Impact study of climatic variations over the hydrochemical parameters for irrigational use of groundwater in Dharamshala area of Himachal Pradesh, India

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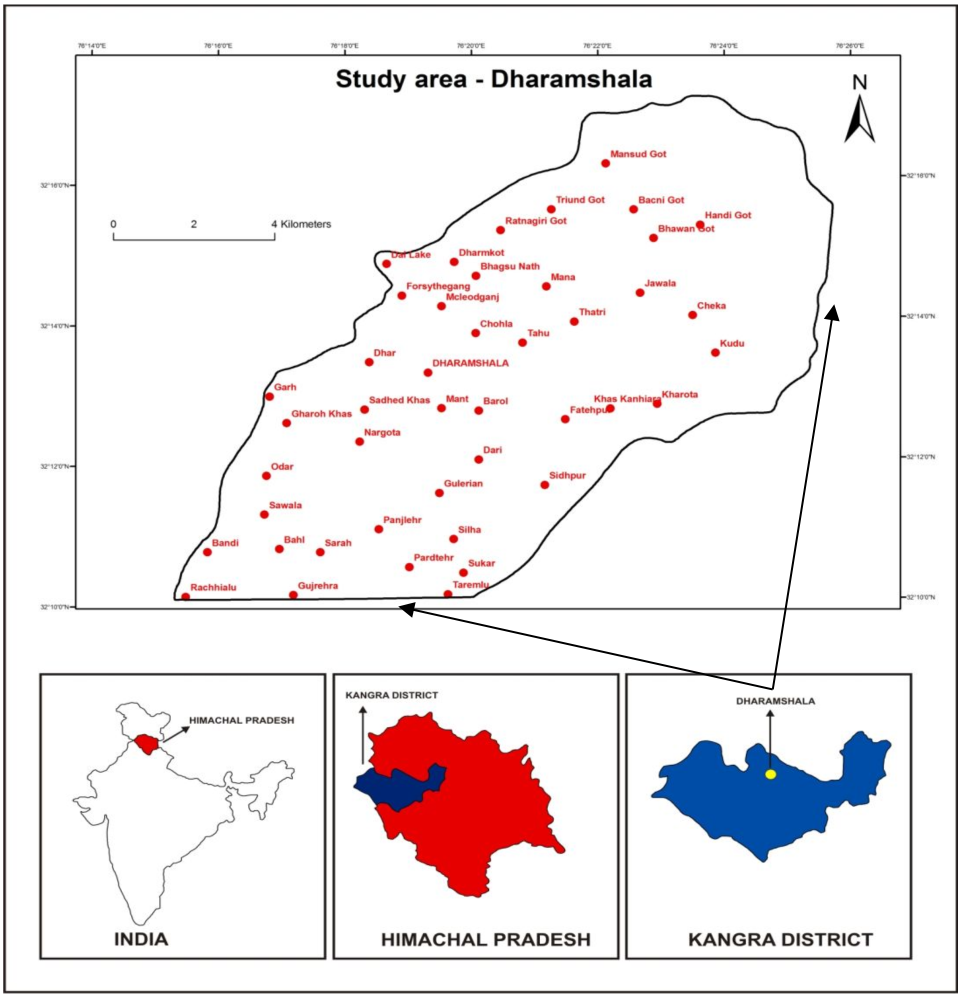
Abstract: *The present study focused on the chemical characteristics of groundwater in Dharamshala area of Himachal Pradesh to analyze its suitability for agricultural purposes. Groundwater samples were collected from seventeen stations of the study area during pre-monsoon (May, 2009) and post-monsoon (October, 2009) seasons and were analyzed for physico-chemical parameters such as pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Calcium (as Ca^{2+}), Magnesium (as Mg^{2+}), Sodium (Na^{+}), Potassium (K^{+}), Carbonate (CO_3^{2-}), Bicarbonate (HCO_3^{-}) , Sulphate (SO_4^{2-}) and Chloride (Cl^{-}). Based on these analyses, parameters like Percent Sodium (% Na), Sodium adsorption ratio (SAR), Residual sodium carbonate (RSC), Kelley's ratio (KR), Magnesium hazard (MH) and Permeability index (PI) were calculated. These indexes for water irrigation were compared with standard limits. The results of irrigational parameters showed that the groundwater of the study area is fit for irrigational purposes during both pre-monsoon and post-monsoon seasons except few sites where the values of % sodium, kelley's ratio, magnesium hazard and permeability index has crossed the acceptable limit and falls under unsuitable category. Presentation of geochemical data in the form of US Salinity diagram and Wilcox Salinity diagram helps to recognize the various hydrochemical types in groundwater system which further helps in assessing its suitability for irrigation purposes. According to the Wilcox diagram, all the water samples fall under excellent to good category during both pre-monsoon and post-monsoon seasons. US Salinity diagram suggests that the majority of the groundwater samples were good for irrigation. The plot of chemical data on Trilinear (Piper) diagram reveals that majority of samples fall in the field of 1, 3 and 5 suggesting that alkaline earth (Ca + Mg) exceeds alkalis (Na + K) and weak acids (CO_3 + HCO_3) exceeds strong acids (SO_4 + Cl) respectively. The ions representing carbonate hardness (secondary alkalinity) exceeds 50%. From the above it can be concluded that total hydrochemistry of groundwater is dominated by alkaline earths and weak acids. The results indicate that Ca-Mg-HCO_3 is the dominant water type during both pre-monsoon and post-monsoon season.*

Keywords: *Groundwater, hydrochemistry, Wilcox diagram, US Salinity diagram, Piper diagram.*

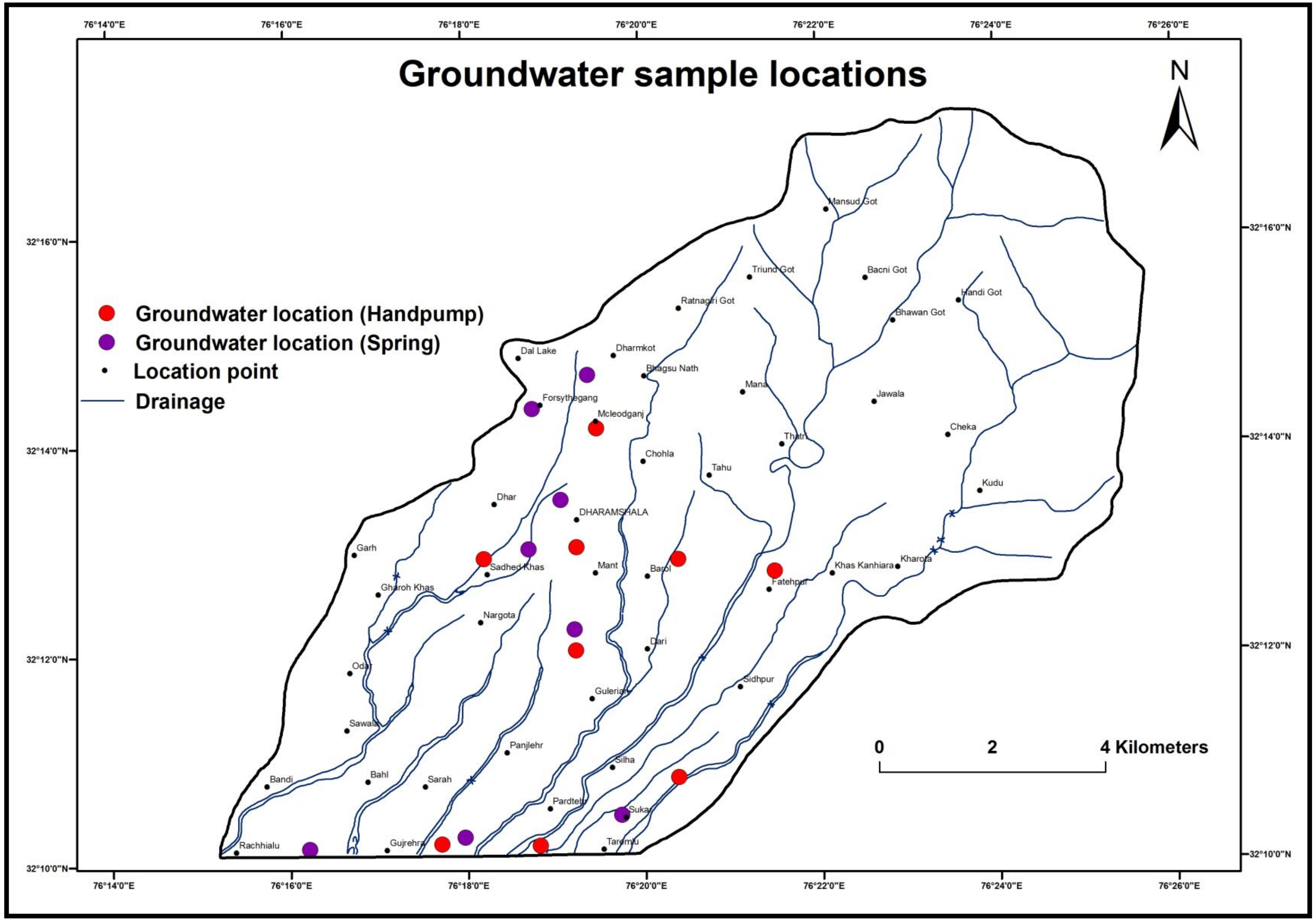
1. Introduction: Water is practically a universal solvent and dissolves some of everything it comes in contact with [1]. Water is life and its quality has direct implication on the health of animals, human beings, yield of crops and even the quality of product whose production in industries utilizes water [2]. An understanding of the chemical quality of groundwater is essential in determining its usefulness for different purposes like domestic, industrial and agricultural purposes. Good quality of water has the potential to cause better crop yields under good soil and water management practices [3]. Each groundwater system in an area is known to have a unique chemistry depending on a number of factors, such as general geology, degree of chemical weathering of the various rock types, quality of recharge water, inputs from the atmosphere, soil and water rock reactions as well as pollutant sources such as mining, land clearance, agriculture, acid precipitation, and domestic and industrial wastes. Such factors and their interactions result in a complex groundwater quality [4-9]. Suitability of water for various uses depends on type and concentration of dissolved minerals and groundwater has more mineral composition than surface water [10]. The quality of groundwater is constantly changing in response to daily, seasonal and climatic factors. Continuous monitoring of water quality parameters is highly crucial because changes in the quality of water have far reaching consequences in terms of its effects on plant growth and human health [11-16]. Water quality data is essential for the implementation of responsible water quality regulations for characterizing and remediating contamination and for the protection of the health of humans and the ecosystem. Regular monitoring of groundwater resources thus plays a key role in sustainable management of water resources [16]. Therefore, any study that can aid in identifying new sources or threats to groundwater is desirous not only around the study area but anywhere. There is no life without water, therefore, it is essential to safeguard the future of our water resources by studying its past and present both quantitatively and qualitatively [17]. Importance of hydrochemistry of groundwater has led to a number of detailed studies on quality of groundwater [18-34]. Important information on the suitability of groundwater for agricultural purposes is revealed from groundwater chemistry [30, 35]. Major chemical elements including calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride, sulphate and nitrate play a significant role in classifying and assessing groundwater quality [36]. Irrigation water criteria take in account some variables such as Total Dissolved Solids (TDS), Percent sodium (% Na), Sodium adsorption ratio (SAR), Residual sodium carbonate (RSC) and Permeability index (PI) [37]. Presentation of geochemical data in the form of graphical charts as the US Salinity diagram and Wilcox salinity diagram help to recognize the various hydrochemical types in a groundwater system. It further helps in evaluation of the suitability of groundwater for irrigation purposes [38].

Hence, the present work had the objective to study the chemistry of groundwater for both pre-monsoon and post-monsoon period to properly evaluate its quality for irrigational use in Dharamshala region of Himachal Pradesh, India. Various physicochemical parameters such as EC (Electrical conductivity), TDS (Total dissolved solids), major cations (calcium, magnesium, sodium, potassium) and anions (carbonate, bicarbonate, chloride, sulphate, nitrate) were analyzed. Chemical data were used for mathematical calculations for determining irrigational parameters like Percent sodium (% Na), Sodium adsorption ratio (SAR), Residual sodium carbonate (RSC), Kelley's ratio (KR), Magnesium hazard (MH) and Permeability index (PI). Further, the geochemical data in the form of US Salinity diagram and Wilcox Salinity diagram was also presented which helps in assessing its suitability for irrigation purposes.

2. Location and Description of Study area: Dharamshala, a picturesque hill station is situated in the foothills of the Himalayas in the Kangra District of Himachal Pradesh, India (Figure 1). It lies between North latitudes 32°10'00" to 32°17'16.5" and East longitudes 76°15'15.5" to 76°25'21" (Figure 2). It covers an area of 122 sq. km. The area under investigation falls in the survey of India toposheet nos. 52 D/7 and 52 D/8.



"Figure 1. Location map of the study area"



“Figure 2: Map showing groundwater sampling locations in the study area”

3. Materials & Methods: A total of 17 water samples were collected randomly from whole of the study area during the month of June, 2009 and October, 2009 for pre-monsoon and post-monsoon periods respectively. Sampling locations of groundwater samples are shown in Figure 2. Various parameters such as EC (Electrical conductivity), TDS (Total dissolved solids), major cations (calcium, magnesium, sodium, potassium) and anions (carbonate, bicarbonate, chloride, sulphate, nitrate) were analyzed at Geochemical Laboratory in the Centre for Advanced Study in Geology, Panjab University, Chandigarh using standard methods by APHA [39]. Based on these analysis, parameters like Percent sodium (% Na), Sodium adsorption ratio (SAR), Residual sodium carbonate (RSC), Kelley's ratio (KR), Magnesium hazard (MH) and Permeability index (PI) were calculated to evaluate the quality of groundwater of study area for the criteria of irrigational purpose. Following recommended relationships were followed for the analysis of different irrigational parameters. The results were then compared with standard limits.

Percent Sodium (% Na) was determined by using Wilcox formula (11)

$$\text{Na (\%)} = \frac{(Na^{+} + K^{+}) \times 100}{(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})}$$

Sodium Adsorption Ratio (SAR) was computed by the equation given by Richards [40]

$$SAR = \frac{Na^{+}}{\sqrt{Ca^{2+} + Mg^{2+} / 2}}$$

Kelly's Ratio was calculated using following equation [41]

$$KR = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}}$$

Residual Sodium Carbonate (RSC) has been determined by the formula given by Raghunath [42]

$$RSC = (HCO_3- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$$

Szabolcs and Darab [43] proposed **magnesium hazard (MH)** value for irrigation water as:

$$MH = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100$$

Permeability Index (PI) was calculated by following equation [44]

$$PI = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{(Ca^{2+} + Mg^{2+} + Na^{+})} \times 100$$

Map of the study area showing locations, drainage network and sampling locations was prepared with the help of Arc GIS software.

4. Results & Discussion: The analytical results of all the physico-chemical parameters for the groundwater samples are reported in Table 1 (pre-monsoon period) and Table 2 (post-monsoon period). The results of the different irrigation indices for pre-monsoon (June, 2009) and post-monsoon period (October, 2009) are presented in Table 3 and Table 4 respectively.

"Table 1. Results of physico-chemical analysis of groundwater for pre-monsoon period (June, 2009)"

Analytical Results	Cations (mg/l)				Anions (mg/l)				
	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^{+} (mg/l)	K^{+} (mg/l)	Co_3^{2-} (mg/l)	HCO_3^{-} (mg/l)	Cl^{-} (mg/l)	SO_4^{2-} (mg/l)	NO_3^{-} (mg/l)
Minimum	8.8	2.9	9.1	0.6	10	40	14.2	1.01	1.0
Maximum	40.1	29.2	50.0	2.3	20	210	56.8	1.78	20.1
Average	24.05	8.05	20.15	1.73	14.29	100	26.31	1.31	4.79

"Table 2. Results of physico-chemical analysis of groundwater for post-monsoon period (October, 2009)"

Analytical Results	Cations (mg/l)				Anions (mg/l)				
	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^{+} (mg/l)	K^{+} (mg/l)	Co_3^{2-} (mg/l)	HCO_3^{-} (mg/l)	Cl^{-} (mg/l)	SO_4^{2-} (mg/l)	NO_3^{-} (mg/l)
Minimum	11.2	5.4	5.3	0.9	10	40	14.2	0.94	1.0
Maximum	85.0	24.9	60.0	3.4	20	250	49.7	2.95	52.0
Average	27.72	10.34	17.75	2.25	18	115.29	24.64	1.22	6.1

"Table 3. Evaluation of groundwater samples for irrigation for pre-monsoon period (June, 2009)"

S. No.	Location	Latitude & Longitude	pH	Temp. (°C)	EC (µS/cm)	TDS (mg/l)	% Na	SAR (meq/l)	KR (meq/l)	RSC (meq/l)	MH (%)	PI (%)
1.	Cantt. Road (GWS1)	32° 13' 28.4" N 76° 19' 04.6" E	7.6	15	202	130	24.1	0.4	0.7	-0.1	17.1	78.2
2.	Forsythganj (GWS2)	32° 14' 20.9" N 76° 18' 46.0" E	7.0	16	180	116	26.1	0.4	0.7	-0.1	18.0	83.3
3.	McLeod Ganj (GWS3)	32° 14' 40.1" N 76° 19' 23.8" E	8.2	15	215	139	19.4	0.3	0.8	-0.4	23.6	69.5
4.	Sadhed (GWS4)	32° 13' 00.1" N 76° 18' 42.6" E	7.2	20	438	282	23.7	0.7	2.6	-0.4	52.1	56.5
5.	Bagli (GWS5)	32° 10' 14.9" N 76° 17' 57.8" E	6.6	21	169	109	38.1	0.6	1.1	-0.2	28.0	93.9
6.	Sukar Khas (GWS6)	32° 10' 27.1" N 76° 19' 43.8" E	6.2	20	131	85	44.9	0.7	1.4	0.1	33.4	114.8
7.	Depot Bazaar (GWS7)	32° 12' 14.0" N 76° 19' 13.2" E	6.2	18	232	150	53.9	1.5	2.5	-0.3	41.7	82.6
8.	Bandi (GWS8)	32° 10' 09.0" N 76° 16' 12.6" E	6.5	21	169	109	23.8	0.4	1.0	-0.1	36.2	75.5
9.	Sadhed Khas (GWH9)	32° 12' 54.9" N 76° 18' 12.4" E	7.1	18	315	203	26.9	0.6	1.8	BD	44.7	72.0
10.	War Memorial (GWH10)	32° 12' 01.8" N 76° 19' 14.1" E	7.6	20	565	366	19.4	0.6	3.0	-0.5	61.3	57.3
11.	Bagli (GWH11)	32° 10' 11.3" N 76° 17' 42.0" E	8.0	20	97	62	44.8	0.7	1.4	BD	35.3	110.9
12.	Masrehr (GWH12)	32° 10' 09.9" N 76° 18' 48.7" E	6.3	22	123	80	38.2	0.6	1.1	0.2	29.2	107.4
13.	Sukar (GWH13)	32° 10' 48.5" N 76° 20' 22.8" E	6.4	19	118	76	40.2	0.6	1.4	-0.1	40.1	100.7
14.	Khaniyara (GWH14)	32° 12' 46.3" N 76° 21' 29.0" E	8.0	15	270	174	40.4	1.0	1.5	0.3	27.8	80.3
15.	Kand (GWH15)	32° 12' 53.8" N 76° 20' 23.8" E	7.6	20	242	155	21.1	0.4	0.9	0.1	21.9	64.1
16.	Ram Nagar (GWH16)	32° 13' 01.0" N 76° 19' 15.2" E	8.4	20	290	188	61.4	2.0	2.3	1.4	22.9	101.7
17.	McLeod Ganj (GWH17)	32° 14' 09.3" N 76° 19' 29.3" E	6.6	16	369	239	36.4	1.0	1.4	-0.3	24.3	69.8

GWS: Groundwater Spring; **GWH**: Groundwater Handpump; **EC**: Electrical Conductivity; **TDS**: Total Dissolved Solids; **% Na**: Percent Sodium; **SAR**: Sodium Adsorption Ratio; **KR**: Kelly's Ratio; **RSC**: Residual Sodium Carbonate; **MH**: Magnesium Hazard; **PI**: Permeability Index

"Table 4. Evaluation of groundwater samples for irrigation for post-monsoon period (October, 2009)"

S. No.	Location	Latitude & Longitude	pH	Temp. (°C)	EC (µS/cm)	TDS (mg/l)	% Na	SAR (meq/l)	KR (meq/l)	RSC (meq/l)	MH (%)	PI (%)
1.	Cantt. Road (GWS1)	32° 13' 28.4" N 76° 19' 04.6" E	7.2	12.0	205	133	19.6	0.3	1.1	-0.4	32.8	67.2
2.	Forsythganj (GWS2)	32° 14' 20.9" N 76° 18' 46.0" E	6.6	10.0	159	104	13.5	0.2	1.2	-0.5	46.1	65.3
3.	McLeod Ganj (GWS3)	32° 14' 40.1" N 76° 19' 23.8" E	7.6	11.0	179	115	13.6	0.2	1.0	-0.6	34.6	63.3
4.	Sadhed (GWS4)	32° 13' 00.1" N 76° 18' 42.6" E	6.6	18.0	379	246	21.1	0.6	2.6	-0.9	53.2	55.9
5.	Bagli (GWS5)	32° 10' 14.9" N 76° 17' 57.8" E	6.3	18.0	134	87	20.5	0.3	1.2	-0.3	48.7	77.4
6.	Sukar Khas (GWS6)	32° 10' 27.1" N 76° 19' 43.8" E	6.3	14.5	120	78	37.3	0.6	1.5	-0.1	48.2	94.6
7.	Depot Bazaar (GWS7)	32° 12' 14.0" N 76° 19' 13.2" E	6.0	15.0	228	147	47.5	1.3	2.4	-0.5	46.4	81.4
8.	Bandi (GWS8)	32° 10' 09.0" N 76° 16' 12.6" E	6.6	18.0	152	99	27.3	0.5	1.2	-0.3	43.3	79.2
9.	Sadhed Khas (GWH9)	32° 12' 54.9" N 76° 18' 12.4" E	6.8	18.0	306	197	21.3	0.5	1.1	0.1	22.3	64.8
10.	War Memorial (GWH10)	32° 12' 01.8" N 76° 19' 14.1" E	7.0	14.0	495	320	11.2	0.3	1.8	-1.1	27.9	41.5
11.	Bagli (GWH11)	32° 10' 11.3" N 76° 17' 42.0" E	7.3	14.5	162	106	20.2	0.4	1.3	-0.2	47.0	68.7
12.	Masrehr (GWH12)	32° 10' 09.9" N 76° 18' 48.7" E	7.1	18.5	93	60	21.6	0.2	0.9	-0.2	46.2	89.3
13.	Sukar (GWH13)	32° 10' 48.5" N 76° 20' 22.8" E	6.0	18.0	110	71	31.1	0.5	1.3	0.2	46.5	80.1
14.	Khaniyara (GWH14)	32° 12' 46.3" N 76° 21' 29.0" E	7.5	17.0	247	159	38.0	0.9	1.6	0.5	34.7	85.9
15.	Kand (GWH15)	32° 12' 53.8" N 76° 20' 23.8" E	6.8	17.5	230	149	17.2	0.4	1.1	0.2	31.9	62.7
16.	Ram Nagar (GWH16)	32° 13' 01.0" N 76° 19' 15.2" E	7.8	15.5	277	179	67.5	2.5	3.6	1.7	34.4	106.0
17.	McLeod Ganj (GWH17)	32° 14' 09.3" N 76° 19' 29.3" E	6.3	11.5	324	209	34.6	0.9	1.8	-0.3	37.9	71.6

GWS: Groundwater Spring; **GWH**: Groundwater Handpump; **EC**: Electrical Conductivity; **TDS**: Total Dissolved Solids; **% Na**: Percent Sodium; **SAR**: Sodium Adsorption Ratio; **KR**: Kelly's Ratio; **RSC**: Residual Sodium Carbonate; **MH**: Magnesium Hazard; **PI**: Permeability Index

pH: The pH values of groundwater samples varied from 6.2 to 8.4 with an average of 7.15 during pre-monsoon (Table 3), while during post-monsoon period slight lower values were observed i.e. ranging from 6.0 to 7.8 with an average of 6.81 (Table 4). In comparison to post-monsoon, the water of pre-monsoon was slightly more alkaline in nature. At all the locations, pH values were within the desirable limits of 6.5 to 8.5 prescribed by University of California Committee of Consultants [45] for irrigated agriculture.

Electrical Conductivity (EC): The Electrical Conductivity (EC) value varied from 97 µmhos/cm to 565 µmhos/cm with an average value of 242.65 µmhos/cm (Table 3) during pre-monsoon period whereas during post-monsoon period it varied from 93 µmhos/cm to 495 µmhos/cm with an average of 217.25 µmhos/cm (Table 4). According to Wilcox [11] classification based on EC values (Table 5), 11 samples fall in 'excellent' category and 6 samples falls in 'good' category during pre-monsoon period whereas during post-monsoon period 12 samples fall in 'excellent' category and 5 samples falls in 'good' category.

Total Dissolved Solids (TDS): Regarding to the TDS content, the water is considered satisfactory when it contains lesser than 1000 mg/l, fair if it contains between 1000 to 2000 mg/l, and inferior when salinity exceeds 2000 mg/l. TDS value of groundwater samples ranged from 62 mg/l to 366 mg/l with an average value of 156.65 mg/l during pre-monsoon period (Table 3) and ranged from 60 mg/l to 320 mg/l with an average value of 140.63 mg/l during post-monsoon period (Table 4). Accordingly, all sampling stations considered suitable for irrigation use.

Percent Sodium (% Na): The percent sodium (% Na) of samples ranged from 19.4% to 61.4% with the average of 34.08% during pre-monsoon period (Table 3) and it ranged from 11.2% to 67.5% with the average of 26.78% during post-monsoon period (Table 4). During both pre-monsoon and post-monsoon period, 16 samples falls under good to permissible category and single sample (sample no. 16) was under doubtful category (Table 6). According to Eaton [46] classification, 16 water samples fall in safe category and only one sample i.e. sample no. 16 falls under unsafe category during both pre-monsoon and post-monsoon periods (Table 6).

Wilcox Diagram: Wilcox (11) used percent sodium (%Na) and electrical conductivity (EC) in evaluating irrigation water. In Wilcox diagram, the water is classified in to five categories for irrigation purposes i.e. excellent to good, good to permissible, permissible to doubtful, doubtful to unsuitable and unsuitable, on the basis of electrical conductivity and sodium percent. According to the diagram, all the water samples fall under excellent to good category during both pre-monsoon (Figure 3) and post-monsoon periods (Figure 4).

Sodium Adsorption Ratio (SAR): The calculated value of SAR ranged from 0.3 meq/l to 2.0 meq/l with an average of 0.74 meq/l during pre-monsoon period (Table 3) and from 0.2 meq/l to 2.5 meq/l with an average of 0.61 meq/l during post-monsoon period (Table 4). According to the classification given by U.S. Salinity Laboratory's Staff [47] for SAR, all samples fall in 'excellent' category during both pre-monsoon and post-monsoon period (Table 7).

United States Salinity Laboratory (USSL) Diagram: The United States of Salinity Laboratory's (USSL) classification of the water is based on electrical conductivity (EC) and sodium adsorption ratio (SAR) describing 16 classes with reference to SAR as an index for Sodium hazard (S) and EC as an index of salinity hazard (C). According to USSL diagram, it was found that during pre-monsoon period (Figure 5), 10 samples belong to C1S1 (low salinity and low sodium content class), which is suitable for irrigation on almost all soil types and 6 samples belong to C2S1 (medium salinity and low sodium content class). Water belonging to this class can be used for irrigation on almost all soils with little danger of sodium problem, if a moderate amount of leaching occurs. During post-monsoon period (Figure 6), 11 samples belong to C1S1 and 5 samples belong to C2S1. Value of EC less than 100 µmhos/cm are not shown in the figure.

Kelley's Ratio (KR): Kelly's Ratio is 1 or < 1 for good quality water. The calculated values ranged from 0.7 meq/l to 3.0 meq/l with an average of 1.51 meq/l during pre-monsoon period (Table 3) and ranged from 0.9 meq/l to 3.6 meq/l with an average of 1.56 meq/l during post-monsoon period (Table 4). Out of 17 samples, only 5 samples (sample no. 1, 2, 3, 8, and 15) were within the limit during pre-monsoon period and only 2 water samples (sample no. 3 and 12) were of good quality during post-monsoon period.

Residual Sodium Carbonate (RSC): According to Eaton's classification (1950), water with RSC greater than + 2.5 meq/l is considered unsuitable for irrigation. The water with RSC of + 1.25 meq/l to + 2.5 meq/l is considered as marginal and those with a value less than + 1.25 meq/l are safe for irrigation purpose. The calculated values ranged from -0.5 meq/l to 1.4 meq/l with an average of -0.03 meq/l during pre-monsoon period (Table 3) and from -1.1 meq/l to 1.7 meq/l with an average of -0.15 meq/l during post-monsoon period (Table 4). It was observed that during both the periods, 16 water samples fall under safe category and single sample was in marginal category (Table 8).

Magnesium Hazard (MH): The magnesium hazard (MH) values ranged from 17.1% to 61.3% with an average of 32.8% during pre-monsoon period (Table 3) and from 22.3% to 53.2% with an average of 40.26% during post-monsoon period (Table 4). MH value more than 50 is considered harmful and unsuitable for irrigation use. It should be less than 50 to ensure safe and suitable water for irrigation. According to this classification, 15 samples during pre-monsoon and 16 water samples during post-monsoon period fall in 'excellent' category (Table 9). Sample no. 4 during both pre-monsoon and post-monsoon period and sample no. 10 during pre-monsoon period fall under unsuitable category.

Table 5: Salinity hazard classes (Wilcox, 1955) for groundwater samples

EC in µmhos/cm at 25°C	Quality of Water	No. of groundwater samples	
		Pre-monsoon	Post-monsoon
<250	Excellent	11	12
250-750	Good	6	5
750-2250	Permissible	Nil	Nil
2250-5000	Doubtful	Nil	Nil
>5000	Unsuitable	Nil	Nil

Table 6: Quality of groundwater samples based on Na%

Classification	Percent Sodium	Water Class	No. of groundwater samples	
			Pre-monsoon	Post-monsoon
Wilcox, 1955	< 20	Excellent	2	5
	20 – 40	Good	9	10
	40 – 60	Permissible	5	1
	60 – 80	Doubtful	1	1
Eaton, 1950	< 60	Safe	16	16
	> 60	Unsafe	1	1

Table 7: Quality of groundwater based on SAR (after U.S. Salinity Laboratory Staff, 1954)

S.A.R.	Water Class	No. of groundwater samples	
		Pre-monsoon	Post-monsoon
<10	Excellent	17	17
10 – 18	Good	Nil	Nil
18 – 26	Fair	Nil	Nil
>26	Poor	Nil	Nil

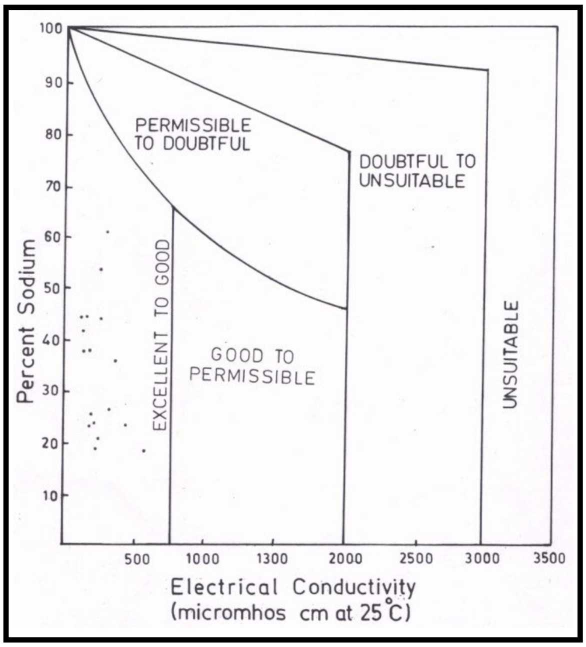
Table 8: Quality of groundwater based on Residual Sodium Carbonate (Eaton, 1950)

RSC (meq/l)	Remark on quality	No. of groundwater samples	
		Pre-monsoon	Post-monsoon
<1.25	Safe	16	16
1.25 – 2.5	Marginal	1	1
>2.5	Unsuitable	Nil	Nil

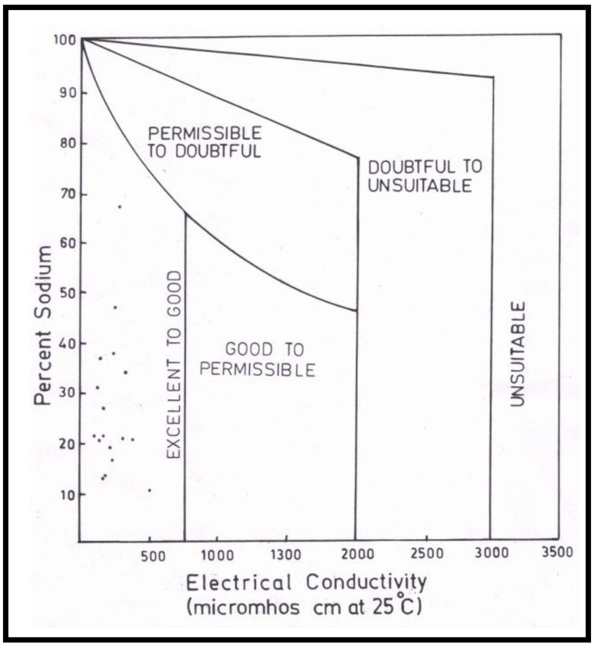
Table 9: Quality of groundwater based on Magnesium Hazard (MH)

Classes of water	MH range (%)	No. of groundwater samples	
		Pre-monsoon	Post-monsoon
Excellent	<50	15	16
Unsuitable	>50	2	1

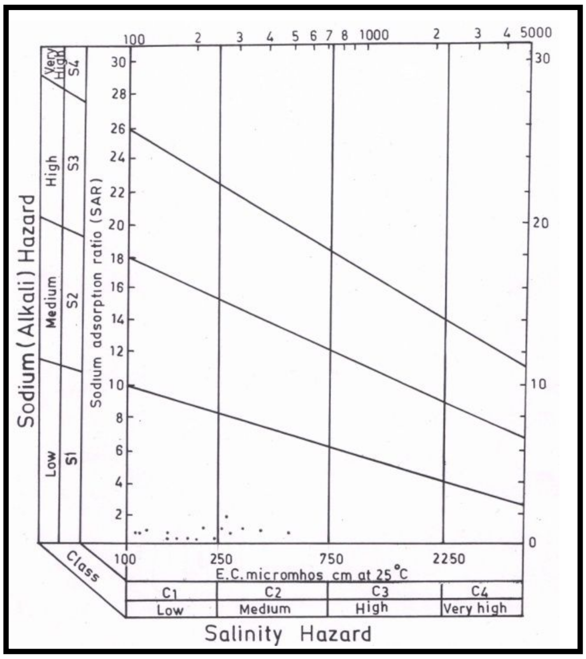
Permeability Index (PI): Based on permeability Index, Doneen (1964) classified water as Class I, Class II and Class III to find out suitability of water for irrigation purpose. Class I and II water are categorized as good for irrigation with 75% or more of maximum permeability. Class III water is unsuitable with 25% of maximum permeability. The PI values of samples ranged from 56.5% to 114.8% with an average of 83.44% during pre-monsoon period (Table 3) and from 41.5% to 106.0% with an average of 73.96% during post-monsoon period (Table 4). According to Doneen (1964) classification, 5 samples (sample no. 6, 11, 12, 13 and 16) during pre-monsoon (Figure 7) and 1 sample (sample no. 16) during post-monsoon (Figure 8) fall under Class III i.e. water on these locations was unsuitable for irrigation.



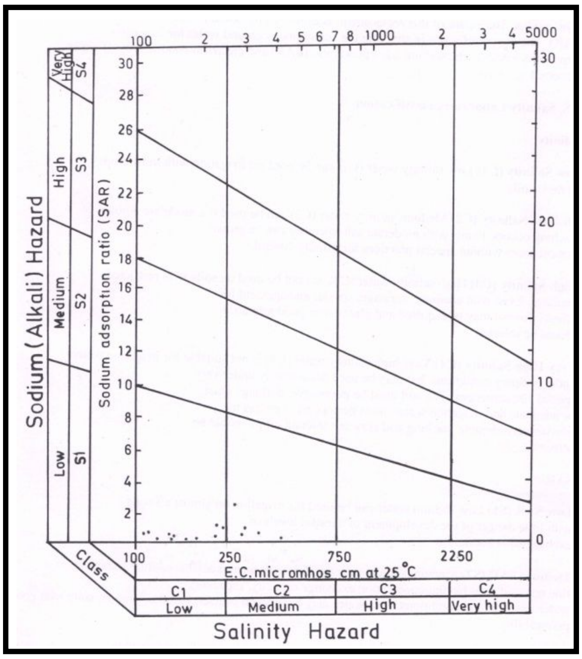
"Figure 3. Suitability of Groundwater for irrigation in Wilcox Diagram during pre-monsoon season"



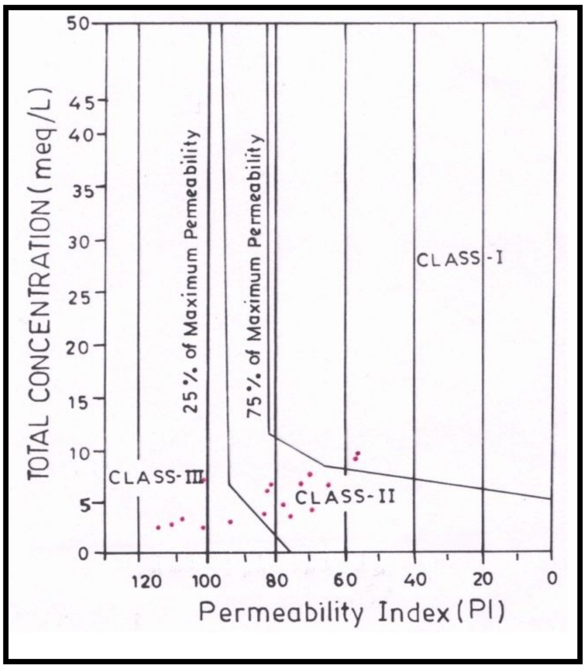
"Figure 4. Suitability of Groundwater for irrigation in Wilcox Diagram during post-monsoon season"



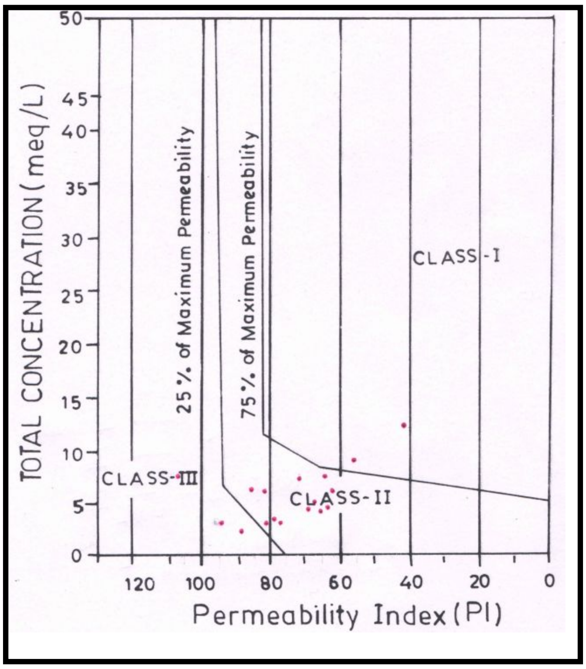
"Figure 5. US Salinity diagram for classification of groundwater for irrigation for pre-monsoon period"



"Figure 6. US Salinity diagram for classification of groundwater for irrigation for post-monsoon period"



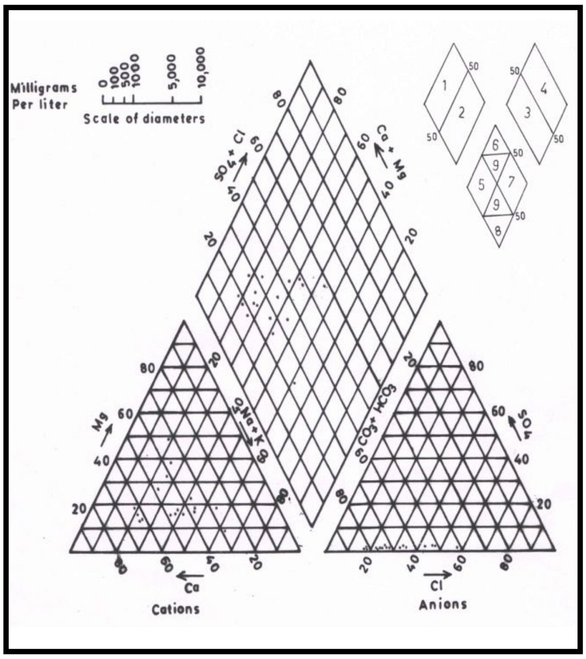
"Figure 7. Classification of groundwater for irrigation based on the permeability index for pre-monsoon season (Doneen's plot)"

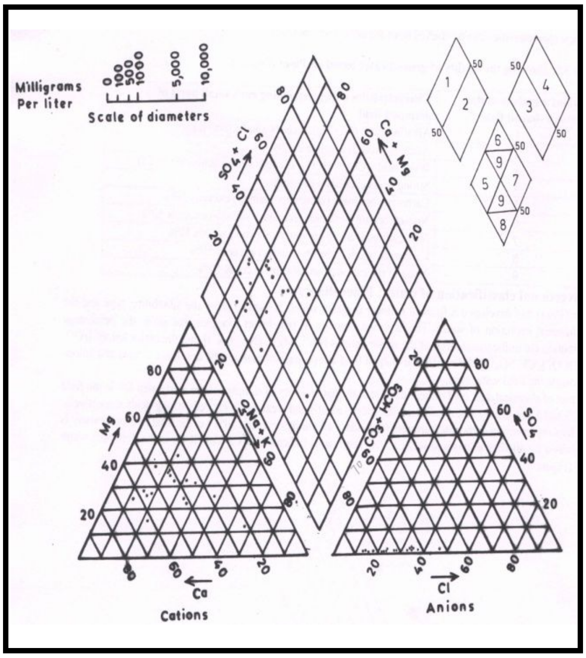


"Figure 8. Classification of groundwater for irrigation based on the permeability index for post-monsoon season (Doneen's plot)"

Convectional classification of water (Piper Diagram): Piper [48] has developed a form of trilinear diagram which is used to show the suitability, type and the geochemical evolution of water. This diagram consists of two lower triangles that show the percentage distribution (in milliequivalents) of the major cations [Ca^{2+}, Mg^{2+}, (Na^{+} + K^{+})] and the major anions [(CO_2^{3-} + HCO_3^{-}), Cl^{-}, SO_4^{2-})] and a diamond-shaped field above that summarizes the dominant cations and anions to indicate the final water type.

The plot of chemical data on Trilinear diagram reveals that majority of samples fall in the field of 1, 3 and 5 suggesting that alkaline earth (Ca + Mg) exceeds alkalis (Na + K) and weak acids (CO_3 + HCO_3) exceeds strong acids (SO_4 + Cl) respectively (Table 2.11). The ions representing carbonate hardness (secondary alkalinity) exceeds 50%. From the above it can be concluded that total hydrochemistry of groundwater is dominated by alkaline earths and weak acids. The results indicate that Ca-Mg-HCO_3 is the dominant water type during both pre-monsoon (Figure 9) and post-monsoon (Figure 10) period.





"Figure 9. Distribution of the groundwater samples according to Piper diagram for pre-monsoon period"

"Figure 10. Distribution of the groundwater samples according to Piper diagram for post-monsoon period"

5. Summary And Conclusion: The results of irrigational parameters showed that the groundwater of the study area is fit for irrigational purposes during both pre and post-monsoon periods except few sites where the values of % sodium, kelley's ratio, magnesium hazard and permeability index has crossed the acceptable limit and falls under unsuitable category.

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7. References:

1) V. Singh and U. C. Singh, "Assessment of groundwater quality of parts of Gwalior (India) for agricultural purposes", *Indian Journal of Science and Technology,* 1 (4), 1-5, 2008.

2) A. S. Abdullahi, F. I. Isa, D. B. B. Muhammad and A. S. Ayodele, "Study of Suitability of Groundwater for Household and Irrigation Purposes in Parts of Adamawa State, Northeastern Nigeria", *International Archive of Applied Sciences and Technology*, 1 (2), 48-56, 2010.

3) S. Mukherjee, B. A. Kumar and L. Kortvelyessy, "Assessment of Groundwater Quality in the South 24-Parganas, West Bengal Coast, India", *Journal of Environmental Hydrology*, 13, 1-8, 2005.

4) P. A. Domenico and F. W. Schwartz, *Physical and chemical hydrogeology,* New York: John Wiley and sons, 1990.

5) C. A. G. Apello, and D. Postma, *Geochemistry, Groundwater and Pollution*, 4th Edition, Balkerma, Rotterdam, Netherlands 1993.

6) C. Guler and G. D. Thyne, "Hydrologic and geologic factors controlling surface and groundwater chemistry in Indian Wells –Owens Valley area, southeastern California, USA", *Journal of Hydrology, 285*, 177–198, 2004.

7) T. Ayenew, M. Demlie and S. Wohnlich, "Hydrogeological framework and occurrence of groundwater in the Ethiopian aquifers", *Journal of African Earth Sciences, 52*, 97–113, 2008.

8) L. Giridharan, T. Venugopal and M. Jayaprakash, "Evaluation of the seasonal variation on the geochemical parameters and quality assessment of the groundwater in the proximity of River Cooum, Chennai, India", *EnvironmentalMonitoring and Assessment, 143*, 161–178, 2008.

9) W. J. Zhang, F. B. Jiang and J. F. Ou, "Global pesticide consumption and pollution: with China as a focus", *Proceedings of the International Academy of Ecology and Environmental Sciences*, 1(2), 125-144, 2011.

10) R. Mirabasi, S. M. Mazloumzadeh and M. B. Rahnama, "Evaluation of irrigation water quality using fuzzy Logic", *Research Journal of Environmental Sciences*, 2(5), 340-352, 2008.

11) Wilcox, L.V. (1955). Classification and use of irrigation waters. USDA, Circular 969, Washington DC, USA.

12) D. K. Todd, *Groundwater Hydrology*, Wiley, New York, 1980.

13) WHO, *Guidelines for drinking water quality*, World Health Organization, Geneva, 1984.

14) J. D. Hem, *Study and interpretation of the chemical characteristics of natural water*, Scientific publishers, Jodhour, India, 1991.

15) C. Almeida, S. Quintar, P. González and M. Mallea, "Assessment of irrigation water quality-A proposal of a quality profile", *Environ. Monit. Assess*., 142, 149-152, 2008.

16) M. Ackah, O. Agyemang, A. K. Anim, J. Osei, N. O. Bentil, L. Kpattah, E. T. Gyamfi and J. E. K. Hanson, "Assessment of groundwater quality for drinking and irrigation: the case study of Teiman-Oyarifa Community, Ga East Municipality, Ghana", *International Academy of Ecology and Environmental Sciences*, 1(3-4), 186-194, 2011.

17) A. S. Abdullahi, F. I. Isa, A. S. Ayodele, Z. Peter and D. B. B. Muhammad, "Investigation of Groundwater quality for Domestic and Irrigation purposes around Gubrunde and Environs, northeastern Nigeria", *Journal of American Science*, 6 (12), 2010.

18) S. R. Prakash and G. K. Rao, "The chemistry of Ground waters in Paravada area with regard to their suitability to domestic & irrigational purposes", *Indian J. Geochem*., 4 (1), 39-54, 1989.

19) S. Amlathe, C. Padmakar and B. Tirupati, “Ground water quality evaluation of shallow aquifer – Tawa canal command area”, *BHU-JAL NEWS*, 11, 9-21, 1995.

20) A. K. Singh, R. K. Jaiswal and S. Mukherjee, “Groundwater quality assessment of Varanasi city”, *Hydrology*, XIX (4), 23-33, 1996.

21) C. K. Jain and M. K. Sharma, “Regression analysis of ground water quality data of Sagar district, Madhya Pradesh”, *Ind. J. Environ. Health*, 42 (4), 159-168, 2000.

22) D. Sujatha and R. B. Rajeswara, “Quality characterization of groundwater in the south-eastern part of the Ranga Reddy district, Andhra Pradesh, India”, *Environ. Geol*., 44(5), 579-586, 2003.

23) T. Subramani, L. Elango and S. R. Damodarasamy, “Groundwater and its suitability for drinking and agricultural use in Chithar River Basin, Tamil Nadu, India”, *Environ. Geol*., 47, 1099-1110, 2005.

24) C. M. Laluraj, G. Gopinath and D. Kumar, “Groundwater chemistry of shallow aquifers in the coastal zones of Cochin, India”, *Applied Ecology and Environmental Research,* 3(1), 133-139, 2005.

25) M. J. Focazio, D. Tiptan, S. D. Shapiro and L. H. Geiger, “The chemical quality of self-supplied domestic well water in the united states”, *GW Monitoring & Remediation*, 26 (3), 92-104, 2006.

26) N. S. Rao, “Seasonal variation of groundwater quality of Srikakulam district, Andhra Pradesh, India”, *Environ Geol*, 49, 413-429, 2006.

27) N. J. Raju, “Hydrogeochemical parameters for assessment of groundwater quality in the upper Gunjanaeru River basin, Cuddapah District, Andhra Pradesh, South India”, *Environ. Geol.* 52, 1067-1074, 2007.

28) C. Sadashivaiah, C. Ramakrishnaiah and G. Ranganna, “Hydrochemical analysis and evaluation of groundwater quality in Tumkur Taluk, Karnataka State, India”, *Intl. J. Environ. Research Public Health*, 5(3), 158-164, 2008.

29) R. K. Tatawat and C. P. S. Chandel, “Quality of Ground water of Jaipur City, Rajasthan (India) and its suitability for domestic and irrigation purpose”, Applied Ecology And Environmental Research, 6 (2), 79-88, 2008.

30) A. A. Embaby and S. M. A. El-Barbary, “Evaluation of Quarternary aquifer for agricultural purposes in North West Sinai, Egypt”, *Journal of American Science*, 7 (3), 344-361, 2011.

31) G. I. Obiefuna and A. Sheriff, “Assessment of shallow groundwater quality of Pindiga Gombe area, Yola area, NE, Nigeria for irrigation and domestic purposes”, Research Journal of Environmental and earth Sciences, 3 (2), 131-141, 2011.

32) N. Aghazadeh and A. A. Mogaddam, “Investigation of hydrochemical characteristics of groundwater in the Harzandat aquifer, Northwest of Iran”, *Environ. Monit. Assess*., 176,183-195, 2011.

33) S. Umapathy, “A study on ground water quality of Neyveli area, Cuddalore District, Tamil Nadu”, *International Journal of Geomatics and Geosciences*, 2 (1), 49-56, 2011.

34) V. Bhardwaj and D. S. Singh, “Surface and Groundwater quality characterization of Deoria District, Ganga Plain, India”, *Environ. Earth Sci*., 63, 383-395, 2011.

35) M. A. K. Mridha, M. H. Rashid and K. H. Talukder, “Quality of groundwater for irrigation in Natore district”, *Bangladesh J. Agril. Res*., 21, 15-30, 1996.

36) L. Khodapanah, W.N.A. Sulaiman and N. Khodapanah, “Groundwater quality assessment for different purposes in Eshtehard District, Tehran, Iran”, European J. Sci. Research, 36(4), 543-553, 2009.

37) C. Tathy, L. Matini, G. M. Nkaya and B. Mabiala, “Assessing Factors Controlling the Hydrochemistry and Suitability for Irrigation Purposes of Aquifer AQ-2 in Pointe-Noire, South-West Congo-Brazzaville”, *Research Journal of Applied Sciences, Engineering and Technology*, 3(7), 617-624, 2011.

38) L. Belkhiri, A. Boudoukha and L. Mouni, “Groundwater quality and its suitability for drinking and agricultural use in Ain Azel plain, Algeria”, *Journal of Geography and Regional Planning*, 3(6), 151-157, 2010

39) APHA Standard methods for the examination of water and wastewater. 21st edn. American Public Health Association, Washington, DC, USA, 2005.

40) L. A. Richards, *Diagnosis and improvement of saline and alkali soils*, US Department of Agriculture, handbook, 60, 160, 1954.

41) W. P. Kelly, “Use of Saline Irrigation Water”, *Soil Sci.*, 95, 355-391, 1963.
42) H. M. Raghunath, *Groundwater*, 2nd edition, Wiley Eastern Ltd., New Delhi, India, 1987.

43) I. Szabolcs and C. Darab, “The influence of irrigation water of high sodium carbonate content of soils”, *Proceedings of 8th international congress of ISSS*, II, 803-812, 1964.

44) L. D. Doneen, “Notes on water quality in agriculture”, *Water science and engineering paper 4001*, Department of water Sciences and Engineering, University of California, California, 1964.

45) University of California Committee of Consultants, *Guidelines for Interpretations of water quality for irrigation*, Technical Bulletin, University of California Committee of Consultants, California, USA, 20-28, 1974.

46) F. M. Eaton, “Significance of carbonate in irrigation waters”, *Soil Sci.,* 95, 123-133, 1950.

47) U.S. Salinity Laboratory Staff, *Diagnosis and improvement of saline and alkali soils*, USDA, Handbook, 60, 147, 1954.

48) A. M. Piper, “A graphic procedure in the geochemical interpretation of water analyses”, *Trans. Am. Geophysical Union*, 25, 914-928, 1944.