Indian Journal of Ecology (2022) 49(5): 1743-1749
DOI: https://doi.org/10.55362/IJE/2022/3728

Manuscript Number: 3728
NAAS Rating: 5.79

GIS approach on Determining Domestic Groundwater Quality in Villupuram District of Tamil Nadu

K. Senthilraja, S. Vinothkanna[1], R. Rajee[1] and P. Jothimani[2]

Directorate of Crop Management, Tamil Nadu Agricultural University, Coimbatore-641 003, India
[1]Department of Geography, Madurai Kamaraj University, Madurai-625 021, India.
[2]Department of Environmental Sciences, Tamil Nadu Agricultural University, Coimbatore-641 003, India
**E-mail: senthilrajaens@gmail.com*

Abstract: An investigation was conducted using the secondary data to identify the domestic groundwater quality through Water Quality Index (WQI) method. Piper diagram for to understand groundwater chemistry indicates mixed type of water, with the relative order of $Cl^{-}>HCO_3>SO_4^{2-}$ for anions and $Na^{+}/K^{+}>Mg^{2+}>Ca^{2+}$ for cations. Pearson Correlation Coefficient technique were adopted to find out the relationship between the water quality parameters were identified positive correlation between $HCO_3^{-} – F^{-}$ during pre-monsoon and with Na^{+} - pH and K^{+} - pH during the post-monsoon season at a significant level of 0.01. The WQI results revealed that 52 percent of samples during pre-monsoon and 40 percent in post-monsoon are under the excellent category during the study period. About 9 and 16 percent of samples fall under poor quality during the study period. The quality of groundwater for domestic purposes in the study area is slowly changing its original quality.

Keywords: WQI, Correlation, Piper plot, Na, GIS

Groundwater quality is one of the important components that need to be a concern for domestic as well as agriculture. Surface and groundwater is the only source for drinking and other activities in arid and semi-arid regions of India (Sakram and Adimalla 2018). The quality of water is mainly distorted by geology and anthropogenic activities as well (Vinothkanna et al 2021a). Jalali (2011) reveals that the quality of water in many countries has getting deteriorated in past few years. In India, one of the hectic problem is groundwater pollution due to unintended drainage facilities, applying a large number of fertilizers in the agricultural field, over-exploitation of groundwater, *etc*. The quality of water once lost its original chemical composition is very difficult to restore to its original content (Vinothkanna et al 2020a) and can be identified using geochemical studies (Kumar et al 2016). Geochemistry of water determines the suitability of groundwater for domestic as well as irrigation purposes (Kumar et al 2014, Vinothkanna et al 2021b). Particularly, in the case of drinking water purpose, the quality of water should be at the standard level prescribed by the Bureau of Indian Standards (BIS) or World Health Organization (WHO) otherwise it leads to human health problems. Assessing water quality using the Water Quality Index (WQI) method is an efficient tool because it integrates multiple water quality parameters (Jamshidzadeh and Barzi 2018). Many studies in Tamil Nadu used WQI to determine the quality of water (Vinothkanna et al 2016 for Namakkal district; Karthikesan et al 2019 for Nagapattinam district). For the past few decades; there is a tremendous increase in population as well as urbanization (Adimalla et al 2018). So the demand for fresh water is increasing rapidly. Hence, quality studies getting important to understand the groundwater chemistry in any study area. Therefore an attempt has been made in this study to know the quality of groundwater in Villupuram district of Tamil Nadu. GIS (Geographic Information System) is a widely used tool for mapping and monitoring spatial data and it will act as a decision support system for fast management activities.

MATERIAL AND METHODS

Study area: Villupuram district extends between 11°30' to 12°35' north Latitude, and 78°37' to 80°00' east longitude (Fig. 1). The normal annual rainfall of the district is 1029.4 mm and the district receives maximum rainfall during the northeast monsoon season followed by the southwest monsoon season. The total geographical area of the district is 7190 sq/km and experiencing a semi-arid tropical climate.

Geologically the district is underlain by crystalline metamorphic complex and sedimentary tracks in the western and eastern sides respectively. The majority of the area is covered by metamorphic crystalline rocks. Red loam and clay loam are the dominant soil group and paddy is the major crop cultivated in the study area. As per the 2011 census, the total population of the district is 34, 58, 873 people with a population density of 481 people / sq.km.

Methods: The secondary data collected from State Ground and Surface Water Resource Data Centre, Tharamani, Chennai were used for drinking water quality analysis. Out of 107 sample wells, 97 common wells found in pre and post-monsoon season were identified and used for this analysis. To determine the groundwater quality, ten parameters were considered (Table 1). Weight has been given based on the importance of the quality parameter, and relative weight of respective parameters were computed using a weighted arithmetic index method.

The Pearson Correlation technique has been used to find out the relation between each water quality parameter using R. The values are attributed to GIS (Geographic Information System) tool and interpolation technique mainly IDW (Inverse Distance Weight) were used to show the map spatially. Finally, WQI (Water quality Index) is calculated based on BIS standards.

Table 1. BIS standards, weight and relative weight for each parameter

Chemical parameters	BIS standards	Weight (Wi)	Relative weight
pH	8.5	3	0.103
TDS	500	5	0.172
SO_4^{2-}	200	3	0.103
Cl^-	250	3	0.103
Na^+	200	3	0.103
K^+	12	1	0.034
Ca^{2+}	75	2	0.069
Mg^{2+}	30	2	0.069
F^-	1	5	0.172
		Σwi=27	ΣWi = 1.00

Water Quality Index (WQI) = Σqiwi

Where qi (water quality rating) = 100 X (Va-Vi) / (Vs-Vi), Va = actual value present in the water sample, Vi = ideal value (0 for all parameters except pH and DO which are 7.0 and 14.6 mg l^{-1} respectively). Vs = standard value. Wi (unit weight) = K/S_n

K (constant) =1

1/Vs1 + 1/Vs2 + 1/Vs3 + 1/Vs4…….. + 1/Vsn

S_n = 'n' number of standard values.

Mechanism controlling groundwater chemistry: Piper trilinear diagram for plotting water quality data is simple and easy to identify water types. The diamond shape indicates that the study area is dominated by the mixed type of water that is mixed Ca^{2+}-Mg^{2+}-Cl^- type followed by Ca^{2+}-HCO_3^- type. It generally denotes that no one cation-anion pair exceeds 50%.

Cations that constitute Mg^{2+}, Ca^{2+}, Na^+ and K^+ are on the left side and anions comprise Cl^-, SO_4^{2-}, CO^3 and HCO_3^- is on the right side of the triangle. The cations clearly define that no dominant type of water is present in the study area (Fig. 2). Na^+/ K^+ >Mg^{2+} > Ca^{2+} is the relative order for cations and for anions Cl^->HCO_3^->SO_4^{2-}. Anions clearly portray that chloride type of water is dominated followed by bicarbonate type in both monsoon seasons.

RESULTS AND DISCUSSION

pH and TDS: The pH is 7.80 and 7.85 during pre and post-monsoon respectively indicates pH value in the study area is under permissible limit and alkaline in nature. The 99 and 100 percent of samples are under the permissible limit in pre and post-monsoon season respectively. The concentration of TDS during pre-monsoon is varied from 115 to 2890 mg l^{-1} with a mean of 1502.5 mg l^{-1} and for the post-monsoon

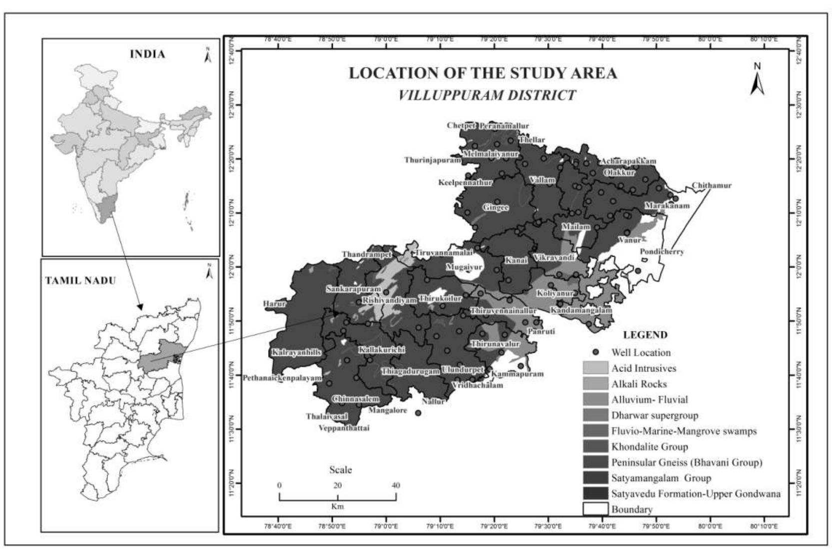


Fig. 1. Location of the study area

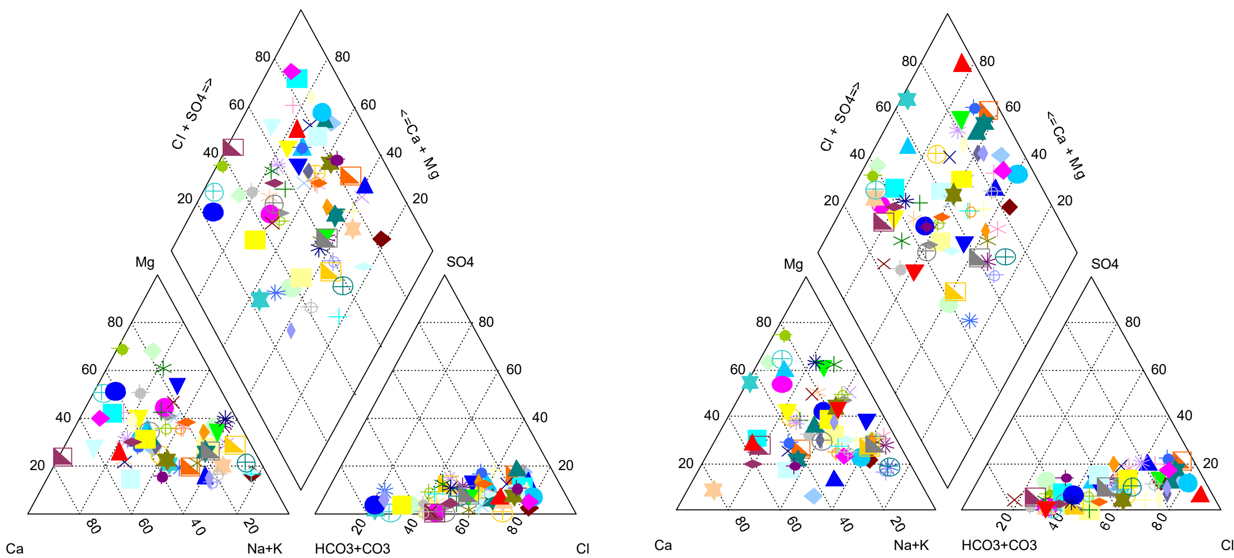
season, the value is varied from 88 to 3271 mg l^{-1} with a mean of 1679.5 mg l^{-1}. There are 27 samples (27 %) that are under the not permissible limit in both monsoon seasons.

Mg^{2+} and Ca^{2+}: The mean value of calcium is 224 and 148 mg l^{-1} in pre and post-monsoon season respectively. Generally, in natural surfaces both calcium and magnesium are found abundant (Prasanth et al 2012) which is mainly found in silicate rocks and dolomite deposits (Sharma et al 2016). The mean value of magnesium is 80.19 and 74.11 mg l^{-1} with 8 and 6 samples are not permissible during pre and post-monsoon season respectively.

Na^{+} and K^{+}: Sodium is varied from 2 - 761 mg l^{-1} and 1 - 812 mg l^{-1} with a mean of 381 and 406 mg l^{-1} having 26 and 19 percent of samples are not permissible in pre and post-monsoon seasons respectively. The mean potassium is 18 and 123 mg l^{-1} with 13 and 9 percent of samples are under not permissible limit during pre and post-monsoon season respectively.

Cl^{-} and SO_4^{2-}: The mean value of chloride is 569 and 728.5 mg l^{-1} with 60 and 57 percent of samples are under the desirable limit during pre and post-monsoon season respectively. With respect to Sulphate, 99 percent of pre-monsoon samples and 96 percent of post-monsoon samples are under the desirable limit as per BIS standards over the study area.

F^{-} and HCO_3^{-}: Fluoride and bi-carbonate in the study area are under the permissible limit in both monsoon seasons. The mean value is 0.79 and 0.85 mg l^{-1} for fluoride and 381 and 378 mg l^{-1} for bi-carbonate for pre and post-monsoon seasons respectively.



a) Pre Monsoon

b) Post Monsoon

Fig. 2. Piper diagram for pre and post-monsoon seasons

Table 2. Water quality parameters

Category	Parameters	Pre-monsoon			Post-monsoon		
		Minimum	Maximum	Mean	Minimum	Maximum	Mean
General	pH	7.2	8.4	7.8	7.1	8.6	7.8
	TDS	115	2890	1502.5	88	3271	1679.5
Anions	Mg^{2+}	2.4	157.9	80.1	4.8	143.3	74.1
	Ca^{2+}	16	432	224	16	280	148
	Na^{+}	2	761	381.5	1	812	406.5
	K^{+}	0.1	35	17.5	0.1	246	123.0
Cations	Cl^{-}	11	1127	569	25	1432	728.5
	SO_4^{2-}	1	270	135.5	1	266	133.5
	F^{-}	0.05	1.5	0.7	0.05	1.65	0.85
	HCO_3	61	701.5	381.2	24.9	732	378.4

The summary of water quality parameters such as minimum, maximum and mean values are shown in Table 2 and their classifications on BIS standards are shown in the Table 3. The spatial distribution of WQ parameters which are under not permissible limit are shown in Figure 3.

Correlation analysis: The physico-chemical parameters of waters are correlated using the Pearson correlation coefficient technique. A significant positive correlation was identified between HCO_3^- – F^- during pre-monsoon and with Na^+ - pH and K^+ - pH during the post-monsoon season. There is a significant negative correlation between pH - TDS, SO_4^{2-} - pH, F^- - Ca in the pre-monsoon season and there is no negative significant correlation during the post-monsoon season. The graphical diagram portrays the bivariate scatter plot with a fitted line in the bottom of the diagonal and values of correlation and its significance as a star in the upper diagonal (Figure 4 & 5).

Groundwater quality index: The quality of groundwater is classified into 5 categories based on the index value (Vinothkanna et al 2020b). During the study period, 52 percent of samples from pre-monsoon and 40 percent in post-monsoon are under the excellent category which is

Table 3. Water quality parameters based on BIS standards

Parameters	Classification on BIS standards	Water classes	Post-monsoon season		Pre-monsoon season	
			Total wells	%	Total wells	%
pH	< 8.5	Desirable	96	98.97	97	100.00
	>8.5	Permissible	1	1.03	Nil	---
TDS	<500	Desirable	29	29.90	30	30.93
	500-1000	Permissible	41	42.27	40	41.24
	>1000	Not Permissible	27	27.84	27	27.84
Mg^{2+}	<30	Desirable	17	17.53	19	19.59
	30-100	Permissible	72	74.23	72	74.23
	>100	Not Permissible	8	8.25	6	6.19
K^+	<20	Permissible	84	86.60	88	90.72
	>20	Not Permissible	13	13.40	9	9.28
Ca^{2+}	<75	Desirable	57	58.76	63	64.95
	>75	Permissible	40	41.24	34	35.05
Na^+	<200	Permissible	72	74.23	79	81.44
	>200	Not Permissible	25	25.77	18	18.56
SO_4^{2-}	<200	Desirable	96	98.97	93	95.88
	>200	Permissible	1	1.03	4	4.12
Cl^-	<200	Desirable	58	59.79	55	56.70
	>200	Permissible	39	40.21	42	43.30
F^-	<1	Desirable	87	89.69	88	90.72
	>1	Permissible	10	10.31	9	9.28
HCO_3^-	<200	Desirable	49	50.51	45	46.39
	> 200	Permissible	3	3.09	3	3.09

Table 4. Groundwater quality index for Villupuram district, 2018

WQI	Water class	Pre-monsoon season		Post monsoon season	
		Total well	%	Total well	%
< 50	Excellent	50	51.54	39	40.20
50-100	Good	38	39.17	42	43.29
100-200	Poor	9	9.27	16	16.49
200-300	Very poor	-	-	-	-
> 300	Unfit for drinking	-	-	-	-

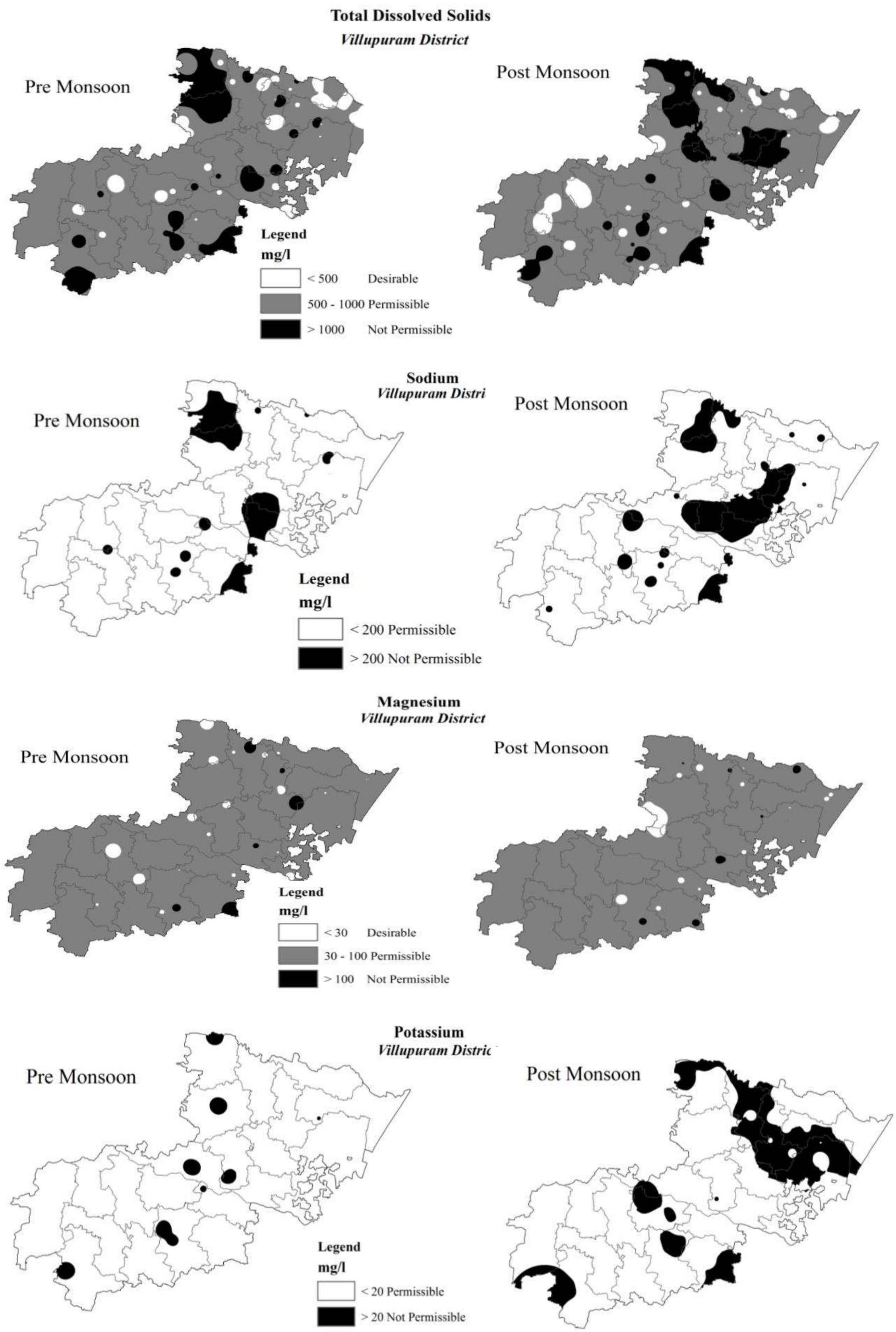


Fig. 3. Spatial distribution of WQ parameters under not permissible limit

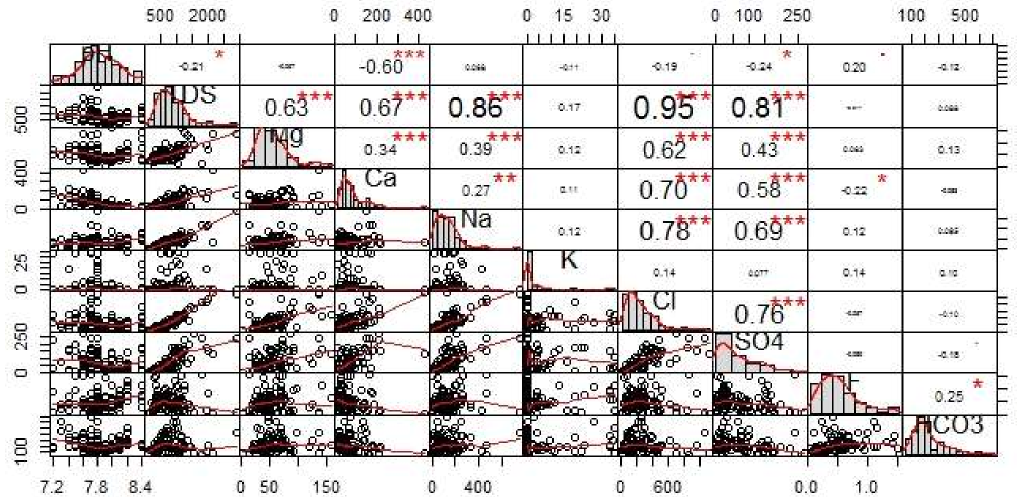


Fig. 4. Correlation plot for pre-monsoon season-2018

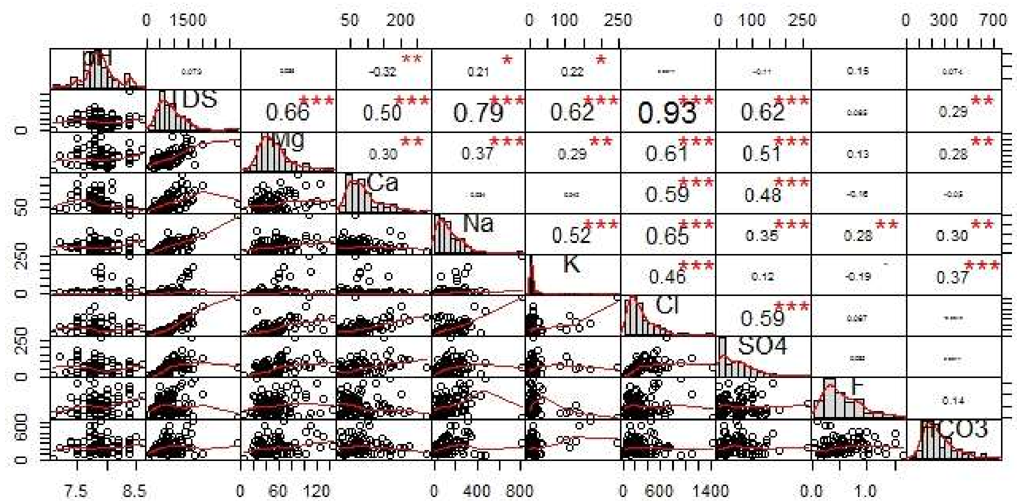


Fig. 5. Correlation plot for the post-monsoon season - 2018

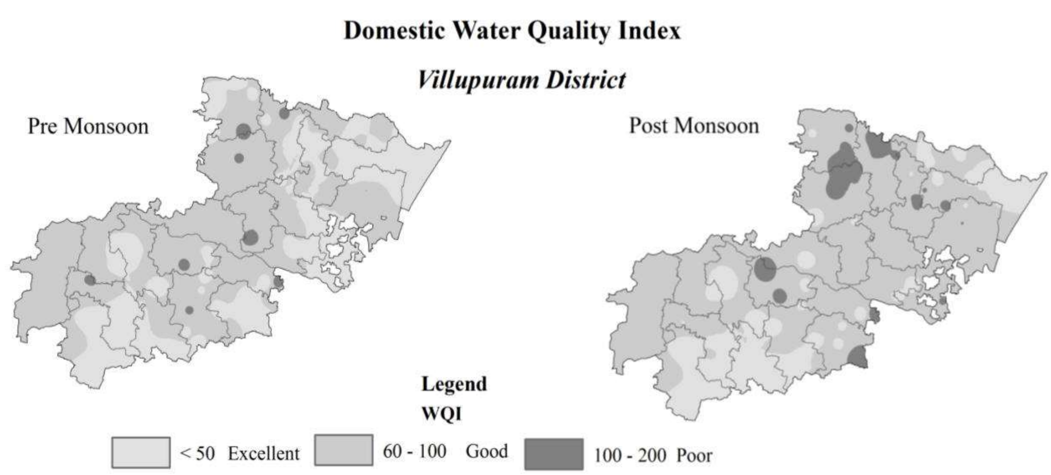


Fig. 6. Domestic water quality index - 2018

spatially distributed in the eastern part of the study area. Among the samples, 38 samples (39%) and 42 samples (43%) are under the good category during pre and post-monsoon season respectively.

The good category is spatially distributed in the entire district mainly over the western and central part of the study area in both monsoon periods. Only 9 samples in pre-monsoon and 16 samples in post-monsoon season are under poor quality for drinking purposes which are spread mainly over the northwestern and in central part as a patch over the study area (Table 4). There are no samples that fall under the very poor and unfit for drinking category during the study period over the study area (Fig. 6).

CONCLUSION

The present study evaluates the domestic groundwater quality in Villupuram one of the coastal district of Tamil Nadu. The groundwater quality parameters were determined based on BIS standards and WQI was identified. Results suggested that the quality of groundwater over the study area is excellent for domestic purposes. The use of the GIS tool for producing spatial maps is a useful technique for water quality studies. Even though the study area is safe for domestic purposes it is necessary to maintain its quality being it is near to the coastal area, speeding of natural weathering process due over exploitation of groundwater. The intrusion of saltwater may increase the salinity in groundwater. The people should have a responsibility to retain their original quality by doing proper waste management practices, avoid boreholes near coasts, etc.

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Received 12 May, 2022; Accepted 09 September, 2022