 175-1550 mg L^{-1} (avg. 770 mg L^{-1}) respectively for pre- and post-monsoon periods. As per WHO prescribed limit the maximum allowable and desirable limit for drinking purposes is 500 mg L^{-1} and 100 mg L^{-1}. The most considerable limit for total hardness is 80-100 mg L^{-1} (Freeze and Cherry 1979). The groundwater samples surpassing a limit of 300 mg L^{-1} are thought out to be very hard [28]. Out of 41 groundwater samples collected, 31 samples exceeded the maximum permissible limit of 500 mg L^{-1}. The highest value of TH for pre- and post-monsoon periods respectively of the study area is observed near Jutur and Varkur villages of Aspari and Kodumuru mandal of Kurnool dist, respectively. This is because effluent from nearby industrial units is discharged. The total hardness spatial distribution map for the study area is given in figure 4(g, h).

Table 8. Groundwater classification on the basis of hardness (Sawyer and McMcartly 1967)

Total hardness as $CaCO_3$ (mg L^{-1})	Type of water	Pre monsoon			Post monsoon		
		Sample numbers	No of samples	% of samples	Sample numbers	No of samples	% of samples
<75	soft				NIL	NIL	NIL
75-150	moderately high	19	1	2.44	NIL	NIL	NIL
150-300	hard	1, 15, 16, 18, 30, 38	6	14.63	1, 11, 16	3	7.32
>300	very hard	2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 17, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 31, 32, 33, 34, 35, 36, 37, 39, 40, 41	34	82.93	2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14, 15, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41	38	92.68
Total			41			41	

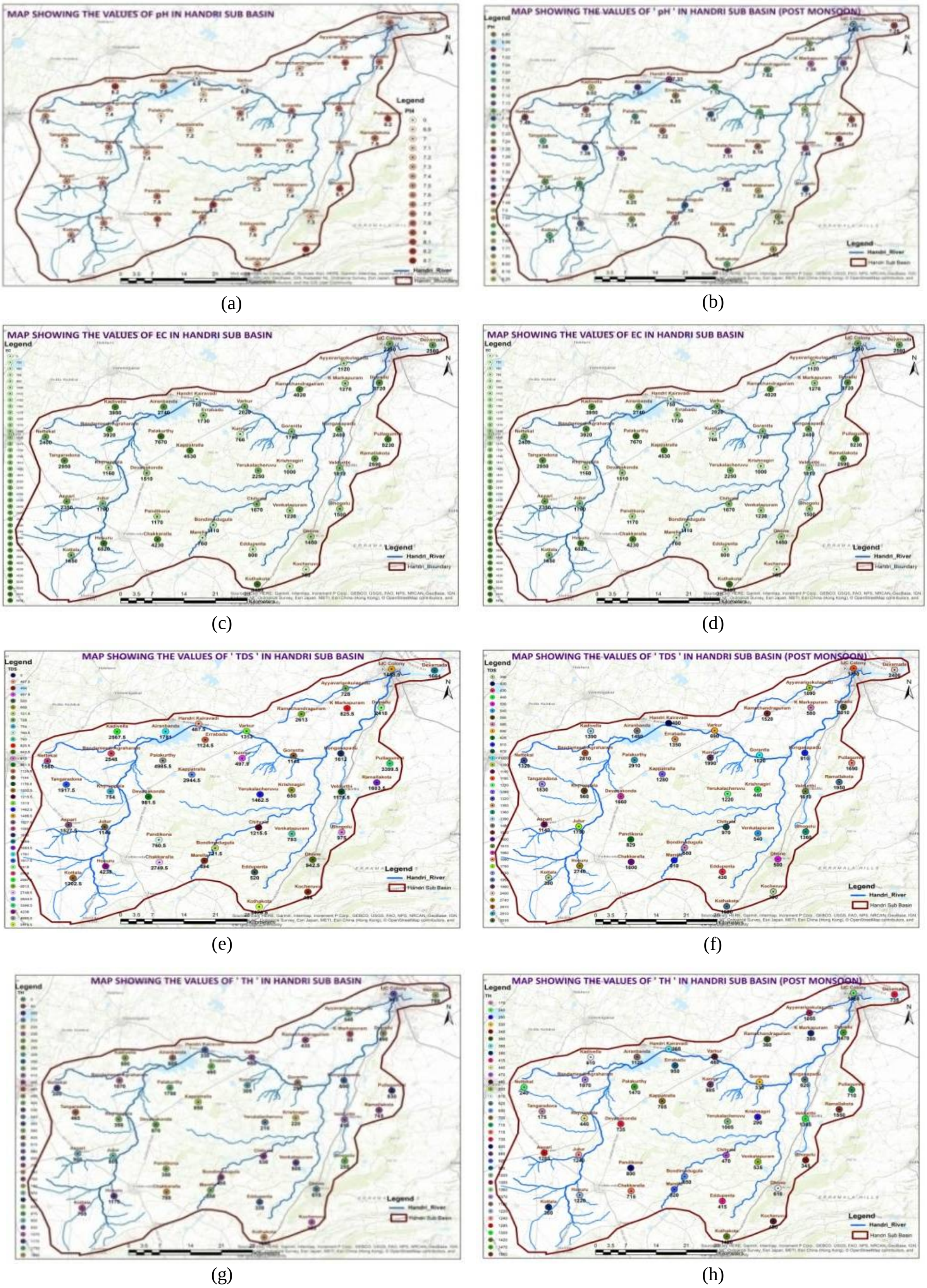


Figure 4. Spatial distribution maps of physicochemical parameters of ground water for pre-monsoon and post-monsoon seasons (a)(b) pH, (c)(d) EC, (e)(f)TDS, (g)(h)TH.

Chloride: The chloride concentration ranges from 21 to 2488 mg L^{-1} with an average of 560 mg L^{-1} and 30 to 2327 mg L^{-1} with an average of 675 mg L^{-1} for the pre- and post-monsoon periods, respectively (Table 1). The chloride ion concentration exceeds the maximum permissible limit of 600 mg L^{-1} at 13 and 20 locations. The chloride concentration is observed is maximum near jutur (1830 mg L^{-1}) of Asparimandal and A.Gokulapadu (1550 mg L^{-1}) of Kallurmandal of both periods. The spatial distribution map of chloride concentration for the study area is given in Figure 5 (a, a1).

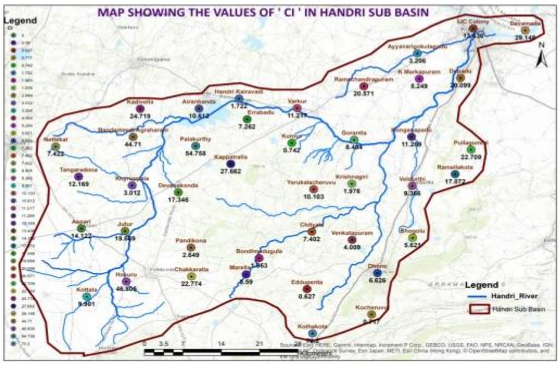
Nitrate: The nitrate concentration in the study area ranges from 1.4 to 1609 mg L^{-1} with an average of 335 mg L^{-1} and 0.167-754 mg L^{-1} with an average of 275 mg L^{-1} respectively for pre- and post-monsoon seasons (Table 1). The nitrate concentration in groundwater is obtained naturally from biosphere [29]. The nitrogen is directly fixed by plants belong to leguminacea family. The roots of these plants contain rhizobium bacteria which fix nitrogen directly from atmosphere and converts into nitrates in soil. The nitrate concentrations of 35 and 31 pre- and post-monsoon sample sites surpass the appropriate upper limit of 45 mg L^{-1} as recommended by WHO guidelines (Table 1, 4). The higher concentration of nitrate is lethal to newborn babies in groundwater. This causes baby blue syndrome/methahaemaglobanemia and carcinoma gastric carcinoma [30, 31]. Industrialization and urbanization are the primary causes of higher nitrate concentrations in groundwater.

Sulphate: The concentration of sulphates varies from 0-14 mg L^{-1} to 0-1.5 mg L^{-1}, with an average of 0.61 and 0.13 mg L^{-1} for pre- and post-monsoon seasons respectively (Table 1, 4). But most of the samples are far below the allowable 400 mg L^{-1} limit. The higher concentration of sulfate continues to interfere with human organs and induces laxative effects in groundwater on human systems with greater magnesium content. The map of spatial distribution of sulfate concentration for the area of study is given in figure 5 (b)(b1).

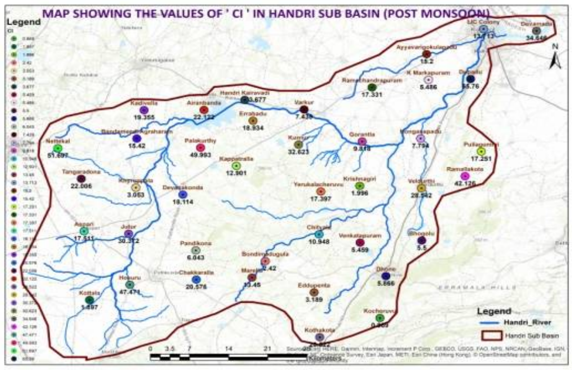
Fluoride: Fluoride (F-) occurs in trace quantities in groundwater and is derived from natural fluoride minerals such as fluorite and apatite. Fluoride is useful in acceptable quantities to resist tooth loss and to preserve skeletal stability. Excess concentration can therefore contribute to dental fluorosis and skeletal fluorosis [32]. The concentration of fluoride in groundwater ranged from 0.15-4.56 mg L^{-1} (avg: 1.23) and 0.14-3.82 (avg: 1.25) during the pre and post monsoon seasons respectively (Table 1). According to WHO (Table 4) prescribed limit, the maximum allowable limit of fluoride is 1.5 mg L^{-1}. For the pre- and post-monsoon seasons, concentrations above the permissible level are observed at 11 and 8 sites. A maximum fluoride concentration 3.8 (village Dupadu) and 4.5 mg L^{-1} (village Jutur) is observed.

Na^+ and K^+: The Na+ and K+ values in the study region differ between 0-296 mg L^{-1} (avg: 63.7 mg L^{-1}) and 0-258 mg L^{-1} (avg: 58 mg L^{-1}) respectively for pre and post-monsoon seasons. The maximum allowable limit is 200 mg L^{-1} according to WHO (1993) (Table 1, 4) [33] guidelines, and 7 percent of the samples are above this limit. Higher concentrations of more than 200 mg L^{-1} make the water unsafe for domestic use and cause severe health issues such as asthma, congenital abnormalities, renal defects and nervous disorders in the human body [34, 35]. The potassium concentration for natural water is typically below 10 mg L^{-1} (WHO, 1993) (Table 1, 4). In the study site, potassium concentrations in groundwater vary from 0 to 168.34 mg L^{-1} (avg: 24.6 mg L^{-1}) and 0 to 493 mg L^{-1} (avg: 82.9 mg L^{-1}) respectively for pre-and post-monsoon seasons. The allowable limit of K+ for drinking water is set as 12 mg L^{-1} L as per WHO (1993), nearly 29.26 and 48 percent of the samples are above the defined limit. The spatial distribution map of concentration of Na and K in the area of study is given in figure 5(c, c1 and d, d1).

Calcium (Ca^{2+}) and Magnesium (Mg^{2+}): The calcium concentration in the study area's groundwater samples varies from 0 to 235.9 mg L^{-1} (avg: 40.4 mg L^{-1}) and 0 to 76.1 mg L^{-1} (avg: 21 mg L^{-1}) respectively for pre- and post-monsoon seasons (Tables 1, 4). Calcium solubility in groundwater varies with the volume of CO_2 and in the presence of HCO_3. The maximum allowable calcium level (WHO 1993) is 200 mg L^{-1}. Just 10 percent of groundwater samples have a Ca^{2+} concentration above the WHO (1993) allowable limit (Table 1, 4). In the study area values of magnesium varies between 0 and 24.64 mg L^{-1} (avg: 1.57 mg L^{-1}) and 0 to 40.3 (avg: 12.3 mg L^{-1}) for pre- and post-monsoon seasons respectively (Tables 1, 5). The magnesium limit required in groundwater for drinking purposes is 150 mg L^{-1} (WHO 1993).



(a)



(a1)

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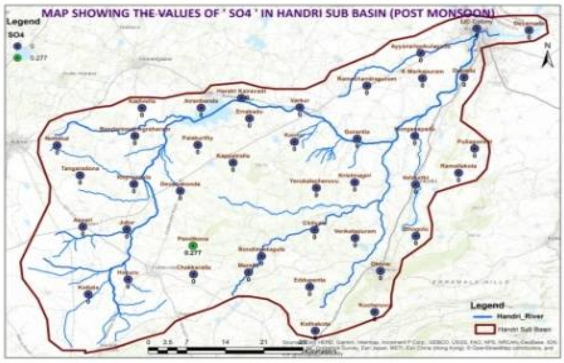
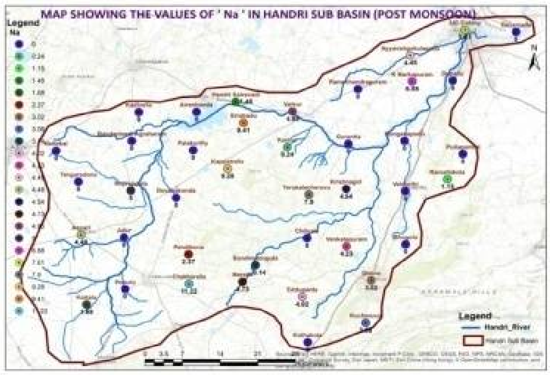
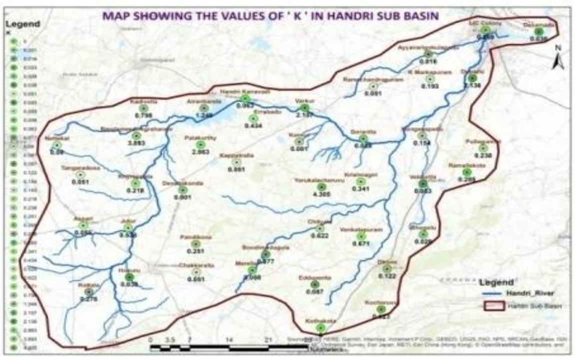


(b1)

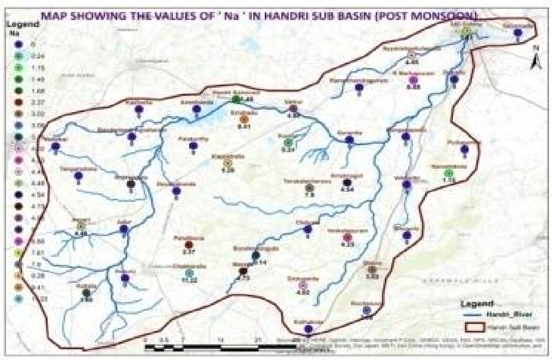
(c)



(c1)



(d)



(d1)

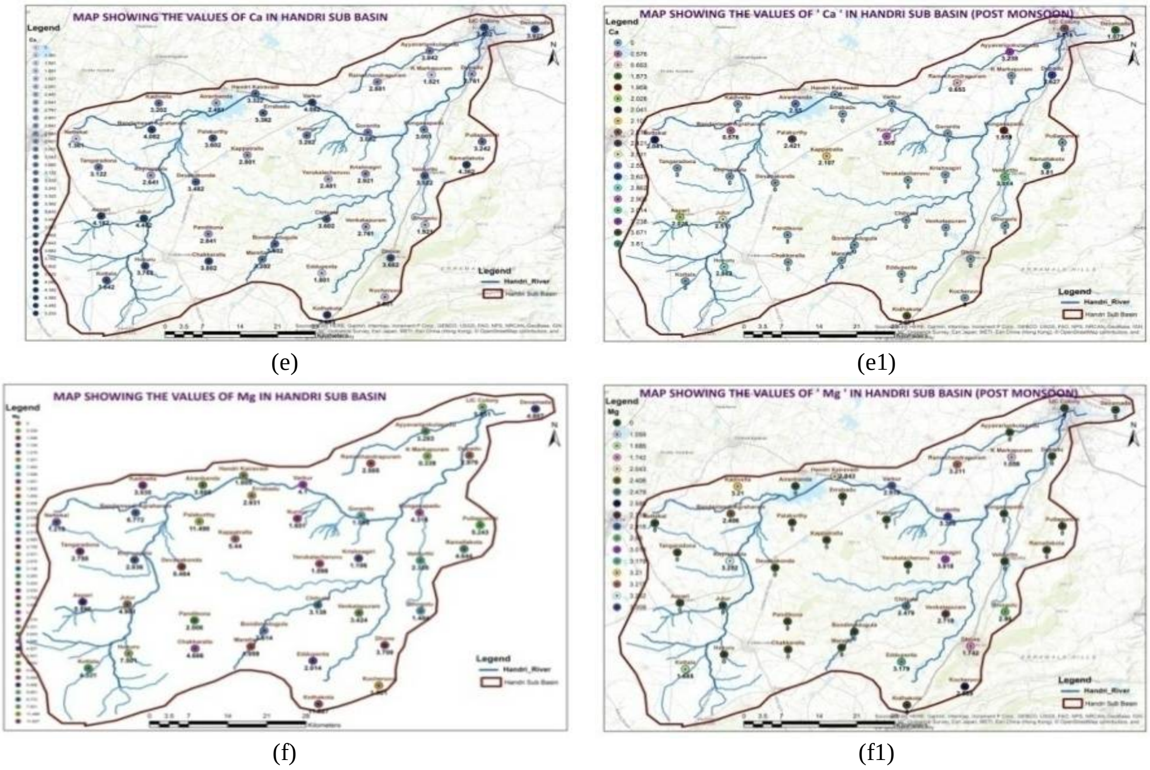


Figure 5. Spatial distribution of major anions and cations in groundwater in pre- and post monsoon (a,a1) chloride, (b,b1) Sulphate ,(c,c1) Sodium,(d,d1) potassium, (e,e1) calcium, (f,f1) magnesium

Irrigation water quality: Due to undue amounts of dissolved ions such as sodium, bicarbonate and carbonates in irrigation water, plants and agricultural soil are physically and chemically affected, Thus reducing the soil productivity. These ions effect physically by reducing the osmotic pressure in structural cells of plants. Thus further prevents the water from reaching the branches and leaves. The chemical effects of these ions are to disrupt plant metabolism. The plant growth is mainly influenced by the concentration of sodium and boron than the total concentration of other ions [36, 37]. The plants absorbs salts and nutrients from the soil based on osmotic pressure in plants. The higher salinity lessens the osmotic activity in plants there by intervene in the process of absorption of nutrients and water from the soil [38].

Sodium Absorption Ratio (SAR): Important factor used to decide the suitability of groundwater for irrigation purpose. As it assess the ratio of alkali by sodium hazard to crops.

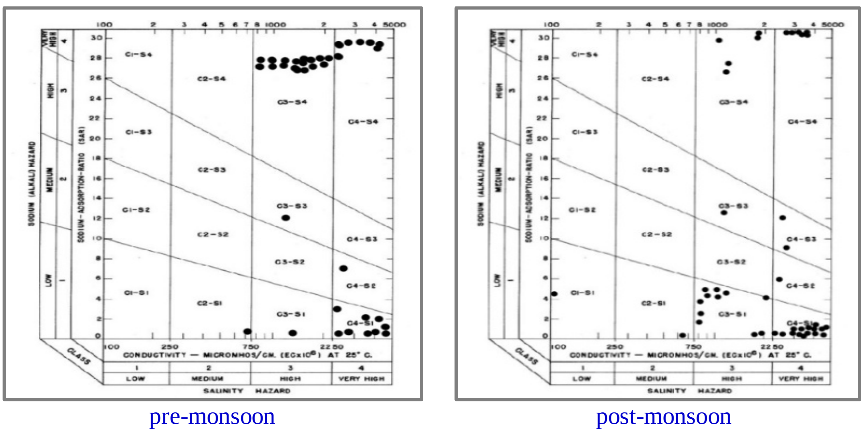


Figure 6. Salinity and Alkalinity hazard of irrigation water in US salinity diagram.

$$SAR=\frac{Na^{+}}{\sqrt{(Ca^{2+}+Mg^{2+})+/2}}[meq\ L^{-1}]$$

The SAR value for the study area varied in pre- and post-monsoon seasons from 0 to 12.5 (avg: 2.64) and 0 to 10 (avg: 5.85), respectively (Table 1). Nearly all groundwater samples have SAR values of less than 10 (Table 9) indicating that the samples are suitable for irrigation purposes.

Further in-depth irrigation suitability study was conducted by drawing the U.S. salinity laboratory diagram (USSL, 1954) [39, 40], where salinity hazard, alkalinity hazard and SAR are shown in the EC. The USSL plot signify that greater part of the groundwater samples in pre monsoon belonged to C3S4 (48%) and C4S4 (31%) class and post monsoon period to C4S1 (34%) and C3S1 (29%) class (Figure 6), representing high salinity, high alkali hazard water which needed proper drainage if not can badly affect [41] and salinity, low alkaline hazard water that can be used to irrigate plants with good salt acceptance in all soils. For both seasons the study area's overall groundwater falls into poor to good classification except for a few samples.

Table 9. Irrigation water salinity and alkalinity hazard in U.S. salinity diagram

Classification	SAR/EC	Pre-monsoon			Post-monsoon		
		Sample numbers	No of samples	% of samples	Sample numbers	No of samples	% of samples
C4-S1	SAR low EC very high	1, 14, 21, 22, 32, 37	6	14.65	1, 2, 3, 7, 8, 10, 17, 20, 23, 25, 32, 37, 39, 40	14	34.15
C4-S2	SAR medium EC very high	5	1	2.43	24	1	2.43
C4-S3	SAR high EC very high				14, 41	2	4.87
C4-S4	SARvery high EC very high	2, 3, 8, 10, 11, 15, 20, 23, 24, 33, 39, 40, 41	13	31.70	5, 11, 13, 15, 22, 33	6	14.65
C3-S1	SAR low EC high				4, 6, 9, 12, 16, 18, 21, 28, 29, 31, 35, 38	12	29.30
C3-S3	SAR high EC high	13	1	2.43	19	1	2.43
C3-S4	SAR very high EC high	4, 6, 7, 9, 12, 16, 17, 18, 19, 25, 26, 27, 28, 29, 30, 31, 34, 35, 36 ,38	20	48.79	26, 27, 34	3	7.31
C2-S1	SAR medium EC low	Nil	Nil	Nil	30	1	2.43
C1-S1	SAR low EC low	Nil			36	1	2.43
Total			41	100		41	100

Residual Sodium Carbonate (RSC): The residual sodium carbonate (RSC) decides the unsafe impacts of carbonate and bicarbonates on appropriateness of groundwater for irrigation [42]. When total carbonate levels surpass the total amount of calcium and magnesium, the water quality may be reduced [43]. If the carbonates are less than alkaline earths, it signifies that the RSC is negligible. Surplus carbonates (residual) combine with alkaline earth metals (Ca + Mg) and form scale that comes to rest out in water. Residual sodium carbonate (RSC) is determined by deducting from carbonate (CO_3^{2-}+ HCO_3^{-}) the basic earths (Ca^{2+}+ Mg^{2+}) as follows:

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})\ [meq\ L^{-1}]$$

The RSC in the pre- and post-monsoon seasons ranged from – 3.6 to 9.4 (avg. 4.1) and – 3.2 to 22.5 (avg. 5.6), respectively (Table 1). A high value of RSC in water prompts to an increase in the adsorption of sodium in soil [44]. USSL (1954) classified water into good (<1.25 meq L^{-1}), doubtful (1.25-2.5meq L^{-1}), and unsuitable (>2.5 meq L^{-1}) categories based on RSC. It is viewed that 97.5 and.80.8% samples of pre and post monsoon seasons were unsuitable for irrigation use (Table 10).

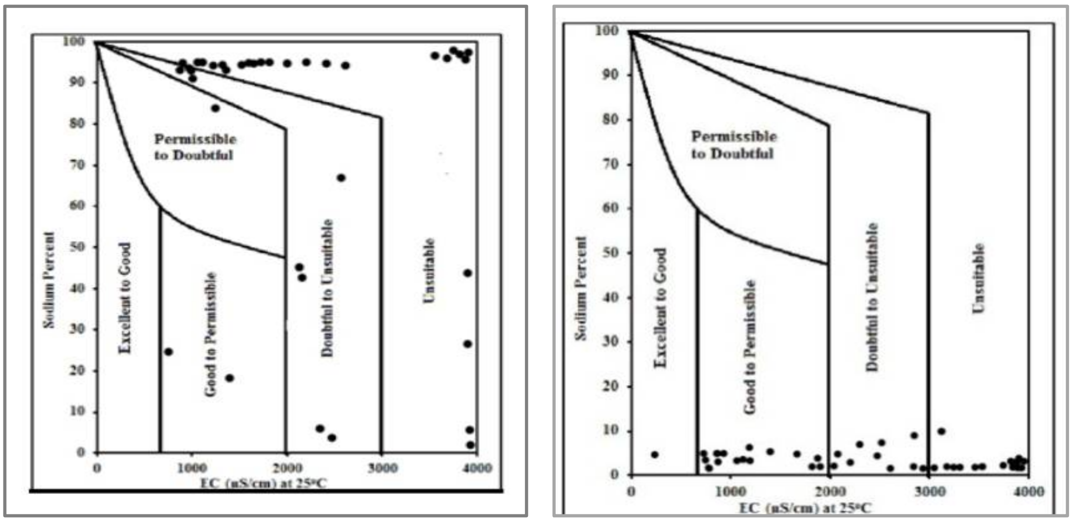
Table 10. Irrigation quality of ground water based on Residual sodium carbonate

RSC (meq L^{-1})	Classification	Premonsoon			Postmonsoon		
		Sample numbers	No of samples	% of samples	Sample numbers	No of samples	% of samples
<1.25	Good	26	1	2.44	4,41	2	4.88
1.25-2.5	Doubtful	0	0		9,12,23,29,3,38	6	14.64
>2.5	Unsuitable	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41	40	97.56	1, 2, 3, 5, 6, 7, 8, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 24, 25, 26, 27, 28, 30, 32, 33, 34, 35, 36, 37, 39, 40	33	80.48
Total			41	100		41	100

Sodium percentage: Sodium percentage (Na %) is calculated using the formula given below

$$Na\% = \frac{(Na^{+}+K^{+})}{(Ca^{2+}+Mg^{2+}+Na^{+}+k^{+})} X100 \text{ [meq } L^{-1}]$$

The Wilcox diagram (1955) [45] (figure 7) relating to sodium % and overall concentration indicates that 78, 14.5 percent of samples belongs to unsuitable, doubtful and good categories for pre monsoon where as 36.5, 24.3, 36.5 percent belongs to good, doubtful and suitable categories for post monsoon period (Table 11, 12). The unsuitable percentage of samples is reduced from pre-monsoon to post-monsoon duration which may imply dilution or exchange of ions with respect to sodium level [46]. The soil water content for irrigation is measured on the basis of sodium concentration, as sodium as a tendency to induce an increase in soil hardness and a decrease in soil permeability [47].



Pre-monsoon Post-monsoon

Figure 7. Electrical conductivity-related water content and Na per cent (Wilcox diagram).

Table 11. Classification of groundwater (Wilcox)

Classification	Pre monsoon			Post monsoon		
	Sample numbers	No of samples	% of samples	Sample numbers	No of samples	% of samples
Excellent to good	--	--	--	36	1	2.43
Good to permissible	4,13	2	4.88	4, 6, 12, 16, 19, 21, 26, 27, 28, 29, 30, 31, 34, 35, 38	15	36.59
Permissible to doubtful	19	1	2.43	Nil	Nil	Nil
Doubtful to unsuitable	1, 7, 21, 34, 35, 38	6	14.64	1, 5, 9, 14, 15, 18, 24, 39, 40, 41	10	24.40
Unsuitable	2, 3, 5, 6, 8, 9, 10, 11, 12, 14, 15, 16, 17, 18, 20, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 36, 37, 39, 40, 41	32	78.05	2, 3, 7, 8, 10, 11, 13, 17, 20, 22, 23, 25, 32, 33, 37	15	36.58
Total		41	100		41	100

Table 12. Irrigation quality of ground water based on sodium percentage

%Na	Classification	Pre monsoon			Post monsoon		
		Sample numbers	No of samples	% of samples	Sample numbers	No of samples	% of samples
<20	Excellent	1,13,14,21,22,32,37	7	17.0	1,13,14,21,22,32, 37	7	17.0
20-40	Good	3,4	2	4.87	3,4	2	4.87
40-60	Permissible	2,41	2	4.87	2,41	2	4.87
60-80	Doubtful	23	1	2.43	23	1	2.43
>80	Unsuitable	5,6,7,8,9,10,1112,15 ,16,17,18,19,20,24,2 5,26,27,28,29,30,31, 33,34,35,36,38,39,4 0	29	70.73	5,6,7,8,9,10,11,12 ,15,16,17,18,19,2 0,2425,26,27,26,2 9,30,31,33,34,35, 36,38,39,40	29	70.73
Total			41	100		41	100

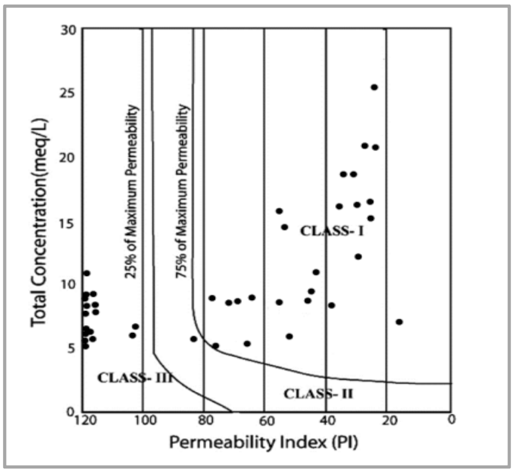
Permeability Index: To assess groundwater suitability for irrigation purposes Doneen (1964) [48] diagrams use the permeability index as criteria. The equation used to calculate PI of groundwater is

$$PI = \frac{Na^{+} + \sqrt{HCO_3-}}{Ca^{2+} + Mg^{2+} Na^{+}} [meq\ L^{-1}]$$

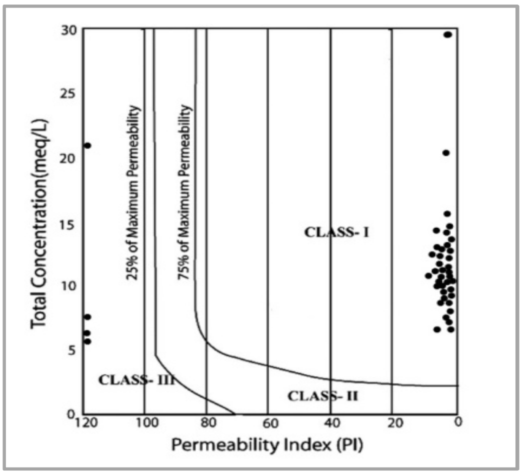
The ground water PI values for the pre and post monsoon season are between 15.9 and 946 (avg. 596 and 0.64-1.95(avg. 1.10), respectively (Table 1). According to Doneens chart (1964 irrigation water are grouped into 3 classes based on permeability. Class I and Class II groundwater type with 75% or more permeability is suitable for irrigation purposes while Class III with a maximum permeability of 25% is unsuitable for irrigation purposes (Figure 8). Almost all samples of both seasons belong to class I and class II. Doneens chart indicates that groundwater in both seasons is suitable for irrigation.

Kelly's Ratio: The groundwater is also categorized for irrigation purposes, based on the ratio of Kelly. To determine this parameter sodium is calculated by Kelly (1940) [49] against the sum of calcium and magnesium concentrations. The ratio to Kelly is estimated as follows

$$\text{Kelly's Ratio} = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}}$$



Pre-monsoon



Post-monsoon

Figure 8. Permeability index for pre and post-monsoon period.

Kelly's ratio of more than one indicates more sodium in water, as a result of which water is unfit for irrigation purpose where less than one Kelly ratio means water is suitable for irrigation purposes (Table. 13).The ratio of Kelly from the study area table ranges from 0 to 5.1(Avg. 0.68) and 0 to 6.4(Avg. 1.08) (Table 1) for pre- and post-monsoon seasons, respectively.. In the present study 26.8% and 48.8% of groundwater samples are suitable for irrigation purpose with Kelly's ratio less than one and 73.1% and 51.2% of samples (Table 13) are unsuitable for irrigation purpose with Kelly's ratio greater than one, for both the seasons pre and post monsoon seasons respectively.

Table 13. Irrigation quality of ground water based on Kelly's Ratio

KR	Classification	Premonsoon			Postmonsoon		
		Sample numbers	No of samples	% of samples	Sample numbers	No of samples	% of samples
<1	Suitable	1,, 2, 3, 4, 13, 14, 21, 22, 32, 37, 41	11	26.82	1, 2, 3, 4, 7, 8, 10, 17, 18,20, 21,23, 25, 28, 30, 31, 32, 37, 39, 40	20	48.78
>1	Not suitable	5, 6, 7, 8, 9, 10, 11, 12, 15, 16, 17, 18, 19, 20, 23, 24, 25, 26, 27, 28, 29, 30, 31, 33, 34, 35, 36, 38, 39, 40	30	73.18	5, 6, 9, 11, 12, 13, 14, 15, 16, 19, 22,24 ,26, 27, 29, 33, 34, 35, 36, 48, 41	21	51.22
Total			41	100		41	100

APPLICATION

Hydrogeochemistry data, spatial temporal distribution of groundwater quality showed that unsuitable for either drinking or irrigation use. Hence, this data might be quite useful for policy-makers and public health officials to takeup mitigation measures to supply potable water.

CONCLUSION

The groundwater had been in Handri river basin dominant by NaCl, $NaHCO_3$ and $CaCl_2$ type. Rock weathering is the principal competitive force in the control of groundwater chemistry and most of the groundwater samples (82.9% and 92.6% pre and post monsoon) are hard to very hard type. The data showed that the abundance sequence of the major anions and cations is in the order of Cl^- > HCO_3^->

NO_3^- and $Na^+ > K^+ > Ca^{2+} > Mg^{2+}$.Concentrations of Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, SO_4^{2-} have been found to be fit for drinking purposes as permitted by WHO. A total of 26.8 and 19.5% of the samples had F^- concentrations exceeding the WHO recommended limits of 1.5 mg L^{-1} during pre and post monsoon season, respectively. Similarly, a total of 85.3% and 75.6% of the samples beyond their regulatory limits of NO_3^- i.e., 45 mg L^{-1} during pre and post monsoon seasons, respectively. In addition, major ion correlation analysis revealed that most groundwater samples are due to natural processes such as mineral dissolution / precipitation and cation exchange. Based on parameters such as sodium adsorption ratio (SAR), sodium residual carbonate (RSC), Kelly's ratio (KR), permeability index (PI), EC, percentage Na, groundwater in the Handri river region was found to be unsuitable for irrigation purposes. The USSL plot for salinity hazard and alkali hazard denoted that majority of the groundwater (48.7% and 34.1% in pre and post monsoon, respectively) samples fall into to C3-S4 and C4-S1 class, representing very high salinity hazard and high-low alkali hazards water, which requires proper drainage otherwise it, can adversely affect the soil. Such studies suggest adverse impacts on the productivity of soils and crops. Therefore it is recommended that the mixture of low and high salinity water be used for irrigation to mitigate salinity hazard.

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