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An Evaluation of Groundwater Quality in Some Parts of Tehsil Sikar (Rajasthan) Using Multivariate Statistical Approach and Water Quality Index (WQI)

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ABSTRACT

The ground water quality in tehsil sikar has been concerned due to elevated levels of fluoride and other contaminants. The main objective of present research work is to evaluate various physico-chemical parameters, correlation analysis and water quality index (WQI) of ground water of study area. A comprehensive physico-chemical analysis was conducted after the total 32 groundwater samples were collected from different sampling locations of study area during pre and post monsoon session (2024). The physico-chemical parameters such as dissolved oxygen, pH, electrical conductivity, total dissolved solids, total alkalinity, total hardness, fluoride, chlorides, nitrate, bicarbonate, sodium, potassium, calcium and magnesium were analyzed to observe the current status of the groundwater quality of study area. The results were compared with the water quality standards of the World Health Organization (WHO) and Bureau of Indian Standard (BIS). Except of pH, TA, TH and magnesium most of the samples found exceeded the permitted limit. Water quality index revealed that the groundwater of the study area is poor category and unsuitable for drinking purposes. The evaluation of groundwater quality index WQI could be useful for groundwater users and policy makers to take remedial measures. Therefore it was inferred that the groundwater of the contaminated areas must be treated and made potable before consumption. The outcomes of the present study will be helpful for the regulatory boards and policymakers for defining the actual impact and remediation goal.

Key words:- Groundwater contamination, physicochemical parameters and water quality index (WQI).

Introduction

Water resources have played a critical and vital role throughout history in the growth and continue to be a factor of importance in the economic growth of all contemporary societies. In societies with developing economics, the optimum development, efficient utilization and effective management of their water resources should be the dominant strategy for economic growth, but in recent years unscientific management and use of water resources for various purposes, almost invariably has created undesirable problems, water logging and

salinity in the case of agriculture use and environment pollution of various limits as a result of mining, industries and municipal use (*Kumar et al., 2013*).

Groundwater is fresh water located in the subsurface pore space of soil and rocks. It is also water that is flowing within aquifers below the water table. An aquifer is a unit of rock or an unconsolidated deposit when it can yield a usable quantity of water. Water table is the depth at which soil pore spaces or fractures and voids in rock become completely saturated with water. The qualities of groundwater resources vary naturally and widely depending on climate, season and geology of bedrock as well as anthropogenic activities. Groundwater is the ultimate, most suitable fresh water resource with nearly balanced concentration of the salts for human consumption. In India, most of the population is dependent on groundwater as the only source of drinking water supply. The groundwater is believed to be comparatively much cleaner and free from pollution than surface water (*Tewari et al., 2010; Patil Geeta and Patil 2013*). Groundwater's hydro-geochemical evolution depends on various factors, i.e., water–aquifer matrix interaction, groundwater residence time within the aquifer and the associated chemical process during recharge. Generally three hydrogeochemical processes control the hydro-geochemical evolution of the groundwater when the major solutes intruded to the aquifer matrix: evaporite dissolution, carbonate dissolution and silicate weathering (*Mukherjee et al., 2012, Verma et al., 2015, Pant et al., 2021, Drever and Stillings 1997*).

However, groundwater quality has been influenced by both natural and anthropogenic activities. The natural processes influencing groundwater quality include groundwater recharge, rock-water interactions, mineral weathering and contaminated water from the adjoining aquifer. Anthropogenic activities include improper groundwater exploitation, intensive applications of agrochemicals, industrial production, waste and wastewater discharge, and urbanization *(Laonamsai et al., 2023; Abdessamed et al., 2023; Lu et al., 2024; Obeidat & Awawdeh 2021; Ferhati et al., 2023).* Groundwater contamination can impact human health, environmental quality and socioeconomic development. Many studies have shown that high levels of fluoride, nitrate, metals, and persistent organic pollutants are health risk for human populations. This is especially critical for infants and children who are more susceptible to the effects of these contaminants than adults (*Wu and Sun 2016*; *Mthembu et al. 2020;*; *Subba Rao et al. 2020*;). Human health also can be affected by the groundwater contamination through effects on the food production system. Irrigation with groundwater contaminated by heavy metals and wastewater containing persistent contaminants can result in the accumulation of toxic elements in cereals and vegetables, causing health risks to humans (*Jenifer and Jha 2018; Yuan et al. 2019; Njuguna et al. 2019*).

Groundwater contamination also can negatively affect the quality of lands and forests. Contaminated groundwater can lead to soil contamination and degradation of land quality. Many agricultural areas in arid regions, high groundwater salinity is one of the major factors influencing soil salinization. The soluble salts and other contaminants, such as toxic metals, can accumulate in the root zone, affecting vegetation growth. Groundwater contaminants can also be transported by surface water- groundwater interactions, leading to deterioration of surface water quality (*Teng et al., 2018*). Sustainable economic development requires a balance between the rate of renewal of natural resources and human demand. Freshwater is probably the most valuable of the natural resources. However, chronic groundwater contamination may reduce the availability of freshwater, breaking the balance between water supply and demand and leading to socioeconomic crises and even wars. Water shortages induced by contamination may become a factor causing conflicts among citizens in the future (*Schillinger et al. 2020*) possibly delaying the socioeconomic development of a nation.

Therefore, it is necessary to ascertain the status of groundwater quality for drinking as it is directly or indirectly associated with public health. This study uses statistical and analytical methods to evaluate the influence of the various anthropogenic factors which alter the water composition. (*Chakraboty Monica et al. 2022*).

Material and Methodology

Sikar tehsil is a part of Shekhawati region, and located in Sikar District which is a semi –arid region of northern Rajasthan, India. Its geographical location is 27.61^0 N latitude and 75.14^0 E longitudes. Maximum temperature in summer can reach 45^0C to 47^0C in May –June and minimum temperature can go low as 0^0C to 4^0C dips in December- January. The rainfall pattern is highly variable and irregular, most rainfall occurs during the southwest monsoon (July- September) and average annual rainfall is 450 mm to 550 mm. Predominantly loamy sand , sandy loam and calcareous soils are found in this area which has moderate fertility prone to erosion.

The entire study area is divided in eight zones for more efficient investigation and better understanding of groundwater quality, so as to get representative samples as follows:- North zone:- [Jagmalpura –Govt. hospital (TW), Bhadwasi – Raghunath ji temple (TW)], North- East zone:- [Kurli- Govt. Se. Sec.School (TW), Katrathal - Bus stand (TW)], East zone:- [Piprali – Panchayat samiti (TW), Raghunathgarh – Govt. Se. Sec. School (TW),], South- East zone:- [Bajor – Bus stand (TW), Shyampura – Govt. hospital (TW)], South zone: - [Devgarh – Post office (OW), Gokulpura- Govt. Se. Sec. School (TW)], South- West zone:- [Harsh- Ramdev ji temple (TW), Dujod- Jamwai mata temple (TW)], West zone:- [Chandpura - Govt Upper Primary School (TW), Nani- Sarswati TT College (TW)], North- West zone:- [Sabalpura - Teja ji temple (OW), Dhaka Ki Dhani – Shiv Ji Temple (OW)].

A total of thirty two (32) ground water samples were collected from open wells, tube wells and hand pumps of different sampling sites. The ground water samples were collected during the pre monsoon (May 2024) and post monsoon session (October 2024). The ground water samples were systematically collected in pre cleaned, dry and sterilized plastic bottles of one liter capacity. At the time of sampling, sample bottles are thoroughly raised 2-3 times using the ground water to be sampled. These water samples are collected after pumping the water for 10 minutes. The samples were stored at a temperature below 4 ^{o}C prior to analysis. Various physico-chemical parameters have been analyzed using standard methods recommended by American Public Health Association (*APHA 2012*). Correlation analysis and water quality index (WQI) have also been carried out. Temperature and pH were determined immediately at the place of collection while Turbidity, EC (electrical conductivity), TDS (total dissolved solids) and DO (dissolved oxygen) were determined at the same day of sampling using Water Analyzer (Systronic-371). Analytical grade reagents were used for the assessment of samples and double distilled water was used for preparation of solutions.

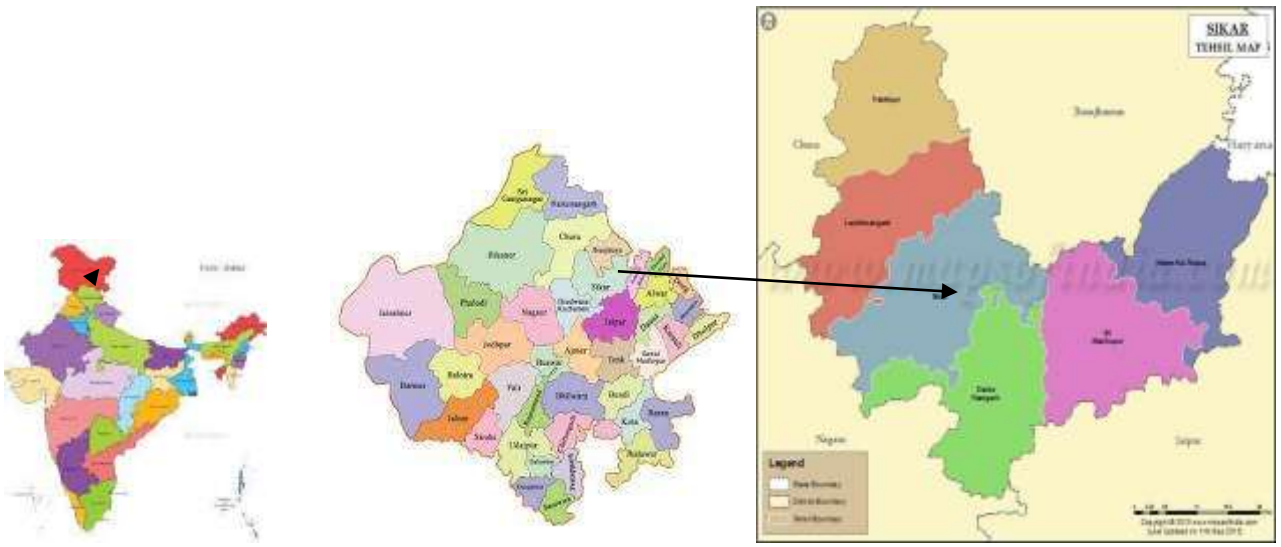


Fig.1. Map of study area

Table - 1:- Physical parameters of ground water samples of some parts of Sikar Tehsil (pre monsoon -2024)

S.No.	Village	Sample Site	Code	Source	Temp.	DO	pH	EC	TA	TH	CaH	MgH	TDS
1	Jagmalpura	Govt. Hospital	SKT1	TW	22	3.2	7.78	931	226	265	177	88	596
2	Bhadwashi	raghunath ji temple	SKT2	TW	21.9	3.4	7.75	1034	215	287	191	96	662
3	Kurli	Govt.Sen.Sec.School	SKT3	TW	24.2	2.5	7.88	1769	349	269	179	90	1132
4	Katrathal	Bus Stand	SKT4	TW	21.4	3.6	7.76	1102	336	375	250	125	704
5	Piprali	CBEO Office	SKT5	TW	22.5	3.3	7.95	1273	246	342	228	114	815
6	Raghunathgarh	Govt.Sen.Sec.School	SKT6	TW	23.9	2.6	7.88	1392	259	323	215	108	892
7	Malkhera	Bus Stand	SKT7	TW	22.8	2.9	8.1	1729	355	257	171	86	1106
8	Shyampura	Govt Aayrvedic Hos.	SKT8	TW	21.6	3.6	7.82	1188	251	328	219	109	760
9	Devgarh	Post office	SKT9	TW	23.5	2.6	7.85	1716	292	269	179	90	1098
10	Gokulpura	Govt.Sen.Sec.School	SKT10	TW	23.2	3.4	7.16	1175	265	381	258	129	752
11	Harsh	Ramdev ji temple	SKT11	TW	21.6	3.6	7.79	1358	278	292	195	97	869
12	Dujod	Jamwai Mata Temple	SKT12	TW	22.7	2.9	7.77	1011	220	385	264	132	647
13	Chandpura	Govt.UPS	SKT13	TW	22.3	3.4	7.95	1525	294	349	233	116	976
14	Nani	Sarswati TT College	SKT14	TW	23	3.2	7.9	1389	280	372	248	124	889
15	Sabalpura	Tejaji temple	SKT15	OW	23.7	2.8	8.05	1750	331	289	193	96	1120
16	Dhaka ki Dhani	Shiv ji Temple	SKT16	OW	22.9	3.3	7.91	1539	286	361	241	120	985

All values of parameters are expressed in mg/L, except pH, Temperature (^{0}C) and EC in µS/cm.

Table - 2:- Chemical parameters of ground water samples of some parts of Sikar Tehsil (pre monsoon -2024)

S No.	Village	Sample Site	Code	Sample Source	F^-	NO_3^-	SO_4^{-2}	Cl^-	CO_3^{-2}	HCO_3^-	Ca^{+2}	Mg^{+2}	Na^+	K^+
1	Jagmalpura	Govt. Hospital	SKT1	TW	1.60	29	14	91	3.2	223	70.8	21.4	252	3.6
2	Bhadwashi	raghunath ji temple	SKT2	TW	1.44	25	9	110	4	210	76.4	23.3	244	4.1
3	Kurli	Govt.Sen.Sec.School	SKT3	TW	1.61	28	17	237	2.4	341	71.6	21.9	497	7.2
4	Katrathal	Bus Stand	SKT4	TW	1.20	23	12	125	5.7	230	100	30.4	258	3.9
5	Piprali	CBEO Office	SKT5	TW	1.34	29	15	154	4.9	241	91.2	27.7	310	4.4
6	Raghunathgarh	Govt.Sen.Sec.School	SKT6	TW	1.37	32	19	166	4.2	265	86	26.2	367	4.7
7	Malkhera	Bus Stand	SKT7	TW	1.65	41	24	209	0	355	68.4	20.3	489	6.8
8	Shyampura	Govt Aayrvedic Hos.	SKT8	TW	1.40	23	20	123	4.5	246	87.6	26.5	284	3.6
9	Devgarh	Post office	SKT9	TW	1.62	37	21	252	2.5	289	71.6	21.9	486	6.5
10	Gokulpura	Govt.Sen.Sec.School	SKT10	TW	1.14	15	8	127	5.9	258	103.2	31.3	265	4.1
11	Harsh	Ramdev ji temple	SKT11	TW	1.53	34	15	149	3.4	275	78	23.6	359	4.7
12	Dujod	Jamwai Mata Temple	SKT12	TW	1.10	21	10	86	4.7	216	105.6	32.8	232	3.4
13	Chandpura	Govt.UPS	SKT13	TW	1.41	28	16	193	3.1	291	93.2	26.2	390	4.9
14	Nani	Sarswati TT College	SKT14	TW	1.39	20	9	176	3.4	277	99.2	30.1	348	3.6
15	Sabalpura	Tejaji temple	SKT15	OW	1.58	36	20	235	0	331	77.2	23.3	492	6.9
16	Dhaka ki Dhani	Shiva ji Temple	SKT16	OW	1.32	25	17	212	2.8	283	96.4	29.2	386	4.3

Table - 3:- Physical parameters of ground water samples of some parts of Sikar Tehsil (Post monsoon -2024)

S.No.	Village	Sample Site	Code	Source	Temp.	DO	pH	EC	TA	TH	CaH	MgH	TDS

1	Jagmalpura	Govt. Hospital	SKT1	TW	19.7	3.5	8.16	1281	245	270	180	90	820
2	Bhadwashi	raghunath ji temple	SKT2	TW	18.5	3.6	7.80	1225	237	312	208	104	784
3	Kurli	Govt.Sen.Sec.School	SKT3	TW	19.4	2.8	7.92	2010	352	284	189	95	1286
4	Katrathal	Bus Stand	SKT4	TW	18.7	3.9	7.78	1208	245	396	264	132	772
5	Piprali	CBEO Office	SKT5	TW	19.3	3.4	7.90	1405	268	353	235	118	825
6	Raghunathgarh	Govt.Sen.Sec.School	SKT6	TW	18.8	2.7	7.96	1512	285	337	225	112	968
7	Malkhera	Bus Stand	SKT7	TW	19.5	3.3	8.12	1945	367	276	184	92	1245
8	Shyampura	Govt Aayrvedic Hos.	SKT8	TW	18.6	4.2	7.85	1339	259	342	228	114	857
9	Devgarh	Post office	SKT9	TW	20.4	2.5	7.88	2056	386	287	191	96	1316
10	Gokulpura	Govt.Sen.Sec.School	SKT10	TW	19.1	3.6	7.79	1350	293	398	265	133	864
11	Harsh	Ramdev ji temple	SKT11	TW	18.8	3.9	7.86	1525	296	315	210	105	976
12	Dujod	Jamwai Mata Temple	SKT12	TW	19.3	3.2	7.82	1186	232	407	271	136	759
13	Chandpura	Govt.UPS	SKT13	TW	19	3.5	7.89	1695	310	363	242	121	1085
14	Nani	Sarswati TT College	SKT14	TW	19.6	3.3	7.76	1488	291	416	277	139	952
15	Sabalpura	Tejaji temple	SKT15	OW	20.2	3.0	8.09	1916	343	294	196	98	1226
16	Dhaka ki Dhani	Shiv ji Temple	SKT16	OW	19.8	3.6	7.97	1675	306	377	251	126	1072

Table - 4:- Chemical parameters of ground water samples of some parts of Sikar Tehsil (Post monsoon -2024)

S No.	Village	Sample Site	Code	Sample Source	F^-	NO_3^-	SO_4^{-2}	Cl^-	CO_3^{-2}	HCO_3^-	Ca^{+2}	Mg^{+2}	Na^+	K^+
1	Jagmalpura	Govt. Hospital	SKT1	TW	1.58	37	19	142	0	249	72	21.9	320	9.7
2	Bhadwashi	raghunath ji temple	SKT2	TW	1.40	28	17	139	5.2	232	83.2	25.3	297	8.1
3	Kurli	Govt.Sen.Sec.School	SKT3	TW	1.52	32	20	290	2.9	351	75.6	23.1	572	11.3
4	Katrathal	Bus Stand	SKT4	TW	1.16	25	15	134	5.8	239	105.6	32.1	258	6.9
5	Piprali	CBEO Office	SKT5	TW	1.22	31	21	168	5.1	2693	94	28.7	341	7.4
6	Raghunathgarh	Govt.Sen.Sec.School	SKT6	TW	1.30	39	23	179	4.7	280	90	27.2	383	8.8
7	Malkhera	Bus Stand	SKT7	TW	1.54	44	29	245	0	367	73.6	22.4	556	10.9
8	Shyampura	Govt Aayrvedic Hos.	SKT8	TW	1.33	27	25	156	4.8	254	91.2	27.7	325	9.5
9	Devgarh	Post office	SKT9	OW	1.51	42	27	270	3	383	76.4	23.3	591	11.6
10	Gokulpura	Govt.Sen.Sec.School	SKT10	TW	1.10	26	13	142	6.2	287	106	32.3	318	7.8
11	Harsh	Ramdev ji temple	SKT11	TW	1.44	38	18	173	3.9	292	84	25.5	396	8.3
12	Dujod	Jamwai Mata Temple	SKT12	TW	1.06	29	14	140	5.1	227	108	33	254	7.5
13	Chandpura	Govt.UPS	SKT13	TW	1.35	34	19	216	3.6	306	96.8	29.4	435	9.9
14	Nani	Sarswati TT College	SKT14	TW	0.82	23	12	191	6.8	284	110.8	33.8	357	7.7
15	Sabalpura	Tejaji temple	SKT15	OW	1.49	42	26	249	0	343	78.4	23.8	542	10.8
16	Dhaka ki Dhani	Shiv ji Temple	SKT16	OW	1.26	29	23	227	3.5	302	100.4	30.6	431	9.3

Table 5:- Correlation-Matrix of Various Groundwater Quality Parameters of some part of Sikar Tehsil (Pre monsoon 2024)

Parameters	pH	EC	TA	TH	TDS	F^-	NO_3^-	Cl^-	HCO_3^-	Ca^{2+}	Mg^{+2}	Na
pH	1											
EC	0.5209	1										
TA	0.3642	0.7633	1									
TH	-0.3975	-0.3989	-0.2400	1								
TDS	0.5209	0.9999	0.7620	-0.3992	1							
F^-	0.5523	0.5748	0.3829	-0.9293	0.5749	1						
NO_3^-	0.6770	0.6149	0.4240	-0.7782	0.6150	0.7903	1					
Cl^-	0.4947	0.9763	0.7225	-0.3708	0.9763	0.5588	0.5661	1				
HCO_3^-	0.4565	0.9386	0.8287	-0.4358	0.9384	0.5990	0.5789	0.8653	1			
Ca^{+2}	-0.4151	-0.4116	-0.2563	0.9985	-0.4118	-0.9388	-0.7828	-0.3882	-0.4430	1		
Mg^{+2}	-0.4428	-0.4461	-0.2904	0.9846	-0.4463	-0.9529	-0.7957	-0.4193	-0.4816	0.9889	1	
Na	0.5604	0.9829	0.7520	-0.5386	0.9830	0.6910	0.7112	0.9565	0.9379	-0.5484	-05747	1

Table 6:- Correlation-Matrix of Various Groundwater Quality Parameters of some part of Sikar Tehsil (Post monsoon 2024)

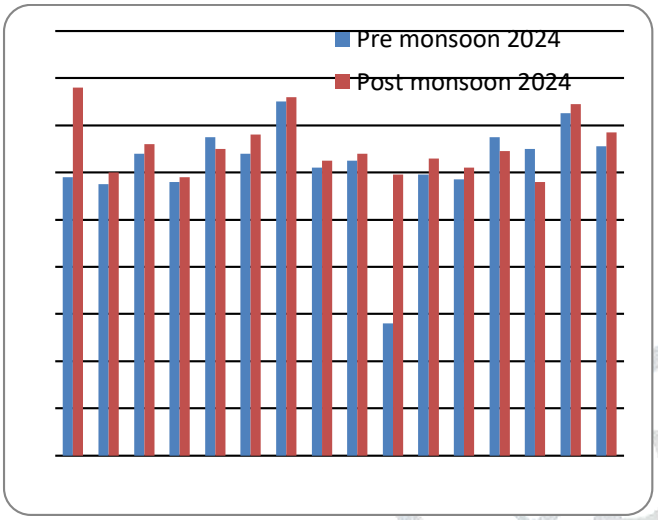
Parameters	pH	EC	TA	TH	TDS	F^-	NO_3^-	Cl^-	HCO_3^-	Ca^{2+}	Mg^{+2}	Na
pH	1											
EC	0.4281	1										
TA	0.3521	0.9733	1									
TH	-0.6979	-0.5310	-0.4732	1								
TDS	0.4233	0.9955	0.9711	-0.0537	1							
F^-	0.6888	0.5085	0.4340	-0.9423	0.5122	1						
NO_3^-	0.7381	0.6464	0.6221	-0.7730	0.6432	0.7593	1					
Cl^-	0.3794	0.9798	0.9234	-0.4772	0.9746	0.4447	0.5357	1				
HCO_3^-	0.0115	-0.0533	0.8120	0.0335	-0.1475	0.0883	-0.0233	0.0473	1			
Ca^{+2}	-0.6977	-0.5399	-0.4738	0.9999	-0.5382	-0.9419	-0.7729	-0.4787	0.3260	1		
Mg^{+2}	-0.6990	-0.5366	-0.4704	0.9999	-0.5354	-0.9437	-0.7763	-0.4738	0.0385	0.9998	1	
Na	0.4786	0.9940	0.9645	-0.6235	0.9903	0.5838	0.6931	0.9663	-0.0596	-0.6244	-0.6211	1

Table-7:- Average WQI values of Groundwater Samples of some part of Sikar Tehsil (Pre Monsoon 2024)

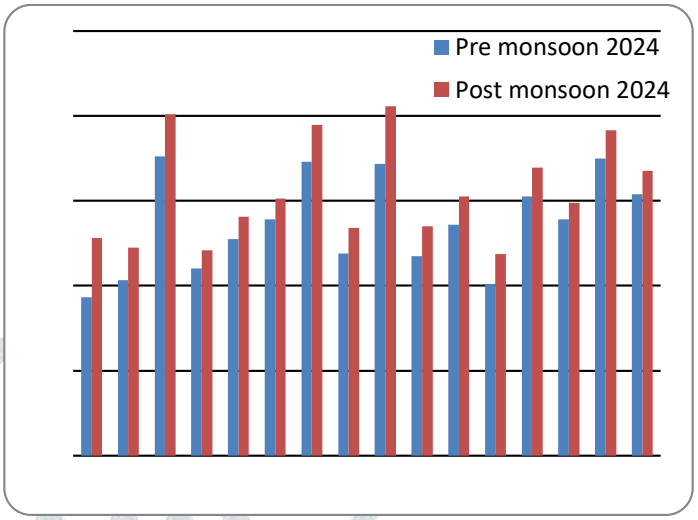
S. No.	Parameters	Ci (Observed value)	Si (Standard value)	Qi (Quality rating	W (weight)	Wi (Relative weight)	SI (Sub Index)
1	pH	7.83	7.5	104.40	5	0.1136	11.86
2	EC	1367	1000	136.70	4	0.0909	12.43
3	TA	280.2	200	140.10	4	0.0909	12.74
4	TH	321.5	200	160.75	3	0.0682	10.96
5	TDS	874.9	500	174.98	4	0.0909	15.91
6	F^-	1.42	1.5	94.67	5	0.1136	10.76
7	NO_3^-	27.87	50	55.74	5	0.1136	6.33
8	Cl^-	165.3	250	66.12	3	0.0682	4.51
09	Ca^{+2}	86.3	75	115.07	3	0.0682	7.85
10	Mg^{+2}	26	50	52.00	3	0.0682	3.55
11	Na	353.7	200	176.85	5	0.1136	20.10
					WQI		**117.00**

Table-8:- Average WQI values of Groundwater Samples of some part of Sikar Tehsil (Post Monsoon 2024)

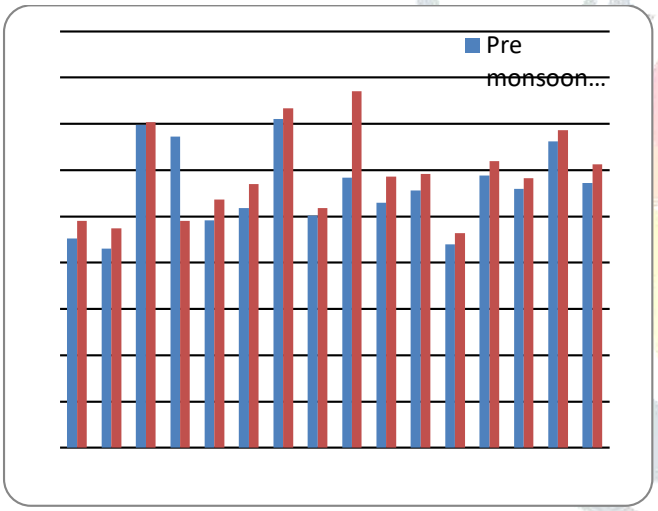
S. No.	Parameters	Ci (Observed value)	Si (Standard value)	Qi (Quality rating	W (weight)	Wi (Relative weight)	SI (Sub Index)
1	pH	7.91	7.5	105.47	5	0.1136	11.98
2	EC	1551	1000	155.10	4	0.0909	14.10
3	TA	294.63	200	147.32	4	0.0909	13.39
4	TH	339.19	200	169.59	3	0.0682	11.56
5	TDS	987.94	500	197.59	4	0.0909	17.96
6	F^-	1.32	1.5	88.00	5	0.1136	10.00
7	NO_3^-	32.88	50	65.76	5	0.1136	7.47
8	Cl^-	191.31	250	76.52	3	0.0682	5.22
09	Ca^{+2}	90.38	75	120.50	3	0.0682	8.22
10	Mg^{+2}	27.5	50	55.00	3	0.0682	3.75
11	Na	398.5	200	199.25	5	0.1136	22.64
						WQI	**126.29**



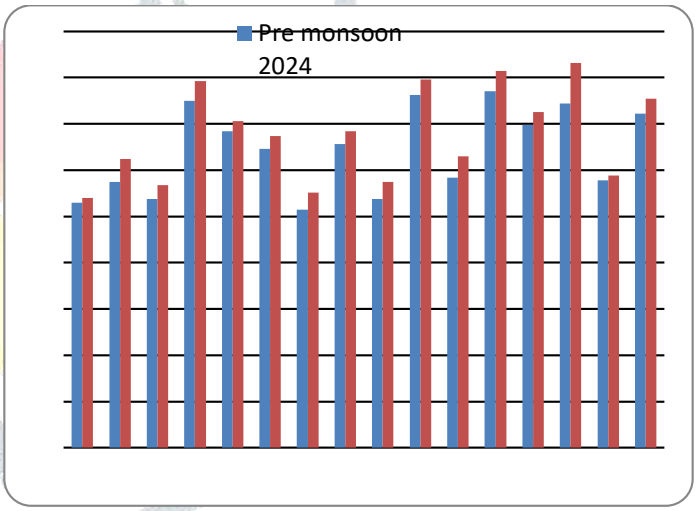
(a) pH Variation in pre and post monsoon 2024



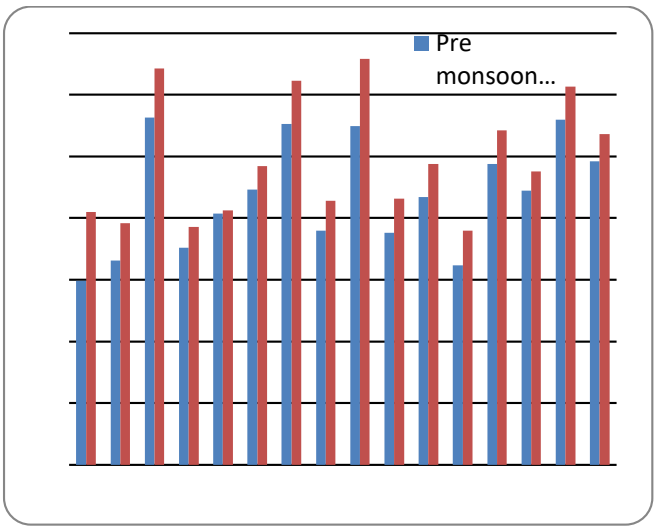
(b) EC Variation in pre and post monsoon 2024



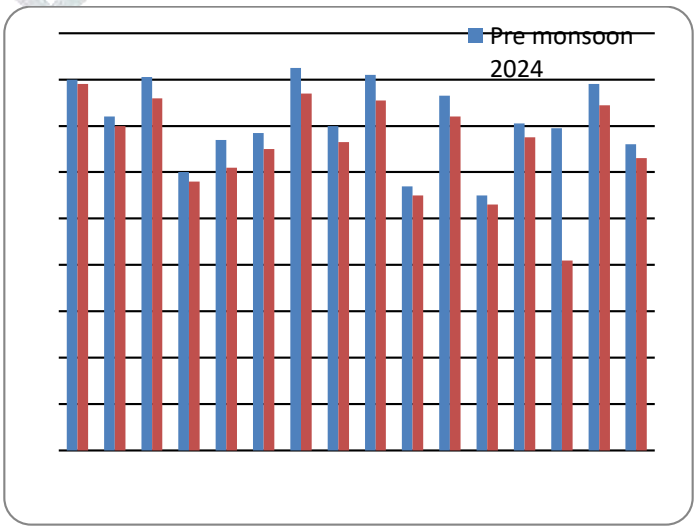
(c) TA Variation in pre and post monsoon 2024



(d) TH Variation in pre and post monsoon 2024

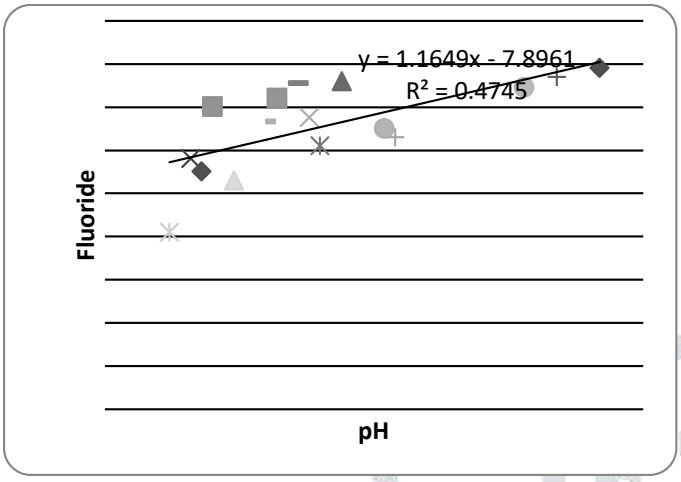


(e) TDS Variation in pre and post monsoon 2024

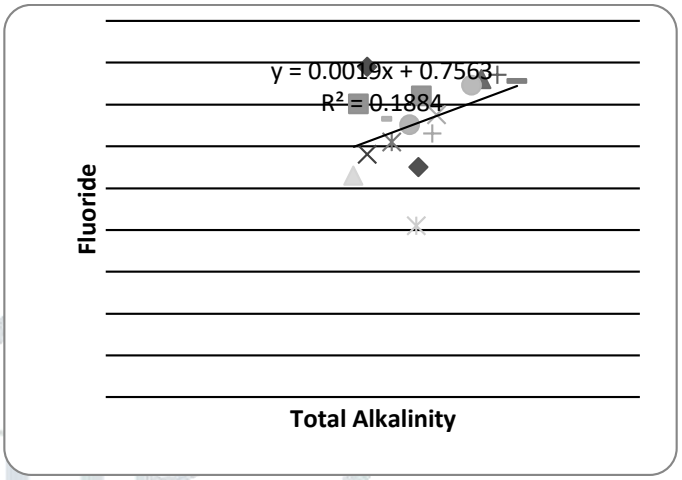


(f) Fluoride Variation in pre and post monsoon 2024

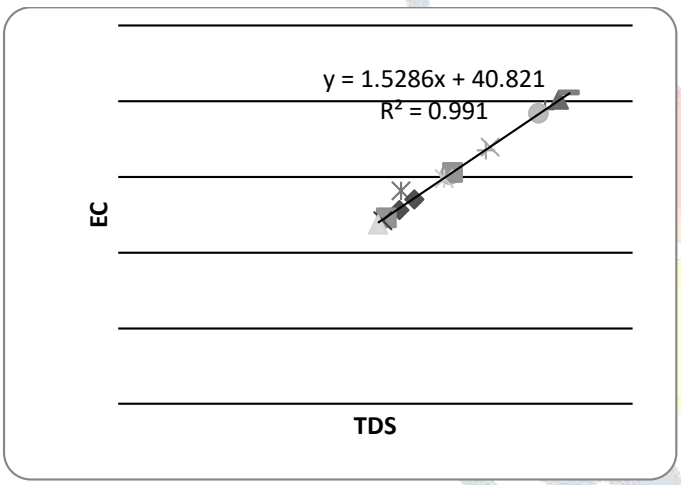
Fig.1(a-f). Seasonal changes in various physicochemical parameters of groundwater in some parts of Sikar Tehsil, during pre and post monsoon 2024.



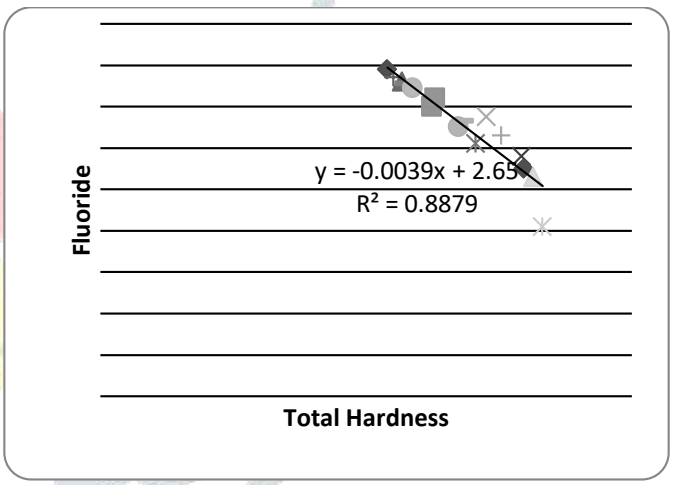
(a)



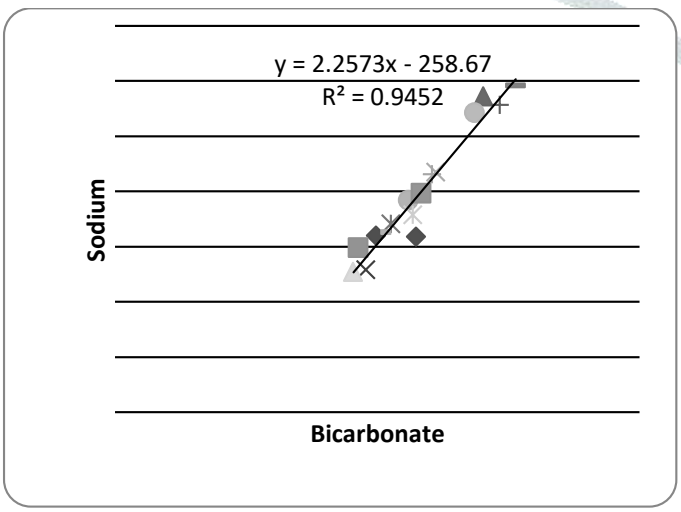
(b)



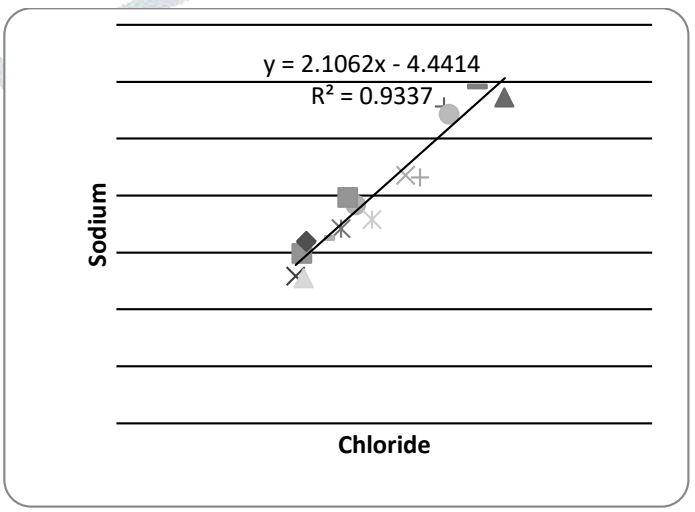
(c)



(d)



(e)



(f)

Fig.2 (a-f). Scatter diagram showing correlation between various physicochemical parameters of groundwater in some parts of Sikar Tehsil, during post monsoon 2024.

Result and Discussion

The analysis of physicochemical parameters across the 32 sampling points indicates significant variability in water quality of study area (Table 1 to Table 4). Seasonal changes in various physicochemical parameters of groundwater of study area during pre and post monsoon 2024 are depicted in Fig.1.a to Fig.1.f.

Electrical conductivity is the measurement of capacity of a substance to conduct the electric current. Most of the salts in water are present in their ionic forms and capable of conducting current and conductivity is a good indicator to assess groundwater quality (*Chaurasia Sadhana and Gupta Anand Dev 2022*). During pre monsoon EC values ranged from 966 µS/cm to 1769 µS/cm with an average value of 1370 µS/cm and in post monsoon ranged from1186 µS/cm to 2056 µS/cm with an average value of 1551µS/cm.

pH is one of the important water quality parameters that determines the alkalinity or acidity of groundwater. pH of groundwater strongly influence by mineralogy of aquifer materials and geochemistry of groundwater systems. The lower pH may cause corrosion while the higher values may produce incrustation, sediment deposit and difficulties in chlorination for disinfection of water (*Piyathilake et al., 2022*). The pH level of the groundwater in the study area in pre monsoon ranged from 7.16 to 8.10 with an average value of 7.83 and in post monsoon ranged from 7.76 to 8.16 with an average value of 7.91, which indicates that groundwater of study area is slightly alkaline. In pre and post monsoon season all the ground water samples of the study area were within the prescribed value of pH (6.5–8.5) by World Health Organization 2012.

Total alkalinity is the combined activity of the values of carbonates and bicarbonates in water. The organic matter present in the water system oxidizes to produce carbon –di-oxide facilitating mineral dissolution and contributing to HCO_3^- enrichment (*Khashogji and Maghraby (2013*). Weathering of silicate minerals also contributes to HCO_3^- enhancement (*Gastmans et al., 2010; Saha et al., 2019*). Total alkalinity in pre monsoon ranged from 215 mg/L to 355 mg/L with an average value of 280.2 mg/L, and in post monsoon ranged from 232 mg/L to 386 mg/L with an average value of 294.69 mg/L. All the groundwater samples of study area were within the prescribed value of total alkalinity.

Total Hardness is considered as a major character of drinking water. Hardness is defined as the concentrations of calcium and magnesium ions. Calcium and magnesium are dissolved from most soils and rocks. In general, hardness has got no adverse effect on human health. Water with hardness above 200 mg/L may cause scale deposition in the water distribution system and more soap consumption. Total hardness value during pre monsoon varies from 257 mg/L to 385 mg/L with an average value of 321.5 mg/L, and in post monsoon ranged from 270 mg/L to 416 mg/L with an average value of 339.2 mg/L.

Total Hardness value of all groundwater samples of study area were within the prescribed value by World Health Organization. A high concentration of TDS and electrical conductivity in irrigation water may increase the soil salinity, affecting the plant's salt intake. High level of TDS in water used for drinking purposes leads to many diseases which are not water-borne but due to excess of salts (*Parihar et al., 2012*).

Total dissolved solids (TDS) value during pre monsoon varies from 618 mg/L to 1132 mg/L with an average value of 876.6 mg/L, and in post monsoon ranged from 769 mg/L to 1316 mg/L with an average value of 987.94 mg/L. In pre and post monsoon season all samples exceeded the permitted limit recommended by WHO.

Chloride in the groundwater can be derived from rocks, seawater intrusion, or pollution by domestic sewage and industrial waste. Lower chloride content represents low salinity in the groundwater of the region (*Maruthi Devi and Usha Madhuri 2011*). The higher consumption of chloride can cause significant increase in the development of hypertension, risk for stroke, left ventricular hypertension, osteoporosis, renal stones and asthma in human beings (*McCarthy 2004*)**.** Chloride value during pre monsoon varies from 86 mg/L to 248 mg/L with an average value of 165 mg/L, and in post monsoon ranged from 134 mg/L to 290 mg/L with an average value of 191.44 mg/L. In pre monsoon all samples within the permitted limit recommended by WHO, but in post monsoon 18.75 % samples are exceeded the permitted limit, which indicating a salty taste in the groundwater.

Calcium Value during pre monsoon varies from 68.4 mg/L to 105.6 mg/L with an average value of 86.03 mg/L and in post monsoon ranged from 72 mg/L to 110.8 mg/L with an average value of 90.38 mg/L. In pre monsoon 75 % and in post monsoon 87.5 % of samples exceeding the permissible limit of calcium by WHO. Magnesium Value during pre monsoon varies from 20.3 mg/L to 32.8 mg/L with an average value of 26 mg/L and in post monsoon ranged from 21.9 mg/L to 33.8 mg/L with an average value of 27.51 mg/L. All the water samples are within the permissible limit of magnesium.

The presence of magnesium normally increased the alkalinity of the soil and groundwater (*Xu et al., 2019*). For all the collected groundwater samples, calcium concentration is higher than magnesium. This can be explained by the abundance of carbonate minerals that compose the water-bearing formations as well as ion exchange processes and the precipitation of calcite in the aquifer. Ca^{2+} was observed as the most abundant alkaline earth metal, and Mg^{2+}can be derived from sources such as the weathering of dolomite and ferromagnesium minerals (*Nagarajan and Gowtham 2021*).

Fluoride naturally occurring in the earth's crust has a remarkable effect on human physiology. It is essential for developing dental health however; higher concentrations will result in toxic effects such as dental and skeletal fluorosis which can damage bones and joints. Fluoride concentration decreases with the increase of total hardness, calcium and magnesium hardness (*Shahjad et al., 2024*). The fluoride concentration during pre monsoon varies from 1.1 mg/L to 1.65 mg/L with an average value of 1.42 mg/L mg/L and in post monsoon ranged from 0.82 mg/L to 1.58 mg/L with an average value of 1.32 mg/L. In pre monsoon 37.5 % and in post monsoon 31.25 % samples exceeded the permitted limit (<1.5 mg/L) recommended by WHO. Fluoride values are slightly decreased in post monsoon compare to pre monsoon season.

Sodium levels in pre monsoon varies from 232 mg/L to 497 mg/L with a mean of 353.7 mg/L and in post monsoon varied from 254 mg/L to 591 mg/L with an average value of 398.5 mg/L. In pre monsoon and post monsoon all samples exceeding the permissible limit. Potassium levels in pre monsoon range from 3.4 mg/L to 6.9 mg/L with a mean of 4.79 mg/L and in post monsoon varied from 6.4 to 9.6 mg/L with an average value of 8.38 mg/L. All the water samples are within the recommended levels of potassium. Sodium is most abundant alkali metal in ground water and its sources like the weathering of halite and silicate minerals. However, by-products of agricultural activities may increase the sodium concentration of the groundwater. Content of $Na^+ > K^+$ because the rate of Na^+ dissolution is much higher than that of K^+ (*Ritusmita et al., 2022*).

Correlation Analysis

Pearson's correlation matrices were used to find relationships between two or more variables and two sets of data (*Bajpayee et al., 2012*). It is a simplified statistical tool to show the degree of dependency of one variable to another. The correlation coefficients of various water quality parameters were calculated and the values of the correlation coefficients are given in Table- 5 and Table-6. A positive correlation between fluoride concentration and pH was observed, which is consisted with other study (*Das and Nag 2015; Vasquez et al., 2006*). This may be due to the similar ionic radii of F^- and OH^- which often substitute for each other within minerals. Clay minerals are able to hold F^- ions on their surfaces, but at high pH, OH^- ions can displace F^- ions, which are then released to groundwater (*Sreedevi et al., 2006*). This fact indicates that the groundwater samples of study area have high levels of fluoride.

Fluoride also has positive correlation with electrical conductivity, total alkalinity, total dissolved solids, bicarbonate, chloride, sodium and negative correlation with total hardness, calcium and magnesium. A positive correlation between fluoride and total alkalinity indicates the alkaline nature of groundwater, which promotes the leaching of fluoride and thus increasing the fluoride concentration of groundwater (*Saxena and Ahmed* 2001). Total alkalinity has positive correlation with total dissolved solids, bicarbonate, chloride and sodium and negative correlation with total hardness. High positive correlation of total hardness with calcium and magnesium ions

exhibits that hardness is mainly due to presence of calcium and magnesium salts in water. Total dissolved solids has positive correlation with chloride, sodium, bicarbonate, fluoride, nitrate, sulphate and negative correlation with total hardness, calcium and magnesium (*Sharma* 2004). High positive correlation of electrical conductivity with total dissolved solids and chloride indicates the high mobility of ions. EC indicates that these ions tend to increase in concentration as the salinity of the water increases. The salinization of the groundwater can be expected to result from the ionic concentrations increasing due to both evaporation of recharge water and to the effects of interactions between the groundwater and the geological formations (*Indrani Mukherjee and Umesh Kumar Singh 2022*).

Scatter diagram for highly significant positive correlation (F^- -pH, EC-TDS, F^- -TA, HCO_3^- - Na^+, Cl^- - Na^+) and negative correlation (F^--TH) in pre monsoon and post monsoon season are shown in Fig.2.a to Fig.2.f.

Water Quality Index (WQI)

The WQI is calculated by performing a series of computations to convert several values from physicochemical data into a single value which reflects the water quality level's validity for drinking. The type of the material surrounding the groundwater or dissolving from the aquifer matrix is usually reflected in the physicochemical parameters of the groundwater. These metrics are critical in determining groundwater quality and are regarded as a useful tool for determining groundwater chemistry and primary control mechanisms (*El Osta et al., 2022*). For calculation of WQI these steps are followed (*Ramakrishna et al.,2009*).

$$WQI = \sum SI_i , \qquad SI_i = Wi\ q_i , \qquad q_i = (C_i / S_i)\ X\ 100$$

Where C_i = concentration of each parameter and S_i = respective Indian standard value.

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

Where *W*i is the relative weight, *w*i is the weight of ith parameter and *n* is the number of chemical parameters.

pH, fluoride, nitrate and sodium are assigned maximum weight 5, because of their relative importance in water quality. Electrical conductivity, total alkalinity and total dissolved solids are assign weight 4, while total hardness, chloride, calcium and magnesium are given minimum credit of 3 as they play a low significant role in water quality assignment. Water quality index was found 117 and 126.29 in pre monsoon and post monsoon respectively, which indicate that groundwater of study area is poor category and unsuitable for drinking purpose.

Categorization of drinking water by ranges of WQI.

Range	Type of water
< 50	Excellent water for drinking
50–100	Good water for drinking
101- 200	Poor water for drinking
201–300	Very poor water for drinking
> 300	Water unsuitable for drinking purpose

Conclusion

The results conclude that most of the physico chemical parameters of groundwater of study areas are increases in post monsoon compared to pre monsoon season except for fluoride and exceeded the permitted limit except of pH, TA, TH and magnesium. Elevated values of electrical conductivity, total dissolved solid, total hardness, fluoride and chloride in groundwater samples were mainly due to rock water interaction and high rate of evaporation. Fluoride values are slightly decreased in post monsoon compared to pre monsoon season. Fluoride concentration decreases with the increase of total hardness, calcium and magnesium hardness. Water quality index revealed that the groundwater of the study area is in poor category and unsuitable for drinking purposes. The evaluation of groundwater quality index WQI could be useful for groundwater users and policy makers to take

remedial measures. Therefore, it is suggested that the groundwater of the study area must be treated and made potable before consumption. The conclusions provided by this study may be helpful for the local governing structures and also for researchers to gather basic information about the region, which is useful to develop sustainable management of groundwater resources in the studied area.

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