Asian Journal of Chemistry; Vol. 33, No. 11 (2021), 2645-2652

ASIAN JOURNAL OF CHEMISTRY

https://doi.org/10.14233/ajchem.2021.23378

A Study on Distribution of Water Quality Parameters in Potable/Ground Waters of Visakhapatnam Coastal Region with Multivariate Factor Analysis

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Received: 20 June 2021; *Accepted*: 30 July 2021; *Published online*: 20 October 2021; AJC-20543

Chemical components of the earth crust influence the ground water quality. In addition, anthropogenic activities also contribute in deteriorating the quality of ground waters and contaminate the water sources. In present study, 22 water samples were collected from the potable/ground water sources in south coastal region of Visakhapatnam district, India during pre- and post-monsoon seasons and characterized for physico-chemical parameters *viz.*, pH, electrical conductivity (EC), total dissolved solids (TDS), salinity, oxidation reduction potential (ORP), dissolved oxygen (DO), temperature, total hardness (TH), total alkalinity (TA), bicarbonate, carbonate, chloride, fluoride, sulphate, nitrate, phosphate, calcium, magnesium, sodium and potassium. The distribution of parameters was explained by Box-Whisker plot. Further Piper diagrams were drawn to identify the geochemical expressions between the parameters. Multivariate factor analysis was used to assess the degree of factor loadings and to identify the group of parameters influencing the variance of different water quality parameters. The analytical data indicated that majority of water samples in the study area have higher concentration of TDS, TH, TA, Ca^{2+}, Mg^{2+}, Na^+, Cl^-, HCO_3^- and F^-.

Keywords: Groundwater, Water quality parameters, Distribution, Factor analysis.

INTRODUCTION

Coastal regions are the ecological transition zones between the ocean and continent with an interface of natural and human activities. Hectic activities of sea shore transportation and industrial developments will have impacts on the ground water quality in the coastal areas. Deterioration of groundwater quality in coastal aquifers is a common and serious problem [1]. In rural areas, groundwater normally polluted due to agricultural activities and excessive usage of chemical fertilizers, which generally become the major source for nitrate contamination [2]. In urban coastal regions, the urban environment is a major cause for groundwater contamination [3-6]. The research results revealed the aquifer mineralogy is another main source for variation of hydro-geochemical characteristics of groundwater sources in the Alleppey District, India. Study on hydrochemistry and evaluation of groundwater quality in the Markandeya river basin, Belgaum district, India revealed that changes in groundwater chemistry are due to rock weathering and reverse ion exchange processes [7]. Interactions of soil-rock-water contribute different chemical constituents, like calcium, magnesium, sodium and potassium ions to the groundwater were originated by weathering and dissolution of plagio-clase and orthoclase feldspars and ferromagnesium minerals [8,9]. Associated weathered basement complex of biotite is a probable source of fluoride [10]. High fluoride ion concentration in drinking water implies health risks to around 200 million people in the world from 25 nations [11]. Ground water quality deterioration is being affected by land use patterns, geological formation, rain fall pattern and infiltration rate [12]. Seawater intrusion may contribute to the elevated levels of Na^+ and Cl^- ions in coastal groundwater [13]. Multivariate analysis is employed by several researchers [14-16] to evaluate the ground water quality. For assessment of hydro-geological aspects and potability of ground water multivariate analysis and principal component analysis can be applied [17-19].

Keeping in view the geological aspects of coastal region of Visakhapatnam district of India and also the anthropogenic activities, the waters collected were characterized for physico-chemical parameters in this present study. Multivariate factor analysis was also applied to assess the loadings of various parametric values to identify the influencing parameters.

EXPERIMENTAL

Study area: The study areas identified for the present research are located in Narsipatnam revenue division of Visakhapatnam District, India. For sampling the study area was divided into grids with a dimension of 6 km × 6 km and the sample was collected more particularly from the centre of the grid. Around 22 potable/ground water samples were collected from each grid during pre and post-monsoon seasons of the year 2018. The sampling locations, source of water along with coordinates are presented in Table-1 and the sampling map is shown in Fig. 1.

Sampling and analysis: Pre-acid cleaned bottles were used to collect water samples. Physico-chemical parameters *viz.*, pH, EC, TDS, salinity, temperature (multi parameter tester, make: Eutech, Model-PCS Tester35), ORP (ORP tester, Eutech, Model-PCS Tester35), DO (DO meter, make: Thermo scientific Model-Orion 3 star), hardness, alkalinity, calcium, magnesium, fluoride, chloride, nitrate, sulphate, phosphate, sodium and potassium were determined as per BIS & WHO protocols [20,21].

The distribution of parametric values in pre- and post-monsoon seasons was explained by box-whisker plots. Hydrogeochemistry of waters was assessed by Piper diagram. Correlation matrix was prepared for the correlation analysis.

Factor analysis: Hydrochemistry can be assessed by using statistical tool to derive the factor loadings by Multivariate factor analysis. The water quality parameters were used as variable inputs, the data was standardized according to criteria [22]. The procedure renders factor pattern in which each factor was described in terms of only those variables and affords greater ease for interpretation. The degree of closeness between the variables has been explained by factor loadings, which indicate the interdependence of the parameters that can influence the water quality.

TABLE-1
SAMPLING LOCATIONS AND THEIR COORDINATES

Location details	GPS Coordinate (WGS 84, decimal)		Source of water
	Latitude	Longitude	
Haripalem	17.60691	82.97782	Bore well
Atchutapuram	17.56698	82.97846	Bore well
Bhogapuram	17.55676	82.99141	Bore well
Kandipudi	17.29688	82.54439	Bore well
Satyavaram	17.32510	82.58963	Bore well
Guntapalli	17.36413	82.59753	Open well
Nellipudi Village	17.36802	82.65841	Open well
N.Narsapuram	17.38415	82.70567	Bore well
Nakkapalli	17.41189	82.72235	Bore well
Pedadoddigallu	17.43581	82.68887	Bore well
Godicharla	17.39379	82.62064	Bore well
Pulaparthy	17.48577	82.78634	Bore well
Purushottapatnam	17.50378	82.79408	Bore well
Regupalem	17.51840	82.81421	Open well
Yelamanchali	17.54845	82.85768	Bore well
Theruvupalli	17.52025	82.87272	Open well
Rambilli	17.46525	82.92682	Bore well
Dibbapalem	17.52805	82.94452	Bore well
S.Rayavaram	17.45286	82.80737	Bore well
Vakapadu	17.44105	82.84974	Bore well
Koruprolu	17.42533	82.75757	Bore well
Chelapuram	17.46752	82.72069	Bore well

By verifying the factor loadings, communalities and eigen values the significance of the major parameters can be evaluated in terms of the total data set and in terms of each factor. Factor loadings with eigen values > 1 were considered.

Geochemical expression using Piper diagrams: Piper diagram is an effective graphic pattern to segregate relevant analytical data to understand the sources of the dissolved consti-

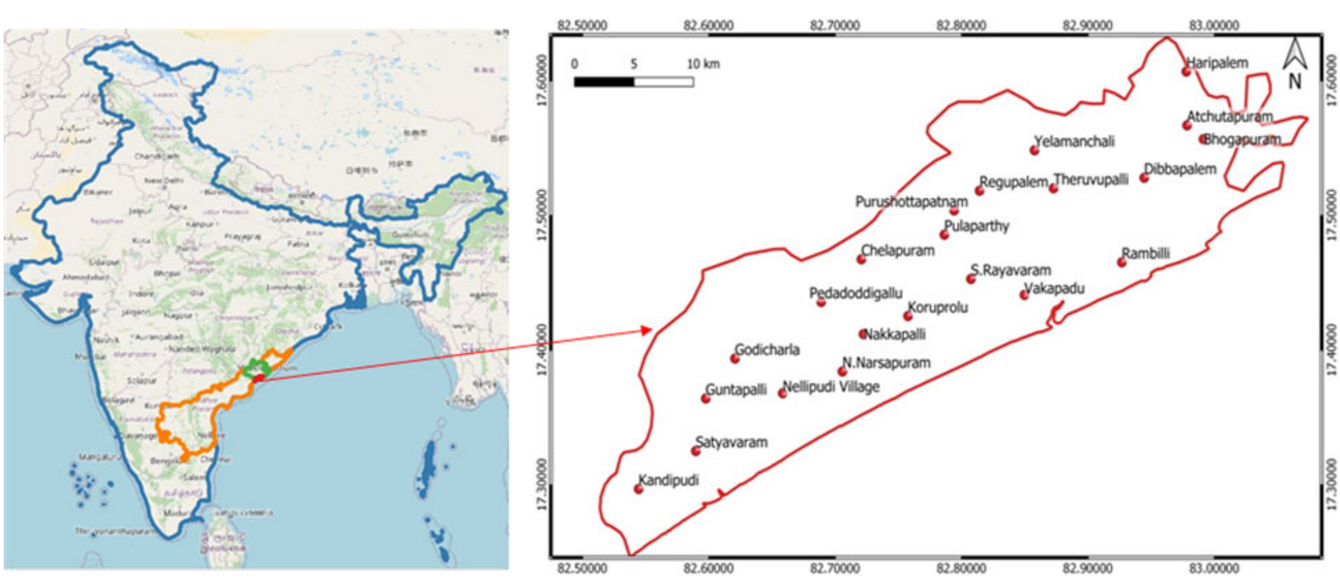

Fig. 1. Study area map [QGIS Software version 3.8]

tuents in water [23]. Most abundant cations of alkaline earths (calcium, magnesium) and alkali (sodium, potassium), most common anions of weak acid (bicarbonate) and strong acids (sulphate, chloride) considered for the classification of geochemical expression.

RESULTS AND DISCUSSION

Measurement of physico-chemical parameters: Details of water quality parametric values during pre- and post-monsoon seasons are summarized in Table-2, the correlation matrix of parametric values is presented in Table-3.

Representation of water quality parameters by Box-Whisker diagrams: The distribution of waters quality parameters with minimum, maximum and mean values along with standard deviation have been explained by Box-Whisker plot and described in Figs. 2-6.

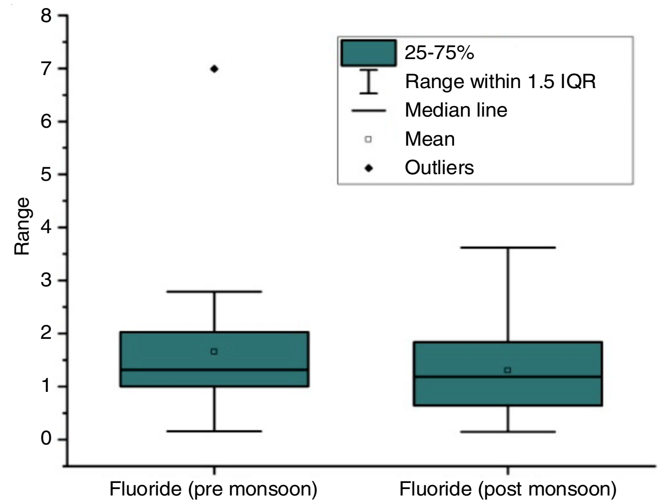

Fig. 3. Distribution of fluoride

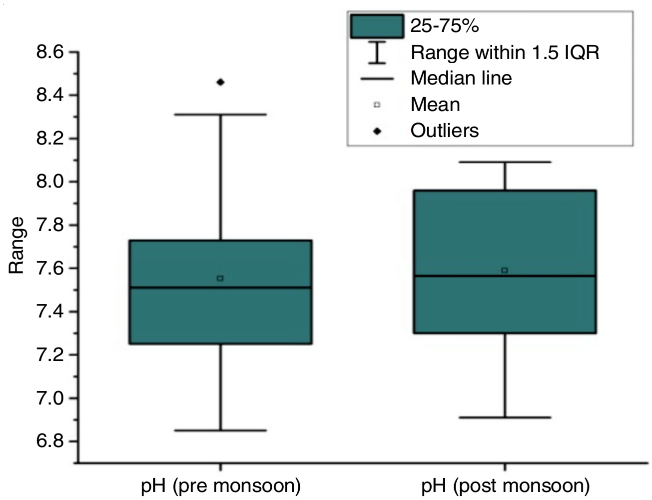

Fig. 2. Distribution of pH

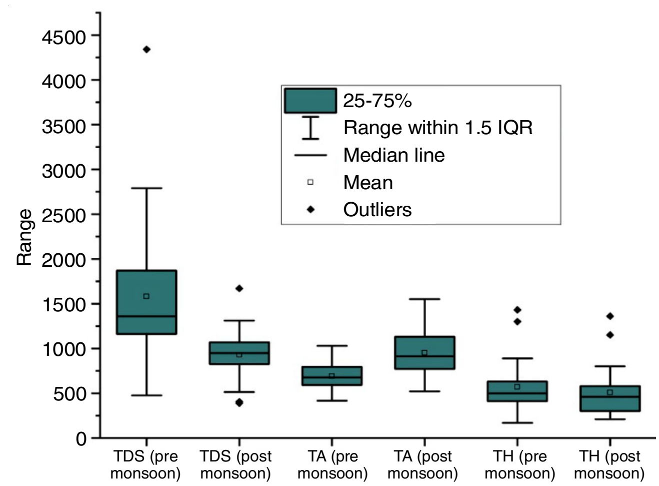

Fig. 4. Distribution of TDS, TA and TH

TABLE-2
PARAMETRIC VALUES DURING PRE AND POST MONSOON SEASONS

Parameter	Pre monsoon					Post monsoon				
	Min	Max	Mean	Med	Std. Dev	Min	Max	Mean	Med	Std. Dev
pH	6.85	8.46	7.55	7.51	0.37	6.90	8.09	7.59	7.57	0.35
EC (μS/cm)	668	6130	2227	1918	1191	546	2350	1297	1318	425
TDS (ppm)	475	4340	1580	1360	844	388	1670	926	949	300
Salinity (ppm)	341	3460	1202	1016	678	278	1190	663	670	216
ORP (mV)	-79	165	95	123	68	40	144	102	102	22
Temp. (°C)	27.5	30.9	29.2	29.2	1.0	25.0	30.4	28.4	28.3	1.1
DO (ppm)	1.02	5.94	3.10	3.24	1.23	0.80	2.94	1.90	1.81	0.56
TH (ppm)	170	1430	569	500	311	210	1360	506	460	298
TA (ppm)	415	1030	690	678	162	520	1550	951	910	262
CO_3^{2-} (ppm)	< DL	36	2.45	< DL	8.42	< DL	< DL	< DL	< DL	< DL
HCO_3^- (ppm)	506.0	1256.6	836.3	811.3	201.0	634.0	1891.0	1160.0	1110.0	320.0
F^- (ppm)	0.16	6.99	1.66	1.32	1.39	0.20	3.62	1.30	1.19	0.91
Cl^- (ppm)	42.5	1864.7	505.0	356.3	449.0	49.0	1140.0	385.2	310.5	303.0
NO_3^- (ppm)	11.7	947.0	146.9	82.7	99.5	14.0	508.0	127.9	84.8	121.0
SO_4^{2-} (ppm)	25.6	307.3	152.0	138.0	71.8	17.0	281.0	107.2	99.5	70.6
PO_4^{3-} (ppm)	0.10	1.40	0.16	0.10	0.28	< DL	0.99	0.13	0.10	0.19
Ca^{2+} (ppm)	60	188	145.6	152	35.1	28	188	123.3	128	44.2
Mg^{2+} (ppm)	2.44	236.68	49.91	26.84	61.2	2.4	220	48.36	35.38	53.2
Na^+ (ppm)	10.02	66.87	28.59	26.12	16.30	7.17	61.33	26.16	23.77	15.20
K^+ (ppm)	0.28	14.63	3.80	2.03	2.42	0.11	13.17	3.08	1.28	2.94

Min = Minimum; Max = Maximum; Med = Median; Std. Dev. = Standard deviation and < DL: Less than detection limit

TABLE-3
CORRELATION MATRIX OF WATER QUALITY PARAMETERS

Parameter	pH	EC (µS/cm)	TDS (ppm)	Salinity (ppm)	ORP (mV)	Temp. (°C)	DO (ppm)	TA (ppm)	TH (ppm)	F^- (ppm)	Cl^- (ppm)	NO_3^- (ppm)	SO_4^{2-} (ppm)	PO_4^{3-} (ppm)	Ca^{2+} (ppm)	Mg^{2+} (ppm)	Na^+ (ppm)	K^+ (ppm)
Pre monsoon																		
pH	1.00																	
EC (µS/cm)	-0.07	1.00																
TDS (ppm)	-0.07	1.00	1.00															
Salinity (ppm)	-0.03	1.00	1.00	1.00														
ORP (mV)	0.11	-0.06	-0.06	-0.05	1.00													
Temp. (°C)	0.21	-0.40	-0.40	-0.40	-0.12	1.00												
DO (ppm)	0.31	0.14	0.13	0.14	0.50	0.03	1.00											
TA (ppm)	0.03	0.58	0.58	0.58	-0.15	-0.11	0.20	1.00										
TH (ppm)	-0.43	0.80	0.80	0.78	0.09	-0.54	0.02	0.28	1.00									
F^- (ppm)	0.38	-0.17	-0.17	-0.16	-0.07	0.40	-0.06	0.02	-0.39	1.00								
Cl^- (ppm)	0.06	0.95	0.95	0.96	-0.12	-0.37	0.13	0.50	0.69	-0.11	1.00							
NO_3^- (ppm)	-0.16	0.66	0.66	0.67	0.22	-0.37	0.06	0.24	0.66	-0.24	0.58	1.00						
SO_4^{2-} (ppm)	-0.24	0.88	0.88	0.86	-0.05	-0.35	0.13	0.62	0.81	-0.09	0.78	0.44	1.00					
PO_4^{3-} (ppm)	0.10	0.10	0.10	0.10	0.13	-0.20	0.14	0.37	0.03	-0.25	0.02	-0.07	0.24	1.00				
Ca^{2+} (ppm)	-0.66	0.56	0.56	0.52	-0.23	-0.40	-0.09	0.34	0.76	-0.50	0.44	0.22	0.69	0.10	1.00			
Mg^{2+} (ppm)	-0.30	0.80	0.80	0.79	0.19	-0.53	0.05	0.23	0.97	-0.31	0.70	0.74	0.77	0.01	0.60	1.00		
Na^+ (ppm)	-0.11	0.35	0.35	0.33	-0.28	0.11	-0.15	0.26	0.09	0.09	0.36	-0.21	0.42	0.15	0.26	0.02	1.00	
K^+ (ppm)	0.06	0.06	0.06	0.05	0.38	-0.23	0.34	0.07	0.01	-0.42	-0.01	0.00	0.10	0.40	0.12	-0.03	0.14	1.00
Post monsoon																		
pH	1.00																	
EC (µS/cm)	-0.08	1.00																
TDS (ppm)	-0.08	1.00	1.00															
Salinity (ppm)	-0.08	1.00	1.00	1.00														
ORP (mV)	0.05	-0.47	-0.46	-0.47	1.00													
Temp. (°C)	-0.18	-0.10	-0.09	-0.09	-0.10	1.00												
DO (ppm)	0.33	-0.31	-0.31	-0.31	0.23	-0.08	1.00											
TA (ppm)	0.00	0.48	0.49	0.48	0.23	-0.35	-0.02	1.00										
TH (ppm)	-0.65	0.41	0.39	0.41	-0.29	-0.02	-0.25	0.08	1.00									
F^- (ppm)	0.41	0.34	0.34	0.34	-0.02	0.21	0.03	0.43	-0.33	1.00								
Cl^- (ppm)	-0.18	0.84	0.83	0.84	-0.53	-0.03	-0.30	0.18	0.71	0.16	1.00							
NO_3^- (ppm)	-0.49	0.32	0.30	0.32	-0.13	-0.09	-0.17	0.09	0.76	-0.24	0.56	1.00						
SO_4^{2-} (ppm)	-0.47	0.62	0.61	0.62	-0.22	-0.18	-0.30	0.26	0.82	-0.17	0.80	0.58	1.00					
PO_4^{3-} (ppm)	0.06	0.07	0.06	0.06	0.06	-0.68	-0.23	0.20	-0.03	-0.30	-0.04	-0.13	0.11	1.00				
Ca^{2+} (ppm)	-0.65	0.38	0.38	0.38	-0.23	-0.07	-0.29	0.17	0.81	-0.47	0.48	0.53	0.64	0.07	1.00			
Mg^{2+} (ppm)	-0.56	0.36	0.34	0.36	-0.28	0.00	-0.20	0.02	0.96	-0.21	0.72	0.77	0.79	-0.07	0.60	1.00		
Na^+ (ppm)	0.14	0.89	0.88	0.88	-0.31	-0.18	-0.22	0.57	0.31	0.50	0.81	0.32	0.56	0.10	0.19	0.32	1.00	
K^+ (ppm)	-0.01	0.11	0.10	0.11	0.03	-0.48	-0.12	0.15	0.25	-0.41	0.13	0.48	0.21	0.41	0.24	0.22	0.15	1.00

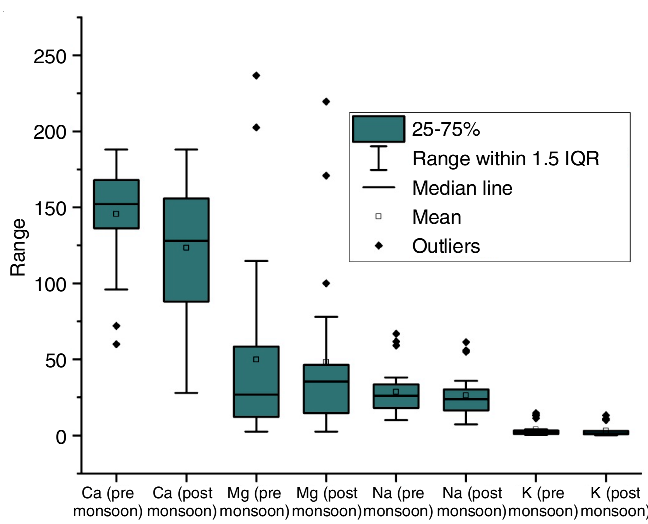

Fig. 5. Distribution of cations

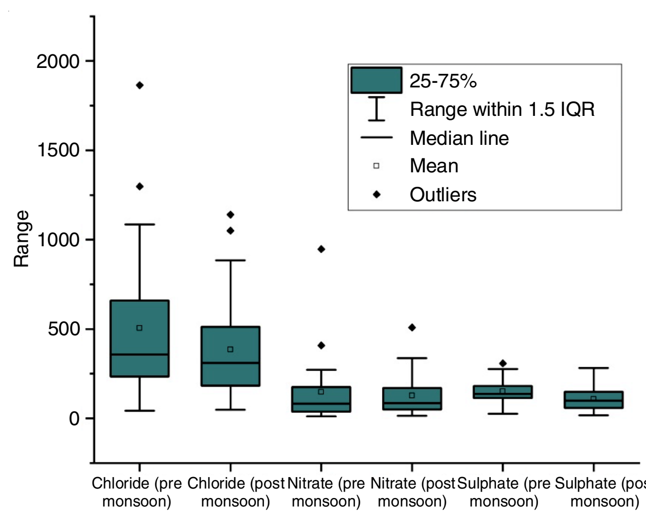

Fig. 6. Distribution of anions

Physico-chemical parameters: pH during pre-monsoon ranges from 6.85-8.46 with an average of 7.55, median value 7.51 and with standard deviation 0.37 while in post-monsoon the pH ranges from 6.90-8.09 with an average value 7.59, median 7.57 and standard deviation 0.35. The pH of waters in both seasons is within the guideline value 6.5-8.5 of BIS and WHO for drinking and domestic purposes [20,21,24].

EC ranges from 668-6130 µS/cm with an average of 2227 µS/cm, median 1918 µS/cm and with a standard deviation value of 1191 µS/cm during pre-monsoon while the EC values during post-monsoon varied from 546-2350 µS/cm with an average of 1297 µS/cm, median 1318 µS/cm and observed standard deviation 425 µS/cm. The higher EC indicates presence of soluble salt content in the waters.

TDS ranges from 475-4340 ppm with an average of 1580 ppm, median 1360 ppm and standard deviation 844 ppm during pre-monsoon season. TDS observed in the range of 388-1670 ppm with an average of 926, median 949 and standard deviation 300. Higher TDS levels show the presence of excessive dissolved solids in the waters.

Salinity during pre-monsoon ranged from 341-3460 ppm with an average 1202 ppm, median 1016 ppm and standard deviation 678 ppm. Salinity of waters in post-monsoon season ranged from 278-1190 with an average of 663 ppm, median 670 ppm and standard deviation 216. These values indicate the occurrence of salts, which are dissolved in the waters.

Oxidation reduction potential (ORP) of waters during pre-monsoon ranged from -79 to 165 mV with an average 95 mV, median 123 and standard deviation 68 mV, while during post-monsoon season it ranged from 40-144 mV with an average 102 mV, median 102 and standard deviation 22 mV. The ORP values imply the oxidation states of the ions, which are in dominant concentration in waters.

Temperature during pre-monsoon ranged from 27.5-30.9 ºC with an average 29.2 ºC, median of 29.2 ºC and standard deviation 1.0, while during post-monsoon season it varied from 25.0-30.4 ºC with an average 28.4 ºC, median 28.3 and standard deviation 1.1.

Dissolved Oxygen (DO) in pre-monsoon season varied from 1.02-5.94 with an average of 3.10 ppm, median 3.24 ppm and standard deviation 1.23 ppm. During post-monsoon season DO ranges 0.80-2.94 ppm with an average 1.90 ppm, median 1.81 and standard deviation 0.56.

Total hardness (TH) ranges from 170-1430 ppm during pre-monsoon season with an average 569, median 500 ppm and standard deviation 311 ppm, while during post-monsoon season the TH value ranges from 210 to 1360 ppm with an average value 506, median 460 and standard deviation 298 ppm. TH of samples in the most of the samples crossed permissible value (200 ppm) [20,21,24].

Total alkalinity (TA) of waters during pre-monsoon season varied from 415-1030 ppm with an average 690 ppm, median 678 and standard deviation 162 ppm. During post-monsoon season it ranges from 520-1550 ppm with an average 951 ppm, median 910 ppm and standard deviation 262 ppm. Most of the TA values are observed to be higher than the guide line value of 200 ppm [20,21,24] for drinking purposes. Carbonate ranges from < DL (less than detection limit) to 36 ppm in the waters during pre-monsoon season with an average 2.45 ppm and standard deviation 8.42 ppm while during post-monsoon season it is observed to be less than the detection limit (DL).

Bicarbonate concentration in waters during pre-monsoon season ranges from 506.0-1256.6 ppm with an average of 836.3 ppm, median 811.3 ppm and standard deviation of 201.0 ppm. During post-monsoon season the bicarbonate ion concentration ranges from 634.0-1891.0 ppm with an average 1160.0 ppm, median 1110.0 ppm and standard deviation 320.0 ppm.

Fluoride ion concentration of waters during pre-monsoon season varied from 0.16-6.99 ppm with an average of 1.66 ppm, median 1.32 ppm and standard deviation 1.39 ppm. During post-monsoon season the fluoride ion concentration values ranges from 0.20-3.62 ppm with an average of 1.30 ppm, median 1.19 ppm and standard deviation of 0.91 ppm.

Chloride ion concentration in waters during pre-monsoon season ranges from 42.5-1864.7 ppm with an average of 505.0 ppm, median 356.3 ppm with standard deviation of 449.0 ppm. During post-monsoon season the chloride ion concentration ranges from 49.0-1140.0 ppm with an average of 385.2 ppm, median 310.5 and standard deviation 303.0 ppm. Chloride ion levels crossed the permissible limit [20,21,24] of 250 ppm during pre- and post-monsoon seasons in majority of samples.

Nitrate ion concentration during pre-monsoon season is observed in the range of 11.7-947.0 ppm with an average of 146.9, median 82.7 ppm and standard deviation 99.5 ppm. During post-monsoon season the nitrate ion concentration varied from 14.0-508.0 ppm with an average of 127.9 ppm, median 84.8 ppm and standard deviation 121.0 ppm. Nitrate ion concentration crossed the permissible value [20,21,24] of 45 ppm for drinking purposes in majority of samples.

Sulphate ion concentration of waters during pre-monsoon season in the study area is observed in the range of 25.6-307.3 ppm with an average of 152.0 ppm, median 138.0 and standard deviation 71.8 ppm. During post-monsoon season the sulphate value are ranging from 17.0-281.0 ppm with an average of 107.2 ppm, median 99.5 ppm and standard deviation 70.6 ppm. The sulphate levels in majority samples are well below the drinking water permissible value of 200 ppm [20,21,24].

Phosphate ion concentration of waters during pre-monsoon season ranges from 0.10-1.40 ppm with an average of 0.16 ppm, median 0.10 ppm and standard deviation 0.28 ppm. During post-monsoon season it varied from < DL-0.99 ppm with an average of 0.13 ppm, median 0.10 ppm and standard deviation 0.19 ppm.

Calcium ion (Ca^{2+}) concentration varied from 60-188 ppm during pre-monsoon season with an average 145.6 ppm, median 152 ppm and standard deviation 35.1 ppm. During post-monsoon season the calcium ion values ranges from 28-188 ppm with an average 123.3 ppm, median 128 ppm and standard deviation 44.2 ppm. The Ca^{2+} levels exceeded the permissible value [20,21,24] of 75 ppm in majority of samples.

Magnesium ion concentration ranges during pre-monsoon from 2.44-236.68 ppm with an average 49.91 ppm, median 26.84 ppm and standard deviation 61.2 ppm while during post-monsoon season Mg^{2+} values ranges from 2.4-220 ppm with an average 48.36 ppm, median 35.38 ppm and standard deviation 53.2 ppm. Majority of waters crossed the permissible value of 30 ppm for drinking purposes [20,21,24].

Sodium ion concentration varied from 10.02-66.87 ppm during pre-monsoon season with an average 28.59 ppm, median 26.12 ppm with standard deviation 16.30 ppm. During post-monsoon season the sodium ion values ranges from 7.17-61.33 ppm with an average 26.16 ppm, median 23.77 ppm and standard deviation 15.20 ppm. The sodium ion concentrations were found to be well within the permissible limit of 200 ppm [24].

Potassium ion concentration values during pre-monsoon ranges from 0.28-14.63 ppm with an average 3.80 ppm, median 2.03 ppm and standard deviation 2.42 ppm while during post-monsoon season K^+ values ranges from 0.11-13.17 ppm with an average 3.08 ppm, median 1.28 ppm and standard deviation 2.94 ppm. The majority of samples were found to have K^+ concentrations within the permissible limit [24] of 12 ppm.

Hydro-geochemical characterization: The ionic concentrations in waters are represented by Piper diagram in Figs. 7 and 8. In pre-monsoon season, the waters were found to be magnesium bicarbonate and calcium chloride type and also with mixed type. In post-monsoon season, majority of waters are magnesium bicarbonate type and calcium chloride type. In pre and post-monsoon seasons the concentration of alkaline earths (Ca^{2+} and Mg^{2+}) significantly exceeded the concentrations of alkalis (Na^+ and K^+) and the acids of bicarbonate and chloride exceeded the sulphate.

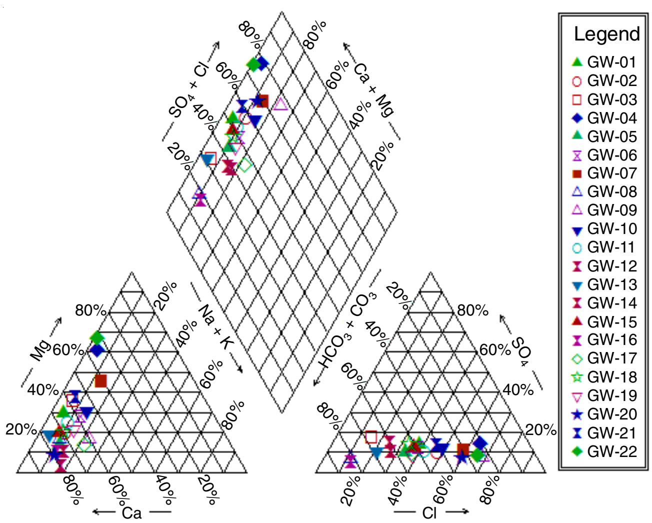

Fig. 7. Piper diagram - pre monsoon

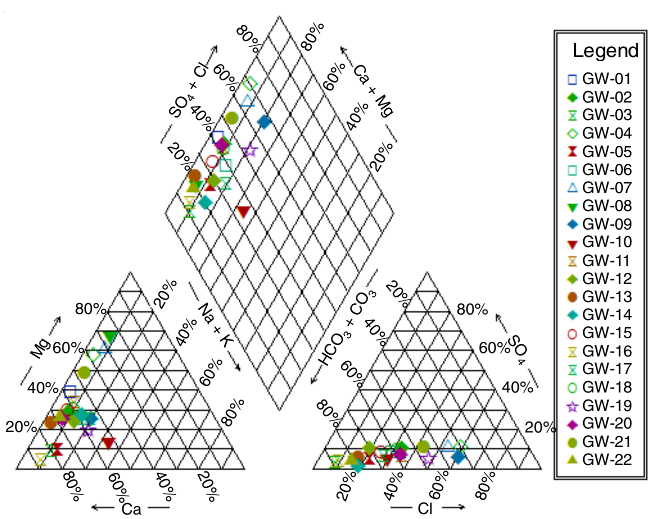

Fig. 8. Piper diagram - post monsoon

Correlation analysis: During pre-monsoon EC values are highly correlated with TDS, salinity, TH, chloride, sulphate and Mg^{2+}, which reveals the magnesium and sulphate ion concentrations are contributing to the higher EC values and corresponding higher TDS and TH. The ORP values are moderately correlated with DO values, which shows the dependence of oxidation reduction potential of the elements on aeration conditions *i.e.* in the presence of dissolved oxidation. Total hardness is strongly correlated with sulphate, Ca^{2+} and Mg^{2+}. Chloride ion concentration is moderately correlated with sulphate and Mg^{2+} while both nitrate and sulphate ion concentrations are moderately correlated with Mg^{2+}. Hence, in pre-monsoon season it was observed that Mg^{2+} is the major cation, which is highly correlated with the majority of other water quality parameters. In post-monsoon, EC is highly correlated with TDS, salinity, chloride and sodium indicating that sodium and chloride ion are contributing more for the higher EC, TDS and salinity. Total hardness (TH) was highly correlated with sulphate, Ca^{2+} and Mg^{2+} and moderately correlated with chloride and nitrate. Chloride ion concentration is highly correlated with Na^+. Chloride, nitrate, sulphate ion concentrations are moderately correlated with Mg^{2+}. In post-monsoon season, Na^+ and Mg^{2+} ionic concentrations are correlated with other water quality parametric values to a maximum extent.

Factor analysis: The total data of water quality parameters in pre- and post-monsoon seasons are reduced into factor loadings with eigen values > 1 and are presented in Tables 4 and 5. All the factor loadings are represented by Scree plot as shown in Figs. 9 and 10.

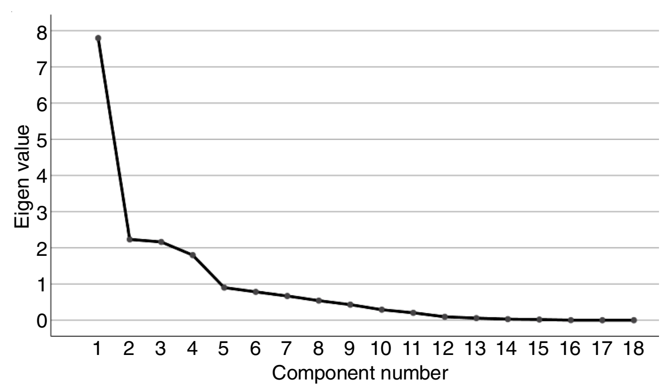

Fig. 9. Scree plot- pre monsoon

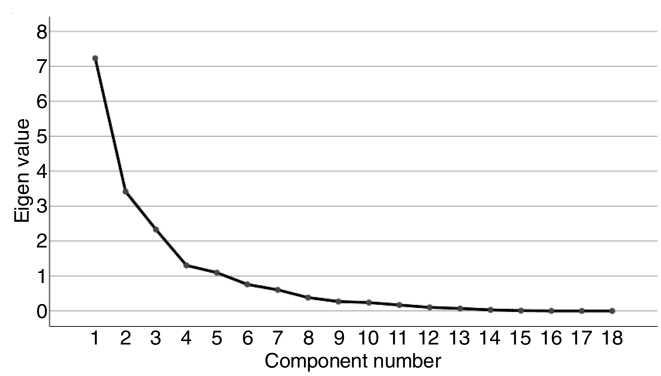

Fig. 10. Scree plot- post monsoon

Pre-monsoon: During pre-monsoon season four factors explained the total variance of 77.7%. Factor-1 accounts for 39.6% of the variance and loaded heavily with EC, TDS,

TABLE-4
FACTOR PATTERN OF WATER QUALITY PARAMETERS

Parameter	Factor-pre monsoon				*FC	Factor-post monsoon					*FC
	F-1	F-2	F-3	F-4		F-1	F-2	F-3	F-4	F-5	
pH	0.0	0.8	0.2	-0.2	0.7	0.2	-0.7	0.2	-0.1	0.5	0.9
EC (µS/cm)	1.0	-0.1	0.1	0.1	1.0	0.9	0.2	0.0	0.0	-0.1	1.0
TDS (ppm)	1.0	-0.1	0.1	0.1	1.0	0.9	0.2	0.0	0.0	-0.2	1.0
Salinity (ppm)	1.0	-0.1	0.1	0.1	1.0	0.9	0.2	0.0	0.0	-0.2	1.0
ORP (mV)	0.0	0.1	0.4	-0.7	0.7	-0.4	-0.1	0.1	0.8	0.1	0.8
Temp. (°C)	-0.4	0.5	-0.2	0.3	0.5	-0.1	0.0	-0.9	-0.2	-0.1	0.8
DO (ppm)	0.2	0.3	0.5	-0.4	0.6	-0.2	-0.1	0.0	0.1	0.8	0.7
TA (mg/L)	0.6	0.2	0.3	0.4	0.6	0.5	0.0	0.2	0.8	0.0	0.9
TH (mg/L)	0.8	-0.5	-0.1	-0.1	0.9	0.2	0.9	0.0	-0.1	-0.1	1.0
F^- (ppm)	-0.1	0.7	-0.4	0.2	0.7	0.6	-0.5	-0.4	0.3	0.2	0.9
Cl^- (ppm)	0.9	0.0	0.0	0.1	0.9	0.8	0.5	0.0	-0.3	0.0	1.0
NO_3^- (ppm)	0.7	-0.2	-0.2	-0.5	0.8	0.2	0.8	0.1	0.0	0.2	0.8
SO_4^{2-} (ppm)	0.9	-0.2	0.2	0.2	0.9	0.5	0.7	0.1	0.0	-0.1	0.8
PO_4^{3-} (ppm)	0.0	-0.1	0.7	0.2	0.6	0.0	-0.1	0.8	0.1	-0.4	0.8
Ca^{2+} (ppm)	0.5	-0.7	0.1	0.3	0.9	0.1	0.8	0.1	0.0	-0.4	0.8
Mg^{2+} (ppm)	0.8	-0.4	-0.1	-0.3	0.9	0.2	0.9	0.0	-0.1	0.1	0.9
Na^+ (ppm)	0.3	0.0	0.2	0.7	0.7	1.0	0.1	0.1	0.1	0.1	0.9
K^+ (ppm)	0.0	-0.2	0.8	-0.1	0.7	0.0	0.3	0.8	0.0	0.1	0.7

*FC = Final communalities

TABLE-5
EIGEN VALUES AND VARIANCE OF FACTOR PATTERN

Parameter	Factor-pre monsoon				Factor-post monsoon				
	F-1	F-2	F-3	F-4	F-1	F-2	F-3	F-4	F-5
Eigen values	7.8	2.2	2.2	1.8	7.2	3.4	2.3	1.3	1.1
Variance	7.1	2.7	2.1	2.0	5.5	4.8	2.3	1.4	1.3
Variance (%)	39.6	15.1	11.7	11.4	30.5	26.8	12.9	7.8	7.4
Cumulative (%)	39.6	54.7	66.4	77.7	30.5	57.3	70.1	78.0	85.4

salinity, TH, chloride, sulphate and Mg^{2+} (Table-3) indicating their inter-association. Factor-2 accounts for 15.1% of variance and loaded with pH and F^-. This factor indicates the inter-dependence of these parameters. Factor-3 accounts for 11.7% and is represented by the loadings of dissolved oxygen and phosphate. Factor-4 accounts 11.4% of total variance and is loaded with sodium ion concentration.

Post-monsoon: In post-monsoon season, five factor loadings were obtained with total variance of 85.4%. Factor-1 accounts for 30.5% of the variance and is loaded with EC, TDS, salinity, chloride and sodium (Table-3) indicating EC, TDS and salinity are mainly driven by sodium and chloride. Factor-2 accounts for 26.8% of total variance and loaded with TH, nitrate, sulphate, calcium and magnesium. This factor indicates the group of ions associated with hardness of waters. Factor-3 accounts for 12.9% and loaded with phosphate and potassium and is inversely correlated with temperature. Factor-4 accounts for 7.8% of variance and loaded with ORP and TA. Factor-5 accounts for 7.4% of total variance and is loaded with DO.

Factor analysis indicates much of the variance is explained by Factor-1 mainly due to EC, TDS and salinity in both the data sets. Phosphate is not found to have any correlation and is identified as a separate factor (Factor-3) along with potassium, leading to a separate source or geochemical process. When pH and F is increasing Ca^{2+} and Mg^{2+} is decreasing and *vice versa* which is indicated by Factor-2. Decrease in ORP values with the increase in Na^+ is indicated by Factor-4 in pre-monsoon. Variation of DO is separately explained by Factor-5 in post-monsoon. The factor loadings indicate the significant parameters causing variance in the observations made in pre-monsoon and post-monsoon season.

Conclusion

The analytical results indicated higher mean values of cations during both pre and post-monsoon season in the order of $Ca^{2+} > Mg^{2+} > Na^+ > K^+$. The anionic concentrations during pre-monsoon season was in the order of $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^-$ but in post-monsoon season the order was $HCO_3^- > Cl^- > NO_3^- > SO_4^{2-}$. pH of waters during pre and post-monsoon were found to be within the permissible limit. Higher ionic concentrations of Ca^{2+}, Mg^{2+}, Na^+, Cl^-, HCO_3^- and F^- were observed in majority of waters. Box-whisker plot of calcium, sodium, magnesium, potassium, chloride, nitrate, sulphate and fluoride with outliers indicated the variation in distribution of chemical species. Piper diagrams confirmed that majority of waters were of magnesium-bicarbonate type. Correlation matrix explained the strong correlation between EC and TDS and magnesium correlation with majority of other parameters. Multivariate factor analysis indicated higher loadings of EC, TDS, salinity, TH, chloride, sulphate and magnesium during pre-monsoon and significant loading of EC, TDS, salinity, chloride and sodium in post-monsoon. The data further confirmed the variation and inter dependence of these water quality parameters, which can explain the groundwater chemistry. It is expected that the comprehensive data generated in this study will serve as a baseline to monitor contamination levels of water sources in the study area region.

ACKNOWLEDGEMENTS

The authors sincerely acknowledge the financial support from Board of Research in Nuclear Sciences (BRNS), Department of Atomic Energy (DAE), Mumbai, India for the present research programme.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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