EVALUATION OF GROUNDWATER QUALITY IN PRE-MONSOON AND POST-MONSOON SEASONS OF A YEAR USING WATER QUALITY INDEX (WQI)

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ABSTRACT

Water Quality Index-WQI is useful to transfer complex information of the groundwater quality data into comprehensible and useable data. In this research work, the investigation is carried out by collecting 66 groundwater samples and amalgamating nine water quality parameters for evaluation of groundwater utilizing WQI in pre- as well as post-monsoon of a year in the villages of Gara Mandal of Srikakulam District in Andhra Pradesh. The results confirmed that most of the groundwater sample locations (54.5% of groundwater samples) showed poor quality in both pre- as well as post-monsoon seasons. On the other hand, the correlation matrix indicates the strong positive correlation exists between the chemical parameters like calcium ion and magnesium ion with chloride, sulphate as well as nitrate ion represents that groundwater in the sampling locations has been polluted due to geological conditions, seepage of sewage and anthropogenic activities. Hence a proper treatment is required before utilized for drinking.

Keywords: Water Quality Index, Groundwater, Physicochemical parameters, correlation, Gara Mandal.

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INTRODUCTION

The earth is known as the “Blue Planet” or “Water planet. Water is nature’s most common chemical compound of all living creatures and the gift of nature. Water is the best of all things and is the most wonderful, abundant and valuable resource for the existence of life on earth.¹ Water is normally got from two noteworthy natural resources; superficial water, for example, freshwater from lakes and streams and groundwater from boreholes and wells. Surface and subsurface water assets are limited and subject to change as the atmosphere and ecological conditions and hence the principle resource of freshwater is groundwater. All most all about 97.2% water is salt water and 2.8% water is freshwater in this universe. Among all the water sources 20% water is available from groundwater. Groundwater is the most significant universal natural resource for the monetary improvement and secure provision of consumable water supply in both urban and rural areas.^{2,3} Groundwater is characterized as water that is found underneath the surface of the earth. It forms an essential portion of the water cyclic process. The water enters into the underground on account of gravity, goes through the rocks and soil until it reaches a profundity wherever the groundwater can no longer penetrate and is stored. The aquifer is an underground permeable and porous rock where the groundwater is stored. Aquifer permits the water to penetrate and permits movement inside the rock.

Moreover, all most all about 97 percent of the world’s useable freshwater is put away as groundwater. The significance of groundwater is escalating exponentially to less vulnerability to surface pollution as different pollutants get chemically and biologically degraded in the unsaturated zone before reaching the groundwater table. The greater part of the world relies upon groundwater for survival and in the present situation, rapid increment in populace results in depletion of water resources. To fulfill the requirement, groundwater goes about as a major source.

The significance of groundwater is rising exponentially to less vulnerability to surface pollution as different pollutants get chemically degraded and biologically degraded in the unsaturated zone before reaching the groundwater table. Human beings in the world are under risk because of an undesired change in the chemical, physical as well as biological characteristics of groundwater. Generally, groundwater is contaminated by anthropogenic sources like waste dumping, animal squanders, public wastewater, pesticides, upkeep spill over and manures which influence the groundwater. Also, the release of raw wastewater through bores and leachate from intuitive disposal of solid wastes, generally polluting groundwater.⁴

Quality of groundwater is the most important need for human beings.⁵ The groundwater quality is considered as an essential factor to judge environment changes which are powerfully connected with social and economic development. Seasonal variations can also affect the quality of groundwater.^{6,7} The monitoring of quality groundwater is one of the significant strategies for sustainable improvement and gives vital data to water supervision.

The Water Quality Index (WQI) technique can impart the water quality information⁸ and is normally used for the identification and evaluation of water contamination by different physicochemical parameters.⁹ It is a solitary number that rates the water quality by totaling different water quality parameters.¹⁰ The WQI procedure has been generally associated to evaluate both groundwater and surface water quality. From this time forward, it has ended up being the most helpful and fruitful technique for the assessment and administration of groundwater quality worldwide, particularly while considering the chance of incorporating drinking water principles generally utilized in water pollution guidelines.¹¹

In this research article, the results were presented related to a physicochemical analysis of groundwater in the villages of Gara Mandal of Srikakulam District, Andhra Pradesh, India. The groundwater quality in the identified sample locations was carried out at seasonally as pre- as well as post-monsoon respectively in the year 2015. Based on the obtained values, the overall groundwater quality is measured by employing the WQI method.

Study Area

Gara Mandal is located 19 kilometers far from the headquarters of Srikakulam district and is close to the inlet of Bay of Bengal. In this paper, latitude in between 18.2484 to 18.4010 and the longitude in between 83.8920 to 84.9345 are taken as study range to determine the groundwater quality. Gara Mandal has expanded about 157Sq.km area and has 24 major villages. Familiar Kurmanadha temple and Salihundam Historic Buddhist places are located in Gara Mandal.

EXPERIMENTAL

Material and Methods

Sample Collection and Analysis

Totally 66 water samples (Fig.-1) were collected from chosen sites (Table-1) at pre- as well as post-monsoon in the year 2015 from wells, hand pumps and bore waters. Groundwater samples were collected in clean two-liter plastic bottles¹² and preserved as per established standard methods and the analysis of water samples was carried out using analytical reagent (AR) grade chemicals. The various physicochemical parameters were analyzed as per standard methods.¹³ The instruments such as Digital pH meter (Systronics- 335 model), Nefleometer (Systronics-132 model), Digital Conductometer (Systronics-306 model), Double beam Spectrometer (Systronics-AU-2701 model), Atomic Absorption Spectrophotometer (Perkin Elmer-model 400AAS), Fluoride ion-selective electrode (Cyber scan 2100-Microprocessor-based bunch PH / Ion meter) were used.

Evaluation of Water Quality Index (WQI)

WQI is determined for the quality of groundwater, as it is an important tool for the evaluation of overall groundwater quality.¹⁴ To measure the WQI, the subsequent main steps have been taken into account. In the initial step, some parameters were chosen from the determined parameters in the water samples and weightage (w_i) which was taken numerically from 1 to 5 depending upon their significance in the evaluation of groundwater quality. The highest weightage of 5 has been allocated to TDS and TH and for

other parameters, 1 to 4 has been allocated depending upon their significance in the evaluation of groundwater quality (Table 2). According to WHO-2004 standards, the desirable limit (S_i) of every parameter in the groundwater samples is considered. In the next step, the relative weights (W_i) of each parameter was calculated by an equation:¹⁵

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

Where ' W_i ' indicates relative weights, ' w_i ' stand for the allocated weight of individual parameter and ' n ' represents the total number of determined parameters.

Fig.-1: Location Map and Groundwater Sample Points in Gara Mandal, Srikakulam District, Andhra Pradesh, India.

Table-1: Ground Water Sample Location in the villages of Gara Mandal

Sam.No	Location site	Source	Latitude	longitude	Sam.No	Location site	Source	Latitude	longitude
1	Vatsavalasa colony	A	18.2923	83.9989	34	Ramachandrapuram-Domaveddi	B	18.2906	83.9497
2	Vastavalasa(Municipal Primary School)	B	18.2905	83.9921	35	Ramachandrapuram- near Rama temple	B	18.2935	83.9621
3	Vatsavalasa –House	C	18.2815	83.9812	36	Simmaoeta Junction	A	18.2917	83.9566
4	Amadalapadu-vatsavala Panchayati office)	C	18.3023	84.0230	37	Deepavali-Bus stand Street	B	18.2840	83.9702
5	Pedatulugu -Segidiveedi	B	18.3034	84.0430	38	Deepavali –Primary School	B	18.2812	83.9630
6	Peddatulugu-Gollaveedi	B	18.3063	84.0437	39	Deepavali- Sondipeta (Sai baba temple)	B	18.2683	83.9691
7	Chinnatulugu Main road	A	18.3175	84.0456	40	Deepavali- Lankapeta(shiva temple)	B	18.2794	83.9802
8	Chinnatulugu -Municipal primary school	B	18.3071	84.0359	41	Gonti –Entrance	B	18.2752	83.9633
9	Nizamabad-Road point	B	18.3028	84.0268	42	Sunkarapalem	A	18.2484	83.9676
10	Nizamabad-Kaalingapeta road point	B	18.3012	84.0249	43	Jalluvalasa-SC colony	B	18.3202	84.0420
11	Nizamabad -SC colony	C	18.2980	84.0150	44	Jalluvalasa (Anjanaya temple)	B	18.3184	84.0456
12	Nizamabad -Primary school	B	18.3046	84.0294	45	Jalluvalasa (Anjanaya temple)	A	18.3201	84.0456
13	Sattivada- Main road Point	B	18.3196	84.0009	46	Korni(Anjanaya temple)	B	18.3389	84.0515
14	Sattivada- Rama Temple	A	18.3020	84.0165	47	Korni(Srisainaveedi)	A	18.3122	84.0799
15	Sattivada-Pedalapur Street	C	18.4010	84.0200	48	Korni-SC colony	B	18.3078	84.0736
16	Sattivada-Gangu Street	B	18.3106	84.0100	49	Korni-SC colony	A	18.3384	84.1077
17	Raghavapuram- Near anjanaya swamy temple	B	18.3220	84.0145	50	Korlam-Main road	B	18.3035	84.0693
18	Raghavapuram –Mangala street -school	B	18.3152	84.0071	51	Korlam Main Road (anadarao house)	B	18.2735	84.0718
19	Raghavapuram-SC-colony	B	18.3061	84.0070	52	Korlam (Anjanaya temple)	A	18.2991	84.0724
20	Syrigam -Polaki Street	B	18.3147	83.9990	53	Gara –Primary school	B	18.3308	84.0554
21	Syrigam -Grama Panchayati Office	B	18.3139	83.9977	54	Gara –Secondary school	B	18.3325	84.0513
22	Syrigam-Sai ram temple Arangepeta	B	18.3125	84.0000	55	Gara-Boravanipeta bus stand primary	B	18.3317	84.0442
23	Rama krishnapuram-Road point	B	18.3172	84.0120	56	Salihundam Board	B	18.3298	84.0479
24	Rama krishnapuram-Primary School	B	18.3220	84.0029	57	Garakothapetta –Primary school	B	18.3297	84.0410
25	Ampolu Colony	B	18.3149	83.9833	58	Kothapetta Primary school	B	18.3310	84.0410
26	Ampolu bus stand street - panchayati office	A	18.3218	83.9839	59	Salihundam Primary school	B	18.3356	84.0357
27	Ampolu-kothapeta	A	18.3089	83.9845	60	Salihundam SC colony	B	18.3350	84.0378
28	Ampolu-kothapeta	B	18.3194	83.9841	61	Konkenapetta –Salihundam	B	18.3281	84.0419
29	Reddy peta	B	18.3229	83.9014	62	Kolluvalasa(near srirama temple)	A	18.2749	84.0126
30	Reddy peta	A	18.3150	83.8920	63	Kollivalasa	B	18.3345	84.0248
31	Vadada- Pangala street	B	18.2683	84.9345	64	Ambalavalasa-Jonnadaveedi	B	18.3362	84.0167
32	Vadada-Chipiri veedi	B	18.2581	83.9358	65	Ambalavalasa-Anjanaya temple	B	18.3364	84.0157
33	Ranachandrapuram- Primary school	B	18.2924	83.9555	66	Booravelli –Ammavari temple	B	18.3467	84.0010
A= Well water, B= Hand pump and C = Bore water									

Subsequently, a quality rating scale (Q_i) is measured for every parameter by the equation:

$$Q_i = \frac{C_i}{S_i} * 100 \quad (2)$$

Where ‘ C_i ’ is the concentration of the determined parameter in each water sample. ‘ S_i ’ represents the standard value, according to the WHO-2004 standards.

Lastly, the WQI is measured with an equation: $WQI = \sum W_i \times Q_i$ (3)

here ‘ W_i ’ indicates the relative weights of each determined parameter and ‘ Q_i ’ indicates the quality rating scale. Following the WQI values, the groundwater is represented into five categories as shown in Table-3.

Table-2: Assigned Weights and Relative Weights of Analyzed Parameters in the Groundwater Samples and Standard Values Given by WHO (2004)

S.No.	Chemical Parameter	Weight(w_i)	WHO Standards(S_i)	Relative weights (W_i)
1	Total Dissolved Solids	5	500	0.1612
2	Total Hardness	5	300	0.1612
3	Chloride	4	250	0.1290
4	Fluoride	4	1.5	0.1290
5	Total Alkalinity	3	200	0.0967
6	Calcium	2	75	0.0645
7	Magnesium	2	50	0.0645
8	Sodium	4	200	0.1290
9	Potassium	2	12	0.0645
		$\sum w_i = 31$		

Table-3: Identification of the Category of Water of Groundwater Samples Collected From the Study Area Using WQI Range in Pre-Monsoon and Post-Monsoon Periods

WQI Range Category		Pre-Monsoon		Post-Monsoon	
		Water Sample Numbers	% category of Groundwater Quality	Water Sample Numbers	% category of Groundwater Quality
< 50	Excellent Water	53,54,56,57,61	7.57%	53,54,61	4.54%
50.1 - 100	Good Water	3,11,13,14,23,24,25,29,39,40,45,46,50,58,59, 62,63	25.75%	3,11,13,14,23,24,25,29,39,40,45,46,50,56,57,58,59, 62,63	28.78%
100.1 - 200	Poor Water	1,2,4,6,7,9,12,15,16,19,21,22,26,27,28,30,31,32,33,34,35,36,37,38,42,43,44,48,49,51,52,55,60,64,65,66	54.54%	1,2,4,6,7,9,12,15,16,19,21,22,26,27,28,30,31,32,33,34,35,36,37,38,42,43,44,48,49,51,52,55,60,64,65,66	54.54%
200.1 - 300	Very Poor Water	5,8,10,17,18,20,41	10.6%	5,8,10,17,18,20,41,47	12.14%
> 300.1	Unfit for Water	47	1.51%	---	---

RESULTS AND DISCUSSION

Groundwater Quality in the Study Region

The obtained results related to pre- as well as post-monsoon seasons, are explained here by the following parameters. The statistical analysis of groundwater samples of pre- as well as post-monsoon, were presented in Table-4 and Table-5. The number of water samples exceeds the acceptable limit prescribed by BIS-2012 and WHO-2004 of each parameter in pre- as well as post-monsoon was presented in Table-6.

Turbidity and pH

Turbidity is caused by algae, particles of soil, metals, organic matter, suspended and inorganic matter in the water. There turbidity values in all places in pre- and post-monsoon were the negligible amount. There is a considerable change in the pH value during pre- as well as post-monsoon and the pH values obtained from 6.24 to 8.51 in the pre-monsoon whereas 6.32 to 8.12 in the post-monsoon. The majority of the water samples having a high pH in pre-monsoon and it might be due to the high temperature in pre-monsoon. Except sample number-8 remaining all water samples having pH values were in permissible limit according to BIS-2012.¹⁶

Electrical Conductivity (EC) and Total Alkalinity (TA)

EC is a vital factor for representing the quality of groundwater and it indicates a salinity risk. High conductivity might arise from anthropogenic sources and natural weathering. EC value during pre- as well as post-monsoon periods, were in the range of 291-6350 (μ mhos/cm) and 332-5786 (μ mhos/cm) respectively. Majority of the water samples have high EC values during pre- as well as post-monsoon representing the presence of more amounts of dissolved salts present in groundwater samples in an ionized state. Metabolic alkalosis is caused by excess intake of high alkalinity containing water. The Total alkalinity obtained from 71 mg l^{-1} to 525 mg l^{-1} and 78 mg l^{-1} to 519 mg l^{-1} in the pre and post-monsoon respectively. 51 out of 66 groundwater samples were exceeding than desirable limit according to BIS-2012.

Total Dissolved Solids (TDS) and Total Hardness (TH)

The TDS stands for the mixture of inorganic minerals (mainly calcium, magnesium, sodium and potassium salts of sulphates, chlorides, and bicarbonates) and little amount of organic components. The TDS obtained from 190 mg l^{-1} to 4062 mg l^{-1} and 212 mg l^{-1} to 3701 mg l^{-1} in pre- as well as post-monsoon respectively. The observed TDS results demonstrate that the majority of the groundwater samples were identified as excess than desirable limits when compared with BIS-2012 standards. The TH in groundwater is mostly owing to the occurrence of calcium and magnesium salts. The TH obtained from 130 mg l^{-1} to 1618 mg l^{-1} and 105 mg l^{-1} to 1550 mg l^{-1} in pre- as well as post-monsoon respectively. There is no drastic difference in the concentrations of total hardness, calcium as well as magnesium ions in pre- as well as post-monsoon. The number of water samples exceeds the acceptable limit prescribed by BIS-2012 and WHO-2004 of TDS and TH in pre- as well as post-monsoon seasons were shown in Table-6.

Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) Hardness

Ca^{2+} and Mg^{2+} ions are important minerals and helpful to the health of humans in several aspects.⁹ Insufficient intake of these ions is capable of imparting adverse health effects. The more intake of calcium can impede the quality of groundwater by causing kidney or bladder stone development, disturbance in urinary section in human beings, encrustation.¹⁷ High intake of Mg^{2+} concentration may cause purgative impact while its deficiency impacts structural and utilitarian changes and is not suitable for the domestic point of view. The Ca^{2+} concentration obtained from 26 mg l^{-1} to 309 mg l^{-1} and 22 mg l^{-1} to 310 mg l^{-1} in pre- as well as post-monsoon respectively. The Mg^{2+} concentration obtained from 14 mg l^{-1} to 253 mg l^{-1} and 12 mg l^{-1} to 245 mg l^{-1} in pre- as well as post-monsoon respectively. There is no drastic difference in the concentrations of calcium and magnesium hardness in pre- as well as post-monsoon. The number of water samples exceeds the acceptable limit prescribed by BIS-2012 and WHO-2004 of calcium and magnesium ions in pre-monsoon as well as post-monsoon was presented in Table-6.

Sodium (Na^+) and Potassium (K^+)

The sodium (Na^+) ion is highly soluble in groundwater and it is a normal constituent of the body and adequate levels of Na^+ are wanted for better health.¹⁸ Potassium (K^+) ion is an essential constituent in humans. It is a fundamental supplement; however, if it is excess, might act as a laxative. Na^+ ion concentration is obtained from 10 mg l^{-1} to 267 mg l^{-1} and 12 mg l^{-1} to 254 mg l^{-1} in pre- as well as post-monsoon respectively. The K^+ ion concentration is obtained from 0.2 mg l^{-1} to 120 mg l^{-1} and 0.82 mg l^{-1} to 112 mg l^{-1} in pre- as well as post-monsoon respectively. There is a slight difference in the concentrations of sodium (Na^+), potassium (K^+) ion in pre- as well as post-monsoon. The number of water samples exceeds the acceptable limit prescribed by BIS-2012 and WHO-2004 of sodium and potassium ions in pre- as well as post-monsoon was presented in Table-6.

Fluoride (F^-) and Chloride (Cl^-)

Fluoride is essential to human beings at low levels and it helps to avoid the tooth rot in children. The excessive intake of high fluoride contained water with a long period can bring about health problems like softening of bones, mottling of teeth, dental fluorosis and different neurologic harms. Chloride is a necessary electrolyte mineral which keeps the quantity of a cell fluid inside and around in a balancing way. It also keeps up appropriate blood volume and pressure of a cell. The Fluoride (F^-) ion is obtained from 24 mg l^{-1} to 547 mg l^{-1} and 0.12 mg l^{-1} to 1.34 mg l^{-1} in pre- as well as post-monsoon. The chloride

(Cl⁻) ion is obtained from 77 mg l⁻¹ to 1230 mg l⁻¹ and 76 mg l⁻¹ to 1226 mg l⁻¹ in pre- as well as post-monsoon respectively. There is no drastic difference in the concentrations of F⁻ and Cl⁻ ion in pre-monsoon as well as post-monsoon seasons. The number of water samples exceeds the acceptable limit prescribed by BIS-2012 and WHO-2004 of fluoride and chloride ions in pre- as well as post-monsoon were presented in Table-6.

Sulphate (SO₄²⁻) and Nitrate (NO₃⁻)

A few soils and rocks generally contain sulfate minerals. Normally groundwater travels through soils and rocks a part of the sulphate- containing minerals are dissolved. The higher amount of sulphate with calcium and magnesium in the groundwater that we consume can have a diuretic impact. Sulphate gives a severe or therapeutic taste to water if it exceeds a concentration of 250 mg l⁻¹. The amount of Nitrate in groundwater is a perfect indicator of anthropogenic contamination particularly it demonstrates contributions of fertilizer used in the agricultural fields. The sulphate (SO₄²⁻) ion is obtained from 24 mg l⁻¹ to 547 mg l⁻¹ and 29 mg l⁻¹ to 553 mg l⁻¹ in pre- as well as post-monsoon. The nitrate (NO₃⁻) ion is obtained from 9 mg l⁻¹ to 73 mg l⁻¹ and 11 mg l⁻¹ to 73 mg l⁻¹ in pre- as well as post-monsoon and the samples exceed than the BIS-standards were shown in Table-6.

Iron (Fe²⁺), Manganese (Mn²⁺) and Chromium (Cr⁶⁺)

Iron is a generally found in earth's crust. Iron is biologically an essential element which is important to all living organisms and is present in haemoglobin. Iron and manganese are minerals mostly found in groundwater and essential nutrients. High amounts of manganese can cause toxic neurological effects in human beings, psychological disorders, hyposexuality. The chromium metal exists in the form of hexavalent (Cr⁶⁺) and trivalent (Cr³⁺) in water. Cr⁶⁺ is considered more hazardous mainly due to its carcinogenic nature. The iron (Fe²⁺) ion is obtained from 0.001 mg l⁻¹ to 0.37 mg l⁻¹ and 0.001 mg l⁻¹ to 0.38 mg l⁻¹ in pre- as well as post-monsoon respectively in the groundwater samples. The manganese (Mn²⁺) ion was found to be in the range of 0.001 mg l⁻¹ to 0.37 mg l⁻¹ and 0.001 mg l⁻¹ to 0.38 mg l⁻¹ in pre- as well as post-monsoon respectively. The Cr⁶⁺ is obtained from 0.0002 to 0.232 mg l⁻¹ and 0.0003 to 0.678 mg l⁻¹ in pre- as well as post-monsoon. The number of water samples exceeds the acceptable limit prescribed by BIS-2012 and WHO-2004 of iron (Fe²⁺), manganese (Mn²⁺) and chromium (Cr⁶⁺) ions in pre- as well as post-monsoon were presented in Table-6.

Table-4: Statistical Analysis in Pre-Monsoon

	pH	EC	Turb.	TDS	TH	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	TA
Mean	7.01	1596	0.064	1020.3	578.9	110	70.0	85.0	25.6	270.1
variance	0.09	1181903	0.003	483764	112915	3855	2460	4381	1032	10324
SD	0.31	1087	0.05	695.53	336.02	62.0	49.6	66.1	32.1	101.6
Skewness	1.35	1.795	1.95	1.79	1.0	0.97	1.41	1.26	1.62	-0.06
kurtosis	7.07	4.622	5.22	4.61	0.793	0.65	2.27	0.69	1.53	0.009
Median	7.01	1356	0.05	867	517	97	56.5	67	13.0	284
Mode	6.95	1354	0.05	684	241	76	36	69	2.3	284
	F ⁻	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻	Fe ²⁺	Mn ²⁺	Cr ⁶⁺			
Mean	0.487	280.4	188	33.4	0.1063	0.0224	0.021	Note: Turb. = Turbidity, TDS =Total Dissolved Solids, TH= Total Hardness		
variance	0.109	45363	17688	276	0.011	0.0015	0.001			
SD	0.330	212.9	132	16.6	0.1072	0.0390	0.032			
Skewness	1.1	1.863	1.24	0.999	1.072	1.9116	4.548			
kurtosis	0.562	4.821	1.075	0.52	0.0223	2.4340	27.48			
Median	0.42	192.5	154	30	0.078	0.0030	0.009			
Mode	0.44	677	232	24	0.009	0.0003	0.004			

Table-5: Statistical Analysis in Post-Monsoon

	pH	EC	Turb.	TDS	TH	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	TA
Mean	7.03	1577	0.073	1009.0	574.3	111	71.5	87.4	24.3	267.0
Variance	0.06	1014287	0.003	415260	105451	3752	2320	3940	854	9381.4
SD	0.25	1007	0.057	644.40	323.73	61.2	48.1	62.7	29.2	96.85
Skewness	0.35	1.667	1.857	1.665	1.000	0.99	1.31	1.33	1.63	0.064
Kurtosis	4.77	3.778	5.369	3.770	0.724	0.75	1.88	0.83	1.60	0.137
Median	7.1	1427	0.06	913.5	514.5	99	60.0	70	12.7	272
Mode	7.12	1102	0.02	375	1080	81	41	78	4.1	289
	F ⁻	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻	Fe ²⁺	Mn ²⁺	Cr ⁶⁺			
Mean	0.502	281.6	189	30.8	0.104	0.021	0.059	Note: Turb. = Turbidity, TDS =Total Dissolved Solids, TH= Total Hardness		
Variance	0.088	43284	16039	262	0.010	0.001	0.020			
SD	0.297	208.0	126	16.2	0.102	0.037	0.144			
Skewness	1.07	1.91	1.121	0.934	0.903	2.070	3.002			
Kurtosis	0.583	5.253	0.901	0.325	-0.21	3.126	8.179			
Median	0.42	128	161	28.5	0.07	0.004	0.009			
Mode	0.41	677	123	18	0.103	0.000	0.003			

Table-6: The Number of Water Samples of each Parameter exceeds the Acceptable Limit Prescribed by BIS-2012 and WHO-2004 in Pre-Monsoon and Post-Monsoon in the Study Region

Parameters	BIS-2012- (Acceptable Limit)	Number of Samples exceed than BIS-2012 (Acceptable Limit)		WHO-2004 - (Acceptable Limit)	Number of Samples exceed than WHO-2004 (Acceptable Limit)	
		Pre- monsoon	Post- monsoon		Pre-monsoon	Post- monsoon
pH	6.5 – 8.5	1	---	6.5 – 8.5	1	---
Turbidity	1.00	---	---	1.00	---	---
EC	---	---	---	1500	25	21
Total Alkalinity	200	51	51	200	51	51
TDS	500	49	49	500	49	49
Total Hardness	200	60	61	300	48	50
Calcium(Ca ²⁺)	75	45	44	75	45	44
Magnesium(Mg ²⁺)	30	51	50	50	36	38
Sodium (Na ⁺)	---	---	---	200	7	7
Potassium(K ⁺)	---	---	---	12	40	38
Fluoride(F ⁻)	1	7	5	1.5	---	---
Chloride (Cl ⁻)	250	24	24	250	24	24
Sulphate(SO ₄ ²⁻)	200	26	25	200	26	25
Nitrate(NO ₃ ⁻)	45	13	8	45	13	8
Ferrous(Fe ²⁺)	0.3	9	2	0.3	9	2
Manganese(Mn ²⁺)	0.1	7	6	0.1	7	6
Chromium(Cr ⁶⁺)	0.05	8	8	0.05	8	8

Except - pH, EC (u mhos/cm), Turbidity(NTU) remaining parameters are in mg l⁻¹**Assess the Quality of Groundwater by Water Quality Index**

For the determination of WQI during pre- as well as post-monsoon, 9 groundwater quality parameters (Table-2) have been chosen. The WQI values have been determined individually (Fig.-2) on the basis of 9 water quality parameters for each sampling regions (66 sampling regions) for pre- as well as post-monsoon periods in the study region. The measured WQI values in pre-monsoon shows that 7.6% of the groundwater samples belong to excellent water, 25.7% good water, 54.5% poor water, 10.6% very poor

water and 1.5% unfit for drinking in which it was lowest for sampling site 54 and highest for sampling site 47 in the study region whereas in post-monsoon season shows that 4.5% of the groundwater samples belong to excellent water, 28.7% good water, 54.5% poor water and 12.1% very poor water for drinking in which it was lowest for sampling site 54 and highest for sampling site 47 in the study region. Based on the obtained results in both pre as well as post-monsoon periods, the majority part of the sampling locations was in poor quality and it is probably owing to geological impact, excess utilization of groundwater, the viable release of effluents and lack of seepage of water. Hence, it needs regular monitoring of groundwater quality and also possible treatment measures to recover the quality of water.

Fig.-2: Graphical Representation of WQI values during Pre-and Post Monsoon Seasons

Correlation Matrix of Various Physicochemical Parameters During Pre- as well as Post-Monsoon

The systematic studies of correlation and regression coefficients of the groundwater quality parameters were useful to measure the overall groundwater quality as well as to determine the relative concentration of pollutants in groundwater.¹⁹ Pearson's correlation coefficient (indicated 'r') is normally useful to find the relationship between the two variables. The parameters having $r > 0.5$ or < -0.5 are considered important. The correlation coefficients of the physicochemical parameters data of pre-monsoon as well as post-monsoon have been given in Table-7 and Table-8, respectively. In both the pre- as well as post-monsoon periods, strong positive correlations exist between Ca^{2+} , Mg^{2+} , Cl^- , SO_4^{2-} and NO_3^- were observed, which represents that these ions contribute considerably to TDS, TH in the groundwater of this study region. A strong correlation of calcium and magnesium with chloride, sulfate and nitrate ion represents that the groundwater samples have been polluted more by these components due to over-exploitation and anthropogenic activities. The main source of calcium, as well as magnesium ions in the groundwater, may owe ion-exchange of minerals among rocks and water.

Table-7: Correlation Matrix Between Water Quality Parameters: Pre-Monsoon

	pH	Turb	EC	TDS	TH	Ca^{2+}	Mg^{2+}	Na^+	K^+	TA
pH	1									
Turb	0.042	1								
EC	0.006	0.1001	1							
TDS	0.006	0.0994	0.999	1						
TH	0.028	0.1417	0.799	0.7946	1					
Ca^{2+}	-0.08	0.1841	0.745	0.7454	0.8701	1				
Mg^{2+}	0.002	0.1078	0.723	0.7241	0.9415	0.6846	1			
Na^+	-0.08	0.2379	0.539	0.5398	0.5041	0.5351	0.412	1		
K^+	0.067	0.0935	-0.02	-0.0231	-0.0163	0.0653	-0.06	0.150	1	
TA	0.003	0.0106	0.006	0.007	0.0070	0.0006	0.012	0.008	-0.06	1

F ⁻	0.151	-0.0543	-0.30	-0.3029	-0.1992	-0.2601	-0.15	0.110	-0.0123	0.016
Cl ⁻	0.083	0.3087	0.672	0.6729	0.7472	0.7064	0.677	0.572	-0.01	-0.001
SO ₄ ²⁻	0.102	0.196	0.618	0.618	0.858	0.732	0.824	0.432	-0.023	0.016
NO ₃ ⁻	0.104	0.158	0.769	0.770	0.95	0.84	0.87	0.55	0.008	0.047
Fe ²⁺	0.007	-0.071	0.697	0.697	0.832	0.728	0.760	0.298	-0.038	0.015
Mn ²⁺	0.040	0.004	0.46	0.46	0.66	0.546	0.643	0.236	0.001	0.001
Cr ⁶⁺	0.149	-0.028	0.277	0.276	0.200	0.11	0.258	0.099	-0.031	-0.140
	F ⁻	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻	Fe ²⁺	Mn ²⁺	Cr ⁶⁺	Note: Turb. = Turbidity TDS =Total Dissolved Solids TH= Total Hardness TA=Total alkalinity		
F ⁻	1									
Cl ⁻	-0.082	1								
SO ₄ ²⁻	-0.104	0.738	1							
NO ₃ ⁻	-0.12	0.710	0.823	1						
Fe ²⁺	-0.239	0.608	0.700	0.789	1					
Mn ²⁺	-0.12	0.478	0.542	0.657	0.818	1				
Cr ⁶⁺	-0.216	0.171	0.115	0.191	0.43	0.49	1			

Table-8: Correlation Matrix Between Water Quality Parameters: Post-Monsoon

	pH	Turb	EC	TDS	TH	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	TA
pH	1									
Turb	0.154	1								
EC	0.005	-0.100	1							
TDS	0.005	-0.100	0.999	1						
TH	-0.021	0.003	0.794	0.7950	1					
Ca ²⁺	-0.097	-0.0256	0.719	0.7193	0.8920	1				
Mg ²⁺	0.033	0.0368	0.751	0.7517	0.9367	0.6830	1			
Na ⁺	0.046	0.1501	0.584	0.5841	0.5130	0.5504	0.425	1		
K ⁺	0.155	0.0771	-0.005	-0.0057	-0.0100	0.0129	-0.020	0.280	1	
TA	0.146	0.1870	0.131	0.1309	0.1457	0.0374	0.200	0.122	-0.037	1
F ⁻	0.093	0.0552	-0.232	-0.2327	-0.2019	-0.2427	-0.146	0.119	0.046	0.238
Cl ⁻	0.060	0.1388	0.665	0.6659	0.7523	0.7033	0.685	0.581	-0.005	-0.019
SO ₄ ²⁻	0.080	0.031	0.622	0.623	0.851	0.740	0.813	0.438	-0.033	0.083
NO ₃ ⁻	0.071	0.035	0.670	0.671	0.901	0.809	0.835	0.510	0.011	0.100
Fe ²⁺	-0.04	-0.19	0.689	0.689	0.765	0.68	0.715	0.28	-0.086	0.05
Mn ²⁺	0.034	-0.09	0.43	0.43	0.67	0.55	0.63	0.24	0.02	0.01
Cr ⁶⁺	0.03	-0.14	0.46	0.46	0.33	0.23	0.36	0.32	0.080	0.06
	F ⁻	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻	Fe ²⁺	Mn ²⁺	Cr ⁶⁺	Note: Turb. = Turbidity TDS =Total Dissolved Solids TH= Total Hardness TA=Total alkalinity		
F ⁻	1									
Cl ⁻	-0.057	1								
SO ₄ ²⁻	-0.097	0.736	1							
NO ₃ ⁻	-0.082	0.702	0.826	1						
Fe ²⁺	-0.17	0.58	0.669	0.699	1					
Mn ²⁺	-0.06	0.46	0.56	0.614	0.68	1				
Cr ⁶⁺	0.11	0.29	0.185	0.29	0.45	0.48	1			

CONCLUSION

The groundwater quality in terms of drinking purpose in the study region was assessed by the WQI method and it is aptly helpful and useful in the evaluation and supervision of the groundwater quality. In this study, the variations in the WQI values were studied and there is an insignificant difference at pre- as well as post-monsoon seasons. Based on WQI data, 54.5% of the groundwater sampling locations in the study region showed poor water. The high WQI values in groundwater samples in this region were mainly owing to the presence of a major amount of total hardness causing ions (Ca²⁺, Mg²⁺) and these are beyond their desirable limits. According to the correlation matrix, the Ca²⁺ and Mg²⁺ were strongly correlated with Cl⁻, SO₄²⁻ and NO₃⁻ which reveal that the groundwater samples in the study region have been vastly

polluted owing to lack of seepage of water and anthropogenic activities. To recuperate the groundwater quality of the study region, treatment measures were required to enhance the groundwater potential both qualitatively and quantitatively.

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