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ORIGINAL ARTICLE

Groundwater suitability evaluation by CCME WQI model for Kadava River Basin, Nashik, Maharashtra, India

V. M. Wagh[1] · D. B. Panaskar[1] · A. A. Muley[2] · S. V. Mukate[1]

Abstract In this study, an attempt has been made to use the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) model to classify groundwater suitability (n = 40) of Kadava river basin during pre and post monsoon season of 2012. The CCME WQI model computed for drinking and irrigation through guidelines of the Bureau of Indian Standards (BIS) and Food and Agricultural Organization (FAO). The pH, EC, TDS, TH, Calcium, Magnesium, Sodium, Potassium, Chloride, Fluoride, Sulfate and Nitrate variables were considered. The groundwater samples were classified into five categories from poor to excellent, ranges from 0 to 100. The result reveals that, the groundwater quality is poor to fair and majority of samples having marginal water quality for drinking. The groundwater quality is quite good for irrigation and it ranges from fair to good type with maximum samples fall in fair category. In the study area, the groundwater quality is considerably affected and found vulnerable in pre monsoon season due to intensive agriculture and anthropogenic activities. Spatial distribution maps of water quality index for pre and post monsoon season were prepared through GIS technique. In pre monsoon season, except Central part, many groundwater samples are found vulnerable and restricting their use for drinking. Three vulnerable hotspots are identified in North, NE and South region in post monsoon season. In pre monsoon season, Central, South and North part is affected; while, in post monsoon season, few patches in North, Central and Southern area are critical for irrigation use. In the study area, few aquifers are found to be problematic and thus limiting their use for drinking and irrigation. The CCME WQI is an effective tool to assess the groundwater quality and to communicate the health of water to multiple users. It gives precise results and water quality report in an easier way to the policy and decision makers. Finally, the study confirmed that the groundwater quality is influenced by agricultural activities and appropriate water management plan is essential to nurture precious groundwater resources in the study area.

Keywords Groundwater · CCME WQI · BIS · FAO · Kadava River · Nashik

✉ V. M. Wagh
Wagh.vasant@gmail.com

D. B. Panaskar
dbpanaskar@rediffmail.com

A. A. Muley
aniket.muley@gmail.com

S. V. Mukate
mukateshrikant@gmail.com

1 School of Earth Sciences, Swami Ramanand Teerth Marathwada University, Nanded, Maharashtra, India

2 School of Mathematical Sciences, Swami Ramanand Teerth Marathwada University, Nanded, Maharashtra, India

Introduction

Groundwater plays a vital role as a source of drinking water for millions of peoples in urban and rural areas of the world; where, surface water is considerably low and besides it used for agriculture. In many countries, drinking water quality has become critical problem due to inadequate fresh water resources; hence, water quality assessment is essential for the sustainable management. Groundwater has an immense importance in drinking due to its consistent temperature, natural quality, widespread availability and low vulnerability as compared to fresh water (Todd and Mays 2005).

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Generally, groundwater quality depends on the amount of precipitation; recharge quality of water, rock water interaction, and residence time of water. The hydro-geochemical processes viz., dissolution, mineralization, weathering of rocks, leaching of salts and ion exchange may influence water quality (Todd 1980; Stallard and Edmond 1983; Tóth 1999). The anthropogenic inputs like intensive agriculture, industrialization and urbanization may influence the water quality (Wagh et al. 2016; Panaskar et al. 2016; Mukate et al. 2015).

Nowadays, to safeguard water resources, it is an important to develop a comprehensive groundwater quality monitoring program at local to global scale. The monitored data help the planners to develop various remediation strategies at their respective regions. In general, when large number of samples and parameters are monitored then it turns out to be difficult to evaluate and represent water quality as single unit (Chapmen 1992; Pesce and Wunderlin 2000, Sanchez et al. 2007; Bordalo et al. 2006; Vasant et al. 2016).

The WQI is a mathematical tool which provides a single digit for the large quantities of water quality data in a broad manner. It has been considered as one of the mathematical model for drinking water classification based on different water quality parameters. The WQI method was initially proposed by Horton (1965) which produces single dimensionless number to represent the quality of water. The National Sanitation Foundation (NSF) developed general WQI (NSFWQI) to provide standardized method to evaluate the water quality based on physicochemical parameters (Brown et al. 1970). However till 1970, more than 20 water quality indices were reviewed worldwide (Ott 1978; Steinhart et al. 1981). In India pioneer work on WQI was done by Bhargava (1983).

The Canadian Council of Ministers of the Environment has developed a Water quality index based on British Columbia Ministry of Environment, Lands and Park and modified by Alberta Environment to simplify the water quality data (Rocchini and Swain 1995; CCME 2001). It is a scientific tool which is used to process multi-variable water quality data against specified water quality standards determined by the users for specified region over time. This index can be used to track changes among different sites with same variables and objectives; otherwise the comparison must be made in terms of category obtained. The index can provide a broad overview of water quality that can be conveyed to the public in an easy to understand format. This index has ability to represent measurements of a variety of variables in a single number and the ability to combine various measurements with a variety of measurement units in a single metric (CCME 2001). The CCME WQI is not used to replace the detailed analysis of variables; nevertheless it can be used as tool to communicate overall quality of water in a more reliable and consistent way. It is a tool that tests multi-variable water quality data against specified water quality benchmarks determined by the user. The index is mainly based on number of input variables, size of the dataset and objectives/standards applied (CCME 2001). It combines three measures of variance (i.e. scope, frequency and Amplitude) to generate a single dimensionless number that represents water quality relative to the objectives. The results range from 0 to 100, where a score of 100 indicates Excellent and 0 as a poor quality of water that is easy to understand to the public (CCME 2001). These index values expressed as classification and represented subjective progression. Assessment of the quality variable by variable and objective wise is quite a difficult task (Rosmand et al. 2009). This tool simplifies the reporting of water quality data and helpful to technical and nontechnical individuals (Khan 2004). Many researchers have been applied the CCME WQI to report the status of watersheds for drinking, recreational, agricultural and protection of aquatic life in their respective regions (Khan et al. 2003, 2004, 2005; Glozier et al. 2004; Lumb et al. 2006).

In case of Kadava river basin, limited studies are available on water quality and its suitability. The aim of the present study is to evaluate and classify groundwater suitability for drinking and irrigation based on CCME WQI model. The BIS (2012) and FAO (1985) standards were considered as guidelines or objectives and different sets of variables (physicochemical parameters) of pre and post monsoon season. The Spatio-temporal maps for drinking and irrigation were prepared to illustrate the water quality index of the study area.

The study area

The Kadava River is tributary of Godavari and it originates in Sahyadri hills of Dindori tehsil. The river flows through NW to SE direction and meet Godavari at Nandur-Madhmeshwar dam in Niphad tehsil. The study area lies between latitude 19,055′ to 20,025′N and longitude 73,055′ to 74,015′E with geographical area 1053 km^2 in Nashik district, Maharashtra (Fig. 1). The SW monsoon contributes 80% rainfall during month of June to September (average 700 mm). The study area fall in semi arid climate with temperature ranges from 5 to 400C in winter and summer seasons (CGWB 2014). The geological formation of the study area includes 'Pahoehoe' and 'Aa' lava flows of Basalt from Cretaceous to Eocene age (GSI 2001). Groundwater generally occurs at unconfined to confined condition at 20–25 m ground level. In the study area major portion of alluvium is encountered in Niphad tehsil. The study area is primarily irrigated through groundwater, river and canal water. Groundwater demand has increased over the couple
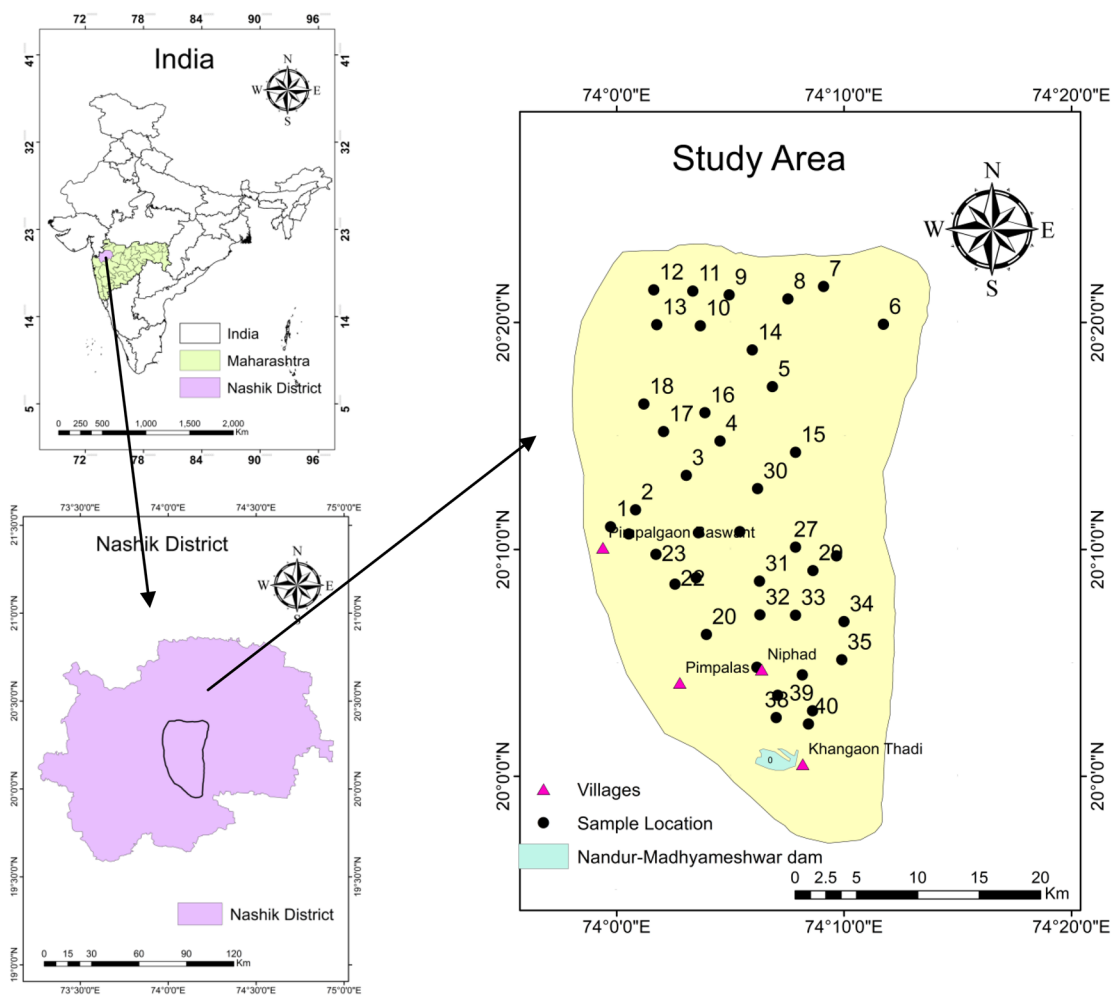
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Fig. 1 Study area map with sample locations

of years due to the population and agricultural expansion in this region. The groundwater quality of study area is primarily deteriorated due to excessive use of chemical fertilizers, pesticides, insecticides, poor sewage management, over irrigation and cropping pattern. Most frequently cultivating crops throughout the year are Grapes, Sugarcane, Onion, seasonal vegetables etc. due to abundant water, fertile soil and climate.

Materials and methods

In the present study, forty (40) representative groundwater samples were collected from different dug/bore wells on the basis of geographical variation during pre and post monsoon season of 2012. Groundwater samples collected in pre-treated plastic cans (1 lit) for avoiding any risk of contamination and labelled properly. Further, samples were transported to analytical lab for physicochemical

analysis followed by standard methods of American Public Health Association (APHA 2005). The methodology includes analytical procedures/ software/ instruments adopted to carry out this work are tabulated in Table 1. The variables chosen were ones that were routinely measured at all sites and had a numeric water quality guidelines for drinking and irrigation of BIS and FAO standards respectively.

Results and discussions

The descriptive statistics of the analyzed physicochemical parameters of pre and post monsoon season 2012 is provided in Table 2. The BIS and FAO standards selected as objectives for computing CCME WQI for drinking and irrigation suitability (Table 3).

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Table 1 Analytical procedures adopted for analysis

Parameters	Methodology
Base map preparation	Survey of India (SOI) toposheet nos 46 L/3, L/4,H/15 and H/16 on 1,50,000 scale
Geo-coordinates	GPS (Explorist 500)
pH and EC	Multi-parameter PCS tester 35
Calcium (Ca) Magnesium (Mg)	Titrimetric method
Sodium (Na) Potassium (K)	Flame Photometer (Elico CL365)
Chloride (Cl) Bicarbonate (HCO_3) Carbonate (CO_3)	Titrimetric method
Nitrate (NO_3) Sulphate (SO_4)	Spectrophotometer (Shimadzu UV-1800)
Ion balance error ($\pm 5\%$)	AquaChem 5.1v software
Statistical analysis	MS-Excel and R software
CCME WQI calculation	Drinking and irrigation standards of BIS (2012) and FAO (1985)
CCME WQI map preparation	Inverse Distance Weighted (IDW) interpolation technique used to prepared spatial variation map of water quality

Table 2 Descriptive statistics of pre and post monsoon season of 2012

Parameters	Pre monsoon 2012		Post monsoon 2012	
	Range	Average	Range	Average
pH	7.8–9	8.5	7.71–8.53	8.1
EC	810–6180	2173.53	824–8120	2741.38
TDS	356.82–2272.96	739.7	494.24–2101.58	861.17
TH	131.95–1028.92	392.43	196.85–1150.19	508.72
Ca	13.63–98.07	39.78	21.04–118.34	50.94
Mg	20.95–231.03	71.48	17.35–255.86	93.06
Na	36.2–501.4	111.2	31–449.4	113.88
K	0.3–8.3	2.49	0.5–14.4	2.52
Cl	31.24–1085.8	210.4	63.3–829.94	229.66
F	0.1–0.7	0.35	0.1–1	0.38
CO_3	0–140	44	0–70	35.25
HCO_3	20–250	99	30–300	121.25
SO_4	31.54–261.41	111.9	49.71–359.95	175.12
NO_3	12.94–69.76	49.09	31.62–65.22	52.62

All major ions and TDS are expressed in mg/L while pH on scale and EC in µS/cm

Table 3 Standards used for drinking and irrigation suitability

Parameters	Desirable-permissible (BIS 2012)	Irrigation (FAO 1985)
pH	6.5–8.5	6.0–8.5
EC	–	1000
Ca	75–200	400
Mg	30–100	60
Na	200	920
K	12	2
Cl	250–1000	1065
SO_4	200–400	1920
NO_3	45	45
F	1–1.5	1.5
TH	300–600	712
TDS	500–2000	–
CO_3	–	60
HCO_3	–	610

All major ions and TDS are expressed in mg/L while pH on scale and EC in µS/cm

Conceptual framework of CCME WQI model

The general steps involved in the computation of CCME WQI model are summarized as follows (CCME 2001):

- Choosing variables (Physicochemical parameters).
- Selecting guidelines/objectives (As per BIS and FAO standards).
- Calculation of index scores.

The Eleven parameters scenario is used for calculating CCME WQI value and their classes. The variables for drinking and irrigation suitability are pH, EC, TDS, TH, Calcium, Magnesium, Sodium, Potassium, Chlorides, Fluorides, Sulfates and Nitrate and objectives were considered from BIS (2012) and FAO standards (1985).

This index is based on three factors such as Scope (F_1), Frequency (F_2) and Amplitude (F_3).

F_1 (Scope) represents the percentage of variables that do not meet their objectives at least during the time period under consideration (failed variables):

$$F_1 = \left[\frac{\text{Number of failed variables}}{\text{Total number of variables}} \right] \times 100 \qquad (1)$$

F_2 (frequency) represents the percentage of individual tests that do not meet objectives (failed tests):

$$F_2 = \left[\frac{\text{Number of failed tests}}{\text{Total number of tests}} \right] \times 100 \qquad (2)$$

F_3 (amplitude) represents the amount by which failed test values do not meet their objectives. It is calculated in three steps:

a. The number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective is termed an "excursion" and is expressed as follows

When the test value must not exceed the objective:

$$excursion_i = \left[\frac{Failed\ test\ value}{Objective_j} \right] - 1 \qquad (3)$$

For the cases in which the test value must not fall below the objective:

$$excursion_i = \left[\frac{Objective_j}{Failed\ test\ value} \right] - 1 \qquad (4)$$

b. The collective amount by which individual tests are out of compliance is calculated as:

$$nse = \frac{\sum_{i=1}^{n} excursion_i}{\#\ of\ tests} \qquad (5)$$

nse is referred to as the normalized sum of excursions.

c. F_3 is calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a range between 0 and 100.

$$F_3 = \left[\frac{nse}{0.01 nse + 0.01} \right] \qquad (6)$$

The CCME WQI is calculated as:

$$CCME\ WQI = 100 - \left[\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right] \qquad (7)$$

The divisor 1.732 normalizes the resultant values to a range 0–100.

Where, 0 represents the worst and 100 represent best water quality.

The first step is an iterative process and subject to available information then, CCME WQI value has been determined and water quality is ranked by relating it to one of the following five categories (Table 4). Figure 2a, b explores the line diagram about sample wise CCME WQI values in pre and post monsoon season. The index values ranges from 27 to 76 and 57 to 92 for drinking and irrigation in pre monsoon. While, in post monsoon season the index varies from 40 to 74 and 91 to 84 for drinking and irrigation. This clearly shows that the index value increases in post monsoon season as compared to pre monsoon season this may be due to the monsoonal rainfall.

In the present study, 40 representative groundwater samples were analyzed for 13 physicochemical parameters during pre and post monsoon season of 2012. The CCME has calculated based on Microsoft Excel frame. The macro Excel is quite flexible for calculating indices based on large number of dataset and water quality parameters. The choice of variables depends on availability of data, it can be easily manipulated. The output is available in the form of table describing the values of F_1, F_2, F_3 and the CCME WQI score is represented in frequency plot (Fig. 3).

Table 4 Water quality classification based on CCME WQI (2001)

Sr. no.	Category	Range	Significance
1	Excellent	95–100	It is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels
2	Good	80–94	It is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels
3	Fair	65–79	It is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels
4	Marginal	45–64	It is frequently threatened or impaired; conditions often depart from natural or desirable levels
5	Poor	0–44	It is almost always threatened or impaired; conditions usually depart from natural or desirable levels

Figure 3 and Table 4 shows that the groundwater quality is poor for drinking and marginal for irrigation in pre and post monsoon season 2012. It shows that the most of the variables were exceeded the drinking and irrigation standards of the BIS and FAO. Figure 3 confirms that the percentage of number of failed variables to the total number of variables is 91 and 100% for drinking and 60 and 50% for irrigation in pre and post monsoon season. The percentage of number of failed test to the total number of

tests is 53 and 44% for drinking and 30% for irrigation in both the seasons. The amplitude values do not meet their objectives are 41 and 29 for drinking and 18 and 23 for irrigation in pre and post monsoon season.

It is found that, the groundwater samples taken are statistically suitable intervals deviates from the relevant variable values. Hence CCME WQI falls in poor category for drinking while marginal for irrigation.
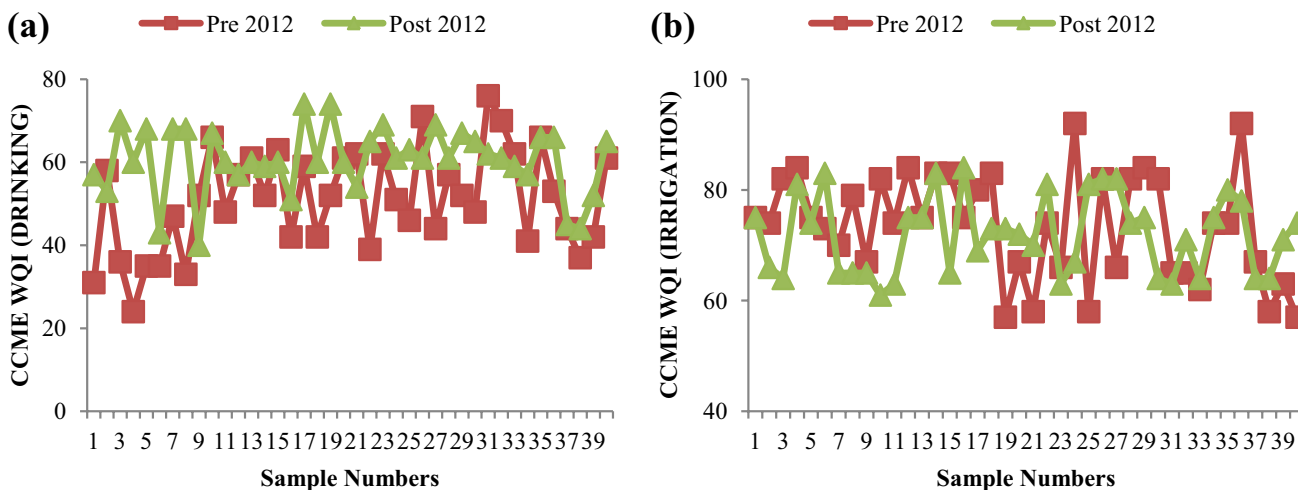

Fig. 2 **a** CCME WQI for Drinking (n = 40). **b** CCME WQI for Irrigation (n = 40)

Fig. 3 Calculated values of CCME WQI, F_1, F_2 and F_3 for drinking and irrigation purpose
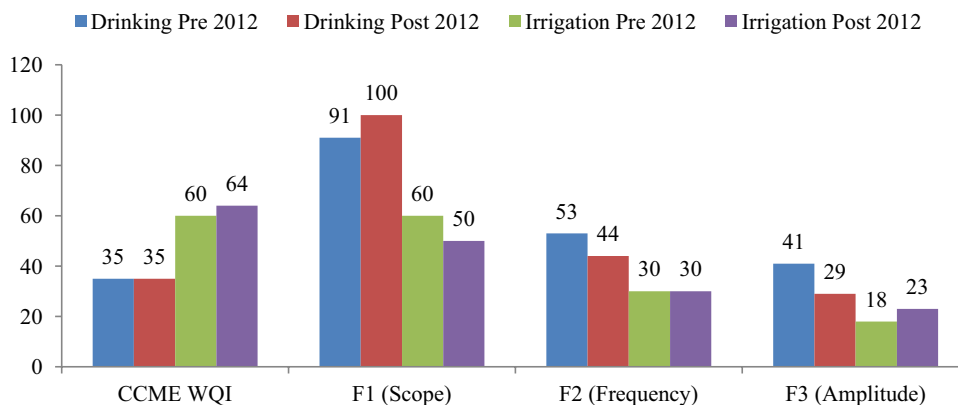

Table 5 Classification of groundwater samples for drinking based on CCME WQI classification

Classes/duration	Sample numbers in pre monsoon 2012	% Of samples	Sample numbers in post monsoon 2012	% Of samples
Poor (0–44)	1,3,4,5,6,8,16,18,22, 27,34, 37,38,39	35.0	6,9,38	7.5
Marginal (45–64)	2,7,9,11,12,13,14,15,17,19,20,21,23,24,2 5,28,29,30,33,36,40	52.5	1,2,4,11,12,13,14,15,16,18,20,21,24,25,26, 28,31,32,33,34,37,39	55.0
Fair (65–79)	10,26, 31,32,35	12.5	3,5,7,8,10,17,19,22,23,27,29,30,35,36,40	37.5
Good (80–94)	–	–	–	–
Excellent (95–100)	–	–	–	–

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Table 6 Classification of groundwater samples for irrigation based on CCME WQI classification

Classes/duration	Sample numbers in pre monsoon 2012	% Of samples	Sample numbers in post monsoon 2012	% Of samples
Poor (0–44)	–	–	–	–
Marginal(45–64)	19,21,25,33,38,39,40	17.5	3,10,11,23,30,31,33,37,38	22.5
Fair (65–79)	1,2,5,6,7,8,9,11,13,16,20, 22,23,27,31,32,34,35,37	47.5	1,2,5,7,8,9,12,13,15,17,18,19, 20,21,24,28,29,32,34,36,39,40	55.0
Good (80–94)	3,4,10,12,14,15,17,18,24, 26,28,29,30,36	35.0	4,6,14,16,22,25,26,27,35	22.5
Excellent (95–100)	–	–	–	–

The CCME WQI quality rating is divided into five classes (Table 4) and the classification of groundwater samples for drinking and irrigation is illustrated in Tables 5 and 6.

Table 5 reveals that, 35 and 7.5% of the samples falls in poor category in pre and post monsoon season; whereas, 52.5 and 55% of the samples lies in marginal category. In pre and post monsoon season 12.5 and 37.5% samples belongs to fair category. It is observed that the water quality is poor to marginal type in pre monsoon season due to the high evaporation and dissolution of minerals. Table 6 depicts that, the 17.5 and 22.5% samples fall in marginal category, while 47.5 and 55.0% comes under fair category. The remaining 35.0 and 22.5% groundwater samples belong to the good category for irrigation. Majority of the samples from pre and post monsoon season belong to good to fair category.

In the study area, GIS-based interpolation technique (IDW) is used to represent the spatial distribution of water quality. The maps visualize and classify the water quality of each location and signify its suitability. The maps are also helpful to identify the good, marginal and vulnerable sites for better management of water resources. The spatial maps of water quality will help to local planners to assess the groundwater quality for drinking and irrigation. It also assists for the identification of suitable/vulnerable sites for extraction of groundwater and remediation strategies. The Fig. 4a, b are representing the groundwater quality is significantly affected in pre monsoon season due to intensive agriculture and anthropogenic inputs. In the study area, except Central part, many of the groundwater samples are vulnerable and proved their restricted use for drinking. In post monsoon season three hotspots are identified in North, NE and South region, where, groundwater quality is adversely affected. In post monsoon season groundwater quality is improved (except sample numbers 9, 6, 17, 19, 37, 38) due to processes like dilution, percolation, etc. In pre monsoon season, the groundwater quality in Central, South and North part is affected; while, in post monsoon season, few patches in North, Central and Southern area are vulnerable for irrigation use (Fig. 4c, d). The groundwater quality may be improved in affected areas by implementing various remediation techniques like rainwater harvesting, percolation ponds, crop rotation, precise applications of fertilizers/pesticides, etc.

Conclusions

The present study evaluated the groundwater quality for drinking and irrigation suitability by calculating the CCME WQI. The Canadian WQI approach is used for development of site-specific objectives was chosen because of the limited amount of water quality data for each site. The 11 physicochemical parameters were considered because these parameters define the ionic constituents present in water required for drinking and irrigation. The index scheme has been used to meet requirements of classification of groundwater according to BIS and FAO standards. The study confirms that, groundwater quality is poor to fair and majority of the samples fall in marginal category for drinking in both the season. From the irrigation point of view quality fair to good type however, 47 and 55% samples are fair for irrigation in pre and post monsoon season. The groundwater quality is significantly affected and found vulnerable in pre monsoon season due to intensive agriculture and anthropogenic inputs. Spatial distribution map for drinking represents that three hotspots in North, NE and South region are identified during post monsoon season whereas, groundwater quality is seems to be affected in Central, South and North part in pre monsoon season. Irrigation suitability maps confirm that, the Central and Southern part, however in post monsoon season, few patches in North, Central and Southern area are found vulnerable for irrigation use. In the study area, agriculture activities impose strong pressure, both upon the quality and quantity on the available water resources. The study investigated that, index methods are effective in deriving the information from complex water quality data sets. This study showed that the CCME WQI with categorization may assist local planners to integrate and interpret the picture of drinking and irrigation suitability. The findings of the study may helpful to local inhabitants for better management of water resources.
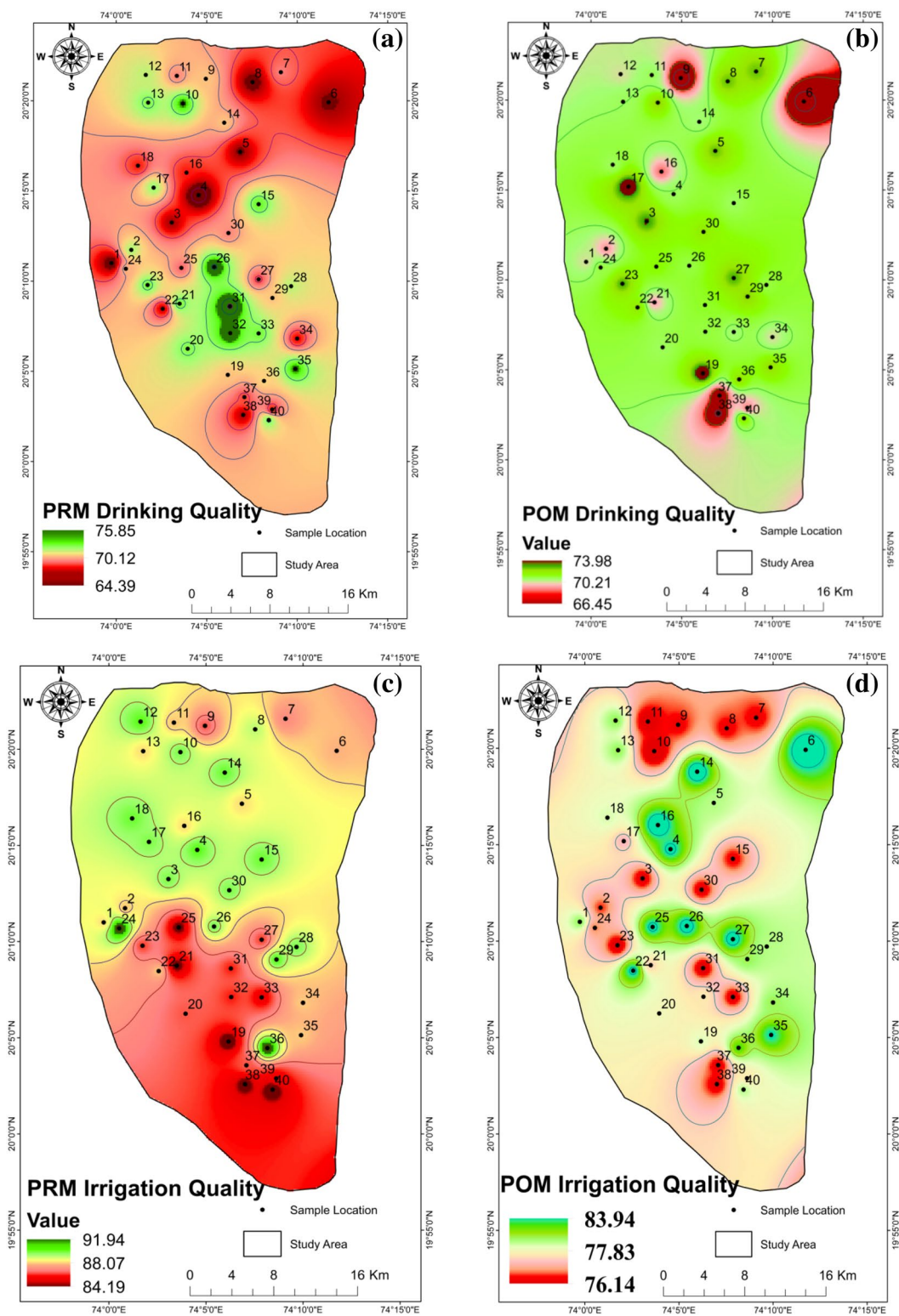
Fig. 4 **a, b** Pre and post monsoon CCME WQI for Drinking. **c, d** Pre and Post Monsoon CCME WQI for Irrigation

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