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Assessment of Groundwater Quality and its Suitability for Drinking and Irrigation in and around Sanchi, Madhya Pradesh, India.

KEYWORDS: Water quality, Groundwater, hydrochemistry, Hydrology, Pre-monsoon, Post-monsoon, Piper's trilinear, Wilcox's diagram, US salinity Diagram, Kelley's Index

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ABSTRACT *Assessment of suitability of groundwater for domestic and irrigation purposes was carried out in and around Sanchi region which is located 46 km north east of Bhopal and falls in Raisen District, Madhya Pradesh, India. The study area covers an area of 317 km2. Groundwater is the major source for domestic and agricultural activities in this area. The study emphasized on groundwater for physical and chemical characteristics, to assess the potability of samples collected from 16 wells during pre-monsoon and post-monsoon periods for the year 2012. The analytical parameters of data were compared with the standard guidelines recommended by the (WHO, 1984) and (BIS, 1991). Suitability of groundwater for irrigation was evaluated based on salinity hazard, sodium percent, sodium adsorption ratio, residual sodium carbonate, Wilcox's diagram and Kelley's Index. The hydrochemistry of the groundwater of the study area indicates the alkaline earth (calcium and magnesium) exceeds the alkalies (sodium and potassium), weak acids exceed (HCO3 + CO3) strong acids (chloride, sulphate and nitrate), Carbonate hardness exceeds 50% and no one cation anion pair exceeds 50%. Groundwater samples were found to be fit for drinking and agricultural purposes.*

Introduction

Water resources have played a critical and vital role throughout the history in the growth and development of human civilization. These water resources include surface as well as sub-surface water. Sub-surface water which occurs beneath the water table in the soils and geologic formation that are fully saturated constitutes groundwater. Understanding of the hydraulic properties of aquifer and hydrochemical characteristics of groundwater are crucial for understanding the assessment, planning and management of groundwater of the area. Generally, the movement of groundwater along its flow paths below the ground surface increases the concentration of the chemical species (Freeze and Cherry, 1979; Domenico and Schwartz, 1990; Kortatsi, 2007). Hydrochemical evaluation of groundwater systems is usually based on the availability of a large amount of information concerning groundwater chemistry (Aghazadeh and Mogadam, 2004; Hossien, 2004). Hence, the groundwater chemistry could reveal important information on the geological history of the aquifers and its suitability for domestic, industrial and agricultural purposes.

Water quality depends upon a number of factors, such as general geology, degree of chemical weathering of the various rock types, quality of being recharged water and inputs from sources other than water rock interaction. Such factors and their interactions result a complex groundwater quality (Domenico and Schwartz, 1990; Guler and Thyne, 2004; Vazquez sunne *et al.*, 2005). Several researchers have carried out groundwater quality suitable mapping in the GIS environment (Champidi *et al.*, 2011; Singh *et al.*, 2011; Magesh *et al.*, 2012). The surface water which directly enters groundwater region has a large number of contaminants result from the human activities and also due to spillage, or disposal of pesticides, fertilizers petroleum hydrocarbons, industrial chemicals, and waste products. Rapid increase in population of a country has led to a large scale groundwater development in some areas. India is one among those countries in which population has increased at a faster rate. The effect of this population growth is felt in every region in general and also in the present area. Hence, groundwater has become an important source of water for drinking, agriculture and industrial uses. The present study is an attempt to assess the quality of groundwater. For the quality assessment and hydrochemical characters of the groundwater system have been observed for pre-monsoon and post-monsoon period separately and presented in (**Table 1** and **Table 2)**.

Geology of the area

Geological successions exposed in this region ranging in age from Late Proterozoic (Vindhyan Supergroup) to Cretaceous- Eocene age (Deccan Trap). The main lithounits of Vindhyan Supergroup comprise of sandstone, limestone and shales. The Deccan Volcanics present in the form of lava flows and its weathered residue as black cotton soil, laterite and it is extensively overlained by alluvium of Recent Age (DRM, 2002).

Materials and Methods

The method of collection of water samples in the field is an important aspect for maintaining the high degree of accuracy of analysis and its use in quality studies. For the purpose of collection of water samples from wells narrow mouth, air tight lid, polyethylene bottles of one litre capacity were used. The bottles were properly cleaned and rinsed with distilled water. At the time of sample collection the bottles were again rinsed with the water to be sampled. The bottles were completely filled upto the brim, its cork was also rinsed and the outer lid was fixed tightly to avoid any leakage and to avoid exposure to air and were labeled systematically.

Total sixteen groundwater samples were collected from shallow and deep dug-wells and hand-pumps at different locations of the study area during pre-monsoon and post-monsoon periods for 2012 (**Fig. 1**). Water samples were analyzed in the laboratory for various physico-chemical

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parameters. The pH and Electrical Conductivity (EC) were measured using digital pH meter and Conductivity metre. Collected water samples were also analyzed in the laboratory for the major cations and anions (Ca, Mg, Na, K, HCO_3, CO_3, SO_4, Cl and F) using the standard methods as suggested by the APHA (1998). Sodium (Na) and Potassium (K) were determined by Flame Photometer. Total Hardness (TH) as $CaCO_3$, Calcium (Ca), Carbonate (CO_3), Bicarbonate (HCO_3) and Chloride (Cl) were analyzed by volumetric methods. Magnesium (Mg) was calculated from TH and Ca contents. Sulfates (SO_4) as estimated using the Nephelometer. Nitrate (NO_3), and Fluoride (F) were determined by double beam UV- VIS spectrophotometer. Geochemical plots were made using AquaChem v.2010.1 software for the representation of groundwater quality of the study area.

Results and Discussion

Physical Characters of Groundwater

Colour of water indicates the presence of organic materials in aquifer from which it is exploited. The colour of water can be observed by naked eye. All groundwater samples collected from the study area are colourless as observed by naked eye. Groundwater samples collected from the present study area are generally tasteless and odourless. No specific type of taste or odour has been noticed in the groundwater of the area. All the groundwater samples of the study area are free from any turbidity. At the time of collection of water samples in the field the temperature was measured with the help of thermometer. The field temperature ranges from 25° to 27° C which is a normal value.

Suitability for drinking and domestic uses

Understanding of the chemical quality of groundwater is important before it is supplied for the drinking and domestic purposes. Hence the geochemical parameters were analyzed for the groundwater and compared with the specifications by WHO (1984) and Bureau of Indian Standard (1991) (**Table 1-3**).

pH: The hydrogen ion concentration in the pre monsoon water samples varies from 6.2 to 7.78 with an average of 7.47 and in post monsoon it varies from 6.5 to 7.5 with an average of 7.06 indicating that the water is slightly alkaline in nature and all the samples of both the seasons fall within the BIS recommended limit for human consumption.

EC: The measured values of electrical conductivity of the groundwater samples of the present area ranges from 78 m mhos/cm to 299 m mhos/cm.

TDS: In the present area the total dissolved solids (TDS) ranges between 50 mg/l to 191 mg/l in pre-monsoon and 50 mg/l to 162 mg/l in post monsoon, which is within the highest desirable limit of WHO and BIS.

Calcium: The calcium occurs in water naturally and found alone in nature also. The calcium was found to be in the range of 40 mg/l to 224 mg/l in pre-monsoon and 28 mg/l to 192 mg/l in post-monsoon water samples and compared with WHO (1984) and BIS (1991) found to be more than the highest desirable limit.

Magnesium: Magnesium is washed from rocks and subsequently ends up in water. Although magnesium in water also has some other sources like chemical industries etc. Magnesium content of the ground water samples ranges from 7.2 mg/l to 180 mg/l in pre- monsoon and 12 mg/l and 91.2 mg/l in post-monsoon season respectively which is also found more than highest desirable limit recommended by WHO and BIS.

Sodium: Sodium ranks sixth among the elements in order of abundance and is present in most of natural waters. Sodium is generally found in lower concentration than Ca and Mg in freshwater. The concentration of Na is varied from 26.7 mg/l to 70.4 mg/l in pre-monsoon and 23 mg/l to 80.5 mg/l in post-monsoon respectively. The maximum permissible limit of sodium is 200 mg/l and it reveals that all the water samples are within the permissible limit of WHO.

Potassium: Potassium is a naturally occurring element; however, its concentration remains quite lower compared with other cations like Ca, Mg and Na. The concentration of K is observed between 1.2 mg/l to 4.3 mg/l in pre-monsoon and 0.78 mg/l to 4.2 mg/l in post-monsoon from the groundwater samples.

Bicarbonate: The value of HCO_3 is observed from 120 mg/l to 460 mg/l in pre-monsoon and 120 mg/l to 390 mg/ l in post-monsoon samples which is found to be in the maximum permissible limit of WHO and BIS. The higher concentration of HCO_3 in the water, points to the dominance of mineral dissolution (Stumm and Morgan 1996).

Sulphate: The Sulphate content in the present study area is within the maximum permissible limit prescribed by BIS and WHO for both the seasons water samples.

Chloride: Chloride content of the groundwater samples ranges from 25 to 425 mg/l in Pre-monsoon and 22 to 460 mg/l in post-monsoon, which is within the maximum permissible limit.

Nitrate: The nitrate concentration ranges from 0 mg/l to 8 mg/l in pre-monsoon and 0 to 2.9 mg/l in post-monsoon season which is within the highest desirable limit. The source of nitrate in area is N fertilizers (commonly urea, nitrate or ammonium compounds) that are used in agricultural practices.

Total Hardness: The total hardness is varying from 100 mg/l to 560/l mg in pre-monsoon and 70 mg/l to 480 mg/l in post-monsoon groundwater samples of the entire study area lies within the maximum permissible limit prescribed by WHO and BIS standards. Sawyer and McCarty (1967) classified groundwater, based on TH, as ground water with TH <75, 75–150, 150–300 and >300 mg/l, designated as soft, moderately hard, hard and very hard, respectively and According to the above categorization The total hardness is varying from 130 mg/l to 894 mg/l in pre-monsoon and 120 mg/l to 860 mg/l in post-monsoon groundwater samples. According to the above categorization, only one water sample falls in moderately hard category and majority of samples fall in hard and very hard category in both seasons. The hardness of the water is due to the presence of alkaline earths such as calcium and magnesium.

Suitability for irrigation uses

Ayers and Westcot (1985) proposed that the total salt concentration, sodium percentage, residual carbonate, sodium adsorption ratio and Kelley's Index are the important parameters used for assessing the suitability of water for irrigation uses.

Sodium percent (Na %): The sodium in irrigation waters is usually denoted as percent of sodium. According to Wilcox (1955), in all natural waters, Na% is a common parameter to assess its suitability for irrigational purposes. The sodium percent (Na %) values were obtained by using the following equation:

Na%=Na+ K ×100/[Ca+Mg+Na+K]

Where all ionic concentrations are expressed in meq/l. The Wilcox diagram relating sodium percent and total concentration shows that 100% of the groundwater samples of the study area fall in the field of excellent to good category in both the seasons **(Fig. 2)**.

Sodium adsorption ratio (SAR): Sodium adsorption ratio (SAR) is also an important parameter for determining the suitability of groundwater for irrigation uses because it is a measure of alkali/sodium hazard to crops. SAR is defined by Karanth as equation

SAR=Na/[(Ca+Mg)/2]1/2

Where all ionic concentrations are expressed in meq/l. The SAR values ranges in the water samples of present area from 0.69 to 2.72 in pre-monsoon and 0.707 to 1.995 in post monsoon. According to the Richards (1954) classification based on SAR values (**Table 4)**, all the groundwater samples of the present area belong to the excellent category (**Table 5).**

The analytical data plotted on the US Salinity Diagram (Richards, 1954) illustrates that the groundwater fall in the field of C1-S1 to C2-S1 classes for both the premonsoon and postmonsoon seasons indicating that water belongs to good category (**Fig. 3).**

Residual carbonate (RC): Residual carbonate has been calculated to determine the hazardous effect of carbonate and bicarbonate on the quality of water for agricultural purpose by the equation.

RC= (CO3 +HCO3) - (Ca+ Mg)

Where all ionic concentrations are expressed in meq/l. The classification of irrigation water based on RC values (Table 4), groundwater of study area is of excellent category in both the seasons for agriculture purpose (Table 5).

Kelley's Index (KI): Kelley *et al.*, (1940) demonstrate that water is suitable for irrigational purpose, if the value of Kelley's ratio is less than unity, if the value of this ratio is beyond 2, the water becomes unsuitable, while the limit between 1 and 2 is marginal for irrigational purposes.

(KI) = Na / (Ca+Mg)

Where all ionic concentration are expressed in meq/l.

KI value in the study area varied from 0.12 to 1.18 in pre-monsoon and 0.12 to 0.42 in post monsoon with an average of 0.33 in pre-monsoon and 0.30 in post-monsoon. The study reveals that the value of Kelley's Index is less than unity in all the groundwater samples except only one sample falls in the range between 1 and 2 showing its marginal nature in pre-monsoon season (**Table 5)**

Hydrochemistry

The values obtained from the groundwater samples were analyzed and their plot on the Piper's diagrams (Piper, 1944) revealed that the dominant cation present in these waters is Ca and the anion is HCO_3.The result of Piper's plot of the groundwater of the study area also indicates that alkaline earth (calcium and magnesium) exceeds the alkalies (sodium and potassium), weak acids exceed (HCO_3 + CO_3) strong acids (Chloride, Sulphate and Nitrate), Carbonate hardness exceeds 50% and no one cation anion pair exceeds 50% (**Fig. 4).**

Conclusion

The groundwater of the study area is fresh, hard to very hard. The sequence of the abundance of the major ions is in the order: Ca > Mg > Na > K and HCO3 > SO4 >Cl. Alkaline earths slightly exceed alkalis ,weak acids exceed strong acids and carbonate hardness exceeds 50% and no one cation anion pair exceeds 50% .

On the basis of above physio-chemical characteristics of sub-surface waters, it is concluded that the natural water of the present area is fit for drinking. Moreover, the values of SAR, Wilcox diagram, US Salinity diagram, RC and Kelley's Index (KI) concludes that the collected groundwater samples were suitable for irrigation purposes.

Acknowledgement

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Table 1: Hydrogeochemical characteristics of groundwater of the area (Pre-monsoon data, 2012).

Well No.	Village	pH	EC	TDS	CO_3	HCO_3	Na	NO_3	SO_4	TH	Ca H	Mg H	Ca	Mg	K	Cl	F
1	Salamatpur	7.5	195	124.8	NIL	300	45.3	NIL	275	820	520	300	208	72.9	3	270	NIL
2	Sunari	7.56	156	99.84	NIL	240	26.7	4	21	180	110	70	44	17.01	2	45	NIL
3	Dhaknagaon	6.2	78	49.92	NIL	120	70.4	6	37	130	100	30	40	7.29	3	55	NIL
4	Sanchi	7.61	266	170.2	NIL	410	36.6	NIL	333	530	370	160	148	38.88	2	250	NIL
5	Rangai	7.7	182	116.5	NIL	280	49.5	NIL	15	300	160	140	64	34.02	3	50	NIL
6	Vidisha	7.65	144	92.16	NIL	222	49.5	2	8.5	240	160	80	64	19.44	4	35	NIL
7	Vidisha A	7.54	286	183	NIL	440	54.9	NIL	301	704	496	208	198	50.54	2	310	NIL
8	Beshnagar	7.67	299	191.4	NIL	460	62.5	6	275	468	280	188	112	45.68	2	180	NIL
9	Chirkhera	7.15	221	141.4	NIL	340	65.2	8	219	894	560	334	224	81.16	2	425	NIL
10	Karaiya	7.78	283	181.1	NIL	436	55.7	2	32	346	200	146	80	35.48	3	63	NIL
11	Sugankhedi	7.66	182	116.5	NIL	280	63.2	7	212	560	300	260	125	63.18	4	180	NIL

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12	Ucher	7.72	143	91.52	NIL	220	45.6	3	109	300	210	90	84	21.87	2	100	NIL
13	Mendki	7.4	188	120.3	NIL	290	43.2	NIL	17	260	140	120	56	29.16	3	30	NIL
14	Mehgaon	7	179	114.6	NIL	276	34.3	6	55	316	220	96	88	23.33	2	55	NIL
15	Chaupra	7.49	171	109.4	NIL	264	39.9	6	77	280	220	60	88	14.58	2	80	NIL
16	Gehunkhedi	7.68	221	141.4	NIL	340	45.9	4	5	336	210	126	84	30.62	2	25	NIL

Table 2: Hydrogeochemical characteristics of groundwater of the area (Post-monsoon data, 2012).

Well No.	Village	pH	EC	TDS	CO_3	HCO_3	Na	NO_3	SO_4	TH	Ca H	Mg H	Ca	Mg	K	Cl	F
1	Salamatpur	7	169	108.2	NIL	260	33.3	1.1	120	760	420	340	168	81.6	1	310	NIL
2	Sunari	7.5	182	116.5	NIL	280	49.5	0.25	80	360	180	180	72	43.2	3.2	130	NIL
3	Dhaknagaon	6.5	78	49.92	NIL	120	70.4	0.15	16	120	70	50	28	12	2.6	22	NIL
4	Sanchi	7.1	240	153.6	NIL	370	35.4	NIL	230	440	250	190	100	45.6	1.4	200	NIL
5	Rangai	7.1	180	115.2	NIL	280	49.5	0.2	22	310	150	160	60	38.4	3.2	60	NIL
6	Vidisha	7.2	156	99.84	NIL	240	26.7	0.15	11	270	160	90	64	21.6	1.9	28	NIL
7	Vidisha A	7	201	128.6	NIL	310	46	0.78	243	720	430	290	172	69.6	2.8	400	NIL
8	Beshnagar	7	247	158.1	NIL	380	67	0.2	190	350	170	180	68	43.2	2.3	210	NIL
9	Chirkhera	7.1	149	95.36	NIL	230	46	1.1	176	860	480	380	192	91.2	2.8	460	NIL
10	Karaiya	7	221	141.4	NIL	340	45.9	1.5	42	260	140	120	56	28.8	2.3	63	NIL
11	Sugankhedi	7	188	120.3	NIL	290	63	2.9	160	530	300	230	120	55.2	3.5	245	NIL
12	Ucher	7.2	120	76.8	NIL	186	47	0.8	74	260	180	180	72	43.2	3.2	110	NIL
13	Mendki	7	149	95.36	NIL	290	49.5	NIL	83	300	230	70	92	16.8	4.3	35	NIL
14	Mehgaon	7.1	195	124.8	NIL	300	45.3	1.5	23	300	230	70	92	16.8	2.3	60	NIL
15	Chaupra	7	253	161.9	NIL	390	36.1	1.8	114	460	300	160	120	38.4	1.2	105	NIL
16	Gehunkhedi	7.1	104	66.56	NIL	280	30	1	118	280	160	180	64	43.2	1	28	NIL

Table 3: Comparison of Groundwater quality parameters of the study area with WHO (1984) and BIS (1991).

S.No.	Water Quality Parameters Units	WHO (1984)		BIS (1991)		Average values of parameters in study area	
		Highest Desirable Limit	Maximum Permissible Limit	Highest Desirable Limit	Maximum Permissible Limit	Pre-monsoon	Post-monsoon
1	Ph	7.0	8.5	6.5	8.5	7.47	7.06
2	TDS(mg/l)	500	1500	500	2000	128	113.25
3	Calcium(mg/l)	75	200	75	200	106.7	96.3
4	Magnesium(mg/l)	30	150	30	100	44.8	43.05
5	Potassium(mg/l)	-	-	-	-	2.473	2.378
6	Sodium(mg/l)	-	200	-	-	49.7	46.3
7	Bicarbonate(mg/l)	200	800	200	600	307.4	284.1
8	Chloride(mg/l)	200	600	250	1000	134.6	154.2
9	Sulphate(mg/l)	200	400	200	400	124.5	106.4
10	Nitrate(mg/l)	50	100	45	100	3.37	0.84
11	Flouride(mg/l)	0.6	1.5	1.0	1.5	0	0
12	Total Hardness	500	600	300	600	266	411

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Table 4 .Classification of groundwater for irrigation based on EC, SAR & RC (Richards, 1954).

Quality of water	EC µmhos/cm	SAR in meq/l.	RC in meq/l.
Excellent	<250	<10	<1.25
Good	250-750	10–18	1.25-2.50
Doubtful	750-2250	18–26	>2.5
Unsuitable	>2250	>26	

Table 5: Computed values of Na%, SAR & RC in the study area in both the seasons.

SAMPLE.NO.	PRE-MONSOON				POST-MONSOON			
	Na %	SAR	RC	KI	Na %	SAR	RC	KI
1	11.032	0.69	-11.5	0.12	32.524	1.995	-10.93	0.36
2	25.149	0.89	0.4	0.32	37.5	1.342	-2.60	0.33
3	54.605	2.72	-0.6	1.18	32.467	0.982	-1.93	0.28
4	13.3625	0.69	-3.7	0.15	31.304	1.390	-2.63	0.33
5	27.133	1.27	-1.4	0.36	38.554	1.193	-1.60	0.34
6	32.034	1.42	-1.2	0.45	26.230	1.069	-1.06	0.34
7	14.806	0.90	-6.9	0.17	22.435	1.304	-9.31	0.24
8	22.9115	1.25	-1.9	0.29	32.008	1.557	-0.77	0.42
9	13.896	0.936	-12.3	0.16	15.153	0.682	-13.42	0.12
10	26.558	1.28	0.2	0.35	29.993	1.238	0.373	0.38
11	16.936	1.02	-9.4	0.20	24.454	1.190	-5.84	0.26
12	25.340	1.156	-2.4	0.33	27.359	1.077	-4.15	0.28
13	27.351	1.18	-0.4	0.36	25.097	1.243	-1.24	0.36
14	19.273	0.84	-1.9	0.23	23.592	1.137	-1.08	0.33
15	21.720	0.955	-2.1	0.27	17.452	0.732	-2.80	0.17
16	23.469	1.09	-1.1	0.30	22.795	0.707	-2.20	0.19

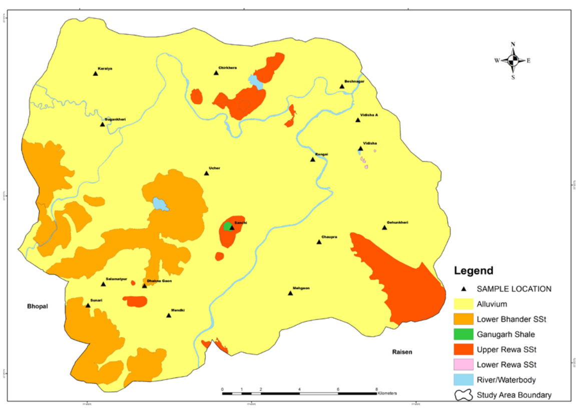

Fig.1: Groundwater Sample Location and Geological Map of the study area.

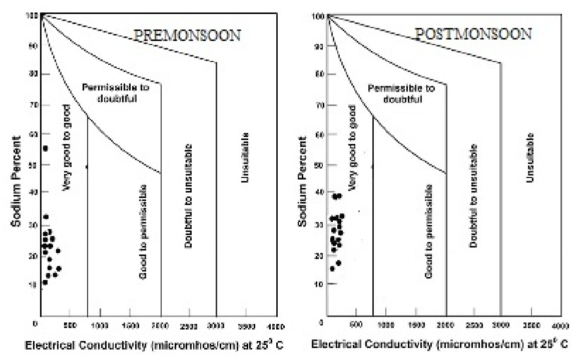

Fig. 2: Wilcox diagram for classification of groundwater quality based on total salt concentration and sodium percent for irrigation purpose (Pre–monsoon & Post-monsoon Data).

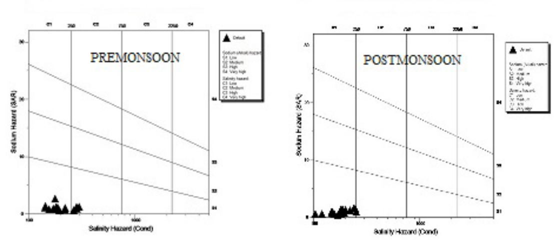

Fig. 3: US- Salinity Diagram (Pre-monsoon & Post-monsoon).

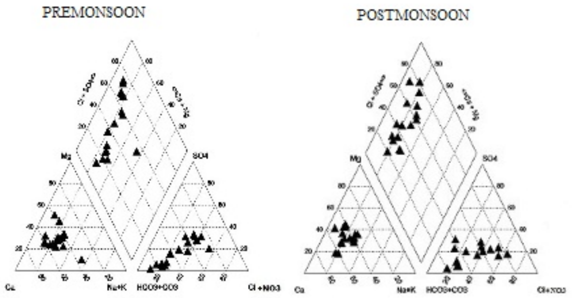

Fig. 4: Chemical facies of groundwater in Piper's diagrams (Pre-monsoon & Post-monsoon).

REFERENCE
• Aghazadeh, N. and A.A. Mogadam (2004). Evaluation effect of geological formation on groundwater quality in the Harzandat plain aquifer. Sym. Geosciences Iran, Vol. 22: 392-395. | • APHA (1998). Standard methods for the examination of water and wastewater, 20th Edition, American Public Health Association. Washington, D.C. | • Ayers, R.S. and Westcot, D.W. (1985). Water quality for irrigation. FAO Irrigation and drainage paper no.20, REV. 1 FAO Rome. | • BIS (1991). Drinking water specifications. Bureau of Indian Standard IS. 10500. | • Champidi, P., Stamatis, G. and Zangana, E. (2011). Groundwater quality assessment and Geogenic and Anthropogenic effect estimation in Erasinos basin, East Attica. Eur. Water, 33: 11-27. | • DRM (2002). District resources map, Raisen district, Madhya Pradesh Geological Survey of India, Kolkata. | • Domenico, P.A. and Schwartz, F.W. (1990). Physical and chemical hydrogeology, John Wiley and Sons, New York: pp. 824. | • Freeze, R.A. and Cherry, J.A. (1979). Groundwater, Prentice-Hall, Englewood Cliffs, NJ, USA. | • Guler, C. and Thyne G.D. (2004). Hydrologic and geologic factors controlling surface and groundwater chemistry in Indian Wells-Owens Valley area, Southeastern California USA. Jour. Hydrol., 285: 177-98. | • Hossien, M.T. (2004). Hydrochemical evaluation of groundwater in the Blue Nile Basin, eastern Sudan, using conventional and multivariate techniques. Hydrogeol. Jour., 12: 144-58. | • Karanth, K.R. (1987). Groundwater assessment, development and management, Tata McGraw Hill, New Delhi: pp.720. | • Kelley, W.P., Brown, S.M. and G.F. (Jr.) Leibig (1940). Chemical effects of saline irrigation waters on soils, 49: pp. 95-107. | • Kortatsi, B.K. (2007). Hydrochemical framework of groundwater in the Ankobra Basin, Ghana, Aquatic Geochemistry, 13(1): 41-74. | • Magesh, N.S., Chanderasekar, N. and Soundranayam, J.P. (2012). Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, GIS and MIF techniques. Geoscience Frontiers, 3(2): 189-96. | • Piper, A.M. (1944). A graphic procedure in the geochemical interpretation of water-analyses, Trans. Amer. Geophy. Union, 25: pp. 914-23. | • Richards, L. A. (1954). Diagnosis and improvement of saline alkali soils: Agriculture, Handbook, US Department of Agriculture, Washington DC, Vol. 60, pp. 160,. | • Sawyer, C.N. and McCarty, P.L. (1967). Chemistry of sanitary engineers, 2nd ed., McGraw Hill, New York, pp. 518. | • Singh, A.K., Tewary, B. K. and Sinha, A. (2011). Hydrochemistry and quality of groundwater in part of Noida metropolitan city Uttar Pradesh, India. Journal of the Geological Society of India, 78(6): 523-40. | • Stumm, W. and Morgan, J.J. (1996). Aquatic chemistry. Wiley, New York, p 1022 | • Vazquez Sunne, E., Sanchez Vila, X. and Carrera J. (2005). Introductory review of specific factors influencing urban groundwater, an emerging branch of hydrogeology, with reference to Barcelona, Spain. Hydrogeol. Jour., 13: 522-33. | • WHO (1984). Guidelines for drinking water quality, Recommendations, World Health Organization, Geneva, Vol. 1, pp. 130. | • Wilcox, L.V. (1955). Classification and use of irrigation water, USDA, Circular, Washington, DC, USA, pp. 969. |