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RESEARCH ARTICLE

GIS BASED APPROACH FOR CHARACTERIZATION OF GROUNDWATER BY USING WATER QUALITY INDEX

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ABSTRACT

Groundwater is the source of approximately 33% of the water supplied to households and to the public. It supplies more than 90 percent of the rural population with drinking water. As groundwater is the major source, its quality can be affected by rocks, sediments, industrial discharges, urban activities, agriculture, groundwater pumping, and disposal of waste. The quality of groundwater is therefore considered an extremely severe problem in many cities in developing countries. The objective of this study is to (1) evaluate the spatial distribution of physio-chemical parameters like pH, hardness, chloride, fluoride, sulphate and nitrate, sodium, and potassium; (2) investigate the quality of drinking water by the Water Quality Index (WQI). An intensive field visit was carried out to collect groundwater samples. 8 different bore wells were chosen for determining groundwater quality. Groundwater samples are collected during the pre-monsoon and post-monsoon months of May and November 2017 respectively. The groundwater samples collected from the field were analyzed in the laboratory for different physio-chemical parameters by using standard procedures. The results obtained were compared with the water quality standards specified by IS: 10500-2012. Based on the physio-chemical parameters, the water quality index has been computed for each water sample. The derived water quality index of the study area ranged from 89 to 120 (pre-monsoon) and 62 to 94 (post-monsoon). It is observed that the WQI for pre-monsoon has deteriorated quality compared to post-monsoon. The influence of precipitation to improve water quality by way of dilutions of the chemical components.

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INTRODUCTION

Due to industrialization and urbanization, the demand for freshwater increases every day. Groundwater plays a major role in irrigation, industry, and drinking as surface water availability is very limited. It is very important to assess the quality of groundwater due to the usage of groundwater for several purposes. Groundwater quality depends on physical and chemical parameters which are heavily influenced by geological formations and anthropogenic activity (Subramani *et al.* 2005; Chin 2006). The chemical parameters of groundwater play a vital role in the classification and evaluation of the quality of water. Geochemical studies of groundwater provide enhanced perceptive on quality changes. Various studies have intense on groundwater quality monitoring and its suitability for drinking, domestic and agricultural uses in the recent decade (Bahar and Reza 2009; Chidambaram *et al.* 2010; Subba Rao *et al.* 2012; Singaraja 2015). The geochemical quality of groundwater is mainly depending on the quantity of rainfall, sub-surface geological formations, and over exploitation of groundwater (Mirzabeygi *et al.* 2017; Yousefi *et al.* 2017). Abbasnia *et al.* (2018) evaluates the groundwater quality for drinking and agricultural purposes and determines the physicochemical characteristics of groundwater. Assessment of groundwater quality is an important factor for safe drinking. The Water Quality Index (WQI) is an important parameter for defining water quality and its sustainability for drinking purposes. Horton (1965) first proposed the concept of the Water Quality Index (WQI), which represents gradation in water quality. WQI is a mathematical equation used to convert large amounts of data on water quality into one number. WQI is one of the most efficient tools for communicating water quality information to the citizens and policymakers concerned (Singh and Hussian, 2016). WQI indicates a single number as a grade, which expresses the overall water quality in a certain area and time based on several parameters of water quality. WQI highlights the composite influence of ingredients that contribute to water

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quality in any water system (Kakatti 2007). The water quality rating can offer clear data about the geological subsurface environment in which the water is present (Raju *et al*, 2011). The WQIs has potential for decision making and management in flag contaminate of concern, predicts potentially harmful conditions, guides prioritization management efforts, and funds, assess overall impacts of water quality interventions, communicate impacts of management and policy decisions, monitor water resource and health (Rawat and Singh, 2018). The development of satellite technology and the geographical information system (GIS) made the mapping of the sampling area very easy. GIS is widely used in water quality mapping to obtain informative and user-friendly maps. The integration of WQIs with GIS provides detailed, quick, and reliable information for decision makers to adopt or implement strategies related to water pollution and scarcity (Singh *et al*., 2013b). Hence, the present study was carried out to characterize the groundwater quality by using the GIS approach with the water quality index.

STUDY AREA: The study area is situated in the southernmost part of South India and is located between altitudes of 8 °08' and 8° 33' N and longitudes of 77° 28' and 78° 52' E. The survey area encompasses an expanse of 0.83 sq. km. Figure 1 shows the location map of the study area obtained from Google earth. Sub dendritic pattern of drainage occurs in the study area. The climate of Sathankulam taluk consists of three main seasons, winter season starts from the middle of November and continues till the end of February. Then follows summer from March till early June and the southwest monsoon season starts from June and continues till the end of September. Northeast monsoon starts from October to December. The rainfall for the field region was obtained from the world weather website. The average high rainfall for the year 2000 to 2012 is to be 420 mm in the month of October.

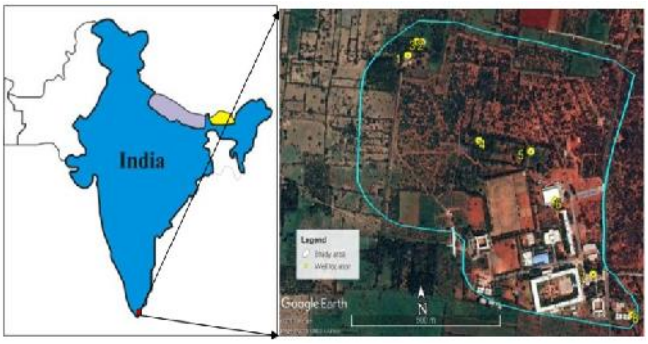

Figure 1. Location of study area

MATERIALS AND METHODS

Groundwater samples were collected from 8 bore wells around the study area during the month of May (pre monsoon) 2017 and November 2017 (post monsoon). The location of borewells is measured by using the Global Positioning System (GPS). Groundwater samples were collected after 10 minutes of pumping and stored in good quality polythene bottles of 1 L capacity previously soaked in 10 % nitric acid (HNO3) for 24 hours and rinsed with deionized water. The Physio-chemical parameters such as pH, Hardness, Chloride, Fluoride, Sulphate, Nitrate, Sodium, and Potassium are analyzed in the laboratory. All the analyses were carried out as per the standard procedures prescribed in the American Public Health Association manual (APHA, 1995). Among the analyzed ions, sodium and potassium were determined by using a flame photometer. Fluoride and nitrate were analyzed using an ion probe. Chloride was estimated by standard AgNO3 titration. Sulfates were estimated by using the colorimetric method. The suitability of groundwater for drinking purposes is evaluated by comparing the values of different water quality parameters with Indian standard specifications (IS 10500: 2012).

GIS-analysis: The spatial analysis of various physio-chemical parameters was carried out using the ArcGIS 10 software. An Inverse Distance Weighted (IDW) algorithm was used to interpolate the water quality parameters spatially throughout the study area.

The IDW technique calculates a value for each grid node by examining the surrounding data points that lie within a user-defined search radius (Burrough and McDonnell 1998). All of the data points are used in the interpolation process and the node value is calculated by averaging the weighted sum of all the points. Water Quality Index (WQI) was calculated by applying a weight factor for physical and chemical parameters. Overall water quality for drinking purposes was determined for the study area.

RESULTS AND DISCUSSION

The important physio-chemical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), and total hardness (TH), and the suitability of groundwater in the study area are discussed below.

Physio-chemical parameters

pH

pH is a measure of the balance between the concentration of hydrogen ions and hydroxyl ions in water. The pH of water gives essential information on the calculation of hardness (Hem 1985). The permissible limit of pH value for drinking water is specified as 6.5–8.5 (WHO 2004; IS 10500: 2012). The pH value of groundwater samples in the study area varies from 7.12 to 8.34 (Figure 3) which clearly shows that the groundwater in the study area is alkaline in nature. The spatial distribution of pH during pre-monsoon and post-monsoon seasons is shown in Figure 3.

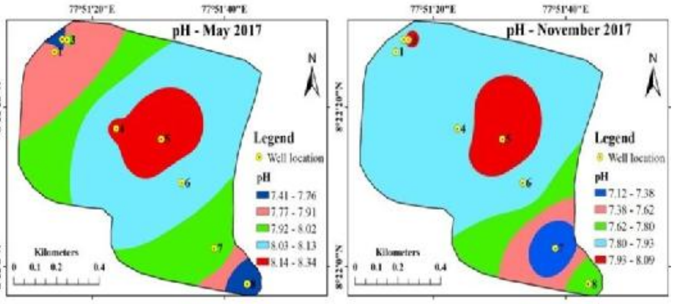

Figure 3. Spatial distribution of pH in pre and post monsoon season

Electrical conductivity (EC): The important physiochemical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), and total hardness (TH), and the suitability of groundwater in the study area are discussed below.

Electrical conductivity is an indirect measurement of salinity and it is temperature-dependent where an increase in water temperature of one degree Celsius causes an increase in electrical conductivity by 2% (Hem, 1985). The most desirable limit of EC in drinking water is prescribed as 1,500 µS/cm (WHO 2004).

The concentration of EC values in the groundwater samples are ranging from 1635 µS/cm to 2624 µS/cm in pre-monsoon and it varies from 1000 µS/cm to 1602 µS/cm in the post-monsoon. All water samples in the study area are lies above the maximum permissible limit for drinking water purposes during the pre-monsoon month of May. After rains, most of EC gets reduced to come under permissible limit. Figure 4 illustrates the spatial distribution of EC in the study area. The value of EC is higher shows the enhancement of salts in the groundwater. The value of electrical conductivity indicates the total content of dissolved solids in water. The increasing pH also increases the dissolution process, which may increase the value of EC.

Total dissolved solids (TDS): The concentration of dissolved solids in groundwater is important to decide its suitability for drinking, irrigation, or industrial purposes. According to WHO specification TDS up to 500 mg/l is higher desirable and up to 1,500 mg/l is the maximum permissible. Groundwater containing more than 1000 mg/l of the total dissolved solids is generally referred to as brackish water. TDS values in the groundwater samples vary from 1004 mg/l to 2484 mg/l in the pre-monsoon season and it varies from 740 mg/l to 1034 mg/l during the post-monsoon season. Figure 5 shows the spatial distribution of TDS in the study area. During the pre-monsoon season, not all the groundwater samples are suitable for drinking (TDS value is greater than 1000 mg/l). After the monsoon season, most of the groundwater samples are permissible for drinking (500-1,000 mg/l). The highest concentration of TDS in the groundwater sample is due to the leaching of salts from the soil and domestic sewage may percolate into the groundwater, which may lead to an increase in TDS values.

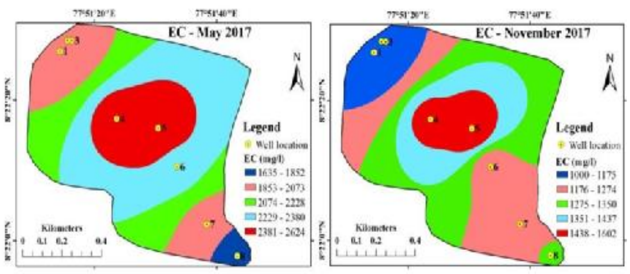

Figure 4. Spatial distribution of EC (µS/cm) in pre and post monsoon season

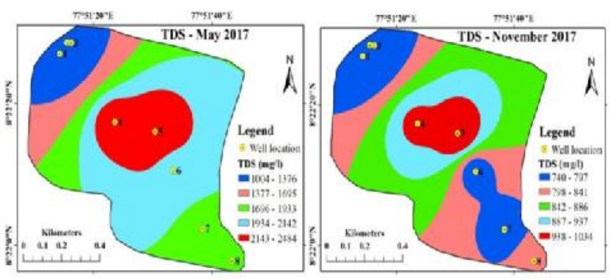

Figure 5. Spatial distribution of TDS in pre and post monsoon season

Total hardness (TH): Figure 6 shows the spatial distribution of total hardness in the study area The total hardness is varying from 250 mg/l to 625 mg/l in pre-monsoon and 200 mg/l to 467 mg/l in post-monsoon. The groundwater of the entire study area lies within the maximum permissible limit (200 mg/l) prescribed by IS 10500: 2012. The outcome of the analysis shows the water in the study area is hard to very hard. The hardness of the water is due to the presence of alkaline earth such as calcium and magnesium.

Nitrate (NO3): The excessive concentration of nitrate in groundwater becomes toxic to humans when exceeds 45 mg/l. Figure 7 shows the spatial distribution of nitrate in the study area. It varies from 47 mg/l to 82 mg/l and 24 mg/l to 74 mg/l in the pre-monsoon and post-monsoon respectively. Pre-monsoon months all the groundwater samples were exceeding the permissible limit, which may be of anthropogenic pollution of pesticides used in agriculture. Some of the samples come under the permissible limit during the post-monsoon season.

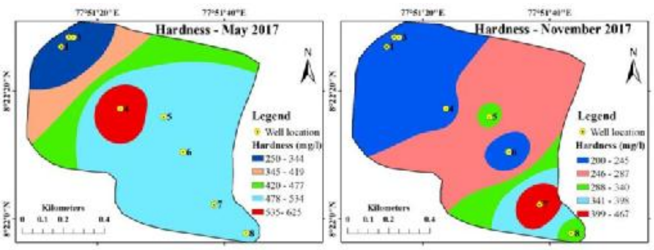

Figure 6. Spatial distribution of Total Hardness in pre and post monsoon season

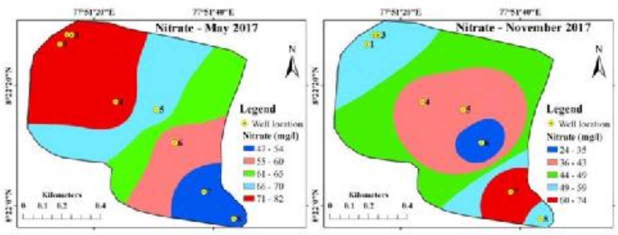

Figure 7. Spatial distribution of nitrate in pre and post monsoon season

Chloride: The presence of chloride in groundwater may be from different sources such as weathering, leaching of sedimentary rocks and soils, intrusion of saltwater, domestic and industrial waste discharges, municipal effluents, etc. (Karanth 1987). The acceptable limit of chloride in drinking water is specified as 250 mg/l. Figure 8 shows the spatial distribution of chloride in the study area. In the study area, the concentration of chloride is between 264 mg/l and 583 mg/l in pre-monsoon. Relatively, the higher concentration of chloride is observed from the well no. 4 and 5 which may be of geological condition.

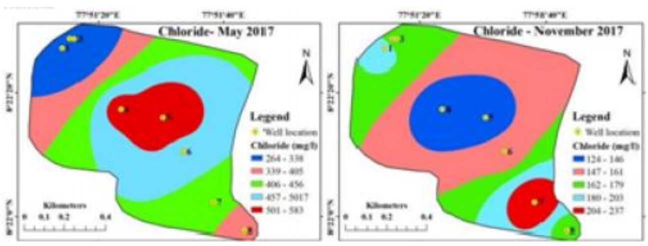

Figure 8.Spatial distribution of Chloride in pre and post monsoon season

Fluoride: Fluoride is one of the important chemicals that has been shown to cause essential effects in people through drinking water. Fluoride has favourable impacts on teeth at low concentrations in drinking water. Fluoride may be a necessary ingredient for a human being (WHO 2004). The source of Fluoride in groundwater is normally attributed to leaching from fluoride-rich rocks and easier accessibility of rainwater to weathered rock, long-term irrigation processes, semiarid climate, and long residence time of groundwater (Srinivasamoorthy *et al.*, 2008). Figure 9 shows the spatial distribution of Fluoride in pre and post-monsoon season. The concentration of Fluoride values varies from 1 mg/l to 2 mg/l during the month of May 2017 and 0mg/l to 1.90 mg/l during November 2017. As per IS10500 –2012, the acceptable limit for Fluoride is 1 mg/l. All the groundwater samples have exceeded the acceptable limit of fluoride during pre-monsoon.

Sulphate: The presence of high concentration sulphate in drinking water causes noticeable taste and might contribute to the corrosion of the distribution pipe network system (WHO, 2004). The acceptable limit of sulphate for drinking purposes is 200 mg/l. Figure 10 shows the spatial distribution of Sulphate in pre and post-monsoon season. The sulphate concentration in the study area ranges between 541 mg/l to 704 mg/l and 123 mg/l to 383 mg/l in pre-monsoon and post-monsoon respectively. Most of the groundwater samples exceed the acceptable limit.

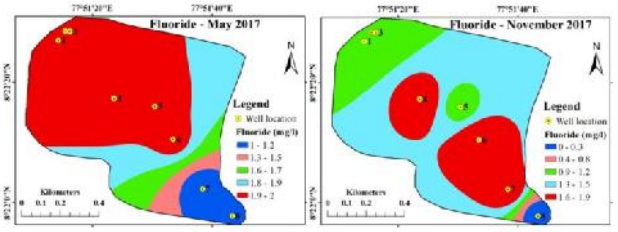

Figure 9. Spatial distribution of Fluoride in pre and post monsoon season

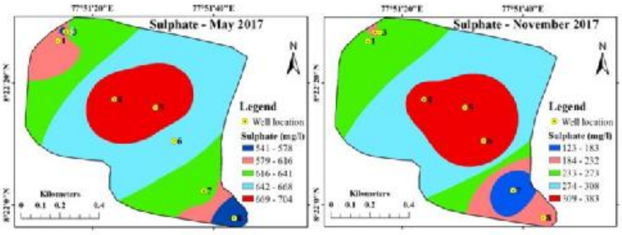

Figure 10. Spatial distribution of Sulphate in pre and post monsoon season

Sodium: The major source of sodium content in the groundwater is due to the presence of salts. The intake of high levels of sodium causes increased blood pressure, arteriosclerosis, oedema and hyperosmolarity. Groundwater with high sodium content is not suitable for agricultural use as it tends to deteriorate the soil. The desirable limit of sodium content in groundwater is 200 - 400 mg/l. Figure 11 shows the spatial distribution of sodium in the study area. All the groundwater samples are within the acceptable limit of sodium.

Potassium: Potassium is essential for plants and animals. Potassium salt in the most rock was not easily dissolved in groundwater (Stumm and Morgan, 1996). The maximum permissible limit of potassium in the drinking water is 12 mg/l. Figure 12 shows the spatial distribution of K in the study area. All the groundwater samples exceed the maximum permissible limit during the pre-monsoon season.

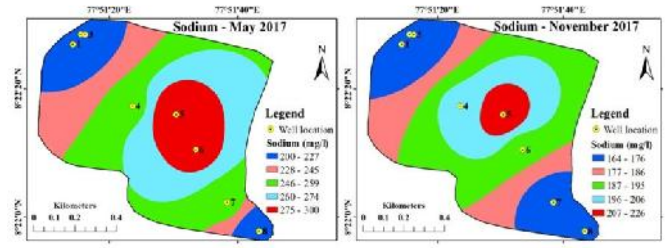

Figure 11. Spatial distribution of Sodium in pre and post monsoon season

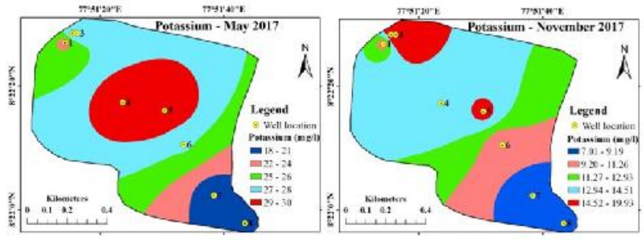

Figure 12. Spatial distribution of Potassium in pre and post monsoon season

WATER QUALITY INDEX

Water quality for drinking purposes: Groundwater chemistry was used as a tool to assess the quality of water for drinking and irrigation (Edmunds *et al.*2002). WQI is an important parameter for demarcating groundwater quality and its suitabilityfor drinking purposes (Tiwari and Mishra 1985; Singh 1992; Subba Rao 1997; Mishra and Patel, 2001; Naik and Purohit 2001; Avvannavar andShrihari 2008). WQI is defined as a rating technique that gives individual water quality parameters a composite influence on overall water quality (Mitra and ASABE Member 1998) for human consumption. The standards for drinking purposes as recommended by WHO (2004) and IS 10500 (2012) have been considered for the calculation of WQI. In computing WQI, three steps are followed. In the first step, each of the 10 parameters (pH, TDS, total hardness, Cl,SO_4, NO_3, F, Na, K, and EC)has been assigned a weight *(wi)* according to its significance in the overall quality of water for drinking purposes (Table 3).

The maximum weight of 5 has been selected to the parameters like nitrate, total dissolved solids, chloride, fluoride, and sulphate due to their major importance in water quality (Srinivasamoorthy *et al.* 2008). Potassium and total hardness are given the minimum weight of 2 as it plays an insignificant role in the water quality. Other parameters like EC, sodium, and pH were assigned a weight of 4 depending on their importance in water quality determination. In the second step, the relative weight (Wi) is computed from the following equation:

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

Where, W_i is the relative weight; w_i is the weight of each parameter; *n* is the number of parameters.

Table 1. Physio-chemical characteristics of groundwater in the study area during pre monsoon

Sample No.	Pre monsoon (May 2017)									
	pH	TH (mg/l)	TDS (mg/l)	Cl (mg/l)	SO4 (mg/l)	N (mg/l)	F (mg/l)	Na (mg/l)	K (mg/l)	EC (µS/cm)
1	7.82	250	1019	284	584	71	1.5	205	23	1847
2	7.41	341	1002	274	542	68	1.98	228	28.4	2004
3	8.1	258	1294	264	684	83	1.8	213	26.4	1954
4	8.14	626	2354	521	698	74	1.97	254	29.1	2541
5	8.35	518	2485	584	705	68	2	301	30	2625
6	8.05	513	2049	489	654	57	1.6	285	26	2315
7	7.98	496	1874	425	624	50	1.2	254	20	2000
8	7.65	483	1745	368	541	47	1.2	200	18.4	1635
Min	7.41	250	1002	264	541	47	1.2	200	18.4	1635
Max	8.35	626	2485	584	705	83	2	301	30	2625
Mean	7.94	435.63	1727.75	401.13	629.00	64.75	1.66	242.50	25.16	2115.13
SD	0.30	136.21	574.17	122.99	67.14	12.37	0.34	37.39	4.29	345.43

Table 2. Physio-chemical characteristics of groundwater in the study area during post monsoon

Sample No.	Post monsoon (November 2017)									
	pH	TH (mg/l)	TDS (mg/l)	Cl (mg/l)	SO4 (mg/l)	N (mg/l)	F (mg/l)	Na (mg/l)	K (mg/l)	EC (µS/cm)
1	7.8	204	740	200	421	50	0.6	164	10	1000
2	7.84	207	748	168	405	57	0.7	169	14	1084
3	8	200	759	165	350	60	1	170	20	1157
4	7.9	237	962	124	580	38	1.6	200	14.2	1504
5	8.1	300	1035	132	620	41	1	226	15	1603
6	7.91	201	760	150	384	24	2	187	10	1188
7	7.12	467	770	237	286	75	1.5	164	6.7	1204
8	7.8	326	820	169	405	58	0.45	175	8.2	1281
Min	7.12	200	740	124	286	24	0.45	164	6.7	1000
Max	8.1	467	1035	237	620	75	2	226	20	1603
Mean	7.81	267.75	824.25	168.13	431.38	50.38	1.11	181.88	12.26	1252.63
SD	0.30	94.02	111.90	36.55	112.86	15.76	0.54	21.70	4.34	205.18

Table 3. Relative weight of chemical parameters

Sl. No	Chemical Parameters	Drinking water standard IS 10500: (2012)	Weight (w_i)	Relative Weight (W_i)
1	pH	7.5	4	0.097561
2	Total Hardness mg/l)	300	2	0.048780
3	TDS (mg/l)	500	5	0.121951
4	Chloride (mg/l)	250	5	0.121951
5	Sulphate (mg/l)	200	5	0.121951
6	Nitrate (mg/l)	45	5	0.121951
7	Fluoride (mg/l)	1	5	0.121951
8	Sodium (mg/l)	200	4	0.097561
9	Potassium (mg/l)	-	2	0.048780
10	EC (mg/l)	-	4	0.097561
			$\Sigma w_i = 41$	$\Sigma W_i = 1$

Table 4. Water quality range and type of water

Range	Type of water	Explanation
Less than 50	Excellent water	Good for human health
50 – 100	Good water	Fit for human consumption
100 - 200	Poor water	Water not in good condition
200 – 300	Very poor water	Need attention before use
Greater than 300	Water unsuitable for drinking purpose	Need too much attention

Table 5. Calculation of WQI for individual water samples

Well No	Pre mosoon		Post monsoon	
	Water Quality Index	Water quality rating	Water Quality Index	Water quality rating
1	158.30	Poor	96.41	Good
2	165.24	Poor	98.52	Good
3	180.06	Poor	105.29	Poor
4	232.16	Very poor	118.97	Poor
5	239.35	Very poor	118.51	Poor
6	208.08	Very poor	115.18	Poor
7	163.50	Poor	97.92	Good
8	148.43	Poor	99.35	Good

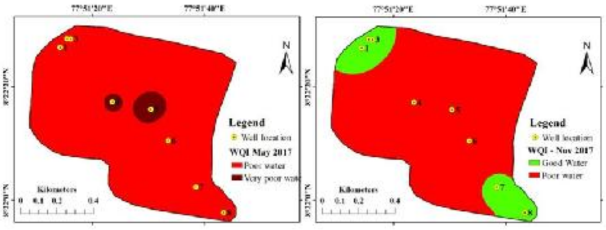

Figure 13. Spatial distribution of water quality index during pre and monsoon month

Calculated relative weight *(W_i)* values of eachparameter are given in Table 3. In the third step,a quality rating scale *(q_i)* for each parameter is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines laid down in the IS 10500 (2012) and the result is multiplied by 100.

$$q_i = C_i / S_i \; X \; 100$$

where q_i is the quality rating; C_i is the concentration of each chemical parameterin each water sample in milligrams perliter; S_i is the Indian drinking water standard for each chemical parameter in milligrams per liter according to the guidelines of the IS 10500(2012).For computing the WQI, the SI is first determined for each chemical parameter, which is then used to determine the WQI as per the following equation

$$S_i = W_i \, x \, q_i$$

$$W = \sum S_i$$

Where SI_i is the sub-index of *I* th parameter; q_i is the rating based on concentration of i^{th} parameter; *n* is the number of parameters. Water quality types were evaluated based on WQI. The computed WQI values range from 148 to 239 in the pre-monsoon season and range from 96 to 119 during the post-monsoon season. The WQI range and type of water can be classified in Table 4. The calculation of WQI for individual samples is represented in Table 5. During post-monsoon month all the groundwater samples exceed the permissible limit and it shows the water quality index of poor and very poor. During the post-monsoon month, well no 1, 2, 7, and 8 are showing good water quality all others are in poor quality (Figure 13). The pre-monsoon samples show poor quality in a greater percentage when compared with post-monsoon. This may be due to effective leaching of ions, overexploitation of groundwater, direct discharge of effluents, and agricultural impact. The water quality index was experienced with chloride and EC selected as pollution indicators. The observed high values of chloride and EC correspond to the same WQI, indicating the poor quality of groundwater in the study area.

Conclusion

Groundwater samples are collected during the pre-monsoon and post-monsoon months of May and November 2017 respectively. The groundwater samples collected from the field were analyzed in the laboratory for different physio-chemical parameters by using standard procedures. The results obtained were compared with the water quality standards specified by IS: 10500-2012. Based on the physio-chemical parameters, the water quality index has been computed for each well location. The derived water quality index of the study area ranged from 89 to 120 (pre-monsoon) and 62 to 94 (post-monsoon). It is observed that the WQI for pre-monsoon has deteriorated quality compared to post-monsoon. The influence of precipitation to improve water quality by way of dilutions of the chemical components.

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