

GIS and Remote Sensing Based Spatio-Seasonal Assessment of Groundwater Quality in the Anjana Sub-Basin, Maharashtra, India

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Abstract

The groundwater is one of the principal sources of drinking and domestic water supply for the semi-arid regions of Maharashtra, and hence, the monitoring of groundwater quality is of utmost significance for the efficient management of water resources in the region. This study has been undertaken to evaluate the spatial and seasonal variation of groundwater quality in the GP-2 watershed of the Anjana sub-basin, located in the Chhatrapati Sambhajnagar district of Maharashtra, India, using hydro-chemical and GIS techniques. Groundwater samples were collected in the pre-monsoon and post-monsoon seasons of 2024, and the groundwater quality parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), total alkalinity, chloride (Cl^-), sulphate (SO_4^{2-}), nitrate (NO_3^-), fluoride (F^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), and potassium (K^+) of the groundwater samples were analyzed using standard analytical procedures for all the fifty groundwater samples collected in the study area. Spatial distribution maps of all parameters were prepared using Inverse Distance Weighting Interpolation Method in GIS. From the results, it is observed that groundwater in the study area is of alkaline type with pH values of 8.01 and 7.77 in pre-monsoon and post-monsoon seasons, respectively. All parameters were within the permissible limits of Bureau of Indian Standards. TDS, hardness, and nitrate values were higher in certain areas of the study region. Calculated values of Water Quality Index (WQI) vary from 23 to 312 in pre-monsoon and 89 to 280 in post-monsoon seasons. From the values of WQI, it is observed that water quality of groundwater is ranging from excellent to unsuitable for drinking in certain areas of the study region. From this study, it is confirmed that water table recharge in pre-monsoon season affects groundwater water quality.

Keywords: GIS, Remote sensing, Groundwater quality, GWQI, Anjana Sub-Basin

1. Introduction

Groundwater is considered to be one of the most important sources of fresh water that supports domestic, agricultural, and industrial activities all over the world, especially in semi-arid and developing countries where surface water is scarce (Gleick, 1996; UNESCO, 2020). Groundwater is considered to be an important source of drinking water, and it covers about 80% of rural drinking water demand and about 60% of irrigation demand in India. Groundwater is considered to be the backbone of water security and is considered to be essential to meet the growing demand for food in India (Central Ground Water Board [CGWB], 2022). With increased rates of urbanization, agricultural and industrial development, and climate change, there is a gradual decline in groundwater quality all over the world, which is of major concern to human health and environmental sustainability (Selvam et al., 2017; Li et al., 2014). Groundwater quality is influenced by natural and anthropogenic factors. Natural factors include rock-water interaction, solution of dissolved minerals, ion exchange, and detention time. These factors influence hydrochemical properties of groundwater (Freeze & Cherry, 1979; Hem, 1985). Anthropogenic factors such as excessive use of fertilizers, sewage, industrial effluent disposal, and poor waste management practices lead to the contamination of groundwater with nitrate, chloride, heavy metals, and microbes (Subba Rao, 2006; Varol & Davraz, 2015). Seasonal variations, especially in monsoon areas, play an important role in regulating groundwater quality by modifying hydrochemical properties of groundwater (Todd & Mays, 2005). Hence, comparative study of groundwater quality with pre-monsoon and post-monsoon seasons is essential.

In the conventional methods of groundwater quality evaluation, it is compared with the permissible values and limits. It is difficult to understand and interpret various groundwater quality parameters at a given time, which is complex and difficult for decision-makers and non-technical people to understand and interpret. In order to solve this issue and simplify it for better understanding and interpretation of groundwater quality parameters at a given time, it is observed that the Water Quality Index (WQI) and various water quality indices like Groundwater Quality Index (GWQI) have

proved to be highly effective and efficient in representing water quality by taking into account various water quality parameters at a given time (Horton, 1965; Brown et al., 1970; Ramakrishnaiah et al., 2009). Geographic Information Systems (GIS) and geostatistics have proved to be highly valuable tools in groundwater quality studies owing to their potential in integrating geodata and visualizing the pattern of distribution of contaminants (Burrough & McDonnell, 1998; ESRI, 2020). Moreover, the location of pollution can be identified, the relationship between hydrochemical factors and geology/land use can be established, and the seasonal variations in groundwater quality can be represented on maps using geoinformatics tools.

In recent years, integrated methodologies such as hydrochemical studies, modeling using WQI/GWQI, and spatial modeling using GIS technology have been successfully applied for groundwater quality evaluation in different hydrogeological environments (Sener et al., 2017; Vasanthavigar et al., 2010). These methodologies are also highly recommended for areas with high rates of land use change, high population increase, and high groundwater exploitation, and for areas where continuous monitoring of groundwater quality is needed to prevent the degradation of aquifers. Therefore, the systematic evaluation of groundwater quality with regard to different physicochemical parameters and seasonal variations is essential for proper groundwater resource management. In the present study, the groundwater quality indexing methodology using GIS technology has been applied to understand the spatial and seasonal variations in groundwater quality and to demarcate the zones of groundwater suitability.

The current study area is the GP-2 watershed of Anjana sub-basin in Chhatrapati Sambhajinagar district of the Indian state of Maharashtra. This is a semi-arid region where groundwater is used as the main source of drinking water. Although it is a region of considerable socio-economic importance, groundwater water quality is not assessed spatially and seasonally. Therefore, it is of considerable importance to assess the hydrochemical characteristics of groundwater and understand its spatial distribution in the region. Hence, the main aim of the current study is to assess the hydrochemical characteristics of groundwater and understand its spatial distribution in the region. For the purpose of the current study, comprehensive groundwater sampling was undertaken in the study area in 2024. In total, 50 groundwater samples were collected from the study area during the pre-monsoon season and another 50 groundwater samples were collected from the study area during the post-monsoon season. The groundwater samples were analyzed for 13 physicochemical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), total alkalinity (TA), chloride (Cl^-), sulfate (SO_4^{2-}), nitrate (NO_3^-), fluoride (F^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), and potassium (K^+). These parameters were analyzed using the standard analytical methods adopted for the purpose of groundwater quality assessment.

Location Map of Study Area

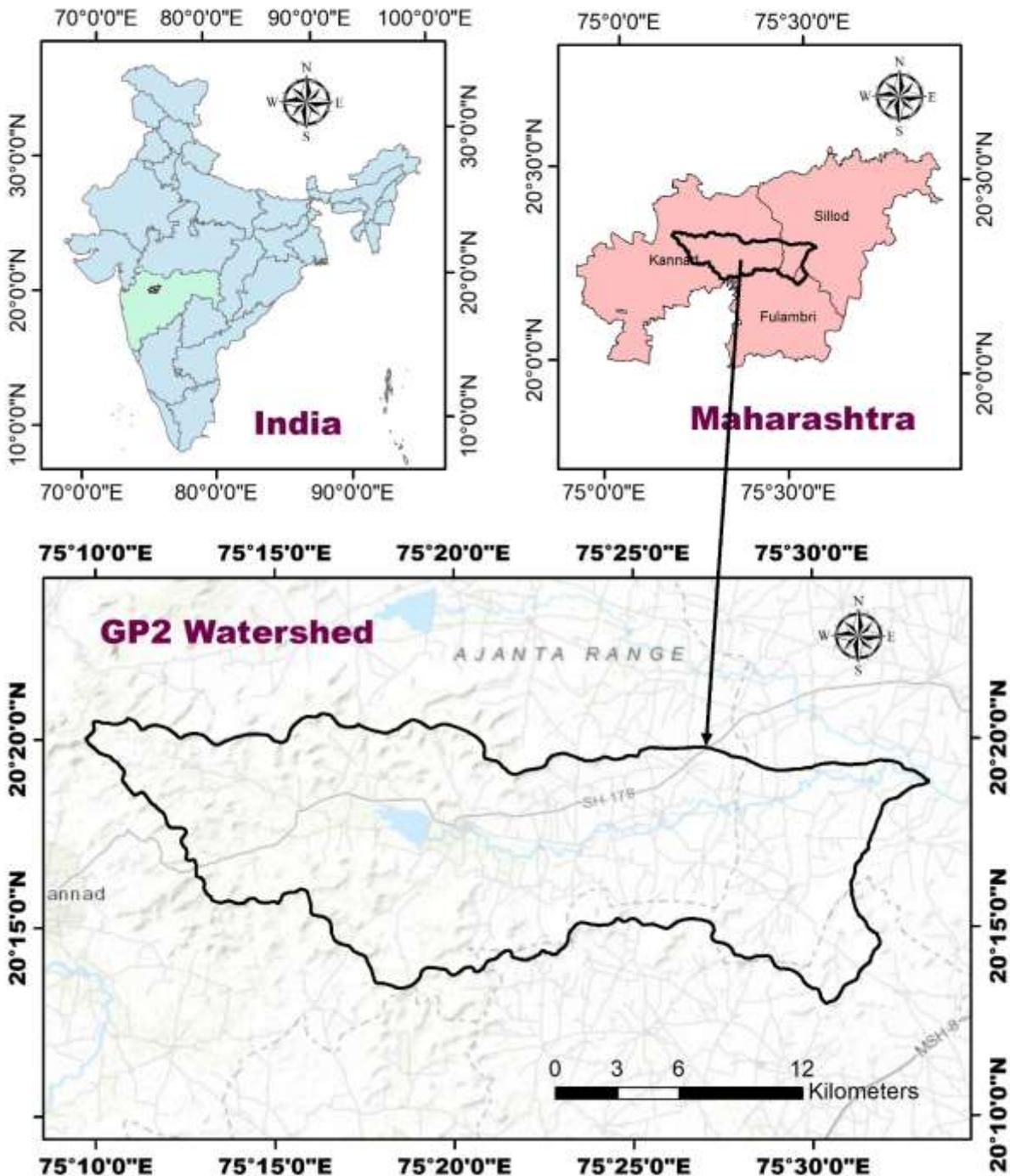


Figure 1: Location Map of Study Area

2. Materials and Methodology

2.1 Groundwater Sampling Strategy

A systematic groundwater sampling strategy was implemented in the GP-2 watershed of the Anjana sub-basins during the year 2024 to assess the groundwater hydrochemical characteristics on a seasonal basis. A total of 100 groundwater samples were collected, which includes 50 groundwater samples collected during the pre-monsoon season and 50 groundwater samples collected during the post-monsoon season. The sampling sites were selected in such a manner that there are uniform spatial distribution and representation of samples throughout the watershed. The geographic location of each sampling site was identified using a handheld GPS device. The groundwater samples were collected from bore

wells, dug wells, and hand pumps using systematic sampling to ensure proper sampling and avoid any kind of contamination and non-representativeness of the samples collected during the study period. Before collecting the groundwater samples, the wells were pumped for a few minutes to remove the stagnant water present in the wells. The groundwater samples collected during the study were properly stored and labeled to ensure proper handling of the samples collected during the study period. The collected groundwater samples were analyzed for 13 physicochemical parameters, viz.: pH, Electrical Conductivity (EC), Dissolved Solids (TDS), Total Hardness (TH), Total Alkalinity (TA), Chloride (Cl^-), Sulfate (SO_4^{2-}), Nitrate (NO_3^-), Fluoride (F^-), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^+), and Potassium (K^+). The analysis of these physicochemical parameters was carried out using standard procedures recommended by the American Public Health Association (APHA, 2012) and drinking water specifications recommended by the Bureau of Indian Standards (BIS, 2012). The physicochemical parameters such as pH and EC were measured in the field using portable digital meters, while the measurement of major ions and chemical parameters was carried out in the laboratory using titrimetric, spectrophotometric, and flame photometric techniques.

2.2 Data Preparation and GIS Database Development

A geodatabase environment has been developed to carry out spatial analysis of the data. Each sampling site has been georeferenced using GPS coordinates and incorporated into a GIS environment. Maps of spatial distribution of each of the physicochemical parameters have been developed to display the concentration patterns of the parameters in the watershed. Satellite images and base spatial data have been used for georeferencing, mapping, and boundary delineation of the study area. GIS software has been used to spatially process the data in the spatial database to facilitate interpolation and visualization of the hydrochemical data.

2.3 Spatial Interpolation Using IDW Technique

Spatial distribution maps of groundwater quality parameter values were constructed through the application of the Inverse Distance Weighting (IDW) interpolation technique. IDW is a deterministic interpolation method, which estimates the unknown values through the use of nearby measured points, with greater weight given to closer points than distant points (Burrough & McDonnell, 1998). The interpolated values are obtained through the calculation of a weighted average of the surrounding points:

$$Z(x_0) = \frac{\sum_{i=1}^n Z_i \times d_i^{-p}}{\sum_{i=1}^n d_i^{-p}}$$

$Z(x_0)$ = estimated value at unknown locations

Z_i = observed value at point i

d_i = distance between sample point and unknown point

P = Power Parameter

2.4 Calculation of Groundwater Quality Index (GWQI)

For the determination of the overall groundwater quality for drinking purposes, a Groundwater Quality Index (GWQI) was calculated using a set of groundwater quality parameters. This was done by incorporating a set of groundwater quality parameters into a single numerical index. This was done using a weighted arithmetic index approach for the calculation of the GWQI. This approach consists of a set of three major steps (Ramakrishnaiah et al., 2009).

Step 1: Assignment of Weight (W_i)

For the calculation of the GWQI, the assigned weights for the parameters were based on the relative importance of the parameters for drinking water quality and the potential health impacts. Parameters such as nitrates and fluoride were assigned higher weights due to their health impacts.

Table 1: showing weight assigned and relative weights calculate from selected parameters

Parameter	Standard (Si)	wi	Wi = wi/42
pH	8.5	3	0.0714
EC (µS/cm)	2000	3	0.0714
TDS (mg/L)	500	4	0.0952
TH as CaCO ₃ (mg/L)	200	2	0.0476
Total Alkalinity (mg/L)	200	2	0.0476
Cl (mg/L)	250	3	0.0714
SO ₄ (mg/L)	200	4	0.0952
NO ₃ (mg/L)	45	5	0.1190
F (mg/L)	1.5	5	0.1190
Ca (mg/L)	75	2	0.0476
Mg (mg/L)	30	2	0.0476
Na (mg/L)	200	3	0.0714
K (mg/L)	12	1	0.0238
Total		42	1.0000

Step 2: Relative Weight (Wi)

Relative Weight for each Parameters was calculated using:

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

w_i = weight of parameters

n=number of parameters

Step 3: Quality Rating (qi)

The Quality rating for each parameter was computed as:

$$q_i = \frac{C_i}{S_i} \times 100$$

C_i =observed concentration of parameters

S_i =standard permissible limit (BSI,2012)

Step 4: Sub-Index (SI)

$$SI_i = W_i \times q_i$$

Step 5: Overall WQI

$$WQI = \sum SI_i$$

Table 2: Classification of Ground water Quality Index

WQI Value	Water Quality
<50	Very Good
50-100	Good
100-200	Moderate
200-300	Poor water Quality
>300	Very poor Water Quality

3.Results and Discussion

The pH values of groundwater in the study region varied between 7.28-8.65 (pre-monsoon) and 7.44-8.40 (post-monsoon) with mean values of 8.01 and 7.77, respectively. The pH values show that the groundwater is slightly alkaline but within the permissible limits of drinking water quality (BIS 2012). The slight decreases in mean pH values during the Post-monsoon period indicates the dilution effect of recharge from rainfall infiltration, which tends to reduce alkalinity and pH (Todd & Mays, 2005). The higher pH regions are characterized by regions of basaltic rocks, which result in the release of bicarbonates into groundwater (Subramani et al., 2010). The low standard deviation values (0.20 pre; 0.19 post) suggest that the pH values are relatively evenly distributed at the sampling points.

Table 3: Statistical summary of groundwater quality parameters for pre-monsoon and post-monsoon seasons

Parameter	BIS Limit	Pre-Monsoon Range	Post-Monsoon Range	Pre-Mean	Post Mean	Pre SD	Post SD
pH	6.5–8.5	7.28–8.65	7.44–8.4	8.01	7.77	0.20	0.19
Alkalinity (mg/L)	200	26.61-545.2	28.87-571.2	211.76	237.60	97.14	99.03
TH (mg/L)	200	16.25-159.8	14.26-433.4	83.86	111.74	33.15	104.8
EC (µS/cm)	2000	40.62-400	36.67-465.5	214.60	246.18	85.75	92.57
TDS (mg/L)	500	62.98-626.3	57.04-728.2	335.28	384.72	134.11	144.7
Sulphate (mg/L)	200	1.134-87.99	11.27-202	34.34	71.14	16.29	35.85
Nitrate (mg/L)	45	2.86-65.91	1.13-87.99	29.52	34.34	13.38	16.29
Chloride (mg/L)	250	8.22-197.8	10.27-209.8	90.74	101.76	49.78	50.78
Calcium (mg/L)	75	6.94-122.8	6.21-129.2	33.78	63.06	24.08	27.75
Magnesium (mg/L)	30	18.17-129	10.17-121	74.72	67.18	25.59	25.27
Sodium (mg/L)	200	26.07-113	24.06-154.2	60.35	64.26	23.02	28.45
Potassium (mg/L)	12	0.0005-11.87	0.1001-13.25	1.73	1.45	2.84	2.68
WQI		23-312	89-280				

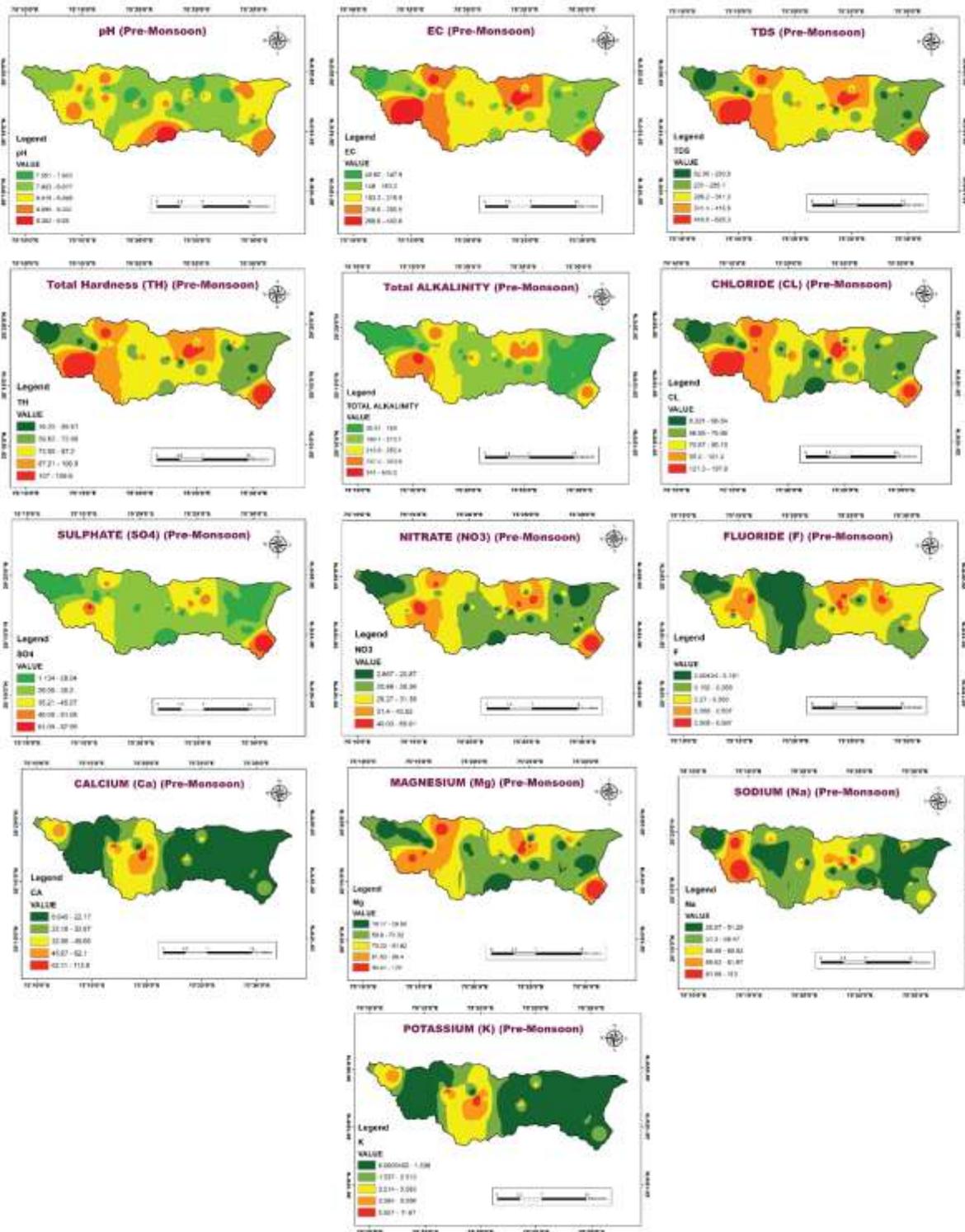


Figure 2: Spatial distribution maps of the groundwater quality parameters in the study area for the pre-monsoon season, such as pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), total alkalinity, chloride (Cl⁻), sulphate (SO₄²⁻), nitrate (NO₃⁻), fluoride (F⁻), calcium (Ca²⁺), magnesium (Mg²⁺), sodium (Na⁺), and potassium (K⁺).

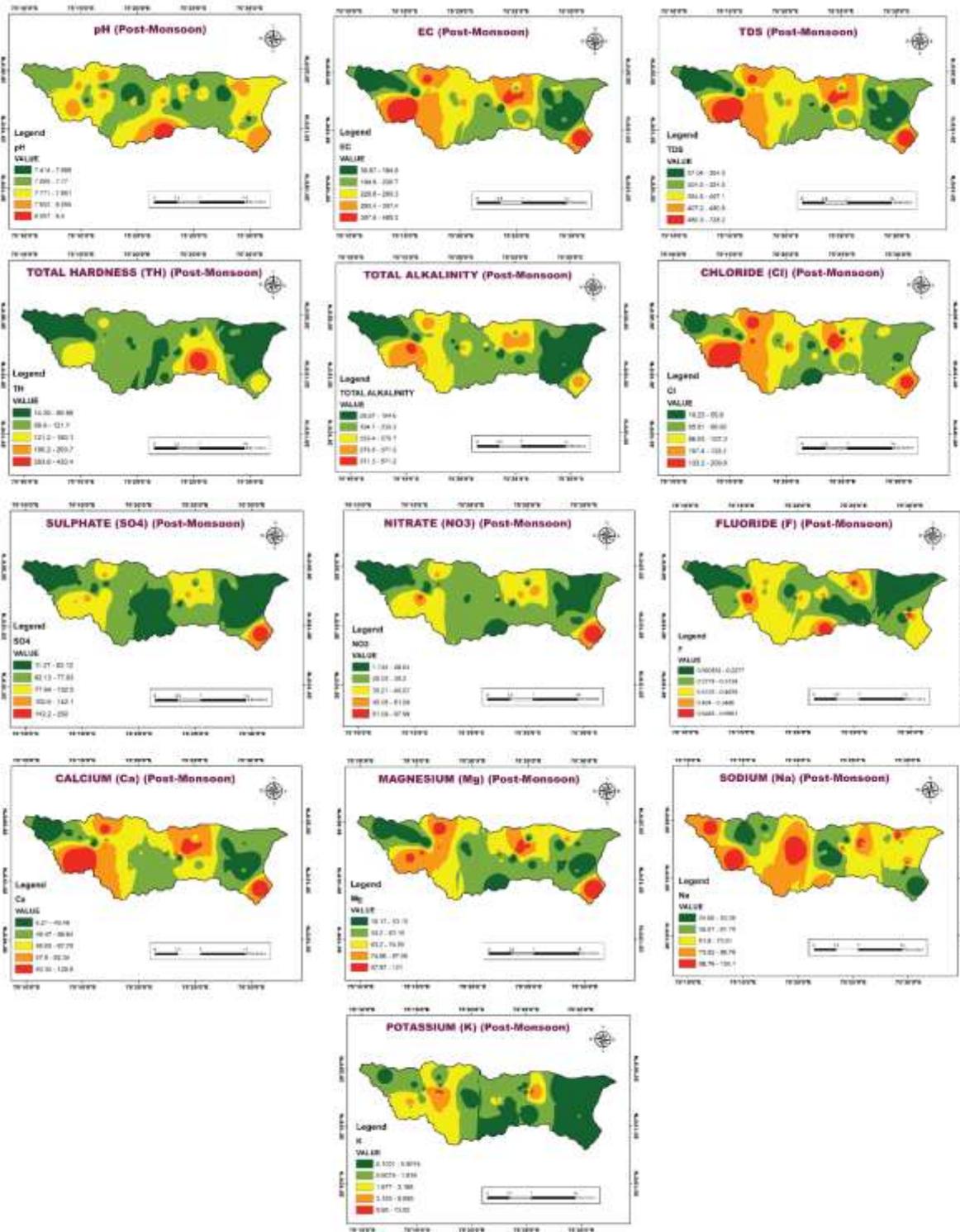


Figure 3: Spatial distribution maps of the groundwater quality parameters in the study area for the post-monsoon season, such as pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), total alkalinity, chloride (Cl⁻), sulphate (SO₄²⁻), nitrate (NO₃⁻), fluoride (F⁻), calcium (Ca²⁺), magnesium (Mg²⁺), sodium (Na⁺), and potassium (K⁺).

The values of alkalinity varied from 26.61-545.2 mg/L (pre) and 28.87-571.2 mg/L (post), with mean values of 211.76 mg/L and 237.60 mg/L, respectively. Total hardness (TH), on the other hand, has shown significant increase from 83.86 mg/L (pre) to 111.74 mg/L (post), which is indicative of greater dissolution of minerals and exchange of ions. High values of standard deviation, i.e., 104.8, are observed during the post-monsoon season, indicating fluctuations in the values because of local hydrogeochemical and human factors. High values of hardness are commonly observed in regions where calcium and magnesium dominant geological formations are present (Hem, 1985).

Values of electrical conductivity (EC) varied from 40.62 to 400 μS/cm (pre) and 36.67 to 465.5 μS/cm (post), with mean values of 214.60 and 246.18 μS/cm, respectively. The increase in post-monsoon values of EC is because of the increase

in ionic mobility after the solution of soluble salts. Total dissolved solids (TDS) also increased from 335.28 to 384.72 mg/L. Though most of the values are within the BIS standard (500 mg/L), some are higher than this value. This may be because of salinity problems, which are possibly linked to return flows from agriculture and leaching from soils (Freeze & Cherry, 1979). High values of standard deviation also support the variations in the level of mineralization.

Major Anions (Cl^- , SO_4^{2-} , NO_3^-)

The concentration values of chloride indicated an increase from 90.74 mg/L (pre) to 101.76 mg/L (post). Higher concentration values of chloride are generally linked with anthropogenic activities such as agricultural runoff and infiltration of domestic waste, as chloride has been recognized as a conservative ion in groundwater (Appelo & Postma, 2005). The concentration values of sulphate indicated a significant increase from 34.34 mg/L to 71.14 mg/L, which could be linked with the increase in the rate of dissolution of sulphate minerals and the oxidation of sulphide deposits during the process of recharge. The concentration values of nitrate indicated an increase from 29.52 mg/L to 34.34 mg/L, with some of the values being higher than the permissible limit of 45 mg/L. Higher concentration values of nitrate are well recognized as being linked with agricultural contamination and the use of fertilizers (WHO, 2017). The results indicated moderate standard deviation values, which suggested the presence of spatial variability.

Major Cations (Ca^{2+} , Mg^{2+} , Na^+ , K^+)

Calcium concentrations increased significantly from 33.78 mg/L (pre) to 63.06 mg/L (post), reflecting enhanced carbonate dissolution during recharge. Magnesium showed a slight decrease in mean concentration (74.72 \rightarrow 67.18 mg/L), suggesting dilution or ion-exchange processes. Sodium increased moderately from 60.35 mg/L to 64.26 mg/L, while potassium decreased slightly (1.73 \rightarrow 1.45 mg/L). The stability of sodium and potassium values indicates that these ions are not affected much by seasonal recharge but are controlled by lithology and soil-water interaction (Domenico & Schwartz, 1998).

Water Quality Index (WQI)

The calculated Water Quality Index (WQI) varies from 23 to 312 in the pre-monsoon season and 89 to 280 in the post-monsoon season. According to the standard Water Quality Index scale, it is inferred that the calculated values indicate that the water quality of the groundwater varies from excellent to unsuitable for drinking purposes in both seasons. However, there is a significant variation in water quality in both seasons. In the pre-monsoon season, it is inferred that there is a greater variation in the Water Quality Index values, ranging from very low (excellent water quality) to very high values above 300, indicating poor to very poor water quality of the groundwater. Such a large variation in Water Quality Index values is indicative of high spatial variability and localized hotspots of contamination/mineralization in the pre-monsoon season. High values of Water Quality Index in the pre-monsoon season are generally indicative of high solute concentration due to evaporation, high water-rock interaction, and low dilution from rainfall recharge (Todd & Mays, 2005). On the other hand, it is evident that there is a decrease in the range of the post-monsoon WQI values, which vary from 89 to 280. It is also evident that there is no occurrence of very low or very high WQI values. This indicates that there is a balancing effect of the monsoon recharge on groundwater quality by reducing the concentration of dissolved ions and salinity. It is evident that there is an improvement in groundwater quality after recharge. Such an improvement has been well documented in hydrogeochemical studies of semi-arid regions of the world (Subramani et al., 2010). It is evident that there is still a presence of moderate to poor WQI even after monsoon recharge. This indicates that there is a presence of geogenic or anthropogenic influences in these regions. It is evident that there is a presence of higher WQI in regions where there is a presence of higher concentrations of TDS, hardness, and nitrate. This indicates that these factors are major contributors to controlling groundwater quality.

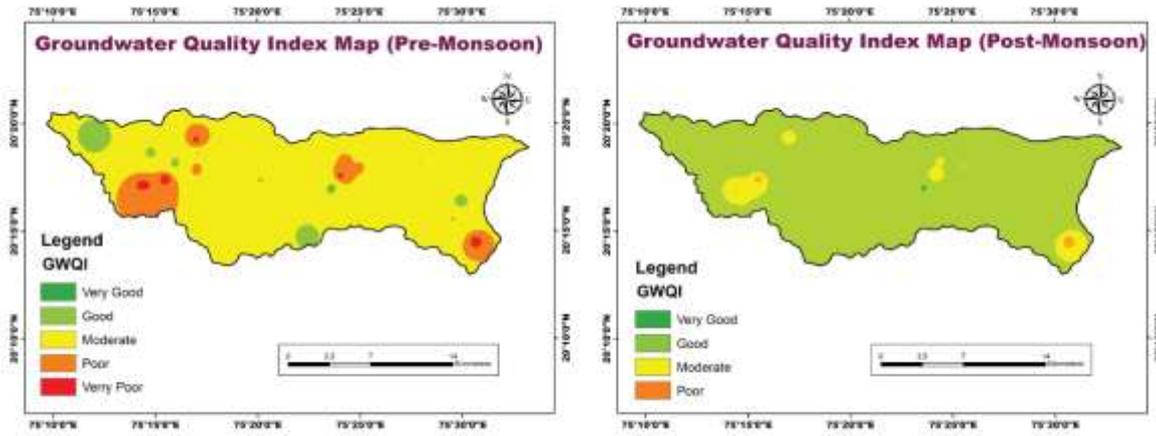


Figure 4: Spatial distribution of the Groundwater Quality Index (GWQI) for the pre-monsoon and post-monsoon seasons in the study area, indicating the quality of groundwater in the study area as very good, and good.

4. Conclusion

The present study aims to evaluate the spatio-seasonal variability of groundwater quality in GP-2 watershed of Anjana sub-basin using physico-chemical analysis and spatial modeling and Water Quality Index methods. The physico-chemical analysis of the groundwater samples shows that the groundwater is slightly alkaline in nature and is dominated by dissolved ions resulting from rock-water interaction processes. Most of the physico-chemical parameters are within the permissible limits of drinking water quality; however, local fluctuations are observed in total dissolved solids, hardness, nitrate, and alkalinity. The comparison of physico-chemical parameters during different seasons shows that the quality of groundwater is dominated by recharge processes during the monsoon season. The pre-monsoon season shows a wider range of values of WQI (23-312), which indicates excellent to very poor water quality. This shows the concentration of dissolved ions in groundwater during the dry season due to evaporation effects. On the other hand, during the post-monsoon season, the values of WQI are lower (89-280), indicating improvement in water quality. This shows recharge is an important controlling factor in controlling groundwater quality in semi-arid basaltic regions, which is supported by hydrogeochemical models. Results obtained from spatial analysis show that regions with higher values of WQI are associated with regions of high TDS, hardness, chloride, and nitrate. These regions are likely to be the result of a combination of lithological weathering, agricultural activities, and human inputs. The existence of regions with moderate to poor quality despite the recharge from monsoons indicates that geological factors and human activities are responsible for the deterioration of groundwater quality.

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CONFLICT OF INTERESTS

No conflict of interests among all the authors.

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