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Original Research Article

GIS Approach based Groundwater Quality Assessment and Evaluation for Irrigation Purpose in a Hard Rock Hilly Terrain of Western India

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ABSTRACT

The research has conducted in a semi-arid hard rock terrain of wakal river basin of Udaipur district of Rajasthan, western India using multi-site pre and post-monsoon groundwater sample. Groundwater quality assessment is important to ensure sustainable safe use of water. The groundwater quality of the Wakal river basin was analyzed which is located between 24° 46' 34.65" to 24° 8' 49.41" N latitude and 73° 6' 23.41" to 73° 35' 54.18" E longitude with an area of 1914.32 km^2. For assessment of groundwater quality in Wakal river basin of Udaipur district, is divided into 66 grid considering size of one grid as 6km x 6km. The water samples were collected from 63 sites during pre monsoon and 60 sites during post monsoon period. These samples were analyzed in the laboratory to find out different water quality parameters such as pH, EC, TDS, Ca, Mg, Na, K, CO_3, HCO_3, Cl and SO_4. The different water quality parameter map of the Wakal river basin was prepared under GIS environment and the assessments of groundwater quality parameters were analyzed. The highest EC, TDS, Na, SO_4 was found in village Kotra and Ca, Mg, Cl in village Bira of Jhadol block of Udaipur district during pre monsoon period. During post monsoon period the highest EC, TDS, Ca, Mg, Na, K, Cl and SO_4 was found in village Kotra. The suitability of groundwater for irrigation use was evaluated on the basis of Sodium Absorption Ratio (SAR), Kelly's Ratio (KR), Residual Sodium Carbonate (RSC), Soluble Sodium Percentage (SSP) and Permeability Index (PI) and found that most of the study area groundwater is suitable for irrigation purpose during both pre and post monsoon period.

Keywords

Groundwater quality, Pre and Post-monsoon, Wakal river basin, GIS, Hard-rock-terrain

Introduction

Water quality analysis is one of the most important aspects in groundwater studies. The hydro chemical study of groundwater play a significant role in classifying and assessing water quality. Water is a vital source of life which is extremely essential for survival of all living organisms. Life is not possible on this planet without water. Earth is also called as 'blue planet' because 70 per cent area of it has been covered by water resource. The total water amount on the earth is about 1.35 billion cubic kilometers. About 97.1 per cent has been locked into oceans as saltwater. Ice sheets and glaciers have arrested 2.1 per cent. Only 0.2 per cent is the fresh water present on the earth, which can be used by human for variety of purposes. Remaining 0.6 per cent is in underground form (Status Report, 2007). But unfortunately, it has been getting polluted day by day due to different anthropogenic activities. The effects of water pollution are not only devastating to people but also to animals, fish, and birds. Polluted water is unsuitable for drinking, recreation, agriculture and industrial purposes. It diminishes the aesthetic quality of lakes and rivers. More seriously, contaminated water destroys aquatic life and reduces its reproductive ability. Eventually, it is a hazard to human health and nobody can escape the effects of water pollution. Therefore, it is burning need, to conserve the water and prevent it from every type of pollution.

Groundwater is one of the most valuable natural and dynamic resources, but it is not unlimited. Its quantity and quality both varies from place to place and season to season. This supports human health, socio-economic development, and functioning of ecosystems (Zektser 2000; Humphreys 2009; Steube et al. 2009). Out of the 37 Mkm^3 of freshwater estimated to be present on the earth, about 22 per cent exists as groundwater, which constitutes about 97 per cent of all liquid freshwater potentially available for human use (Foster 1998). However, the worldwide groundwater overdraft, declining well yields, drying up of springs, stream flow depletion, and land subsidence due to overexploitation of groundwater as well as the growing degradation of groundwater quality by natural and/or anthropogenic pollutants, is threatening our ecosystems and even the lives of our future generations (Bouwer 2000; Shah et al. 2000; Zektser 2000). The quality of groundwater is critical in the regions that are characterized by a semi-arid or arid climate and dominated by agricultural activities. The water quality is generally affected by diffuse contamination originating from intensive irrigated agriculture (Saidi et al. 2009). It is a well-known fact that a polluted environment has a detrimental effect on health of people, animal life and vegetation (Sujatha and Reddy 2003). It is the major source of drinking water, besides it is an important source for the agricultural and industrial sector. Compared to surface water, groundwater offers better insurance against drought because of the long lag between changes in recharge and response to groundwater levels. Thus, groundwater can be a prospective source of future freshwater supplies. Recent research has highlighted the alarmingly high rate at which groundwater levels in various parts of the India are falling. Studies conducted by WHO-UNICEF (2002) indicate that the rate, at which the groundwater reservoirs are being emptied in India, is at least 10 times faster than the rate at which it can be naturally recharged. Therefore, the water table is rapidly falling with unregulated over-exploitation of groundwater.

India has been facing increasingly severe water scarcity in several parts of the country, especially in arid and semi-arid regions. The overdependence on groundwater to meet ever-increasing demands of domestic, agriculture, and industrial sectors has resulted in overexploitation of groundwater resources in several states of India such as Gujarat, Rajasthan, Punjab, Haryana, Uttar Pradesh and Tamil Nadu (CGWB, 2006; Garg and Hassan 2007; Rodell et al. 2009). Out of 53.5 million hectare net irrigated area in the country, only 32 per cent is irrigated through surface water supplies while groundwater accounts for about 56 per cent irrigated area. The groundwater extraction ranges from 98.3 per cent in Punjab, 75.6 per cent in Haryana, 72.1 per cent in Rajasthan, 62.6 per cent in Tamil Nadu, 49.3 per cent in Gujarat, 41.9 per cent in Uttar Pradesh to almost negligible in north-eastern states. Further, nearly 90 per cent of drinking water requirements of India are also met from groundwater resources (CGWB, 2006). The spatial patterns of chemical constituents are useful in deciding the water use strategies for various purposes (Collins et al 1998; Gogu et al., 2001; Dhiman 2005; Shankar et al., 2010).

Status of groundwater in Rajasthan

Rajasthan is the largest state of the country whose geographical area is more than the area of 128 countries in the world but the status of water in the state is most critical. Rajasthan with more than 10.40 per cent of the countries geographical area, supporting more than 5.5 per cent of the human population and 18.70 per cent of livestock has only 1.16 per cent of the total surface water and 1.70 per cent of total groundwater availability of the country (IDWR, 2005). The two third part of the state is a part of the great thar desert which is bigger than most of the states. Out of the total 142 desert blocks in the country, 85 blocks are in the state of Rajasthan (State Water Policy, Rajasthan, 2010). Rajasthan's economic growth is largely affected by availability of water, more specifically of groundwater. Totally 71 per cent of irrigation and 90 per cent of the drinking water supply source is groundwater (Rathore, 2003). Presently, there is tremendous pressure to exploit groundwater by users. Over exploitation and excess use of groundwater has led to substantial decline in water levels, which may ultimately result to drying up of aquifers in larger areas of the state. Therefore, the groundwater condition is quite alarming. The condition has deteriorated very fast in the last two decades. The stage of groundwater exploitation, which was just 35 per cent in 1984, has reached a level of 138 per cent in the year 2008. Out of 237 blocks in the state, only 30 blocks are in safe category (State Water Policy, Rajasthan, 2010). This calls for immediate remedial measures to address the critical water resources situation in the state.

The first groundwater potential estimates in Rajasthan were made during 1983-84. Despite an increase in the area of groundwater potential due to more exploratory studies, there has been a total decline of 39.89 per cent in the groundwater potential from 1984 to 2001. As a result, 'safe' water zones (i.e., those safe for exploitation) declined from 86 per cent in 1984 to 10.6 per cent in 2004. Also in the year 2001, 70.3 per cent of total groundwater potential zones were classified as 'dark' and 'gray' (Rathore, 2005). Depletion in water levels is directly associated with deterioration in quality of groundwater. Salinity increases as low quality water is drawn into heavily pumped fresh water aquifers. In urban and industrial areas, problems of pollution of groundwater due to heavy contamination are also a major threat for the people. This situation calls for the necessity for management, conservation and regulation of groundwater resources. Sustainable management on the state's groundwater resources is thus of fundamental importance to the state's future.

Geographical Information System (GIS)

Geographic information system (GIS) has emerged as a powerful tool for storing, analyzing, and displaying spatial data and using these data for decision making in several areas including engineering and environmental fields (Stafford 1991; Goodchild 1993; Burrough and McDonnell 1998; Lo and Yeung 2003). It allows for swift organization, quantification, and interpretation of a large volume of spatial data, providing an efficient environment.

With the advent of advanced computerized technology, the above said problems are best handled through GIS techniques. The main advantages of using GIS techniques for groundwater quality assessment are the reduction of cost and time needed the fast extraction of information on the groundwater quality and the selection of promising areas for further groundwater exploration (Toleti et al., 2001). The main intent of the present study was to evaluate groundwater quality and characterize its spatial and temporal variations in a semiarid and hilly hard-rock terrain of Rajasthan (i.e., Udaipur district), western India by using multi-site pre and post-monsoon groundwater sample and GIS technique. The present study is first of its kind in western India in general and Rajasthan in particular. The results thus obtained are much more realistic, comprehensive and less time consuming (Machiwal et al., 2011).

Materials and Methods

Description of study area

Wakal river is one of the tributaries of Sabarmati river basin. It is a rain fed river basin lies on the west coast of India between 24° 46' 34.65" N to 24° 8' 49.41" N latitudes and 73° 6' 23.41" E to 73° 35' 54.18" E longitudes and spread across the states of Rajasthan and Gujarat. It is situated in southern part of Rajasthan. Total area of the basin is 1914.32 km^2 whereas maximum length of basin is 71.22 km which is draining to Sabarmati River in Gujarat. The entire Wakal river basin is falling in 5 tehsils i.e. Gogunda, Girwa, Jhadol, Kotra tehsil of Udaipur district of Rajasthan and Khedbrahma tehsil of Sabarakanta district of Gujarat. The 98 per cent area of total basin falls in the Udaipur district of Rajasthan. Most of the rivers or streams in this basin are ephemeral; therefore, groundwater provides the main source of supply for human as well as livestock. The study area falls in Survey of India (SOI) toposheets of 45H/2, 45H/3, 45H/4, 45H/5, 45H/6, 45H/7, 45H/8, 45H/10 and 45H/11. The location map of the Wakal river basin is shown in Fig.1.

Groundwater quality analysis

Analyzing the groundwater quality of the basin, pre and post monsoon groundwater samples were collected in sampling bottles by dividing the entire basin into 6km x 6km grid. The village map of the Wakal river basin is divided into 66 systematic square grids (6km x 6km) as shown in Fig.1. The water samples were collected from 63 sites during pre monsoon and 60 sites during post monsoon period. These samples were analyzed in the laboratory to find out different water quality parameters such as pH, EC, TDS, CO_3, HCO_3, SO_4, Cl, Ca, Mg, Na and K. On the basis of the results of the analysis the different water quality parameter map of the Wakal river basin was prepared under GIS environment.

Water sampling techniques

Water samples for quality assessment are analyzed for chemical constituents. Therefore, more attention was given to avoid the possibility of any external contamination. The samples were collected in plastic bottles thoroughly cleaned and sterilized. The samples were collected using rope and bucket. The water surface were disturbed a little to remove any floating material before collection of the sample. The sampling site in the study area is shown in Fig. 2.

Analysis of water samples

The physicochemical parameters such as

pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^{+}), Potassium (K^{+}), Bicarbonate (HCO_3), Carbonate (CO_3), Chloride (Cl^{-}), and Sulphate (SO_4) were determined using standard methods. AR grade reagents were used for the analysis and double distilled water was used for preparation of solutions. The methods used for estimation of various physicochemical parameters are given in Table 1. The water samples were analyzed in the laboratory of AICRP on groundwater utilization as shown in Plate 1.

Residual sodium carbonate (RSC)

The residual sodium carbonate was calculated simply by subtracting the quantity of Ca + Mg from the sum total of carbonates and bicarbonates determined separately in a given sample and expressed in meq/l. Thus,

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+}) \ldots 1$$

Sodium adsorption ratio (SAR)

Sodium adsorption ratio was calculated using the formula given below.

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

Where, all ionic concentrations are expressed in meq/l.

Soluble sodium percentage (SSP)

Wilcox (1955) has proposed classification scheme for rating irrigation water on the basis of soluble sodoum percentage (SSP). The SSP was calculated by using following formula:

$$SSP = \frac{Na \times 100}{Ca + Mg + Na} \qquad 3$$

Where, the concentration of ions is expressed in meq/l.

Permeability index (PI)

The permeability index was calculated by the following formula:

$$PI = \frac{Na + \sqrt{HCO_3}}{(Ca + Mg + Na)} \times 100 \qquad 4$$

Where, all the values are in meq/l.

Kelly's ratio (KR)

Kelly's ratio was calculated by using the following expression:

$$KR = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \qquad 5$$

Where, concentrations are expressed in meq/l

Results and Discussion

Hydrochemistry of groundwater in the study area

The different physicochemical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), calcium (Ca^{+}), magnesium (Mg^{+}), sodium (Na^{+}), potassium (K^{+}), bicarbonate (HCO_3), carbonate (CO_3), chloride (Cl^{-}), and sulphate (SO_4) present in pre and post monsoon samples of the study area were determined using standard methods. The maximum and minimum values of these parameters of the study area present in the groundwater during pre and post monsoon is presented in Table 2. The variations in individual groundwater quality parameters map are prepared in GIS environments and shown in Fig.3a to Fig.3k for pre monsoon and post monsoon period.

Spatioal and temporal variations of groundwater quality parameters

Eleven groundwater quality parameters, viz., pH, EC, TDS, Ca, Mg, Na, K, HCO_3, CO_3, Cl, and SO_4 were analyzed for determining their spatial and temporal variations. The pH of groundwater varied from 6.0 to 8.0 with a mean of 6.98 in pre monsoon period and 6.5 to 7.6 with a mean of 7.11 in post monsoon period. About 91.36 per cent area of Wakal river basin has pH ranges between 6.75 to 7.25 during post monsoon period (Fig. 3a) and 97.2 per cent area ranges between 6.5 to 7.5 during pre monsoon period (Fig. 3a). The highest pH was observed near the village Bari in Jhadol block during both pre and post monsoon period.

Concentration of TDS, a measure of quality, ranged from 223 to 2600 mg/l with a mean of 641.38 mg/l during pre monsoon and 200 to 2020 mg/l with a mean of 575.17 mg/l in post monsoon period. Fig. 3c shows that concentration of total dissolved solids remains within its maximum permissible limit (500-1500 mg/l) in most of the study area for both pre and post monsoon period. The western part of the study area, namely Kotra village recorded more than 1500 mg/l TDS in both pre and post monsoon period.

The electrical conductivity (EC) varies from 0.40 to 3.20 ds/m with an average of 0.96 ds/m during pre monsoon and 0.30 to 2.90 ds/m with an average of 0.81 ds/m during post monsoon period. Fig. 3b reveals that about 94.4 per cent of the study area during pre monsoon and about 47 per cent area during post monsoon groundwater is not even good to be used for drinking purposes because its EC is more than 0.75 ds/m. The western part of the study area particularly Kotra village found more EC (>2.25 ds/m) during post monsoon period and further it is found in scattered patches during pre monsoon period.

The mean concentration of major ion in groundwater is in the following order: cation:- magnesium>calcium>sodium>potassium during pre monsoon period and calcium> sodium>magnesium>potassium during post monsoon period and Anions:- chloride>sulphate> bicarbonate >carbonate during both pre and post monsoon period. Among the cations, the concentrations of Ca, Mg, Na, and K ions ranged from 1.6 to 7.0, 0.8 to 14.0, 0.2 to 12.1 and 0.0 to 1.2 meq/l with a mean of 3.10, 3.25, 2.98 and 0.13 meq/l, respectively during pre monsoon period and 1.1 to 15.0, 0.0 to 7.4, 0.2 to 6.4 and 0.0 to 0.6 meq/l with a mean of 3.40, 1.94, 2.47 and 0.06 meq/l, respectively during post monsoon period. The major ion chemistry data revealed that Mg and Ca are the most predominant cationic constituents followed by Na during pre monsoon period whereas calcium and sodium are dominated in post monsoon period. The dissolved anions of HCO_3, CO_3, Cl and SO_4 ions ranged from 0.0 to 5.2, 0.0 to 4.2, 2.8 to 19.5 and 0.0 to 17.2 meq/l with a mean of 1.58, 0.24, 4.92 and 2.75 meq/l respectively during pre monsoon period and 0.4 to 5.5, 0.0 to 2.0, 1.5 to 13.5 and 0.0 to 14.2 meq/l with a mean of 1.65, 0.05, 3.69 and 2.52 meq/l respectively during post monsoon period. For the major anions (SO_4, Cl, HCO_3, and CO_3), the chloride and sulphate are found to be the most predominant anions followed by bicarbonate and carbonate during both pre and post monsoon period. Fig. 3d reveals that some part in southeast and southwest of the study area has high calcium content during both pre and post monsoon period. The highest Ca and Mg were found near the village Bira in Jhadol block during pre monsoon period and near the village Kotra during post monsoon period. Figure also reveals that 99 per cent of the study area is within the permissible limit of Ca and Mg during both pre and post monsoon period. The highest Na was found in the village Kotra during both pre and post monsoon period. Most part of the study area was found negligible K and CO_3 during both pre and post monsoon period. The highest HCO_3 was found in the village Nayawas in Kotra block during both pre and post monsoon period. Figure also reveal that about 99 per cent of the study area, the HCO_3 has less than 3.5 meq/l for both pre and post monsoon period. The highest Cl was found in the village Bira in Jhadol block during pre monsoon period and village Kotra during post monsoon period. The highest SO_4 was found in the village Kotra during both pre and post monsoon period.

Fig.1 Map of Wakal river basin with square grid pattern

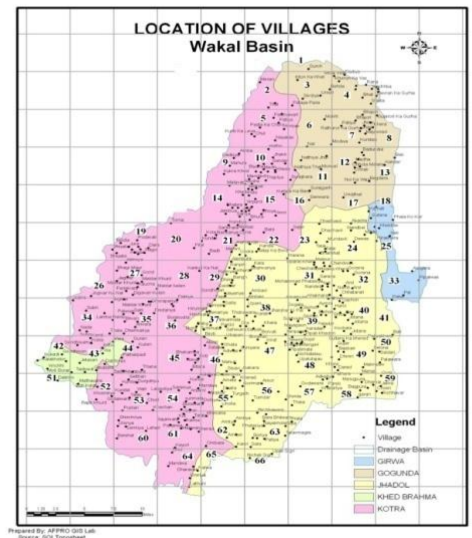
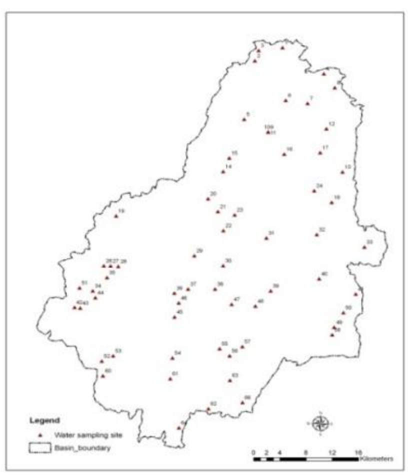
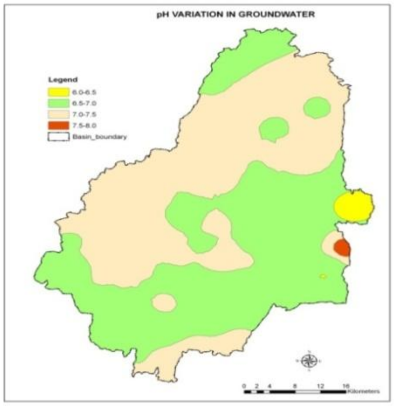
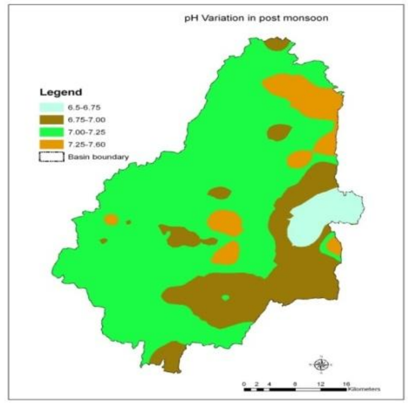


Fig.2 Sampling site in study area

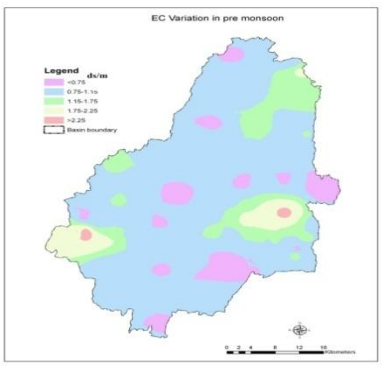


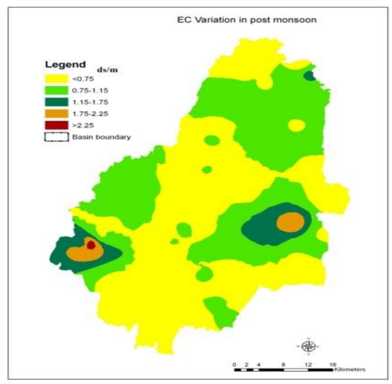




Pre-monsoon Post -monsoon

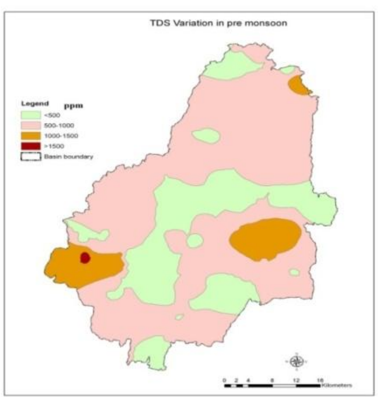
Fig.3a Variation of pH in Wakal river basin during pre-monsoon and post-monsoon

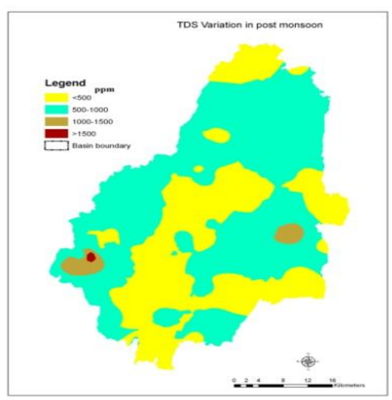




Pre-monsoon Post- monsoon

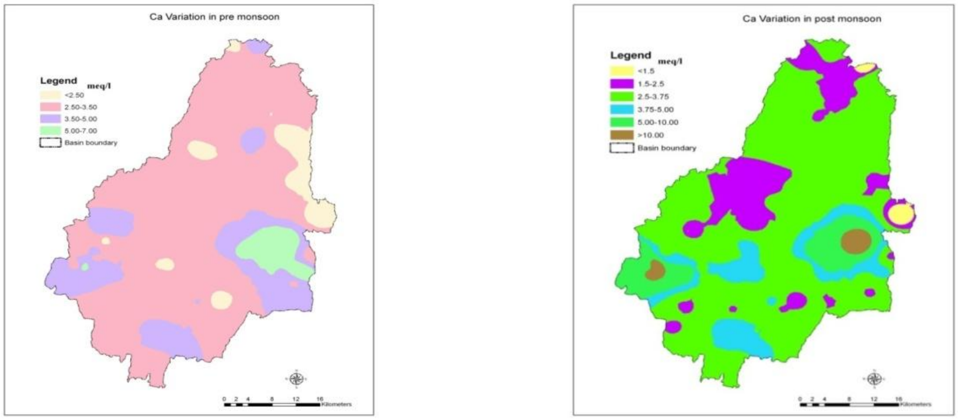
Fig.3b Variation of EC in Wakal river basin during pre-monsoon and post-monsoon





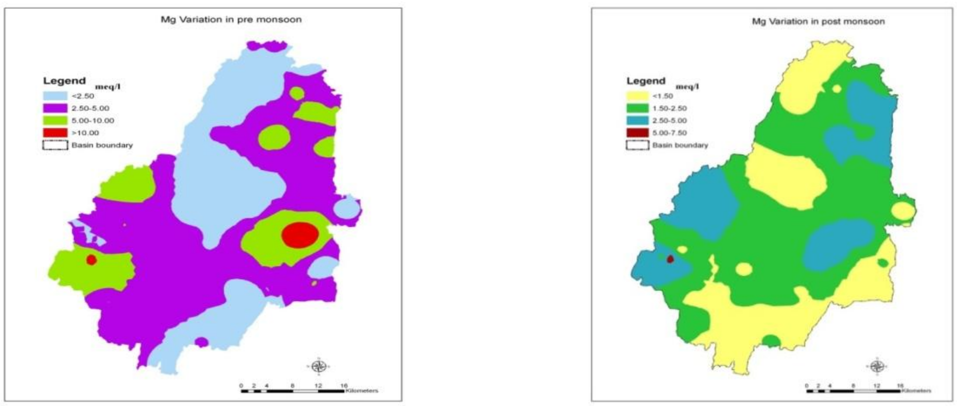
Pre-monsoon Post-monsoon

Fig.3c Variation of TDS in Wakal river basin during pre-monsoon and post-monsoon



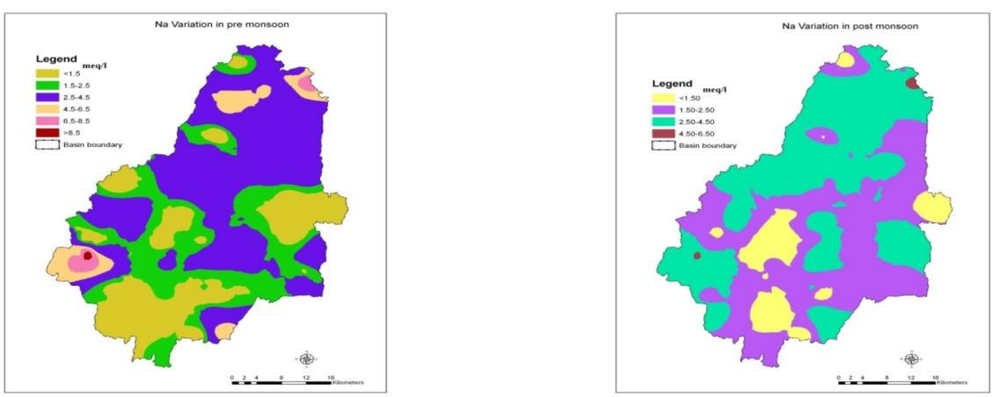
Pre-monsoon Post-monsoon

Fig.3d Variation of Ca in Wakal river basin during pre-monsoon and post-monsoon



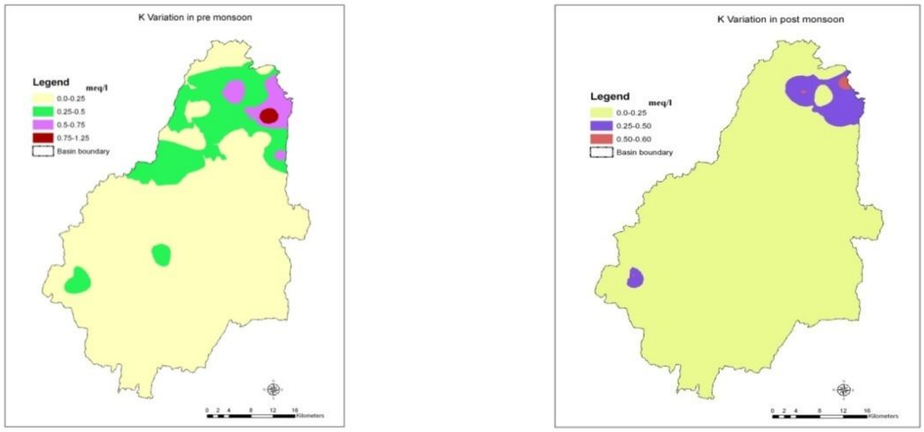
Pre-monsoon Post-monsoon

Fig.3e Variation of Mg in Wakal river basin during pre-monsoon and post-monsoon



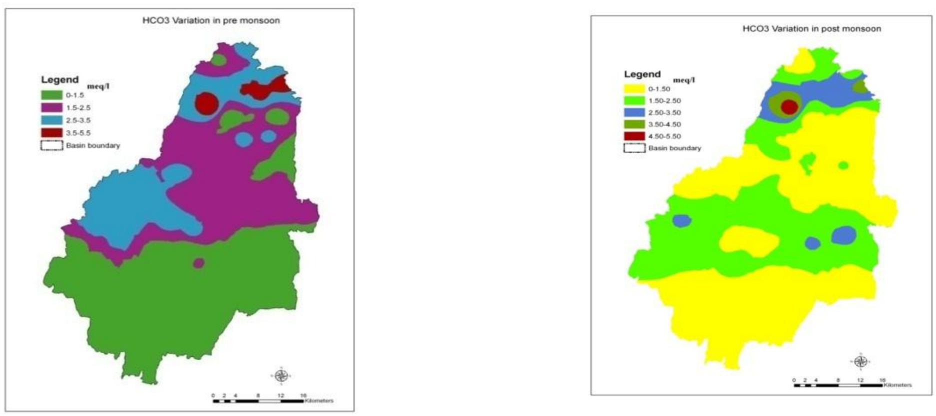
Pre-monsoon Post-monsoon

Fig.3f Variation of Na in Wakal river basin during pre-monsoon and post-monsoon



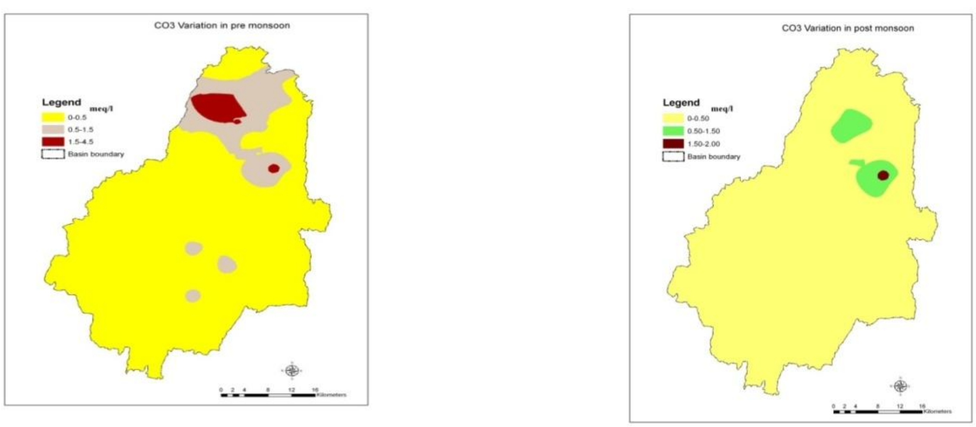
Pre-monsoon Post-monsoon

Fig.3g Variation of K in Wakal river basin during pre-monsoon and post-monsoon



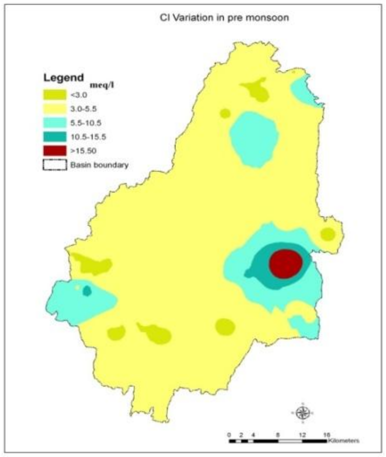
Pre-monsoon Post-monsoon

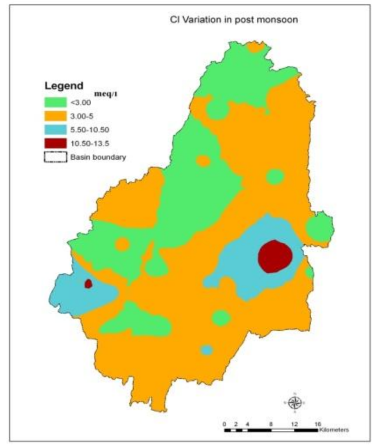
Fig. 3h Variation of HCO_3 in Wakal river basin during pre-monsoon and post-monsoon



Pre-monsoon Post-monsoon

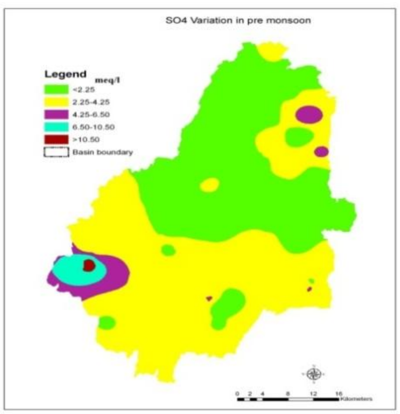
Fig.3i Variation of CO_3 in Wakal river basin during pre-monsoon and post-monsoon

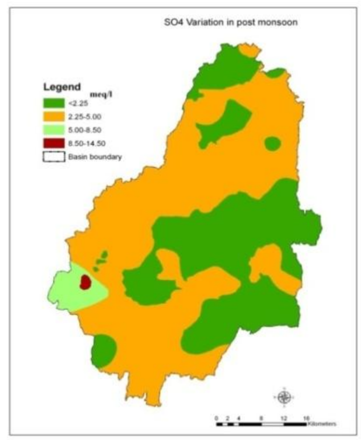




Pre-monsoon Post-monsoon

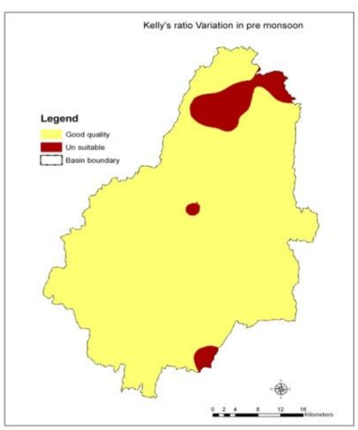
Fig.3j Variation of Cl in Wakal river basin during pre-monsoon and post-monsoon





Pre-monsoon Post-monsoon

Fig.3k Variation of SO_4 in Wakal river basin during pre-monsoon and post-monsoon



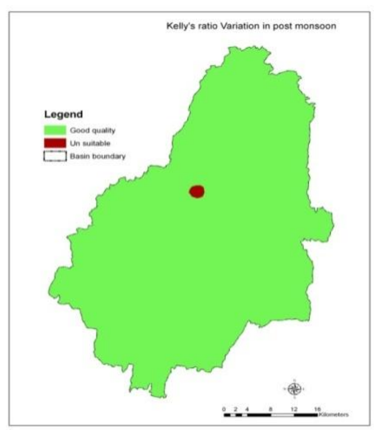
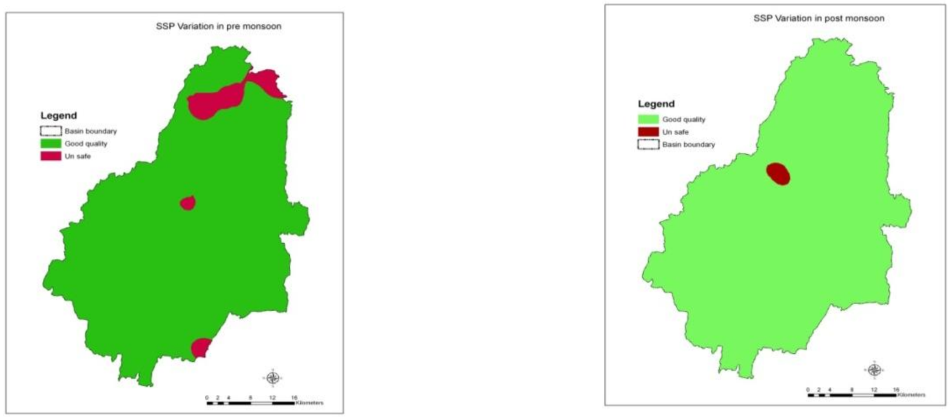
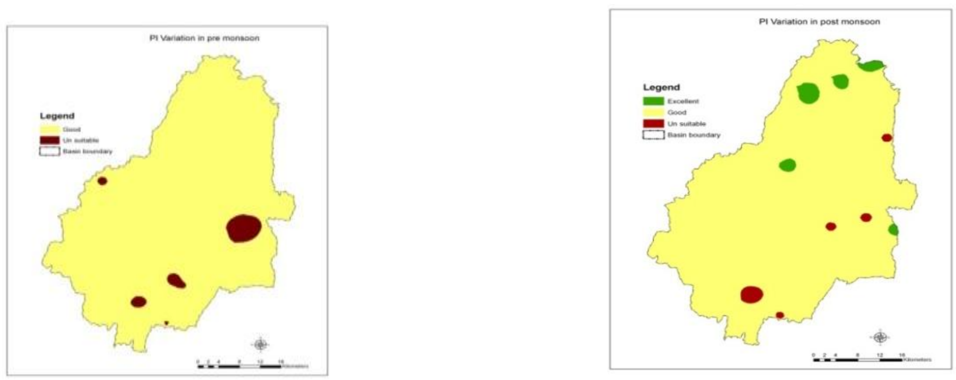


Fig. 4 Variation of Kelly's ratio in Wakal river basin during pre and post-monsoon period



Pre-monsoon Post-monsoon

Fig.5 Variation of SSP in Wakal river basin during pre-monsoon and post-monsoon



Pre-monsoon Post-monsoon

Fig.6 Variation of PI in Wakal river basin during pre-monsoon and post-monsoon

Table.1 Methods used for estimation of physiochemical parameters

S.No.	Parameters	Method	References
1	pH	Using Glass Electrode pH meter	Jackson (1973)
2	Electrical Conductivity	Using EC meter	Wilcox (1950)
3	Total Dissolved Solids	Using TDS meter	Singh and Kalra (1975)
4	Calcium and Magnesium	EDTA titration	Cheng & Bray (1951) and Diehl et. al. (1950)
5	Sodium	Flame Photometric method	Toth et. al. (1948)
7	Potassium	Flame Photometric method	Stanford and English (1949)
8	CO_3 and HCO_3	Titration with standard H_2SO_4	A.O.A.C. (1950)
9	Chloride	Silver Nitrate method	A.O.A.C (1950)
10	Sulphate	Titrimetric method	Munger et. al. (1950)

Table.2 Maximum and minimum value of water quality parameters in groundwater samples

Parameters	Pre-monsoon samples (meq/l)			Post-monsoon samples (meq/l)		
	Min.	Max.	Mean	Min.	Max.	Mean
pH	6.0	8.0	6.98	6.5	7.6	7.11
EC	0.40	3.20	0.96	0.30	2.90	0.81
TDS	223	2600	641.38	200	2020	575.17
Ca	1.6	7.0	3.10	1.1	15.0	3.40
Mg	0.8	14.0	3.25	0.0	7.4	1.94
Na	0.2	12.1	2.98	0.2	6.4	2.47
K	0.0	1.2	0.13	0.0	0.6	0.06
HCO_3	0.0	5.2	1.58	0.4	5.5	1.65
CO_3	0.0	4.2	0.24	0.0	2.0	0.05
Cl	2.8	19.5	4.92	1.5	13.5	3.69
SO_4	0.0	17.2	2.75	0.0	14.2	2.52

Table.3 Groundwater quality characteristic parameters for irrigation in pre-monsoon period

Well/Grid No.	SAR	KR	RSC	SSP	PI
1	1.669	0.449	-4.100	31.000	47.733
2	0.725	0.263	-3.000	20.833	39.467
3	2.001	0.646	-2.800	39.241	57.142
4	2.974	1.079	-0.400	51.899	71.509
5	3.519	1.214	3.000	54.839	79.359
6	3.627	1.316	1.000	56.818	78.379
7	1.664	0.432	-2.400	30.189	48.579
8	4.544	1.290	-2.000	56.338	70.770
9	2.403	0.760	-3.000	43.182	57.556
10	5.060	1.600	-0.400	61.538	66.404
11	1.136	0.323	-5.600	24.390	33.837
12	1.519	0.385	-7.400	27.778	33.634
13	1.560	0.405	-7.000	28.846	34.927
14	2.023	0.682	-2.600	40.541	58.671
15	0.365	0.111	-3.800	10.000	31.082
16	1.091	0.238	-7.700	19.231	32.102
17	2.333	0.778	-1.700	43.750	64.667
18	2.267	0.756	-3.100	43.038	58.015
19	0.452	0.102	-7.000	9.259	24.753
20	2.517	0.813	-2.000	44.828	64.061
21	2.357	0.731	-3.000	42.222	58.703
22	2.721	0.974	-1.900	49.351	67.717
23	2.622	0.905	-2.200	47.500	65.178
24	2.571	0.719	-3.400	41.818	51.777
26	2.330	0.646	-3.700	39.252	54.891

27	2.076	0.567	-3.200	36.190	54.008
28	1.926	0.476	-4.600	32.231	47.912
29	0.923	0.304	-1.600	23.333	52.201
30	1.736	0.538	-2.400	35.000	55.917
31	1.116	0.346	-3.800	25.714	42.617
32	0.837	0.250	-3.600	20.000	40.203
33	0.230	0.088	-2.000	8.108	40.087
34	0.587	0.172	-4.400	14.706	32.106
35	1.035	0.315	-3.600	23.944	42.840
36	0.220	0.061	-5.400	5.714	21.364
37	1.283	0.343	-5.800	25.532	37.186
38	0.974	0.296	-4.400	22.857	29.246
39	1.235	0.254	-10.600	20.270	27.672
40	0.309	0.048	-20.000	4.545	9.091
41	2.233	0.692	-4.600	40.909	49.711
42	2.673	0.714	-5.800	41.667	49.120
43	3.885	0.624	-18.600	38.413	41.252
44	1.497	0.400	-5.800	28.571	39.749
45	1.771	0.560	-3.800	35.897	49.942
46	1.897	0.600	-3.800	37.500	51.193
47	2.459	0.657	-5.500	39.655	50.213
48	1.604	0.429	-5.400	30.000	38.944
49	1.104	0.381	-3.600	27.586	40.941
50	1.744	0.447	-7.000	30.909	37.951
51	0.775	0.250	-4.000	20.000	34.907
52	1.212	0.350	-5.200	25.926	36.968
53	0.481	0.129	-6.200	11.392	22.714
54	1.265	0.400	-4.200	28.571	41.349
55	1.013	0.256	-7.000	20.408	20.408
56	0.126	0.040	-4.200	3.846	21.047
57	1.633	0.667	-2.400	40.000	55.492
58	1.414	0.333	-8.100	25.000	32.906
60	0.881	0.242	-5.200	19.512	33.942
61	0.651	0.176	-6.000	15.000	22.906
62	0.535	0.143	-6.000	12.500	25.000
63	2.001	0.646	-4.000	39.241	50.562
64	1.420	0.458	-4.400	31.429	40.464
66	4.313	1.525	-3.200	60.396	69.252
Max.	5.060	1.600	3.000	61.538	79.359
Min.	0.126	0.040	-20.000	3.846	9.091

Table.4 Groundwater quality characteristic parameters for irrigation in post-monsoon period

Well/Grid No.	SAR	KR	RSC	SSP	PI
1	1.936	0.625	-2.700	38.462	57.040
2	1.073	0.524	-1.300	34.375	62.326
4	2.057	0.920	-0.500	47.917	77.379
5	3.297	1.087	0.900	52.083	76.513
6	2.378	0.912	-0.400	47.692	74.339
7	1.651	0.455	-2.800	31.250	51.556
8	3.349	0.967	-2.200	49.153	65.673
9	2.121	0.750	-2.400	42.857	60.927
10	4.071	1.405	-0.600	58.416	70.940
11	1.278	0.408	-4.100	28.986	41.948
12	1.398	0.391	-6.000	28.090	35.196
13	0.808	0.217	-6.500	17.857	25.386
14	2.133	0.711	-2.700	41.558	58.982
15	0.923	0.304	-3.000	23.333	44.415
16	1.336	0.357	-5.400	26.316	39.631
17	1.370	0.447	-3.200	30.882	48.893
18	1.517	0.500	-4.000	33.333	44.559
19	1.431	0.410	-5.500	29.070	38.077
20	2.767	1.094	-2.000	52.239	68.589
21	3.503	1.364	-1.300	57.692	75.823
22	1.131	0.400	-2.300	28.571	51.854
23	1.687	0.647	-1.900	39.286	61.156
24	1.688	0.509	-2.500	33.735	49.899
26	0.832	0.231	-3.700	18.750	39.667
27	1.185	0.351	-3.100	25.974	46.915
28	2.425	0.700	-3.400	41.176	56.985
29	0.923	0.304	-2.600	23.333	46.904
30	2.263	0.800	-2.000	44.444	64.086
31	1.600	0.533	-3.000	34.783	52.533
33	0.358	0.160	-1.500	13.793	48.276
34	1.257	0.439	-2.000	30.508	55.070
35	0.632	0.200	-2.800	16.667	41.387
36	0.138	0.048	-3.000	4.545	29.442
37	0.802	0.214	-5.800	17.647	30.535
38	0.933	0.311	-3.300	23.729	42.296
39	0.741	0.153	-9.000	13.235	25.539
40	1.026	0.188	-12.100	15.819	25.273
41	2.286	0.933	-0.500	48.276	75.537
42	1.497	0.400	-5.000	28.571	43.002
43	1.912	0.286	-20.400	22.222	27.133
44	1.265	0.400	-3.000	28.571	48.774

45	1.116	0.346	-3.100	25.714	46.416
46	0.597	0.162	-4.700	13.924	32.268
47	2.909	0.920	-2.900	47.917	63.012
48	1.211	0.333	-5.000	25.000	39.374
49	1.446	0.581	-1.900	36.735	59.091
50	2.598	0.750	-4.000	42.857	56.326
52	1.138	0.360	-3.800	26.471	42.580
53	2.055	0.813	-2.400	44.828	60.249
54	1.074	0.385	-3.100	27.778	44.341
55	1.477	0.419	-5.800	29.545	36.732
56	0.580	0.211	-3.400	17.391	31.140
57	1.168	0.455	-2.200	31.250	53.100
58	1.186	0.469	-2.000	31.915	55.222
60	2.192	0.775	-3.200	43.662	56.260
61	0.335	0.094	-5.800	8.571	19.637
62	0.587	0.172	-5.200	14.706	26.097
63	2.139	0.738	-3.600	42.466	53.077
64	1.537	0.537	-3.500	34.921	47.216
66	2.319	0.791	-3.500	44.156	55.772
Max.	4.071	1.405	0.900	58.416	77.379
Min.	0.138	0.048	-20.400	4.545	19.637

Table.5 Sodium hazard classes based on USSL classification

SAR	Sodium hazard class	Remark on quality	Pre-monsoon samples	Post-monsoon samples
<10	S1	Excellent	0.126-5.060 (all 63 samples)	0.138-4.071 (all 60 samples)
10-18	S2	Good	Nil	Nil
18-26	S3	Doubtful	Nil	Nil
>26	S4	Unsuitable	Nil	Nil

Table.6 Groundwater quality based on RSC (Residual sodium carbonate)

RSC	Water class	Pre-monsoon samples	Post-monsoon samples
<1.25	Good	0-1.00 (62 samples)	0-0.90 (all 60 sample)
1.25-2.5	Doubtful	Nil	Nil
>2.5	Unsuitable	3.00 (1 sample)	Nil

Table.7 Salinity hazard classes

Salinity hazard class	EC in ds/m	Remark on quality	Pre-monsoon samples	Post-monsoon samples
C1	0.100-0.250	Excellent	Nil	Nil
C2	0.250-0.750	Good	0.4-0.75 (16 samples)	0.3-0.75 (34 samples)
C3	0.750-2.250	Doubtful	0.8-1.55 (45 samples)	0.80-1.80 (25 samples)
C4	>2.250	Unsuitable	2.22-3.20 (2 samples)	2.90 (1 sample)

Groundwater quality for irrigation purposes

The suitability of water for irrigation purpose depends upon TDS (salinity) and the sodium content in relation to the amounts of calcium and magnesium or SAR (Alagbe, 2006). The suitability of groundwater for irrigation use was evaluated by calculating SAR, Kelly's Ratio (KR), Residual Sodium Carbonate (RSC), Soluble Sodium Percentage (SSP) and Permeability Index (PI) and given in Table 3 and Table 4 for pre and post monsoon period respectively.

The waters having SAR values less than 10 are considered excellent, 10 to 18 as good, 18 to 26 as fair, and above 26 are unsuitable for irrigation use (USDA, 1954). In the present study, the SAR values are less than 10 for all samples during both pre and post monsoon period and therefore it is graded as excellent for irrigation use (Table 5).

The Kelly's ratio of unity or less than one is indicative of good quality of water for irrigation whereas above one is suggestive of unsuitability for agricultural purpose due to alkali hazards (Karanth, 1987). The map of the variation of Kelly's Ratio was prepared in GIS environment and shown in Fig. 4 for pre and post monsoon period. From these figures, it is observed that, during pre monsoon period about 94 per cent area has good quality water and 6 per cent area has unsuitable for irrigation due to alkali hazards, but in post monsoon period 99.85 per cent area has good quality of water for irrigation purposes

The Residual Sodium Carbonate (RSC) value exceeds 2.5 meq/l, the water is generally unsuitable for irrigation. If the value of RSC is between 1.25 and 2.5 meq/l, the water is marginally suitable, while a value less than 1.25 meq/l indicates safe water quality (USDA, 1954). It is evident from Table 6 that, RSC values for all the samples of the study area are less than 1.25, (except one sample in pre monsoon) suggesting that whole study area are under safe limit for irrigation use during both pre and post monsoon period.

Wilcox (1955) has proposed classification scheme for rating irrigation waters on the basis of soluble sodium percentage (SSP). The values of SSP less than 50 indicate good quality of water and higher values (i.e. > 50) shows that the water is unsafe for irrigation (USDA, 1954). The map of the variation of SSP was prepared in GIS environment and shown in Fig. 5 for pre and post monsoon period. From these figures, it is observed that, during pre monsoon period about 95 per cent of basin area has good quality water and 5 per cent area is unsafe for irrigation but in post monsoon 99.5 per cent area has good quality of water for irrigation purposes.

The Permeability Index (PI) values > 75 indicate excellent quality of water for irrigation. If the PI values are between 25 and 75, it indicates good quality of water for irrigation. However, if the PI values are less than 25, it reflect unsuitable nature of water for irrigation. The map of the variation of PI was prepared in GIS environment as shown in Fig. 6 for pre and post monsoon period. From these figures, it is observed that about 98 per cent of basin area has good quality water for irrigation purposes in both pre and post monsoon period.

For the purpose of diagnosis and classification, the total concentration of soluble salts (salinity hazard) in irrigation water can be expressed in terms of specific conductance. Classification of groundwater based on salinity hazard is presented in Table 7. It is revealed from the EC value that only 2 samples during pre-monsoon and 1 sample during post-monsoon period were found to be unsuitable for irrigation purposes.

Hence it is concluded that the present study aimed at in-depth geochemical investigations in the study area for efficient management of scarce groundwater resources. It was analysed in the process of study that use of GIS can make the cumbersome groundwater quality analysis as an easy task. The groundwater quality of the Wakal river basin was analyzed. The different water quality parameter map was prepared under GIS environment and the spatio-temporal variations of groundwater quality parameters were analyzed. The highest EC, TDS, Na, SO_4 was found in village Kotra and Ca, Mg, Cl in village Bira of Jhadol block during pre monsoon period. During post monsoon period the highest EC, TDS, Ca, Mg, Na, K, Cl and SO_4 was found in village Kotra. The suitability of groundwater for irrigation use was evaluated on the basis of Sodium Absorption Ratio (SAR), Kelly's Ratio (KR), Residual Sodium Carbonate (RSC), Soluble Sodium Percentage (SSP) and Permeability Index (PI) and found that most of the study area groundwater is suitable for irrigation purpose during both pre and post monsoon period.

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