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Water Quality Index (WQI) to Evaluate Groundwater Quality in Chickmagaluru District, South Karnataka, India

Pramoda Govindaraju, AyyappanBalasubrahmanian, Doddaia Nagaraju and Vybhav Krishnamurthy

Dept. of Studies in Earth Science, University of Mysore, Manasagangothri, Mysuru.

Abstract

Groundwater quality analysis is essentially prima facie in the present scenario. To evaluate groundwater quality 14 different physiochemical parameters were analyzed for groundwater samples in the study area. Water Quality Index (WQIs) is a composite indicator of water quality. The water quality index contains various parameters that can be quickly and easily communicated to its intended audience. WQI is one of the most effective techniques for determining the appropriateness of groundwater for drinking purposes. The extracted components indicate that geological, agricultural, rainfall, household wastewater, and industrial activities are causing the sources to exceed the permissible limit. The present study contributes in understanding the groundwater quality in the Chickmagaluru district. It also helps in the understanding hydrogeochemical process of groundwater and effective interpretation of groundwater.

Keywords: Groundwater quality, Water Quality Index, Water quality Parameter, Chikamagaluru.

INTRODUCTION

During the last few decades, conserving of water resources has been receiving more and more attention. With the population expansion, water consumption for different purposes such as agriculture, drinking, and industrial growth has increased many folds and investment in the water sphere has become unavoidable for its management. Several processes have impact on the quality of groundwater including anthopogenic activities and the natural ones. Groundwater composition is influenced by soil layers, precipitation and surface water chemistry, climate, topography, and human activities. Water quality evaluation for drinking water purposes includes determining the composition of groundwater as well as remedial procedures to restore water quality (Annapoorna and Janardhana 2015; Neisi et al. 2018). The water quality index (WQI) is a practical and relatively easy method for assessing the overall groundwater quality. It also represents the combined impact of the various water quality indicators.

The present study focusses on characterisation of groundwater quality by testing samples and comparing them with the guidelines stated by the Bureau of Indian Standards (BIS). The standard methods were used to determine parameters such as Electrical Conductivity (EC), pH, Total Dissolved Solids (TDS), Calcium (Ca_2), Magnesium (Mg_2), Chloride (Cl^-), Sulphate (SO_4^-), Nitrate (NO_3^-), Total Hardness (TH), Potassium(K), Bicarbonate (HCO_3), Sodium (Na) Fluorides (F^-), and Iron (Fe). The concentrations or relative abundances of major and minor constituents and patterns of variability in the various water samples were analyzed using different graphical and statistical techniques.

Study Area

The study area (Fig. 1) falls within the state of Karnataka. Chikmagalur district situated in the southwestern part of Karnataka state between 12° 54' 42" - 13° 53' 53" N and 75° 04' 46" - 76° 21' 50"E. The study area is 138.4 km from east to west is 138.4km and 88.5 kn from north-south. The study area is bounded by Tumkur district in the East, Hassan in the South, Dakshina Kannada in the west, Chitradurga in the Northeast, and Shimoga in the North. The overall geographical area of the district is 7201 km^2 consisting of seven taluks namely Chikmagalur, Kadur, Koppa, Mudigere, Narasimharajapura, Sringeri, and Tarikere. The district area is represented in topographical map numbers 48 O and 57 C.

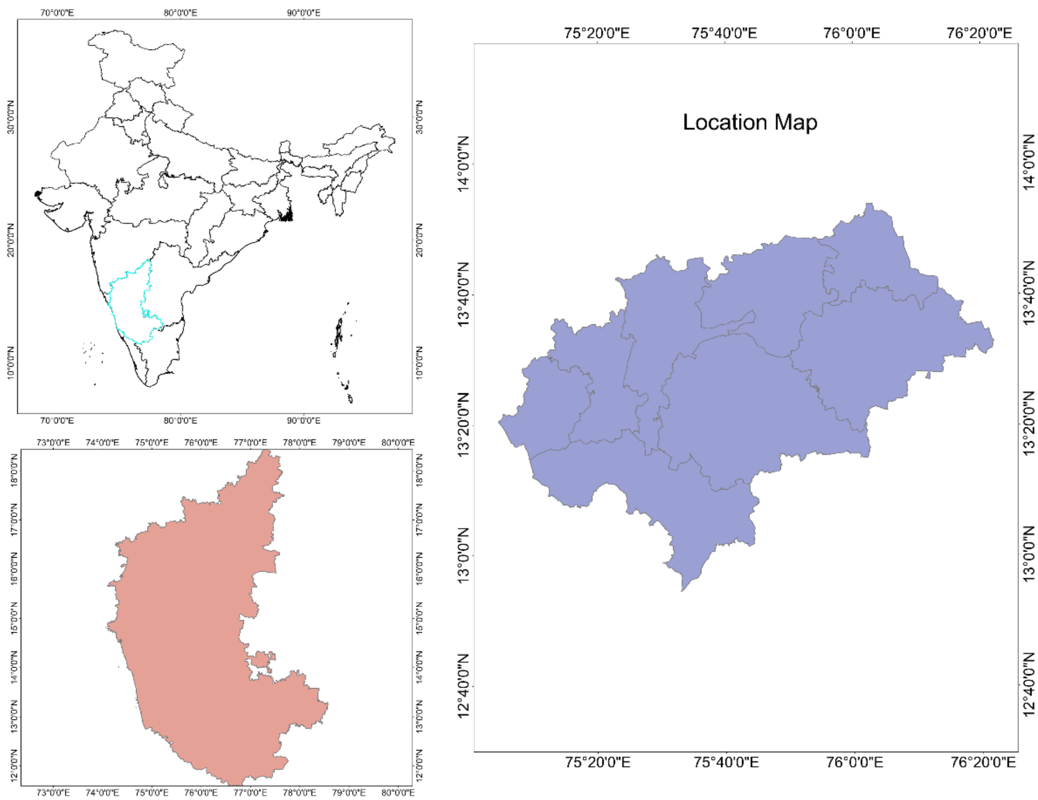


Fig. 1: Study area

Material and Methodology

The groundwater samples (Fig. 2) were collected from both dug/open and bore wells during pre-monsoon and post-monsoon in the year 2019. 95 representative groundwater samples were collected as per the standard protocol recommended by APHA (American Public Health Association) (Tab. 1). The samples were collected after 5 minutes of pumping well and placed in properly washed polythene containers at 4°C until the completion of the study. Each of the samples was analyzed for various physico-chemical parameters such as Electrical Conductivity (EC), pH, Total Dissolved Solids (TDS), Calcium (Ca_2), Magnesium (Mg_2), Chloride (Cl^-), Sulphate (SO_4^-), Nitrate (NO_3^-), Total Hardness (TH), Potassium(K), Bicarbonate (HCO_3), Sodium (Na) Fluorides (F^-), and Iron (Fe^-) (Tab. 2). pH and EC were measured in insitu and other parameters were analyzed in the laboratory using a spectrophotometer. The GPS readings were noted at each location to prepare various thematic maps using the ARC map.

Table 1: Drinking water standards used to calculate WQI

Parameter	Ca	Mg	Fe	F	SO_4	Cl	NO_3	TDS	EC	TH	pH	HCO_3	Na	K
	75	30	0.3	1	200	250	45	500	300	200	6.5 – 8.5	244	20	10

All parameters, except pH, are expressed in Mg/L

Groundwater Quality

pH: In pure form water has pH of 7, which indicates the water's hydrogen ion concentration. For drinking water, the range of pH should be in the range of 6.5-8.5 (BIS, 2012). Groundwater flow through carbonate-rich rocks like limestones and marbles, usually have a pH of greater than 7. The pH in the study area varies from 6.5 to 8.43 in the pre-monsoon and 6.5 to 8.35 after monsoon. All the samples in the study area fall within the allowable cap for both the pre-monsoon and post-monsoon samples (6.5 to 8.5).

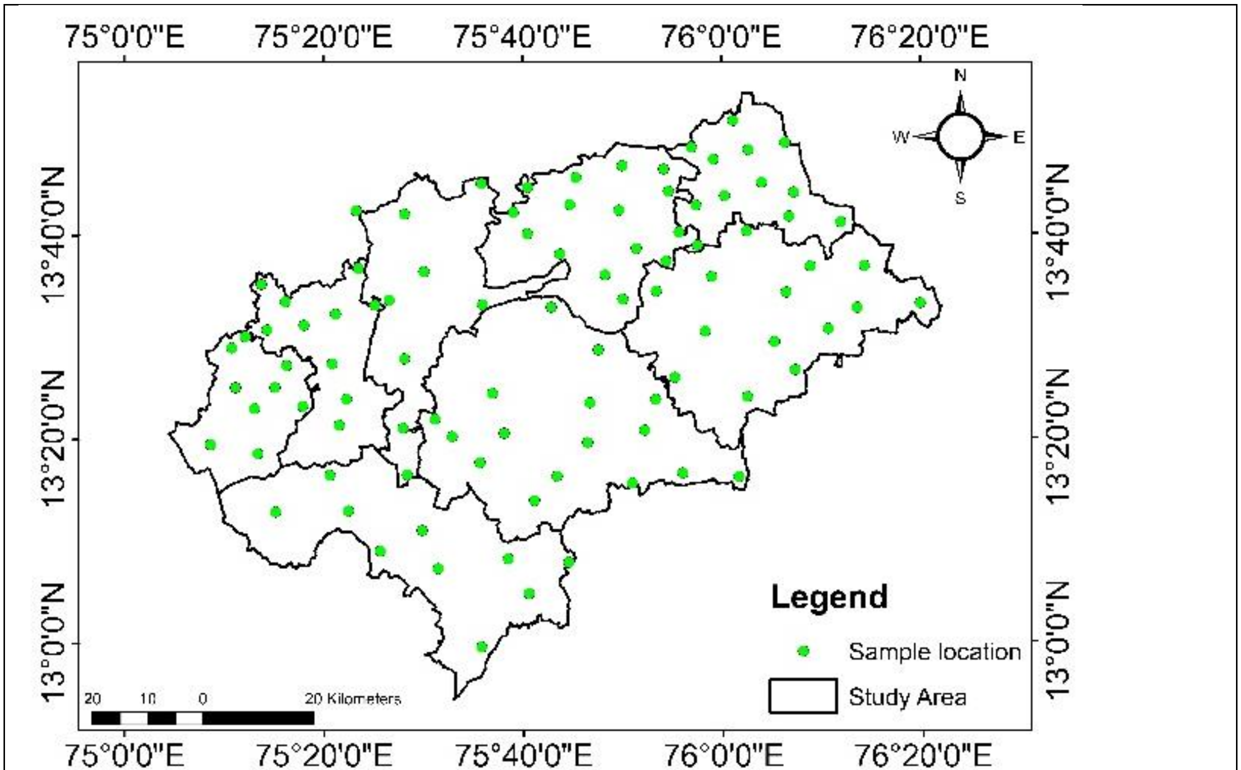


Fig. 2 Sample locations

EC: The quantity of the dissolved material in an aqueous solution is electrical conductivity (EC); the greater the dissolved material in a water sample, the higher the EC. The desirable EC cap for drinking is 300 µS/cm. The electrical conductivity in the present study ranges from 79 µS/cm to 2576 µS/cm in the pre-monsoon and 63 µS/cm to 2249 µS/cm in the post-monsoon samples. Around 41 percent of the samples in pre-monsoon and 47.3 % of the samples in post-monsoon fall under the acceptable limit (300 µS/cm).

Total Hardness: For its usage in the domestic domain, total hardness is a significant parameter of water. The hardness of water is a measure of the capacity of water to produce lather soap, hard water causes problems in the digestive system and the possibility of forming calcium oxalate crystals (Kidney stones) in the kidney. “It happens as a result of calcium and magnesium being present (Arumugam, 2010). Total hardness in the study area ranges from 36. 45 Mg/L to 1916 Mg/L in pre-monsoon and 23.22 Mg/L to 1672.5 Mg/L in the post monsoon samples. Around 53% samples in pre-monsoon and 66.3% samples in post-monsoon fall under the permissible limit of 300 Mg/L.

TDS: It is a consequential parameter for drinking water. Water containing high TDS is not suitable for drinking and it produces an unfavorable physiological reaction. It is made up mostly of inorganic salts, along with some small amounts of organic matter dissolved in water. The main compounds that are usually found in this compound are calcium, magnesium, sodium, and potassium, carbonate, bicarbonate, chloride, and sulfate cations. The optimum TDS for human drinking water, according to the BIS, is less than 500 Mg/L and the maximum permissible limit is 2000 Mg/L. In the study area, the TDS ranges from 68 Mg/L to 2215 Mg/L in the pre-monsoon and 48 Mg/L to 1975 Mg/L in the post-monsoon. Around 53.6% of samples in pre-monsoon and 66.3% samples in post-monsoon fall under the acceptable limit of 500 Mg/L.

Calcium: Calcium divalent cations are one of the important nutrients for living organisms. Calcium is found naturally in water. It will fade out from rocks such as limestone, marble, calcite, dolomite, gypsum, fluorite, and apatite. Calcium is a determining factor of water hardness because it can be found in water as Ca_2^+ ions. Depending on the type of rock, the quality of natural groundwater varies. In the present investigation, the calcium concentration in the study area ranges from 8 Mg/L to 378 Mg/L before monsoon and 5 Mg/L to 330 Mg/L after the monsoon. Around 48.4% of samples in pre-monsoon and 60% samples in post-monsoon fall under the acceptable limit of 75 Mg/L.

Magnesium: Magnesium is always associated with calcium in natural form, but its concentration is generally lower than calcium concentration. The higher magnesium content produces water hardness. Concentration >500 Mg/L imparts an unpleasant taste to water making it unportable. High concentration combined with sulfate acts as a laxative to human beings. In the present investigation, the Magnesium concentration in the study area ranges from 4 Mg/L to 241 Mg/L in pre-monsoon and 2 Mg/L to 221 Mg/L in post-monsoon. Around 43.15% of samples in pre-monsoon and 48.42% samples in post-monsoon fall under the acceptable limit of 30 Mg/L.

Nitrate: Nitrate is the most important nutrient in the ecosystem. Nitrates are of prime concern because when the concentration of methemoglobinemia exceeds 40 Mg/L. A high concentration of nitrates in groundwater may cause mortality in cattle, pigs, and calves. The concentration of Nitrate is 45 Mg/L, the limit imposed by BIS is exceeded, thus making this water unfit for portable. It is very difficult to point out the exact sources of nitrate contamination. One of the main causes of nitrate contamination is anthropogenic pollution. Nitrogen and nitrates from agricultural runoff due to the increased usage of chemical fertilizers. Nitrogen is also found in municipal waste and industrial wastewater, dumps, animal feedlots, septic tanks, and sewage disposal systems. Subsurface geology and the direction of groundwater flow also influence nitrate concentration. The concentration of nitrate in the sampling area ranges from 0.3 Mg/L and 147 Mg/L in pre-monsoon and 0.1 Mg/L to 126.8 Mg/L in post-monsoon. Around 95.78% of samples in pre-monsoon and 96.84% samples in post-monsoon fall under the acceptable limit.

Chloride: Chloride is found in all sorts of natural waters and gives saline flavor to water. High chloride contamination indicates contamination due to organic waste. Greater the chlorine content in water, the more dangerous it is to human health" (Anitha et al., 2011; Sadat-Noori et al., 2014). The concentration of chloride in the present study varies from 15 Mg/L to 610 Mg/L in the pre-monsoon period and 6 Mg/L to 378 Mg/L in the post-monsoon period. Around 85.26% of samples in pre-monsoon and 91.5% samples in post-monsoon fall under the acceptable limit of 250 Mg/L.

Sulfate: Sulfate leach out from rocks such as gypsum, iron sulphides, and other compounds. The sulfate ion is an important constituent of hardness with calcium and magnesium. It has an unpleasant taste at 300-400 Mg/L, is laxative at 1000 Mg/L, and interferes with the proper working digestion. The concentration of sulphate in the study area ranges from 3 Mg/L to 385 Mg/L in the pre-monsoon season and 2 Mg/L to 275 Mg/L in the post-monsoon season. Around 67.36% of samples in pre-monsoon and 87.36% samples in post-monsoon fall under the acceptable limit of 200 Mg/L.

Fluoride: "The main source of fluoride contamination in groundwater is geogenic. High concentration (>3.0 mg/l) of fluoride may cause skeletal fluorosis" (N. Janardhana Raju, 2009). Fluoride presents naturally in public water systems and by runoff from weathering of rocks and soils containing fluoride, leaching from rocks and soil into groundwater, and rainfall that brings the fluoride into the water system. The fluoride concentration in the study area varies from 0.02Mg/L to 1.65Mg/L for pre-monsoon reasons and 0.01Mg/L to 1.55Mg/L fora post-monsoon reason. Around 78.9% of samples in pre-monsoon and 86.3% samples in post-monsoon fall under the acceptable limit of 1 Mg/L.

Iron (Fe): The main source of iron contamination in groundwater is due to the leaching of iron from minerals and rocks, and rainfall that brings iron into the water system. The upper limit of iron is 0.3 Mg/L, if concentration exceeds this limit it results in a negative effect on the skin. In the study area, the iron concentration ranges from 0.014 mg/l to 5.64 Mg/L in pre-monsoon season and 0.003mg/l to 4.12mg/l in post-monsoon season amples. Around 77.8% of samples in pre-monsoon and 91.5% samples in post-monsoon fall under the acceptable limit of 0.3 Mg/L.

Sodium: Sodium is one of the most cation found naturally in water and is derived from weathering of rocks and minerals present in the locality. Domestic sewage and industrial wastes are abundant in sodium. Sodium concentration in the study area varied from 13 mg/l to 255 mg/l in pre-monsoon and 10mg/l to 212mg/l in post-monsoon samples. The acceptable maximum limit is 20 mg/l.

Potassium: Potassium is also a naturally occurring element but occurs at lower concentrations than sodium, calcium and magnesium. It has similar chemistry to sodium and remains in solution without forming any precipitate. As such, it is not very much significant from the health point of view. Sodium concentration in the study area varied from 2mg/l to 88mg/l in pre-monsoon and 2 mg/l to 63 mg/l in post-monsoon samples. Around 85.26% of samples in pre-monsoon and 91.5% samples in post-monsoon fall under the acceptable limit of 250 mg/l.

Table-2 Statistical analysis of analyzed physio-chemical groundwater quality parameter								
Parameter	Max	Min	Mean	Standard Deviation	Max	Min	Mean	Standard Deviation
	Pre-monsoon				Post-monsoon			
Ca	378.0	8	99.43	83.48	330	5	65.94	61.81
Mg	241.0	4	60.76	52.55	211	2	40.11	40.71
Cl	610	15	139.59	135.52	378	6	87.93	87.19
NO3	147	0.3	14.71	22.06	126.8	0.1	9.45	16.78
SO4	385	3	118.93	115.75	2	278	83.45	87.40
F	1.65	0.02	0.52	0.48	1.55	0.01	0.4	0.44
Fe	5.64	0.014	0.36	0.96	4.12	0.003	0.1981	0.62
TDS	2215	68	576	492	1975	48	411	382
EC	2576	79	745	624	2249	63	560	495
TH	1916	36.45	498.60	419.78	1672.5	23.22	329.9	314.80
HCO3	564.0	112	194.77	72.22	501	92	170.06	67.18
K	88.0	2	19.84	17.50	63	2	14.84	13.66
PH	8.43	6.5	7.08	0.5	8.35	6.5	0.4	7.04
Na	255.0	13	58.29	43.24	212	10	48.71	38.06

RESULTS AND DISCUSSION

Pearson's Correlation

All parameters are expressed in Mg/L, except pH and EC expressed in µS/cm
Table 2 shows the descriptive data for 95 groundwater samples. The detailed scrutiny of the correlation matrix is helpful for the interpretation of groundwater in the study area. The role of each parameter and its impact on the hydrochemistry process is depicted in the correlation matrix. (Helena et al., 2000; Khan, 2011). If the values of "r" are ''+ 1 or - 1" in the Pearson's correlation matrix (Table 3 & 4) they are considered as high correlation coefficient i.e., a functional dependence, between two variables. If the values are nearer to zero, it indicates no relationship between bivariate at a substantial level of $P < 0.05$ (Singh et al., 2011). If $r > 0.7$, and within 0.4 and 0.7, it can be considered that the parameters are strongly correlated and moderately correlated, respectively. A correlation matrix is utilised to comprehend any relationship between the empirically observed parameters and the factor loadings using PCA.

In the pre-monsoon samples, Ca^{2+} has a negative correlation with Fe^-, and a strong positive correlation with Na^+, K, Mg^{2+}, HCO_3^-, Cl^-, SO_4, NO_3^-, F^-, TDS, EC, pH, TH and moderate positive correlation with temperature. In the post-monsoon Ca^{2+} shows a strong positive correlation with Na^+, K, Mg^{2+}, HCO_3, Cl^-, SO_4, NO_3^-, F, TDS, EC, and TH and moderate positive correlation with Fe^-, pH and temperature. The pH displays a negative correlation with Fe^- and a positive correlation with all other parameters in pre-monsoon as well as post-monsoon. The Mg_2^+ has a positively strong correlation with Ca_2^+, Na^+, K, Cl^-, SO_4, NO_3^-, F^-, TDS, EC, pH, TH and moderately correlated with HCO_3^- and temperature except Fe^- which shows the negative correlation in the pre-monsoon and the post-monsoon samples Mg^{2+} has a positively strong correlation with Ca_2^+, Na^+, K, Cl^-, SO_4, NO_3^-, F^-, TDS, EC, and TH and moderately correlation with Fe^-, pH, and temperature. The significant association between $Mg^{2+}$and Cl-, Na^+ and Cl-, TDS and Cl- the studied area demonstrates the impact of agronomical activities. In the pre-monsoon EC has a strong positive association with Ca^{2+}, Mg^{2+}, Na^+, K, Cl^-, SO_4, NO_3^-, F^-, TDS, EC, and TH and moderately correlation with HCO_3^- and, T and Fe^- show a negative correlation. In the post-monsoon EC has a strong positive association with Ca^{2+}, Mg^{2+}, Na^+, K, Cl^-, SO_4, NO_3^-, HCO_3^-, Fe^- and TH and moderately positive correlation with F^-, pH, and T suggesting ions have the common source and are entangled in ion exchange reactions (Subbu Rao, 1996). TH is highly correlating with all the parameters except Fe^- in the pre-monsoon as well as the post-monsoon. TDS in the pre-monsoon samples is highly positive with Ca^{2+}, Mg^{2+}, Na^+, K, Cl^-, HCO_3^-, SO_4, NO_3^-, F^-, TDS, EC and TH and negative with Fe^-, when it comes to post-monsoon TDS shows a high positive correlation with Ca^{2+}, Mg^{2+}, Na^+, K, Cl^-, HCO_3^-, SO_4, NO_3^-, F^-, EC and TH and negative correlation with pH, and Fe^-. In general, the concentration of Cl^- is low in the crystalline subsurface (Karanth, 1987). The concentration of Cl^- is low in the post-monsoon as compare to the pre-monsoon samples due to rainfall.. The positive correlation between Na^+ and Cl^- is strong in the pre-monsoon, as well as the post-monsoon samples suggesting possible mizing of the two end-member composition groundwater.

The strong correlation between Mg^{2+} and Cl^-, Na^+ and Cl^-, TDS and Cl^- is related to agronomic activity in the study area. A scatter matrix plot and visual representations are used to interpret the correlation matrix. (Figs 3 & 4). Figure 3 & 4 are the replication of Tables 3 & 4 to understand the correlation easily. To check the adequacy of the data for statistical analysis, Kaiser–Meyer–Olkin (KMO) and Bartlett's tests were conducted; sampling adequacy rate is 0.852 in the pre-monsoon and 0.845 in the post-monsoon samples which show greater than the threshold values given by the test (0.5). KMO and Bartlett's tests assess the appropriateness of data for factor analysis, determining the sampling suitability for each variable in the model. KMO values 0.8 to 1, 0.5 to 0.8, and less than 0.5 are considered as adequate, moderately adequate, and unacceptable or not adequate, respectively.

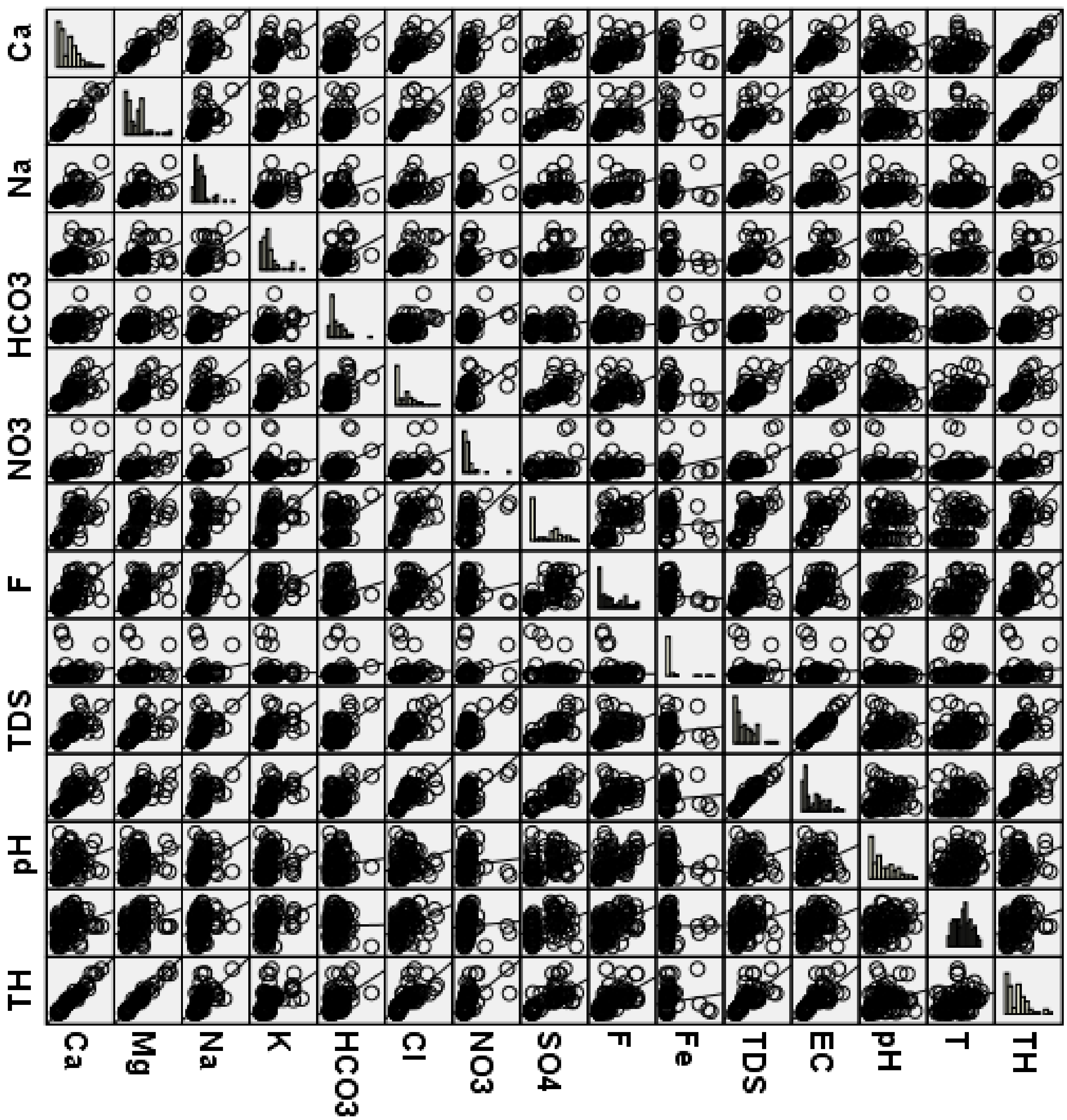


Fig. 3 Scatter matrix plot for pre-monsoon

	Ca	Mg	Na	K	HCO_3	Cl	NO_3	SO_4	F	Fe	TDS	Ec	pH	T	TH
Ca	1														
Mg	0.911	1													
Na	0.683	0.598	1												
K	0.545	0.48	0.564	1											
HCO3	0.433	0.387	0.348	0.471	1										
Cl	0.814	0.743	0.588	0.598	0.393	1									
NO3	0.604	0.542	0.406	0.24	0.481	0.607	1								
SO4	0.737	0.61	0.574	0.451	0.188	0.772	0.466	1							
F	0.588	0.522	0.549	0.35	0.151	0.597	0.164	0.723	1						
Fe	-0.059	-0.021	-0.015	-0.004	0.078	-0.038	-0.055	-0.066	-0.028	1					
TDS	0.827	0.702	0.653	0.461	0.418	0.757	0.756	0.783	0.552	-0.067	1				
Ec	0.844	0.746	0.686	0.51	0.393	0.793	0.69	0.825	0.652	-0.069	0.974	1			
pH	0.473	0.463	0.492	0.342	0.147	0.436	0.19	0.466	0.598	-0.026	0.465	0.529	1		
T	0.212	0.233	0.152	0.046	-0.006	0.132	0.003	0.209	0.286	0.068	0.135	0.18	0.157	1	
TH	0.974	0.978	0.654	0.523	0.418	0.795	0.587	0.686	0.565	-0.047	0.78	0.811	0.477	0.229	1

Table 3 Correlation coefficient matrix pre-monsoon

	Ca	Mg	Na	K	HCO_3	Cl	NO_3	SO_4	F	Fe	TDS	Ec	pH	T	TH
Ca	1														
Mg	0.952	1													
Na	0.607	0.67	1												
K	0.489	0.574	0.587	1											
HCO3	0.417	0.491	0.362	0.441	1										
Cl	0.767	0.793	0.577	0.65	0.484	1									
NO3	0.55	0.564	0.441	0.228	0.511	0.538	1								
SO4	0.733	0.762	0.585	0.541	0.347	0.815	0.469	1							
F	0.654	0.649	0.553	0.392	0.179	0.574	0.153	0.718	1						
Fe	0.124	0.143	0.176	0.011	0.187	0.05	0.228	0.059	-0.029	1					
TDS	0.722	0.779	0.63	0.583	0.544	0.814	0.671	0.838	0.539	0.094	1				
Ec	0.779	0.821	0.662	0.596	0.505	0.829	0.624	0.87	0.619	0.07	0.979	1			
pH	0.358	0.325	0.35	0.201	0.079	0.248	0.073	0.387	0.498	-0.068	0.313	0.37	1		
T	0.336	0.288	0.305	0.351	0.015	0.366	0.056	0.39	0.45	-0.002	0.287	0.35	0.348	1	
TH	0.987	0.986	0.647	0.538	0.458	0.789	0.566	0.756	0.658	0.124	0.759	0.81	0.344	0.317	1

Table 4 Correlation coefficient matrix post-monsoon. (Bold ones are r>0.4 showing the significance level

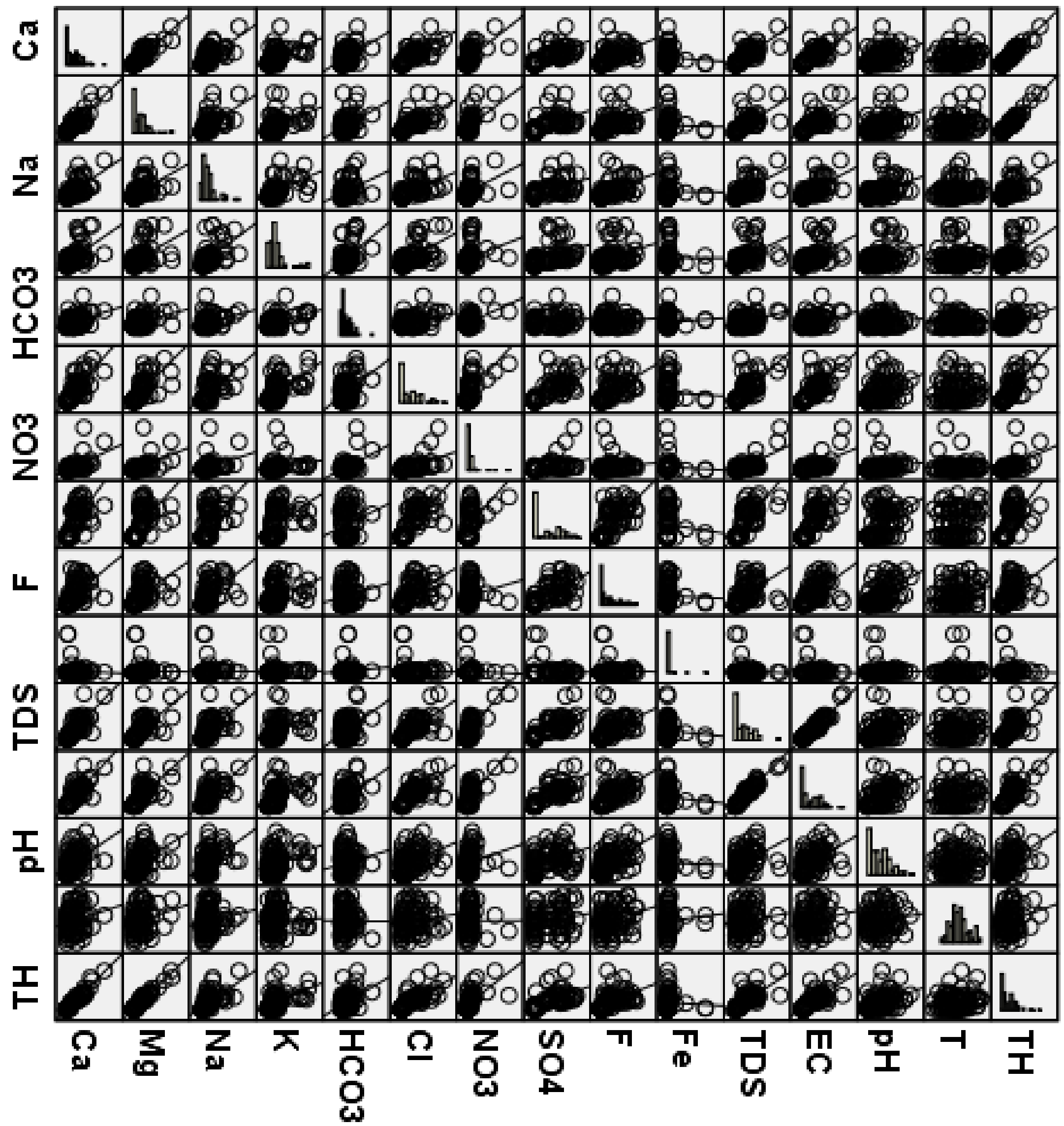


Fig. 4 Scatter matrix plot for post-monsoon

FACTOR ANALYSIS

The factor analysis is a useful technique, where a vast amount of data containing variables can be condensed down to a small number of variables. This methodology also identifies the relationship between the variables and their impact on the objects, i.e., the investigated samples. The PC, which is linear combination of the original variables that can represent the maximum of the overall variance, is a key component of this technique. The remaining parameters determine the greatest residual variability (Behera and Das, 2018). The extracted components are orthogonal to one another. The variances derived from the factors are called eigenvalues, and only factors with eigenvalues larger than 1 are chosen. Factor loadings represent the correlations between original variables and the factors extracted.

To simplify factor analysis data, Varimax with Kaiser normalisation rotation is utilised (Schot and Van der Wal, 1992; Jayakumar and Siraz, 1997; Adams et al., 2001; Aiuppa et al., 2003). The scree plot (fig. 5&6) two factors and three factors for te pre-monsoon and the post-monsoon samples respectively (Table 7 & 8) were used to describe 66.69% and 71.22% of total variances which are enough for obtaining correlation matrix (Cattell and Jaspers, 1967). With the help of these factors, total variance is described as the first component - 52.471% and asecond component – 66.698% in the pre-monsoon and component 1 – 43.989, component 2 – 63.817, and component 3 – 72.226 in the post-monsoon.

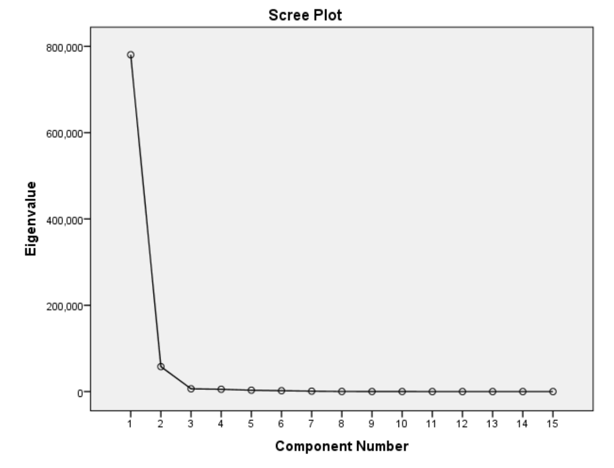


Fig.5 Scree plot graph for pre-monsoon

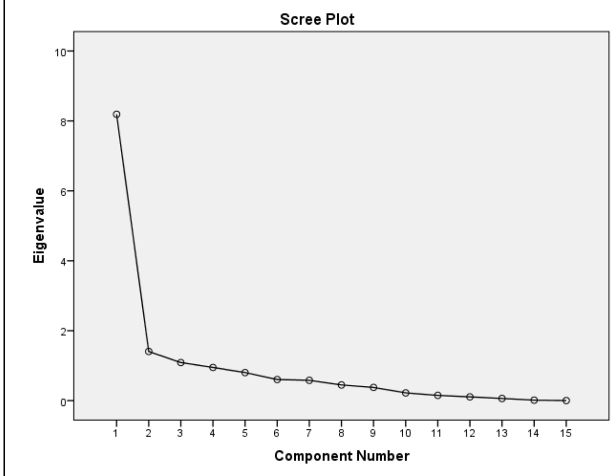


Fig.6 Scree plot graph for post-monsoon

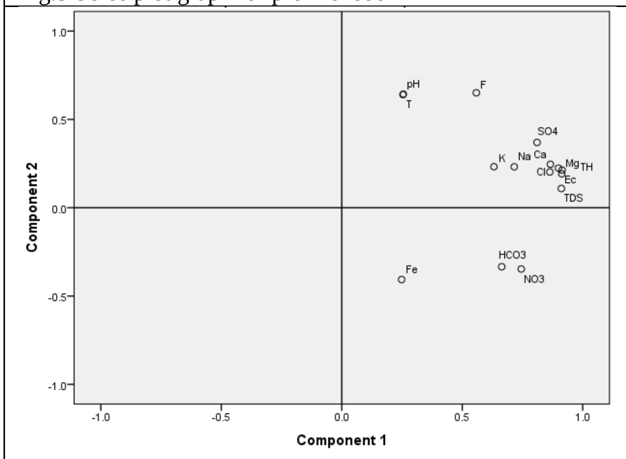


Fig. 7 Rotated components for pre-monsoon

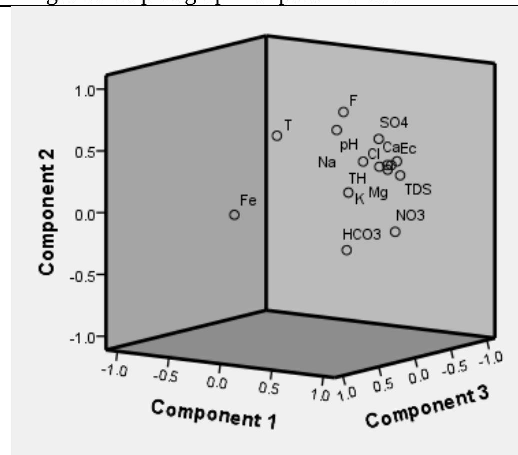


Fig. 8 Rotated components for post-monsoon

Variables with loadings greater than 0.3 are important for assessing the components and have been used to interpret the results (Mahloch, 1974). The absolute value of loading describes the variable's influence. A positive or negative sign indicates the direction of the influence. As a result, a huge negative number indicates that a variable has a significant and negative impact on the factor (Lawrence and Upchurch, 1982). In the pre-monsoon samples, we observed that in the component 1Mg, TDS, TH, and EC show very high loadings, but Ca, Na, K, HCO_3, Cl, NO_3, and SO_4 show moderate to high loadings. In the post-monsoon samples Ca, NO_3,TDS, EC and TH show moderate to high loadings. Ca, Mg, Cl, and SO_4 play important role in determining TDS, EC, and TH in the pre-monsoon as well as the post-monsoon. Component 1 is regulated by various hydro-geochemical processes like mineralization of the sampling location, soil conditions, anthropogenic activity, and rainfall intensity. However, the cation exchange mechanisms at the soil-water interface are controlled by Na and Mg (Guo and Wang, 2004).

Table 5 Total variance (pre-monsoon)

Initial Eigenvalues			
Component	Total	% Of Variance	Cumulative %
1	8.378	55.854	55.854
2	1.627	10.844	66.698
3	.962	6.410	73.108
4	.842	5.616	78.724
5	.698	4.654	83.378
6	.641	4.270	87.648
7	.517	3.445	91.094
8	.468	3.121	94.215
9	.357	2.377	96.592
10	.189	1.262	97.854
11	.163	1.087	98.941
12	.110	.733	99.674
13	.036	.238	99.912
14	.012	.080	99.992
15	.001	.008	100.000
Extraction Sums of Squared Loadings			
Total	% Of Variance		Cumulative %
8.378	55.854		55.854
1.627	10.844		66.698
Rotation Sums of Squared Loadings			
Total	% Of Variance		Cumulative %
7.871	52.471		52.471
2.134	14.227		66.698

Table 6 Total variance (post-monsoon)			
Initial Eigenvalues			
Component	Total	% Of variance	Cumulative %
1	8.190	54.598	54.598
2	1.406	9.373	63.971
3	1.088	7.255	71.226
4	.949	6.324	77.550
5	.803	5.350	82.900
6	.604	4.024	86.924
7	.581	3.877	90.801
8	.448	2.985	93.786
9	.377	2.512	96.298
10	.222	1.477	97.775
11	.150	1.000	98.775
12	.107	.712	99.487
13	.062	.412	99.898
14	.013	.088	99.986
15	.002	.014	100.000
Extraction Sums of Squared Loadings			
Total	% Of Variance		Cumulative %
8.190	54.598		54.598
1.406	9.373		63.971
1.088	7.255		71.226
Rotation Sums of Squared Loadings			
Total	% Of Variance		Cumulative %
6.598	43.989		43.989
2.974	19.828		63.817
1.111	7.409		71.226

In the second component, we can see high loadings in F, pH, and temperature and, Fe shows negative interaction in the pre-monsoon as well as the post-monsoon sampless except Fe. When minerals including silicates, fluorite, fluorapatite, and volcanic ash are dissolved, the concentration of fluoride in groundwater rises (Hem, 1989). Fluorite is most commonly found in sedimentary, volcanic, and plutonic rocks. It can also be found in granite, gneiss, and pegmatite rocks (Rama Rao, 1982; Heinrich, 1948). Weathering of such rocks leaches out fluoride (Singh et al., 2011). Because of the high pH loading, we assume that the sources are likely organic or biogenic. Component 3 is only observed in the post-monsoon samples and most of the components are negatively correlated except Fe which is due to influencing components 1 & 2 present in factor 3.

The current assessment primarily assists in extracting information regarding ion sources and variables impacting groundwater quality (Islam et al., 2018). It can be summarized that four extracted PCs denote four dissimilar processes viz.:

(a) Geological processes such as weathering and dissolution of the minerals matter.

(b) Agricultural activities.

(c) Industrial effluent discharges.

(d) Rainfall intensity.

(e) Domestic waste waters.

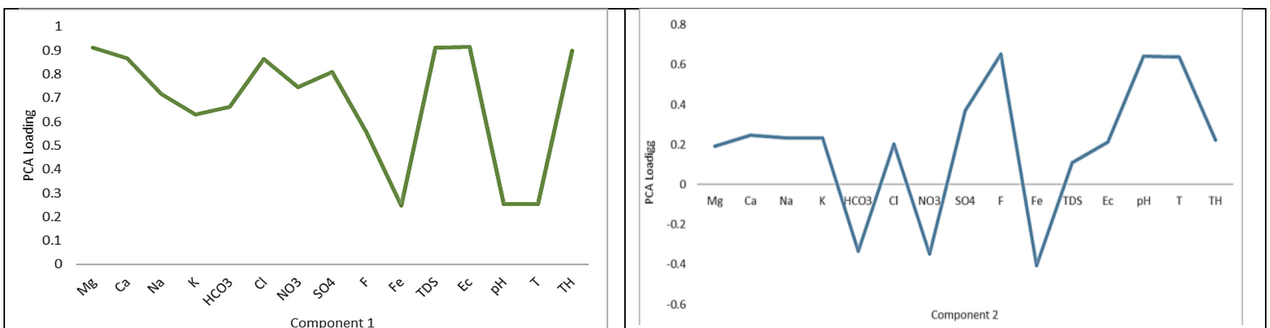
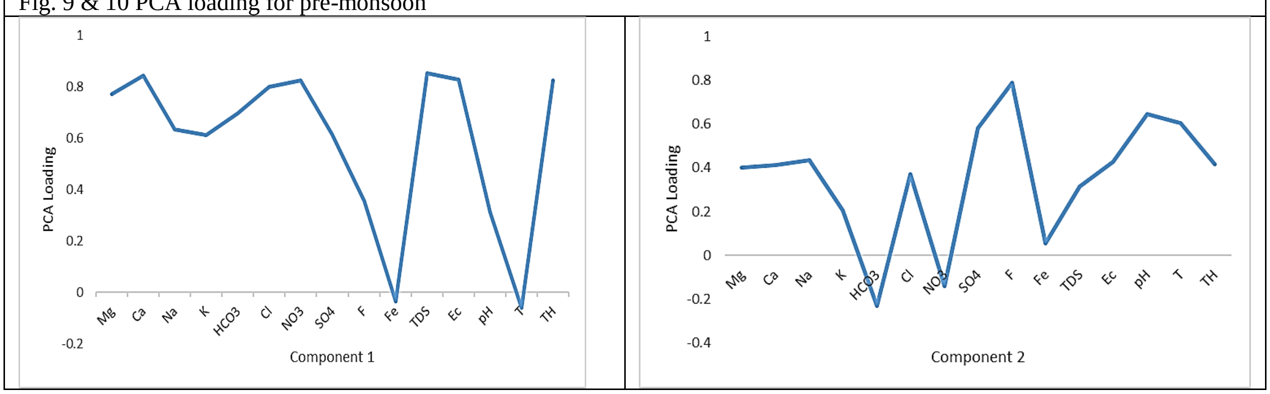


Fig. 9 & 10 PCA loading for pre-monsoon



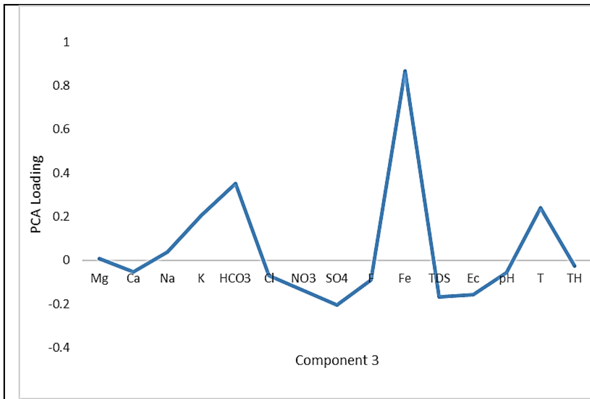


Fig. 11, 12 & 13 PCA loading for post-monsoon

Tab.7 Rotated Component Matrix

	Component	
	1	2
Mg	.913	.192
Ca	.866	.246
Na	.716	.232
K	.632	.232
HCO_3	.664	-.334
Cl	.863	.203
NO_3	.745	-.347
SO_4	.810	.370
F	.558	.651
Fe	.248	-.406
TDS	.911	.109
Ec	.914	.213
pH	.255	.643
T	.254	.640
TH	.899	.224

Tab. 8 Rotated Component Matrix

	Component		
	1	2	3
Mg	.772	.403	.007
Ca	.845	.414	-.052
Na	.636	.435	.039
K	.612	.207	.208
HCO_3	.696	-.230	.352
Cl	.799	.370	-.069
NO_3	.825	-.140	-.136
SO_4	.617	.581	-.206
F	.356	.789	-.089
Fe	-.035	.056	.867
TDS	.853	.316	-.167
Ec	.829	.428	-.156
pH	.313	.644	-.056
T	-.059	.603	.241
TH	.826	.416	-.027

There are different types rotation techniques available such as varimax, equamax, and quartimax, but varimax rotation is largely practiced, which includes an orthogonal rotation and it is complex to explain in the present study. The overall concept of this method was described by Kaiser (1958). Factor analysis extracts and produces new rotational factors (Tables 7 & 8) in which the meaning of each factor may be explained by the variables that have the greatest impact on it. The rotation mode analysis reveals a number of good characteristics that help to analyse the dataset more effectively. For all the samples, factor scores were generated, revealing the significance of a given component at that sample site. Extremely negative and positive PC scores indicate that the area is unaffected and largely influenced, respectively, by the variables influencing PC, whilst a result close to zero indicates that the area is affected to an average degree by the chemical process of that factor (Senthilkumar et al., 2008). This study inferred that the area is moderately affected by the chemical process as the scores are close to zero. Water Quality Index (WQI): For the calculation of the water quality index, 14 relevant parameters were chosen in the present study. The concentration of the WQI was measured using the drinking water quality criteria recommended by the world health organization (WHO), the Indian Standard Bureau (BIS) and the Indian Medical Research Council (ICMR). For the determination of the water's WQI, the weighted arithmetic index method (Brown et. al., 1972) was used.

The WQI was used to obtain a detailed image of overall groundwater quality. WQI is defined as a rating that represents the cumulative effect of various parameters of water quality on the overall water quality. Three steps were taken to compute the WQI. First, the weight (wi) was allocated to each of the 14 parameters i. e., Electrical Conductivity (EC), pH, Total Dissolved Solids (TDS), Calcium (Ca_2), Magnesium (Mg_2), Chloride (Cl^-), Sulphate (SO_4^-), Nitrate (NO_3^-), Total Hardness (TH), Potassium (K), Bicarbonate (HCO_3), Sodium (Na) Fluorides (F^-), and Iron (Fe) and according to its relative significance in the overall water quality for drinking purposes (Table 9).

Tab. 9 Weight (wi) and Relative weight (Wi) of parameter

Parameter	Standard (Sn)	Weightage (wi)	Relative weight (Wi)
Ca	75	1	0.052631579
Mg	30	1	0.052631579
Cl	250	1	0.052631579
NO_3	45	2	0.105263158
SO_4	200	1	0.052631579
F	1	2	0.105263158
Fe	0.3	3	0.157894737
TDS	500	1	0.052631579
EC	300	1	0.052631579
TH	200	1	0.052631579
pH	6.5 – 8.5	1	0.052631579
HCO_3	244	1	0.052631579
Na	20	2	0.105263158
K	10	1	0.052631579
		19	$\sum$ Wi = 1

Step 1

Nitrate was assigned a maximum weight of 5 because of its major importance in determining water quality; zinc was assigned a minimum weight of 1 because of its insignificant importance. Weights between 1 and 5 were assigned to other parameters, such as Electrical Conductivity (EC), pH, Total Dissolved Solids (TDS), Calcium (Ca_2), Magnesium (Mg_2), Chloride (Cl^-), Sulphate (SO_4^-), Nitrate (NO_3), Total Hardness (TH), Potassium (K), Bicarbonate (HCO_3), Sodium (Na) Fluorides (F^-), and Iron (Fe), based on their relative importance in the water quality assessment. The present investigation for F and Fe was given more weightage because of their impact more in the study area.

Secondly, the chemical parameter's relative weight (Wi) was computed using the following equation:

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i}$$

On summation of all selected parameters unit weight factor Wn = 1 (unit).

Step 2

Calculation of Quality rating (Qi) values by using formula.

$$Qi = \frac{Ci}{Si} \times 100$$

Where

Ci = Mean concentration of the n^{th} parameter.

Si = Standard desirable value of the n^{th} parameter.

Vo = Actual values of the parameter in the pure water (Generally, Vo = 0, for most of the parameters except pH and Turbidity)

$$QpH = \frac{\text{VpH} - 7}{8.5 - 7} \times 100$$

Step 3

Calculation of Sub-index (SIi) by using formula:

$$SIi = Wi \times Qi$$

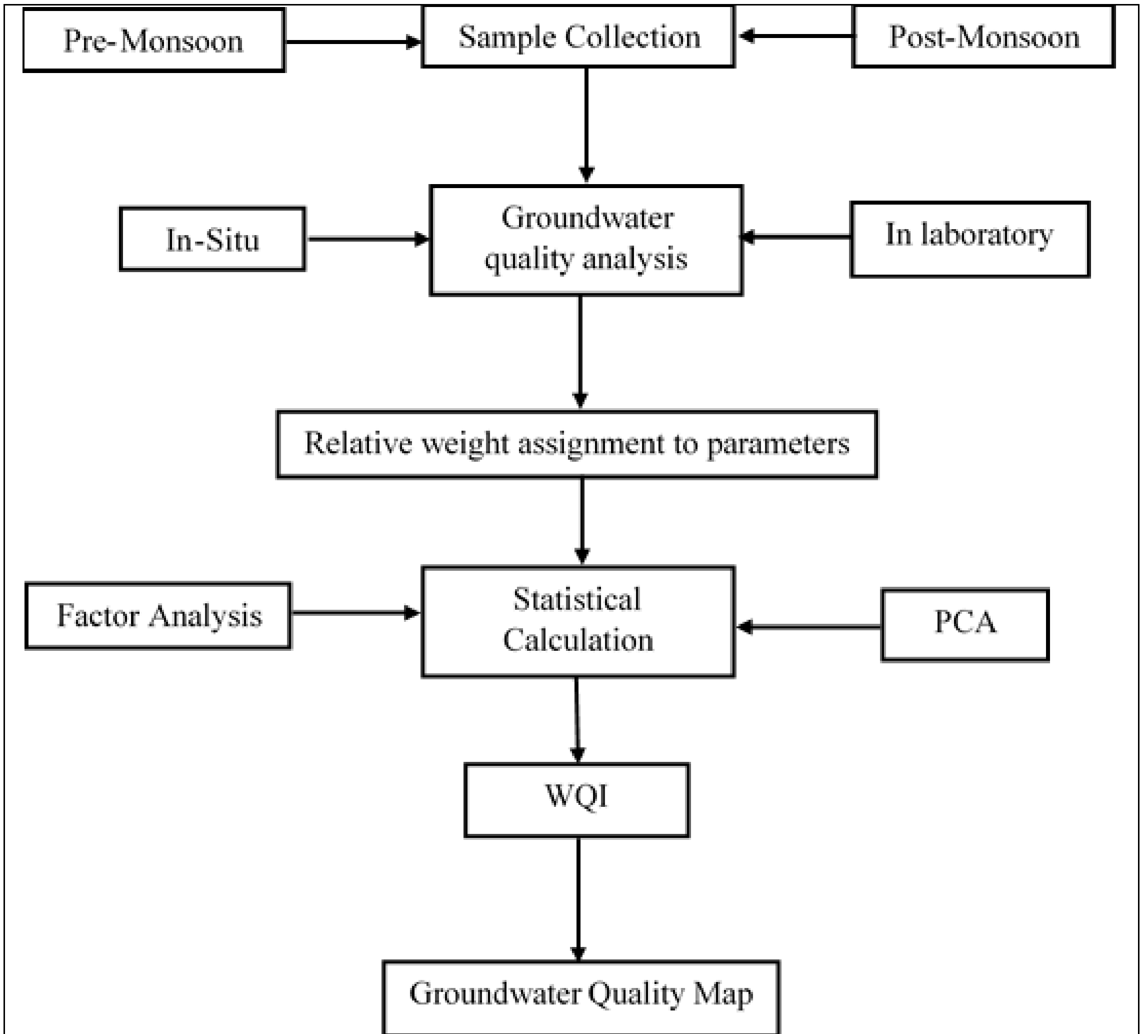


Fig. 16 Flow chart

Step 4

Combining step-2 and step-3. WQI is calculated as follows:

$$WQI = \sum SI\text{i-n}$$

Present study assessment of groundwater for drinking was carried using 14 relevant parameters, then using WQI water was classified. WQI is one of the best tools which work effectively in understanding groundwater quality (Mishra and Patel, 2001; Subba Rao, 1997). By comparing the WQI analytical results to the disclaimers established by the Indian Standards, the groundwater was evaluated for anthropogenic consumption (BIS 2012). The range of ionic concentration of groundwater in Table 2 and the standard of drinking water set by Indian standards is mentioned in Table 1. Classification of groundwater into five classes based on the WQI values (Table 11) and type of groundwater for each groundwater sample is given (Table 10).

Table 11 Classification of WQI					
WQI Range	Class of water	No. of samples			
		Pre-monsoon	%	Post-monsoon	%
0-25	Excellent	35	36.84	56	58.94
26-50	Good	27	28.42	16	16.84
51-75	Poor	9	9.47	9	9.47
76-100	Very Poor	4	4.21	10	10.52
>100	Unfit	20	21.05	4	4.21

In the present analysis, the calculated values of WQI range from 5.42 to 357.51 in the pre-monsoon and 2.52 to 225.97 in the post-monsoon samples. Groundwater was classified into five categories from ‘‘excellent water’’ to ‘‘unfit water for drinking’’. The number of samples of each class and their percentage are given in tale. 11. Geographically study area can be classified as Malenadu and Maidana. Water quality during the pre-monsoon period in Malenadu is excellent to good but in Maidana water qualityis deteriorating, same consequences repeat in the post-monsoon period also but the concentration of minerals is low as compare to the pre-monsoon period. Due to leaching of minerals samples show a higher concentration of ions. The spatial variation in WQI in the pre-monsoon as well as post-monsoon samples is given in figures 15 & 16

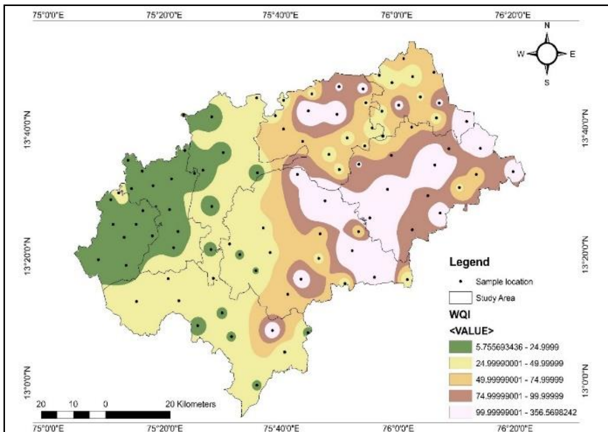


Fig. 15 Spatial distribution of WQI premonsoon

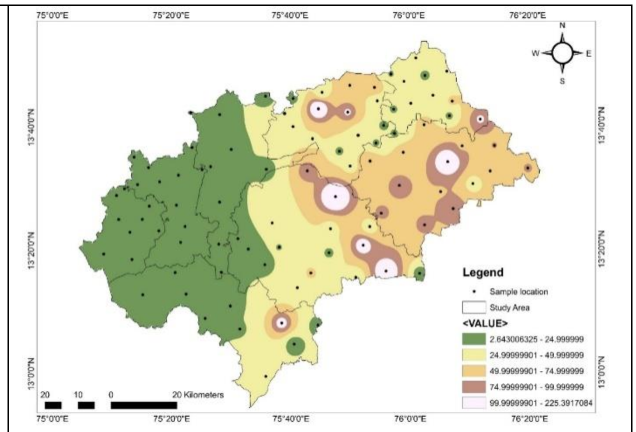


Fig. 16 Spatial distribution of WQI post-monsoon

CONCLUSION

To gain a quick overview of the data and understand the variation in the groundwater quality, descriptive statistics and various themes were used. To better infer the data, Pearson's correlation matrix was constructed using the scatter matrix graph. The correlation matrix is useful because it shows the relationship between variables and the function of each parameter. For groundwater quality, the correlation coefficient and factor analysis using PCA demonstrated that geological processes are important factors, such as weathering, industrial discharges, organic matter, and fertilizers from agricultural activities and dissolution of minerals which determine the quality of groundwater.

Water Quality Indices indicate the overall water quality status of groundwater in the study area. It is necessary to identif and maintain the quality of groundwater for sustainable growth. Allocate resources for drinking water depending on the quality of the groundwater. In the study area, the WQI changes over time indicating a decline in the quality of groundwater. The GIS application was used to create several digital theme maps, according to the analysis of the data generated at different phases of the work. The descriptive statistics and WQI suggest that priority should be given to water quality monitoring and its management in semi-arid areas like Kadur, Tarikere, and the parts of chikamagaluru taluks. Most of the population in the plain area depend on groundwater for drinking.

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Table 10 Water quality index values for groundwater samples.

Sl. No.	Location	Pre-monsoon		Post-monsoon		Sl. N0.	Location	Pre-monsoon		Post-monsoon	
		WQI Value	Remark	WQI Value	Remark			WQI Value	Remark	WQI Value	Remark
1	Jannapura	23.91	Excellent	10.70	Excellent	25	Kalasapura	306.09	Unfit	59.89	Poor
2	Gowthahalli	17.07	Excellent	11.96	Excellent	26	K B Hal	29.00	Good	13.10	Excellent
3	Hosakere	22.35	Excellent	27.16	Good	27	Mavinahalla	55.31	Poor	35.38	Good
4	Kottgehara	16.91	Excellent	38.50	Good	28	Sirivase	42.18	Good	35.46	Good
5	Durgadahalli	43.81	Good	11.79	Excellent	29	Aladagudde	138.5	Unfit	53.03	Poor
6	Mudigere	48.70	Good	19.96	Excellent	30	Lakya	984.41	Unfit	34.13	Good
7	Hornadu	29.04	Good	18.23	Excellent	31	Kichevi	28.95	Good	10.19	Excellent
8	Nidduvale	20.94	Excellent	13.25	Excellent	32	Chikkamagaluru	38.11	Good	18.13	Excellent
9	Innare	21.73	Excellent	22.48	Excellent	33	Magadi	32.03	Good	23.99	Excellent
10	Kuduremuka	131.5	Unfit	17.63	Excellent	34	Kabbinasethuve	52.31	Poor	41.41	Good
11	Balagere	12.02	Excellent	9.71	Excellent	35	Uddeboranahalli	45.15	Good	23.52	Excellent
12	Kerekatte	66.74	Poor	4.60	Excellent	36	Sangameshwarapetd evadana	20.41	Excellent	9.05	Excellent
13	Nemmaru	7.39	Excellent	3.69	Excellent	37	Avathi	39.85	Good	24.1	Excellent
14	Sringeri	9.15	Excellent	4.05	Excellent	38	HosapetTogarihankl u	357.51	Unfit	225.41	Unfit
15	Kavadi	19.36	Excellent	5.19	Excellent	39	Kesavinamane	184.13	Unfit	99.47	Very Poor
16	Begar	46.86	Good	2.74	Excellent	40	kanathi	21.81	Excellent	15.73	Excellent
17	Kigga	12.33	Excellent	11.59	Excellent	41	Mathigatta	90.61	Very Poor	73.64	Poor
18	Kuntur	13.18	Excellent	9.71	Excellent	42	Yagati	89.47	Very Poor	72.90	Poor
19	Asanabalu	13.16	Excellent	8.26	Excellent	43	Hochigalli	111.89	Unfit	75.68	Very Poor
20	Hariharapura	22.26	Excellent	12.02	Excellent	44	Antharagatta	107.75	Unfit	52.86	Poor
21	Kalkere	19.33	Excellent	9.43	Excellent	45	hogarehalli	105.03	Unfit	77.32	Very Poor
22	Jayapura	16.44	Excellent	10.09	Excellent	46	Uligere	62.55	Poor	52.61	Poor
23	Guddethotha	18.43	Excellent	10.27	Excellent	47	Sakkarayapattana	162.79	Unfit	84.07	Very Poor

24	Koppa	22.47	Excellent	8.13	Excellent	48	Singatigere	42.48	Good	33.50	Good
49	Kudregundi	17.69	Excellent	8.64	Excellent	77	Tarikere	162.46	Unfit	109.08	Unfit
50	Kammaradi	17.90	Excellent	5.43	Excellent	78	Saraswathipura	154.6	Unfit	96.70	Very Poor
51	Shanuvalli	17.44	Excellent	9.49	Excellent	79	Hadikere	103.88	Unfit	57.71	Poor
52	Siddaramata	21.47	Excellent	14.99	Excellent	80	Hunsanghatta	44.00	Good	33.79	Good
53	Bhandigadi	11.65	Excellent	2.52	Excellent	81	Mundre	46.81	Good	19.06	Excellent
54	Magudi	31.53	Good	6.81	Excellent	82	DoddaKunduru	69.27	Poor	35.82	Good
55	Balehonnur	19.19	Excellent	7.42	Excellent	83	Sevalal Nagar	28.25	Good	16.00	Excellent
56	Seethur	10.62	Excellent	4.46	Excellent	84	Sasuvehalli	26.63	Good	16.94	Excellent
57	N R Pura	14.57	Excellent	6.42	Excellent	85	attigatta	28.50	Good	22.16	Excellent
58	Muttinakoppa	10.25	Excellent	8.34	Excellent	86	Veerapura	25.03	Good	18.17	Excellent
59	Chikka Agrahara	17.03	Excellent	9.47	Excellent	87	Mugali	43.52	Good	36.67	Good
60	Varkate	5.42	Excellent	9.35	Excellent	88	Koratikere	21.45	Excellent	19.72	Excellent
61	Munduvalli	12.7	Excellent	8.97	Excellent	89	Mudigere	28.70	Good	17.81	Excellent
62	Byrapura	24.6	Excellent	14.07	Excellent	90	Yalambaise	248.73	Unfit	186.2	Unfit
63	Lakkavalli	35.6	Good	24.06	Excellent	91	Panchanahalli	106.57	Unfit	76.13	Very Poor
64	GanteKaneve	35.3	Good	23.92	Excellent	92	Jadakanakatte	113.63	Unfit	98.91	Very Poor
65	Cheeranahalli	52.58	Poor	40.94	Good	93	Hirenalluru	71.89	Poor	57.22	Poor
66	Beeranahalli	64.12	Poor	43.86	Good	94	Birur	76.17	Very Poor	64.74	Poor
67	Ajjampura	118.8	Unfit	39.49	Good	95	Nidagatta	91.62	Very Poor	80.78	Very Poor
68	Nandi	27.97	Good	23.25	Excellent	74	Chowlahiriyur	191.3	Unfit	106.2	Unfit
69	Shivapura	24.68	Excellent	17.41	Excellent	75	Guddadamallenalli	122.5	Unfit	75.79	Very Poor
70	Udevu	33.97	Good	39.45	Good	76	Sambainur	54.84	Poor	36.30	Good
71	Duglapura	224.4	Unfit	77.51	Very Poor						
72	Chikkanvangla	33.81	Good	34.53	Good						
73	Sokke	34.12	Good	19.58	Excellent						

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