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Evaluation of Groundwater Suitability for Drinking Purposes Using GIS and WQI in Chikkaballapura Taluk, Karnataka, India

Sridhara Malur Krishnappa, Sadashivaiah Channabasavaiah[1] and Kiran Dasalukunte Ananda[2]*

Department of Civil Engineering, Government Engineering College, Chamarajanagara, Karnataka – 571313, India
[1]Department of Civil Engineering, Dr Sri Sri Sri Shivakumara Mahaswamy College of Engineering, Byranayakanahalli Bangalore Rural District, Karnataka – 562132, India
[2]School of Systems and Infrastructure, Indian Institute for Human Settlements, Bengaluru – 560080, India
✉ dakiran07@gmail.com

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Abstract: In the present study, groundwater samples were analysed to determine the suitability of groundwater for drinking use in Chikkaballapura taluk (CBT) in 2019. The tests were conducted on the groundwater twice a year, during the pre-monsoon and post-monsoon seasons. The results of 12 physico chemical parameters were used for the calculation of the water quality index (WQI). ArcGIS was used in the study to plot the spatial variation of chloride, nitrate, and fluoride. In urban areas, WQI ranged from 42.94 to 204 during the pre-monsoon season and from 62.67 to 153.93 during the post-monsoon season. Similarly, in rural areas, WQI ranged from 47.78 to 245.98 during the pre-monsoon season and from 35.92 to 405.63 during the post-monsoon season. The results of the WQI show that most samples fall into poor water categories according to the quality rating scale. Also, the results revealed that both in Chikkaballapura rural (CBR) and Chikkaballapura urban (CBU), most of the groundwater samples exceeded the drinking water quality limits during the pre-monsoon season when compared to the post-monsoon season. High levels of fluoride were found in Thippanahalli, Doddapailagurki, Poshettihalli, Kuppahalli, Mandikal and Ajjivara grama panchayaths and a significantly high concentration of nitrate was found in Addagallu and Manchanabele grama panchayaths during the pre-monsoon season in CBR. It was suggested that constant monitoring of groundwater quality in contaminated areas be carried out to prevent further deterioration and related problems and that rainwater harvesting practices be encouraged to help reduce the load on urban and rural water supply systems.

Key words: Fluoride, groundwater, nitrates, urbanisation, GIS, water quality index.

Introduction

In India, groundwater supplies more than half of the country's irrigation needs as well as around 80% of the country's drinking water needs in rural areas and 50% of those in urban areas (CGWB, 2012). Groundwater is an important source of drinking water in India, both in the urban and rural areas. The quality of groundwater greatly influences how suitable it is for various uses. Because of this, maintaining groundwater quality is a major challenge (Packialakshmi et al., 2011). In rural parts of developing countries, where groundwater is the

*Corresponding Author

primary source of drinking water, the long-term effects of chemical contamination of groundwater are especially concerning (Suthar et al., 2008). Many chemicals, including fluorides, nitrates, calcium, potassium, magnesium, and many others, can harm people's health whenever they are present in excess. Given that India is mostly an agricultural country, fluoride, chloride and nitrate contamination of water is very likely. One of the important elements in groundwater is fluoride. Dental and skeletal fluorosis are two conditions that can result from drinking water with too much fluoride (Bharath and Krishna, 2019; Raj and Shaji, 2017). The quality of recharged water, atmospheric precipitation, inland surface water and subsurface geochemical processes can impact groundwater quality (Reza and Singh, 2010). In many regions of the world, low-quality drinking water has an adverse effect on human health and contributes to the occurrence of a variety of acute and chronic disorders (Aly et al., 2015; Milovanovic, 2007).

For mapping water quality, geographic information systems (GIS) and remote sensing are useful tools. The geological formation through which groundwater flows and anthropogenic activities in the groundwater basin determine the spatial variation of groundwater quality (Wu et al., 2017). Groundwater quality maps and the delineation of groundwater potential zones are commonly generated using the GIS interpolation approach. The water quality index (WQI), which specifies a water quality class for drinking purposes, has also been widely used (Rabeiy, 2018). WQI is a mathematical model that converts a water parameter into a single indicator value that indicates the water quality level. It evaluates the water's suitability for drinking and other uses. It converts multiple water parameters into a single individual that may be used to evaluate the overall water quality at a certain time and location (Boateng et al., 2016).

In Karnataka, the groundwater table is predominant, and the primary pathway for groundwater migration is through the hard rock fissures (Radhakrishna, 2004). According to CGWB data, 14 districts in the Karnataka state including Chikkaballapura district are affected by high fluoride content. Due to urbanisation, industrialisation, and agricultural activity, the water table has dropped significantly in the southern interior of Karnataka (Srinivasan, 2021). In the Chickballapur district, groundwater has a significant economic impact on the local farmers. In the past, irrigation facilities provided by numerous widely dispersed tanks were mostly dependent on agriculture. Farmers are now predominantly relying on borewells for their irrigation needs due to drought conditions. According to CGWB 2012 data, there are about 29,016 bore wells in the district, which reflects the dependency of farmers on groundwater. Fluoride concentrations of more than 1.5 mg/L and nitrate concentrations of more than 45 ppm were reported from many parts of the district, as per the CGWB data. Water level depletion and yield decline in significant parts of the district, overexploitation of groundwater sources and water quality issues are all important groundwater challenges and concerns in the Chikkaballapurataluk. These factors motivated the current investigation; the main goal of the current study is to evaluate the groundwater quality in the rural and urban areas of Chikkaballapura taluk and check its suitability for drinking purposes using GIS and WQI.

Materials and Methods

Study Area

Chikkaballapura taluk (CBT) of Chikkaballapura district is located at 13.435455 latitude and 77.731476 longitude. According to the Chikkaballapura district at a Glance report 2019–20, the taluk consists of 3 hoblies, 23 grama panchayaths (GPs) and 251 villages. Chikkaballapura city (urban area) has 31 wards. According to the 2011 census, the population in Chikkaballapura taluk is 212536, of which 148884 constitute the rural population and 63652 the urban population. The taluk has an overall population density of 333 people per sq.km. It is in the semi-arid climatic zone, with an annual normal rainfall of 769 mm, and a temperature range of 14.4°C to 35.7°C. The topography of the district is undulating to plain, and the types of soils distributed range from red loamy soil to red sandy soil and lateritic soil.

In CBT, there are mainly two types of aquifer systems: the phreatic aquifer, comprising the Banded Gneissic Complex and the fractured aquifer, comprising the Fractured Banded Gneissic Complex. Fractured Banded Gneissic Complex/gneisses and laterite are the main water-bearing formations. Groundwater occurs within the weathered and fractured gneisses and laterite under water table conditions and in semi-confined conditions. Bore wells were drilled from a minimum depth of 100 mbgl to a maximum of 500 mbgl. Figure 1 shows the location map of Chikkaballapura taluk of Karnataka.

Grab sampling was carried out in the study in the pre-monsoon and post-monsoon season of 2019 according to the standard procedure. During the pre-monsoon season 142 samples (include samples collected from 22 grama

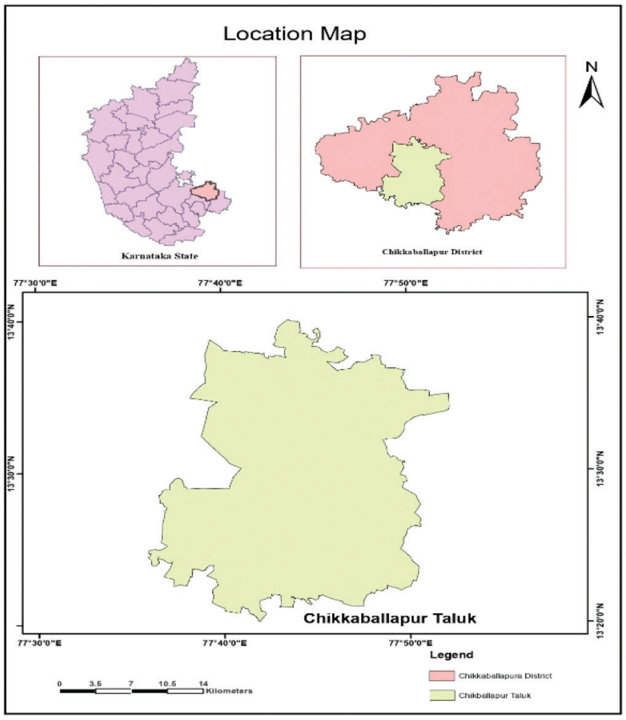

Figure 1: Location map of Chikkaballapura taluk, Karnataka.

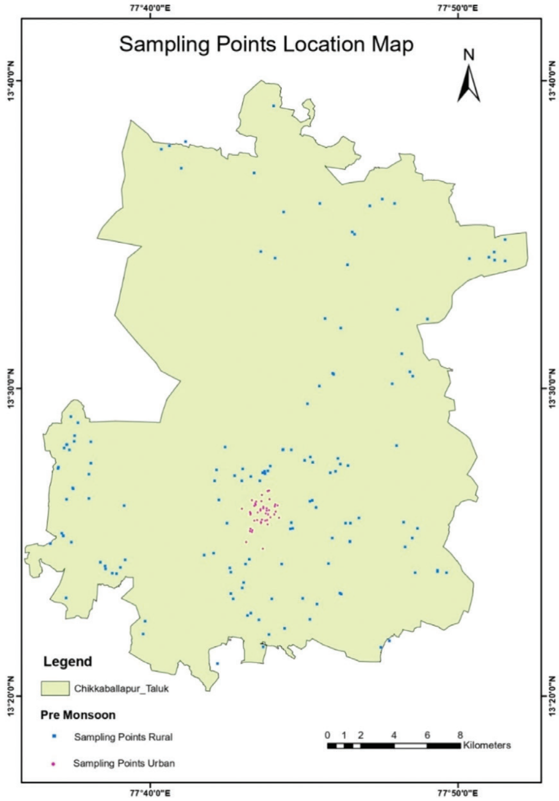

Figure 2: Sampling location map of Chikkaballapura during the pre-monsoon season.

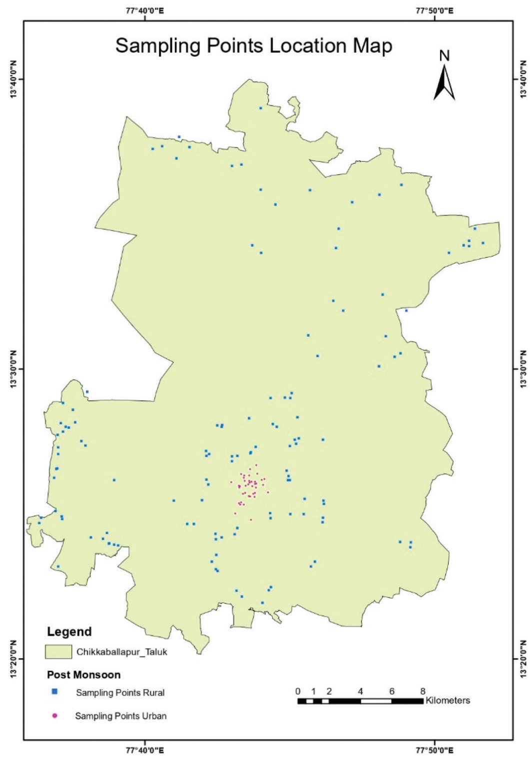

Figure 3: Sampling location map of Chikkaballapura during the post-monsoon season.

panchayath villages) and 45 samples (include samples collected from 31 wards) were collected from the Chikkaballapura taluk rural (CBR) and Chikkaballapura taluk urban (CBU) respectively. In post-monsoon, 128 samples (include samples collected from 18 grama panchayath villages) and 43 samples (include samples collected from 31 wards) were collected from CBR and CBU, respectively. Groundwater tapped through hand pumps from a minimal depth of 180 feet at Mothur village of Poshetihalli GP, and a maximum depth of 350 feet at Anuknoor village of Patrenahalli GP were collected. In addition, samples were collected from deep bore well sources having a minimum depth of 550 feet in Siddaganahalli village, Kammaguttahalli panchayat and a maximum depth of 1400 feet sample in Ajjavara village in Chikkaballapur rural taluk. Samples were collected following standard protocols in pre-cleaned HDPE bottles. Sampling locations for the study area are shown in Figures 2 and 3. Then the samples were stored in an icebox and transported to the laboratory for analysis. Each sample location was acquired by handheld GPS device Garmin eTrex 10 receivers. Measurements of pH and electrical conductivity (EC) were made in the field using a pH meter and a conductivity meter, respectively. The analysis of the other parameters was conducted by adopting standard methods by APHA (2012). Important parameters like pH, EC, total dissolved solids (TDS), hardness (TH), alkalinity (TA), calcium (Ca), magnesium (Mg), chloride (Cl), nitrate (NO_3), sulphates (SO_4), fluoride (F) and iron (Fe) were analysed to assess its suitability for drinking as per BIS 10500:2012 Indian standard drinking water – specifications.

Water Quality Index

Three stages are involved in the calculation process. Each of the factors has been given a weight (w_i) in the first stage depending on how they are expected to affect primary health.

Parameters were assigned a weight between 1 and 5 (Table 1) based on how important they were to the overall quality of water suitable for drinking (Ketata-Rokbani et al., 2011).

Table 1: Physico-chemical parameter weightage and relative weights

Parameters	*Weights, w_i*	*Relative weight (W_i)*
pH	4	0.111111111
TH	2	0.055555556
Calcium	2	0.055555556
Magnesium	2	0.055555556
Chlorides	3	0.083333333
TDS	4	0.111111111
Fluoride	4	0.111111111
Nitrates	5	0.138888889
Iron	4	0.111111111
Sulphate	4	0.111111111
Turbidity	2	0.055555556
	$\sum w_i$=36	$\sum W_i$=1.0000000

The first step is to estimate the relative weight of each parameter as given in Eq. (1) (Shabbir and Ahmad, 2015).

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

where w_i is the weight of each parameter, W_i is its relative weight, and n is the number of groundwater parameters.

The next step is to estimate the quality rating scale (q_i) of each parameter using Eq. (2) (Singh and Khan, 2011)

$$q_i = \left(\frac{V_i - V_{id}}{S_i - V_{id}}\right) \times 100 \quad (2)$$

where q_i is the quality rating for the ith water parameter, V_i is the measured value for the i parameter at a given sampling site, and S_i is the standard permissible value for the i parameter assigned by BIS (Vasanthavigar et al., 2010). V_{id} is the ideal value of i parameter in pure water.

For computing the WQI, the S_i is first determined for each chemical parameter using Eq. (3), which is then used to determine the WQI according to Eq. (4)

$$SI_i = W_i \times q_i \quad (3)$$

$$WQI = \sum SI_i \quad (4)$$

where SI_i is the sub-index of ith parameter, q_i is the rating based on the concentration of ith parameter and n is the number of parameters. Computed WQI values are usually classified into five categories (Table 2): excellent, good, poor, very poor, and unsuitable for human consumption (Sahu and Sikdar, 2008).

A map comprising the geology and geomorphology of the study area was developed using GIS software for the present study and shown in Figures 4 and 5. This indicates that the study area is mainly comprised of grey hornblende biotite gneiss and grey hornblende biotite granite. It also consists of dolorite and laterite. ArcGIS was used to plot the spatial variation of various

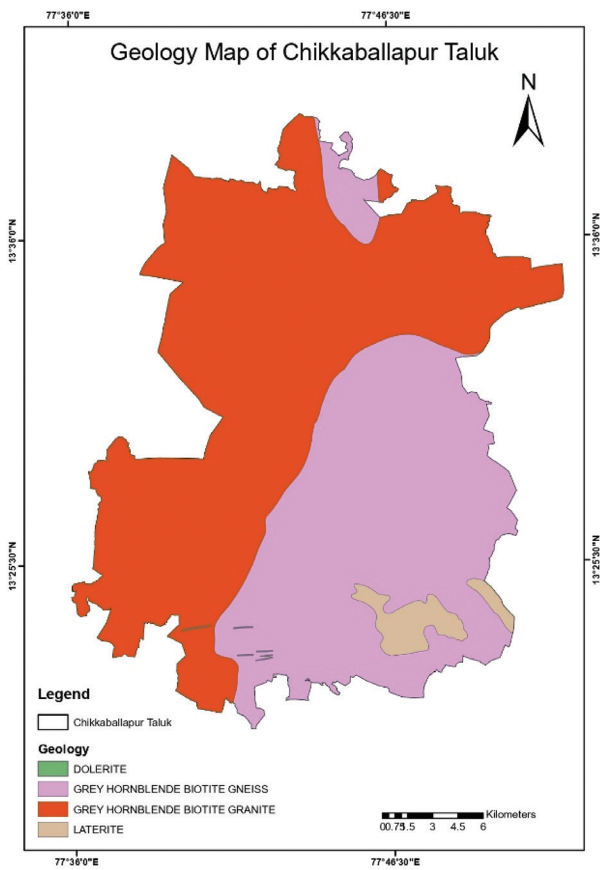

Figure 4: Geology map of the Chikkaballapura taluk.

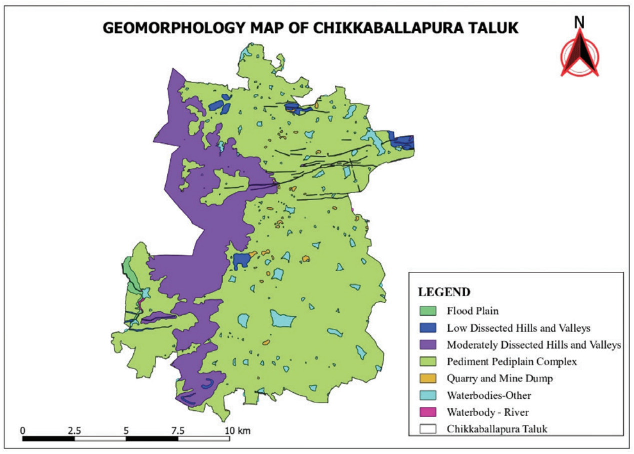

Figure 5: Geomorphology map of the Chikkaballapura taluk.

Table 2: Classification of groundwater quality according to WQI

WQI range	*Type of water*
<50	Excellent water
50–100	Good water
100–200	Poor water
200–300	Very poor water
>300	Water unsuitable for drinking purpose

geochemical parameters in the groundwater of the study area such as chloride, nitrate, and fluoride. The ground water quality data values were interpolated by kriging interpolation to have continuous data across the study area. These ground water quality rates were assigned to the corresponding study area by overlay technique.

Results and Discussions

In Chikkaballapura taluk, water quality parameters like fluoride, chloride and nitrate are the most important parameters to be studied with respect to groundwater contamination as per the literature study, so iso maps were developed to show the spatial distribution of the selected pollutants.

Chloride

The presence of chloride ions in groundwater resources can be due to a variety of factors, such as weathering, the leakage of soil sediments and minerals as well as effluent from settlements and industries into water sources (Krishna Kumar et al., 2015). As chlorides are mineral salts, their reaction with biological activity in sewage is quite minimal. Naturally, this occurs in all water sources (Kiran and Ramaraju, 2022). High chloride concentration was noticed in Aruru,

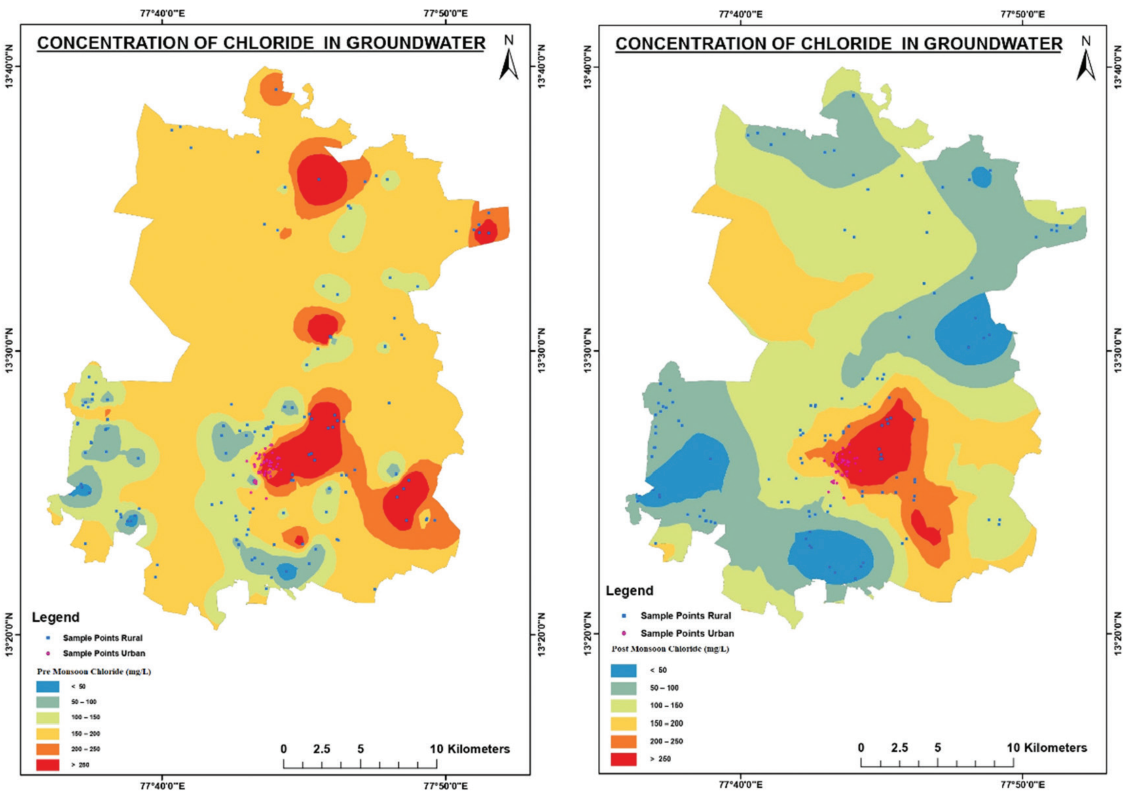

Figure 6: Isomaps of chloride.

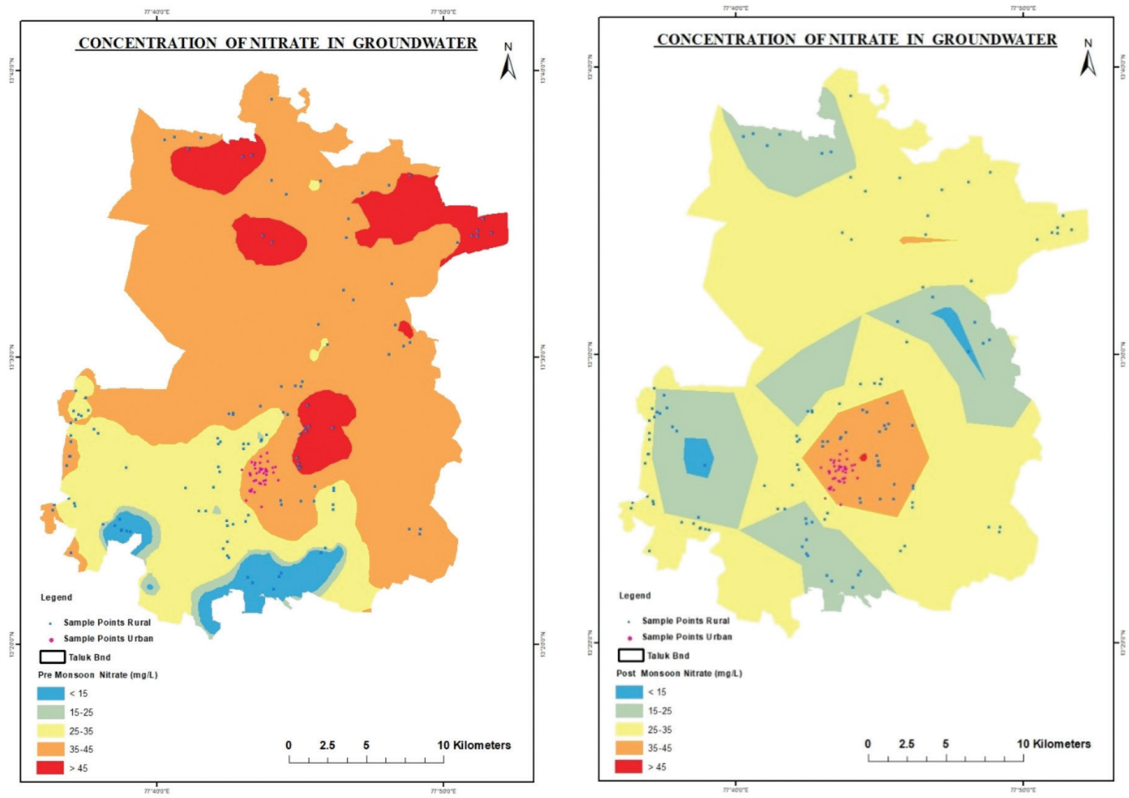

Figure 7: Isomaps of nitrates.

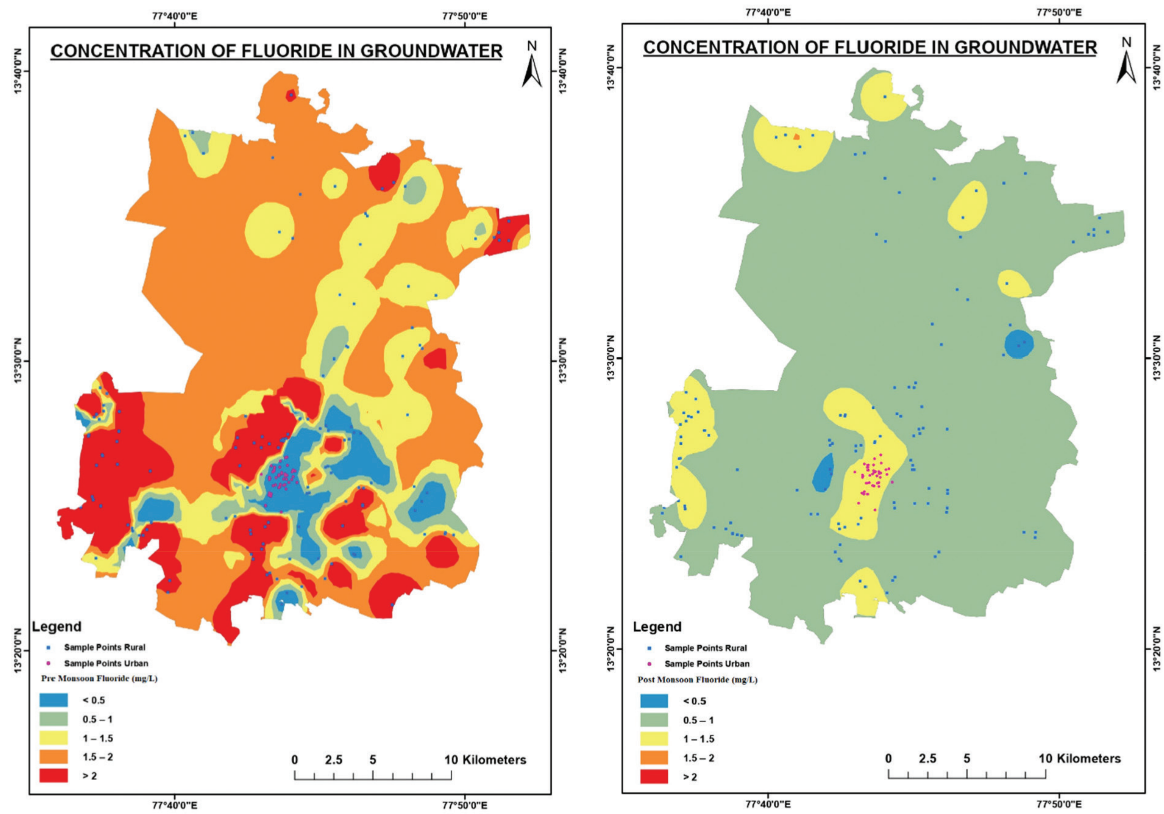

Figure 8: Isomaps of fluoride.

Manchanabele, Patrenahalli and Hosahudya GPs in CBR and 25 samples out of 45 samples showed high chloride content in CBU during pre-monsoon. Manchanabele and Ajjivara GPs in CBR and 25 samples out of 43 samples in CBU showed high chloride concentrations in post-monsoon. Iso maps of chloride, nitrate and fluoride are shown in Figures 6 to 8. The region's rocks and soil, as well as the entry of sewage from settlements and industries, can be attributed to the high level of chloride.

Nitrate

Methaemoglobinemia (blue baby syndrome), stomach cancer, thyroid disease, and diabetes are all caused by nitrate concentrations above 45 mg/l (Krishna Kumar et al., 2015). Water samples from Doddapailagurki, Addagallu, Kammaguttahalli, Aruru, Manchanabele, Patrenahalli and Avagurki GPs in CBR and 31 samples from 45 in CBU showed high values of nitrate during pre-monsoon. Post-monsoon, both in CBR and CBU, water samples had low concentrations of nitrate. The presence of nitrate in groundwater is mainly attributed to the impact of agricultural and human wastewater in the nearby area.

Fluoride

Geogenic sources are responsible for most of the fluoride in drinking water. BIS 10500:2012 indicates that fluoride levels above 1.5 mg/L in drinking water can lead to fluorosis. The results showed that almost all the samples were within the safer limits during the pre-monsoon season, apart from Manchanabele, Peresandra, Patrenahalli, Hosahudya, Angarekanahalli, and Harobande. Poshettihalli, Kammaguttahalli, Aruru and Doddamarali GPs showed high values of fluoride in CBR and 28 samples out of 43 samples were high in concentration in CBU during post-monsoon sampling.

Chikkaballapura Rural (CBR)

During pre-monsoon, the minimum mean concentration of pH was found to be 7.37 at Muddenahalli GP, while the maximum mean concentration was 8.44 at Nandi GP. Similarly, the minimum mean concentration of EC, TDS, TA, Ca, Mg, TH, Cl, NO_3, F and Fe was found to be 350 µS/cm. 227.5 mg/L, 84 mg/L, 44 mg/L, 7.2 mg/L, 140 mg/L, 49.7 mg/L, 12.6 mg/L (Doddamarali), 0.56 mg/L (Patrenahalli) and 0.06 mg/L (Manchanabele), respectively. On the other hand, maximum mean concentrations of EC, TDS, TA, Ca, Mg, TH, Cl, NO_3, F and Fe were found to be 3630 µS/cm, 1562 mg/L (Patrenahalli), 468.9 mg/L (Addagallu), 169.8 mg/L, 97.2 mg/L, 829.6 mg/L (Avagurki), 643.4 mg/L (Patrenahalli), 197.3 mg/L (Manchanabele), 3.07 mg/L (Kuppahalli) and 0.36 mg/L (Patrenahalli), respectively.

In the case of CBR during post-monsoon, the minimum mean concentration of pH was found to be 6.64 in Dibburu GP, and the maximum mean concentration of pH was 7.87 at Aruru GP. Likewise, minimum mean concentration of EC, TDS, TA, Ca, Mg, TH, Cl, NO_3, F, and Fe was found to be 230 µS/cm, 149.5 mg/L, 56 mg/L, 15.5 mg/L, 8.1 mg/L, 72.5 mg/L, 22.3 mg/L, 0.6 mg/L (Dibburu), 0.37 mg/L (Hosahudya) and 0 mg/L, respectively. Similarly, the maximum mean concentration of EC, TDS, TA, Ca, Mg, TH, Cl, NO_3, F, and Fe was found to be 2340 µS/cm, 1522 mg/L, 240 mg/L, 179.3 mg/L, 72.6 mg/L, 750.8 mg/L, 381 mg/L, 22.75 mgL (Patrenahalli), 1.51 mg/L (Kammaguttahalli) and 0.21 mg/L (Patrenahalli), respectively. In the case of sulphates, average concentrations of 17.2 mg/L and 10.6 mg/L were observed in the pre-monsoon and post-monsoon seasons, respectively.

Chikkaballapura Urban (CBU)

With respect to CBU, the average concentrations of the pH, EC, TDS, TA, Ca, Mg, TH, Cl, NO_3, F and Fe are 6.91, 1360µS/cm, 884 mg/L, 328.1 mg/L, 172.8 mg/L, 46.3 mg/L, 618 mg/L, 255.5 mg/L, 91.3 mg/L, 0.36 mg/L and 0.22 mg/L, respectively, during pre-monsoon. Similarly, the average concentrations of the pH, EC, TDS, TA, Ca, Mg, TH, Cl, NO_3, F and Fe are 7.56, 1410 µS/cm, 916.3 mg/L, 200.3 mg/L, 141.1 mg/L, 53.4 mg/L, 579.4 mg/L, 299.6 mg/L, 16 mg/L, 1.22 mg/L and 0.21 mg/L, respectively, during post-monsoon. In the case of sulphates, average concentrations of 20.3 mg/L and 20.6 mg/L were observed in the pre-monsoon and post-monsoon seasons, respectively.

Water Quality Index

In CBU, WQI ranged from 42.94 to 204.90 and the average WQI was 122.06 during the pre-monsoon season and WQI ranged from 62.67 to 153.93 and the average WQI was 108.53 during the post-monsoon season. Similarly, in CBR, WQI ranged from 47.78 to 245.98 and the average WQI was 114.05 during the pre-monsoon season and WQI ranged from 35.92 to 405.63 and the average WQI was 165.60 during the post-monsoon season. In Figures 9 and 10, the X axis indicates GP (Figure 9) and Ward numbers (Figure 10), and the Y axis indicates the average WQI in both figures. As per the WQI results of CBR, both in pre-monsoon and post monsoon, manchanabele and patrenahalli panchayats showed higher WQI values and

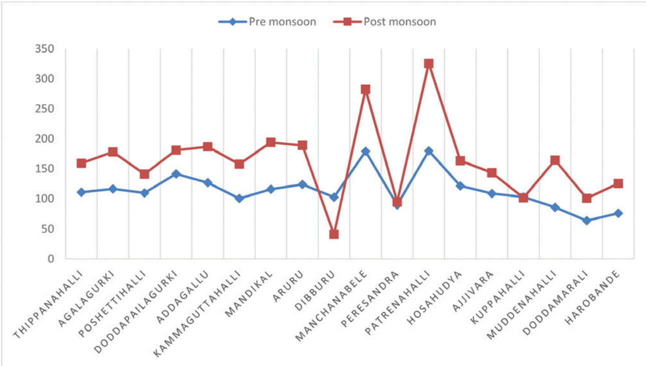

Figure 9: Comparison of mean WQI in CBR.

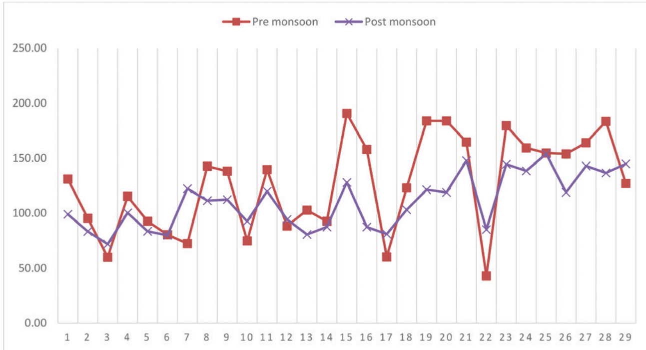

Figure 10: Comparison of WQI in CBU.

Table 3: The percentage of samples exceeded the safe limits

Parameters	*Percentage of samples exceeded the safe limits*				*Acceptable limits: BIS 10500:2012*
	CBR		*CBU*		
	Pre monsoon	*Postmonsoon*	*Pre monsoon*	*Postmonsoon*	
pH	0.7	0	6.6	0	6.5-8.5
TDS	61.3	47.6	84.4	88.4	500
TA	32.4	20.3	91.1	46.5	200
Ca	57	56.2	97.7	97.7	75
Mg	63.4	69.5	75.5	79	30
TH	83.8	86.7	100	97.7	200
Cl	15.5	13.3	55.5	58.1	250
NO_3	23.2	0	68.8	0	45
SO_4	0	0	0	0	200
F	70.4	37.5	0	65.1	1.0
Fe	4.2	0	6.6	0	0.3

most of the mean WQI values exceeded the 100 WQI range. According to the findings, groundwater pollution in rural regions is higher in the pre-monsoon than in the post-monsoon. Table 3 illustrates the percentage of samples that exceed the safe limits.

On an average, about 37.4% of the samples from CBR and 53.2% from the CBU during the pre-monsoon season and 30.1 % of the samples from CBR and 48.4 % from the CBU during post-monsoon season exceed the safe limits of drinking water. Also, it is clearly seen that all the samples were well within the standards for sulphates in both CBR and CBU.

Conclusion

In this study, an attempt has been made to investigate groundwater quality status by the combined use of the WQI and GIS. According to the results, both in CBR and CBU, most of the groundwater samples exceeded the drinking water quality limits during the pre-monsoon season when compared to post-monsoon season. An average, about 37.4% of the samples from CBR and 53.2% from the CBU during the pre-monsoon season and 30.1 % of the samples from CBR and 48.4 % from the CBU during post-monsoon season exceed the safe limits of drinking water. Very high levels of fluoride were found in Thippanahalli, Doddapailagurki, Poshettihalli, Kuppahalli, Mandikal and Ajjivara grama panchayaths and a significantly high concentration of nitrate was found in Addagallu and Manchanabele grama panchayaths during pre-monsoon season in CBR. Also, high concentrations of chlorides were seen in Manchanabele and Patrenahalli grama panchayaths during both seasons. The pH, SO_4 and Fe levels in most of the samples were within acceptable limits. As per the WQI results of CBR, both in pre-monsoon and post-monsoon seasons, manchanabele and patrenahalli panchayats showed higher WQI values and most of the mean WQI values exceeded the 100 WQI range.

In CBU, the samples from ward 30 and ward 27 show higher WQI during pre-monsoon and post-monsoon seasons respectively.

As per the quality rating scale, most samples fall under poor water. It is not recommended for drinking purposes without proper treatment. Also, a few parts of the taluk are overexploited. As a result of this, there is an urgent need to reduce groundwater pollution in CBT's urban and rural areas. In the context of the present groundwater situation, it was suggested that constant monitoring of groundwater quality in contaminated areas be carried out to prevent further deterioration and related problems and that rainwater harvesting practices be encouraged to help reduce the load on urban and rural water supply systems.

Conflict of Interest

None.

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