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Study of groundwater hydrochemistry and drinking appropriateness using Water Quality Index (WQI) modelling in the Jam river basin, India

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ABSTRACT

The goal of the current study is to use Water Quality Index (WQI) modelling approach to understand the hydro-chemistry of groundwater and its suitability for drinking in the Jam river basin. Sixty samples from dug and bore wells were collected and examined for the 2020 pre and post monsoon seasons by following APHA protocols. In line with BIS, the values of pH, Ca, Mg, Na, Cl, NO_3, PO_4, TH, and TDS exceeded the threshold levels in both seasons. It is observed that TDS level exceeded the desired limit (500 mg/l) in the pre- (75%) and post-monsoon (71.66%) seasons. Additionally, the allowed nitrate levels exceeded in 11.66% (pre-monsoon) and 21.66% (post-monsoon) of the groundwater samples than the limit of the BIS (45 mg/l). The permissible limit (100 mg/l) is surpassed in samples with magnesium contents of 61.66% and 26.66% during the pre- and post-monsoon seasons. The permissible limit (600 mg/l) was exceeded by the TH content in 71.66% and 15% of the samples during the pre- and post-monsoon seasons, respectively. In terms of phosphate content, 33.33% and 11.66% of the samples were above the allowable limit (1 mg/l). According to WQI data, 13.33% samples have excellent water quality during post monsoon. 65 and 68.33% of samples have good water quality, 30 and 16.66% have poor water quality, and 5 and 1.66% of samples have very poor water quality during the pre- and post-monsoon seasons. The majority of the groundwater's chemical problems are attributable to manmade activities. Groundwater quality is predominantly affected in the north east of the study area, according to a spatial variation map of WQI.

Key words: *Groundwater quality, Jam river basin, Hydro chemistry, Drinking suitability*

Introduction

India is the second largest populous country where people depend on groundwater for domestic activities. Due to its natural occurrence and decreased susceptibility to water contamination compared to surface water, groundwater is one of the most dependable and important sources of drinking (Wagh *et al*., 2016 a; Paul *et al*., 2019). Groundwater quality is often influenced by natural processes such as precipitation, rock-water interaction, salt dissolution, residence duration, and mineralization (Mukate *et al*., 2019). Groundwater quality in India has declined as a result of over exploitation without balanced recharge and the percolation of excessive amounts of various fertilizers and agrochemicals into the aquatic environment (Wagh *et al.*, 2016 b; Nalawade *et al*., 2012). In order to maintain the water quality in its natural form in arid and semi-arid locations, it is crucial to understand groundwater quality. WQI is used to measure the combined influence of physico-chemical parameters on the whole quality of water for drinking (Mitra *et al*., 2006; Cong *et al*., 2019). Horton created the Water Quality Index by taking the significant physicochemical characteristics into account, ranking them and integrating them (Horton, 1965).

Since groundwater provides the majority of the Jam riverbasin's demands for drinking, domestic use, and agriculture. However, CGWB studies and individual reports have indicated that dissolved salts and nitrate contamination of groundwater affect the suitability and quality of the groundwater (Wagh*et al*., 2018; CGWB, 2014). The material now in print indicates that there has not been any scientific oversight of groundwater quality study in the Jam river basin. Thus, it is essential to continuously monitor water quality to avoid issues with groundwater contamination that endanger human health. The current study's objectives were to (1) use the WQI model to assess the hydro-chemistry and appropriateness of the groundwater in the Jam riverbasin, and (2) pinpoint the variables that influence the local hydro-chemistry.

Study area

The Jam river joins the Godavari river in Kopargaon in the Ahemednagar district. The Godavari river originates from Mhasha hill in Sinnar tehsil of Nashik district. It originates in the eastern portion of Sinnar tehsil and runs 52.2 kilometres until it reaches Kopargaon tehsil in the southwest of the Ahmednagar district of Maharashtra. A total of 636.67 square kilometres make up the basin. The research region is located between $74^{0}6'28''$ and $74^{0}25'56''$E longitudes and $19^{0}44'27''$ to $19^{0}52'18''$N latitudes in the Deccan plateau, an eastern extension of the Kalsubai range (Fig.1). The study region has a semiarid climate and receives of annual rainfall on average from the south-west monsoonal winds that blow from June to September (Sinnar: 568.6 mm, Sangamner: 510.57 mm, and Kopargaon: 483.9 mm). Many villages from Sinnar, Sangamner and kopargaon tehsil are beneficial for drinking and irrigation from this river. Jam river has been crossed by a number of dams and weirs. Some villages from Sinnar and Kopargaon tehsil have been brought under intensive cultivation with sugarcane as a single dominant crop as a result of the construction of the Nandur Madhemeshwar right canal. The study region is well renowned for its agricultural output of seasonal vegetables, soyabean, wheat, sugarcane, onions, and other crops, all of which are grown using a variety of crop patterns along the river's water courses. Therefore, it is crucial for this region in particular to monitor the quality of the groundwater and if it is suitable for drinking and irrigation. In the current study, all potential means of river basin groundwater contamination and scarcity are investigated, and its acceptability for human consumption is determined using Water Quality Index (WQI) modelling.

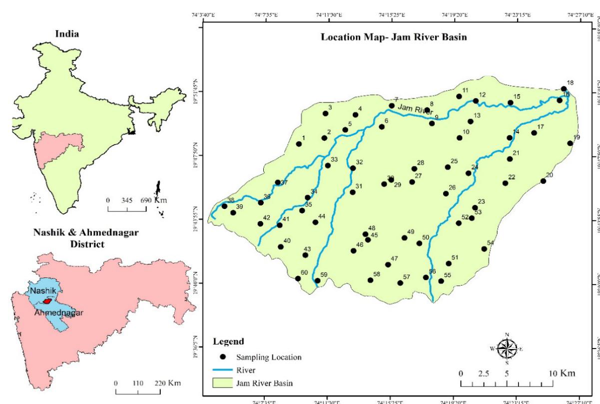


Fig. 1. Study area map with sampling sites

Materials and Methods

In the present study sixty (60) representative ground water samples were collected from different dug/ bore wells on the basis of geographical variation during pre and post monsoon season of 2020. Groundwater samples were 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). pH, EC and TDS were measured at the field by multi parameter tester. Major cations and anions were measured in laboratory. The methodology includes analytical procedures/ software/ instruments adopted to carry out this work are tabulated in Table 1. The variables chosen were routinely measured at all sites and had a numeric water quality guidelines for drinking of BIS (2012) standards. The ion balance error are within (±5%) which confirms analytical accuracy (Table 1).

Conceptualization of Water Quality Index (WQI)

WQI is a tool used to assess the overall impact of several physico-chemical characteristics on the quality of drinking water (Mitra *et al*., 2006; Bhalla and Waykar, 2012; Wagh *et al*., 2017 a;Vasant *et al*., 2019). Based on the results of pH, EC, Cl, F, NO_3, SO_4, HCO_3, Na, K, TDS, TH, Ca and Mg, the WQI provides a single numerical value to evaluate the quality of water. For the determination of the WQI index, the Bureau of Indian Standards (BIS 2012) for drinking was taken into account. Each individual parameter was given a weight based on the estimated risk to the quality of the water. According to their significance in drinking and potential harm to human health, the weights were assigned on a scale of 1 to 5 (Vasant *et al*., 2016; Wagh *et al*., 2017b; Vasant *et al*., 2019). Due of their critical role in the suitability of drinking, TDS, Cl, NO_3, and F were each given the maximum weight of 5. Mg, K, Ca, and HCO_3 were given the lowest weight of 2, while the other parameters (pH, Na, SO_4, TH, and EC) were given the maximum weight of 3. Table 2 displays the relative weights (RW*i*) of each parameter determined using the equation below. The WQI of the groundwater in the Jam riverbasin has been examined using the aforementioned techniques, and results are displayed in Table 4. Excellent (WQI 0-50), good (WQI 50-100), poor (WQI 100-200), extremely poor (WQI 200-300), and unfit for drinking (WQI >300) are the five WQI classifications.

$$RW_i = Aw_i / \Sigma Aw_i \quad .. (1)$$

Where, RW*i* is the relative weight, and Aw*i* is the assigned weight of the *i*th parameter

The following equation is used to compute the quality rating scale.

$$q_i = (c_i/s_i) \times 100 \quad .. (2)$$

where qi is quality rating, *ci* is content of chemical parameter (*i*th) and*si* is permissible standard (BIS 2012). Sub index is calculated by equation 3

$$Sl_i = Rw_i \, X q_i \quad .. (3)$$

$$WQI = \Sigma \, Sl_i. \quad .. (4)$$

Results and Discussion

The hydro-chemical results are divided into three groups: pH, EC, and TDS in Group I; cations in Group II; and anions in Group III; Table 3 shows a statistical overview of each group. The interpretation of the WQI data and their spatial variability is also included.

Group 1: pH, EC and TDS

pH can change water tastes and show relationships with some other indicators of water quality (Wagh *et al*., 2017 a; Deshmukh, 2012). In the pre- and post-monsoon seasons, the pH value ranged from 7.1 to 8.5 and 7.1 to 8.2 with an average of 7.90 and 7.61 respectively, indicating an alkaline nature; the elevated pH values are attributable to the weathered basalt. The spatial variation maps of pH demonstrated that the samples located at west direction have pH value is increased in both the season (Fig. 2a, b).

Table 1. Materials and methods adopted for analysis

Parameters	Materials and methods
Base map preparation	Survey of India toposheet 47 I/1, 47 I/2, 47 I/5 and 47 I/6 on 1:50000 scale
Geo-coordinates	GPS (Garmin eTrex)
pH and EC	Multi-parameter tester
Cations	
Ca and Mg	Titrimetric method
Na and K	Flame Photometer (Elico CL361)
Anions	
NO_3, F, SO_4 and PO_4	Spectrophotometer (Shimadzu UV-1800)
Cl and HCO_3	Titrimetric method
TDS	Multi-parameter tester
Spatial distribution maps	Arc GIS 10.8 v(IDW technique)
WQI analysis	MS-Excel
Ion balance error (IBE)	Σ cations + Σ anions

Table 2. Weightage assigned to each parameter and their relative weights

Parameters	Assigned weight (Aw)	Relative weight (Rw)	BIS 2012
pH	3	0.059	8.5
EC	3	0.059	00
TH	3	0.059	600
Ca^{2+}	2	0.039	200
Na^{+}	3	0.059	200
Mg^{2+}	2	0.039	100
K^{+}	2	0.039	12
TA	2	0.039	100
CO_3^{-}	2	0.039	16
HCO_3^{-}	2	0.039	00
Cl^{-}	5	0.098	1000
F^{-}	5	0.098	1.5
NO_3^{-}	5	0.098	45
SO_4^{2-}	3	0.059	400
PO_4^{2-}	4	0.078	1
TDS	5	0.098	2000
SUM	51	1	

The significance of water's conductivity is that it rises with temperature and TDS (Wagh *et al.*, 2017 b). In pre- and post-monsoon seasons, EC ranges from 108 to 6710 µS/cm (avg. 1763.82 µS/cm) and 109 to 7170 µS/cm (avg. 1586.82 µS/cm). Increased EC is shown on the spatial variation maps of samples from the north-eastern regions. (Fig. 2c, d). The TDS is a crucial parameter for determining whether water is suitable for irrigation and drinking. The range of TDS values in the pre- and post-monsoon seasons was 97-3820 mg/l and 76-4188 mg/l, respectively, with average values of 1054 and 949 mg/l (Table 3). It has been shown that the ideal limit was surpassed by 75% in the premonsoon and 71.66% in the post monsoon seasons, and the permitted limit was exceeded by 13.33% and 10% of the samples (Table 3). Such high TDS in groundwater was caused by anthropogenic sources, prolonged residence period, and rock degradation (Wagh *et al.*, 2017 b).

Group II: Cations (**Ca^{2+}, Mg^{2+}, TH, Na^{+}, K^{+}**)

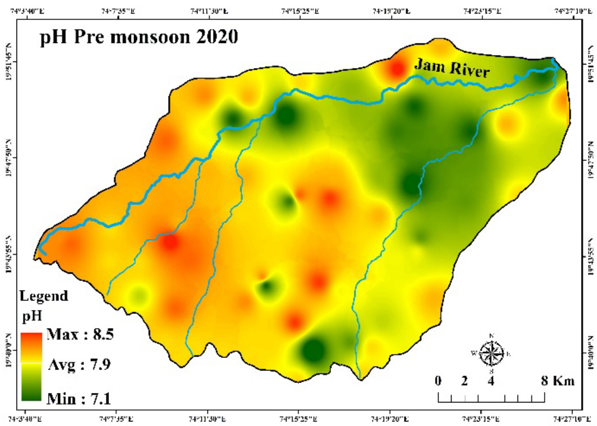
During the pre- and post-monsoon seasons, calcium ranges from 60.52-561.12 mg/l (on average 236.24 mg/l) and 48.09-370.1 mg/l (on average 131.12 mg/l), respectively (Table 3). 56.66% and 10 % of the samples are above the allowable limit. Magnesium concentrations range from 7.89 to 350.4 mg/l and from 4.86 to 331.69 mg/l. Pi-critic fluxes, which contribute to the elevated magnesium in the post-monsoon, are reduced in the summer when the rain stops (Wagh *et al.*, 2018). The spatio-temporal maps of magnesium showed that the research area's north-eastern and southern sections have large concentrations of the element. In the months before and after monsoons, the magnesium hot spots are found in densely populated agricultural areas (Fig. 2e, f).

Table 3. Descriptive statistics of groundwater samples in pre and post-monsoon seasons of 2020 (n=60)

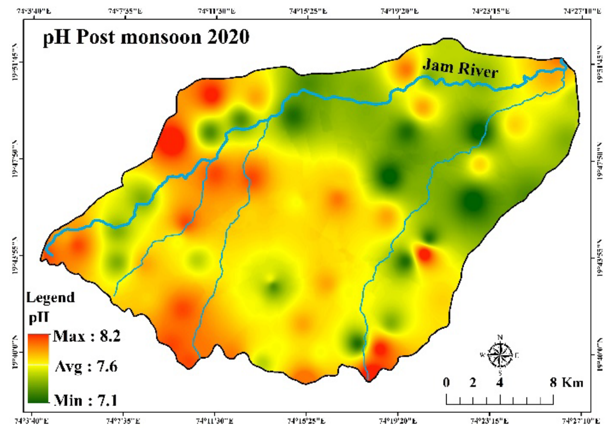
Parameters	(DL-PL)	Average		Range		% of samples above DL		% of samples above PL	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post
pH	6.5-8.5	7.90	7.61	7.1-8.5	7.1-8.2	100	100	1.66	0.00
EC	0	1763.82	1586.82	108-6710	109-7170	0.00	0.00	0.00	0.00
TH	300-600	781.87	492.87	320-2120	120-2110	100	63.33	71.66	15
Ca^{2+}	75-200	236.24	131.12	60.52-561.12	48.09-370.1	96.66	73.33	56.66	10
TDS	500-2000	1054.81	949.5	97-3820	76-4188	75	71.66	13.33	10
Mg^{2+}	30-100	138.39	92.96	7.89-350.4	4.86-331.69	96.66	91.66	61.66	26.66
Na^{+}	200	267.81	196.10	20.18-1080.2	4.80-880.70	0.00	0.00	26.66	23.33
K^{+}	12	2.06	2.00	0.1-7.43	0.1-7.17	0.00	0.00	0.00	0.00
HCO_3^{-}	0	385.88	442.74	125-825	100-1325	0.00	0.00	0.00	0.00
Cl^{-}	250-1000	483.20	419.80	98.6-1704	90.16-1682.32	61.66	50	11.66	5
F^{-}	1-1.5	0.66	0.66	0.17-1.21	0.41-1.37	8.33	10	0.00	0.00
SO_4^{2-}	200-400	177.84	62.48	33.1-1207.49	30.85-192.26	15	0.00	11.66	0.00
PO_4^{2-}	0.2-1	0.68	0.22	0.02-1.94	0.01-1.12	71.66	18.33	33.33	11.66
NO_3^{-}	45	26.27	29.86	5.17-66.14	3.1-79.69	0.00	0.00	11.66	21.66

DL desirable limit, *PL* permissible limit

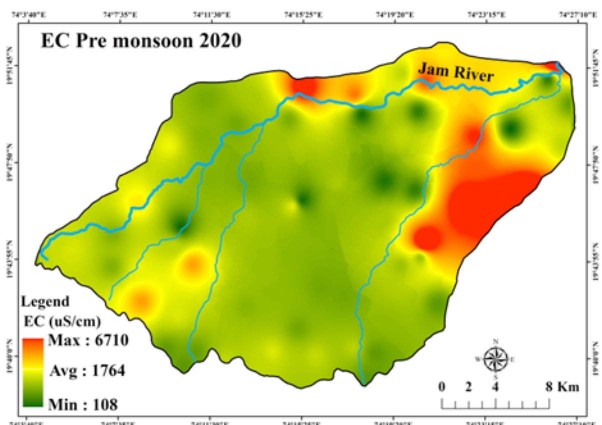
Note: All major ions and TDS are expressed in mg/l while pH on scale and EC in µS/cm.


pH Pre monsoon 2020
Jam River
Legend
pH
Max : 8.5
Avg : 7.9
Min : 7.1
0 2 4 8 Km

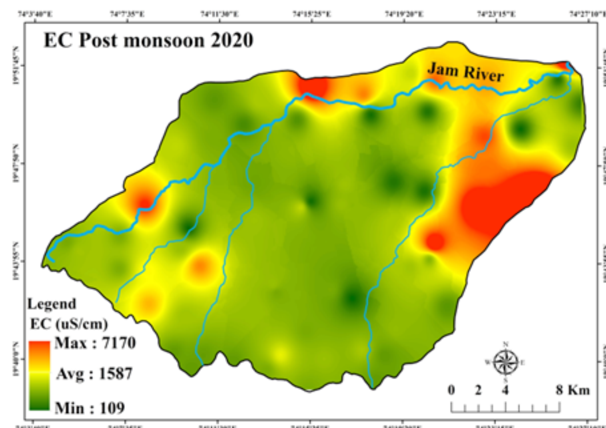
(a)


pH Post monsoon 2020
Jam River
Legend
pH
Max : 8.2
Avg : 7.6
Min : 7.1
0 2 4 8 Km

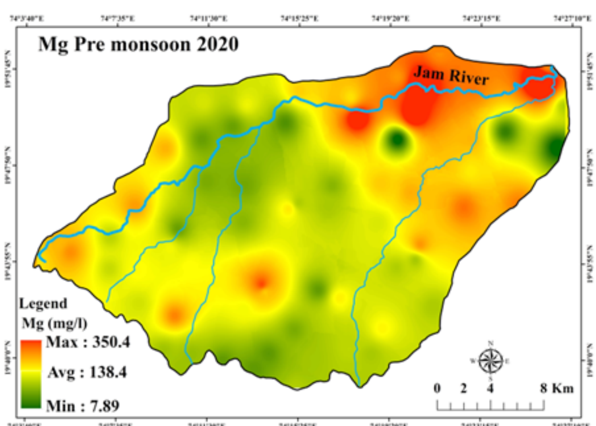
(b)


EC Pre monsoon 2020
Jam River
Legend
EC (uS/cm)
Max : 6710
Avg : 1764
Min : 108
0 2 4 8 Km

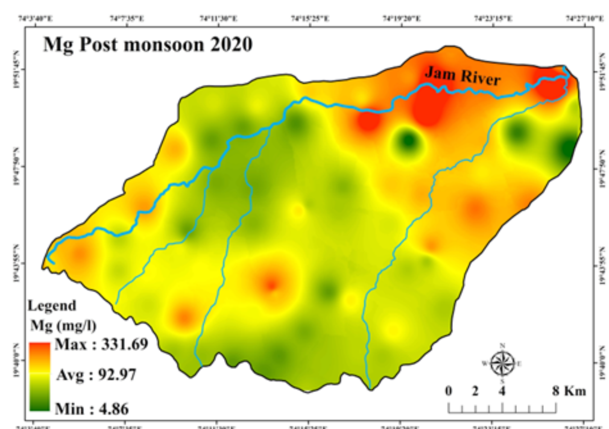
(c)


EC Post monsoon 2020
Jam River
Legend
EC (uS/cm)
Max : 7170
Avg : 1587
Min : 109
0 2 4 8 Km

(d)


Mg Pre monsoon 2020
Jam River
Legend
Mg (mg/l)
Max : 350.4
Avg : 138.4
Min : 7.89
0 2 4 8 Km

(e)


Mg Post monsoon 2020
Jam River
Legend
Mg (mg/l)
Max : 331.69
Avg : 92.97
Min : 4.86
0 2 4 8 Km

(f)

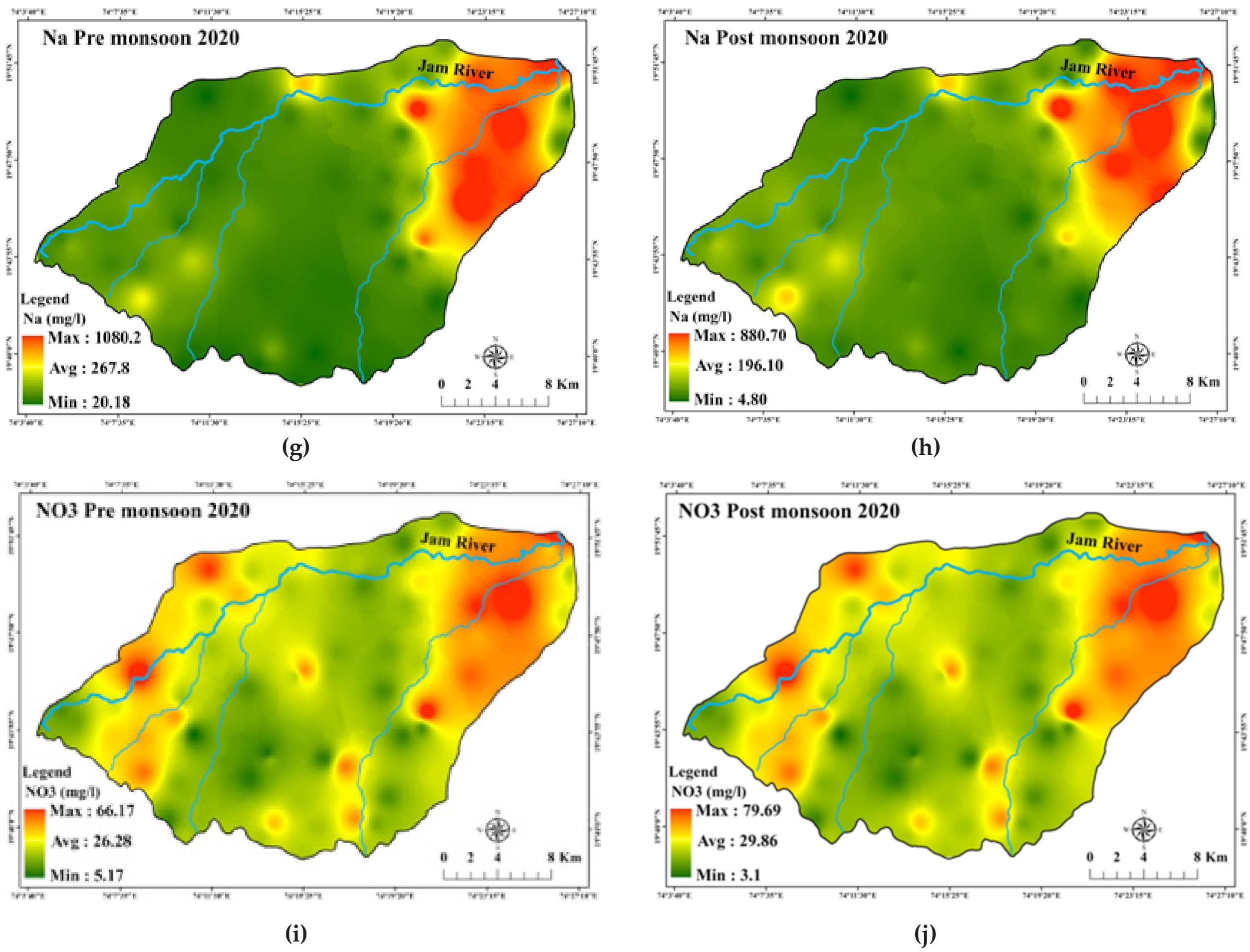


Fig. 2. Spatial distribution of pH, EC, Mg, Na and NO_3 of pre and post monsoon seasons 2020

While the average TH is 781.87 and 492.87 mg/l in the pre- and post-seasons, the total hardness values range from 320 to 2120 mg/l and 120 to 2110 mg/l, respectively. According to analytical findings, in the pre-/post-monsoon season, 100% and 63.33% of samples above the desired level (300 mg/l), while 71.66 and 15% of samples exceeded the permissible limit (600 mg/l) (Table 3). Because of the use of hard water in household activities, urolithiasis and cardiovascular diseases are caused (Mitra *et al.*, 2006; Morrison *et al.*, 2001). An average of 267.81-196.10 mg/l of sodium present in each litre of water, respectively. Drinking water with a high salt concentration can cause heart, kidney, and circulation problems (Vasant *et al.*, 2016). The maps of sodium's spatial distribution show that the north-eastern region has high levels of sodium in both seasons as a result of rock weathering or the dissolving of soil salts in groundwater (Fig. 2g, h). The potassium concentration ranges from 0.1 -7.43 mg/land 0.1 to 7.17 mg/l with an average value of 2.06and 2 mg/l (Table 3). All of the samples are shown to be within the threshold level (12.0 mg/l).

Group III: Anions (Cl^-, F^-, SO_4^{2-}, PO_4^{2-}, NO_3^-, HCO_3^-)

Chloride levels range between 98.6-1704 mg/l (an average of 483.20 mg/l) and 90.16-1682.32 mg/l (an average of 419.80 mg/l) (Table 3). It has been noted that during the pre-monsoon season, the average chloride level is higher. The causes of chloride in groundwater include fertilisers, household garbage, weathering of the halite mineral, and landfill sites (Wagh *et al.*, 2017a). According to BIS standards, in the pre- and post-monsoon seasons, 61.66 and 50% of the samples were above the acceptable level (250 mg/l). In both seasons, the fluoride concentrations are 0.17-1.21 mg/l and 0.41-1.37 mg/l, respectively. Every sample is within the allowed range. In the pre- and post-monsoon seasons, respectively, the sulphate concentration ranges from 33.1 to 1207.49 mg/l, 30.85 to 192.26 mg/l, with an average of 177.84 and 62.48 mg/l, and 11.66% of samples exceed the permitted limit during summer. In pre- and post-monsoon seasons, respectively, the phosphate concentration ranges from 0.02-1.94 mg/l, 0.01-1.12 mg/l, with average values of 0.68 and 0.22 mg/l, and 33.33% and 11.66% of samples exceed the allowable limit. (Table 3). The nitrate levels fluctuate between 5.17 and 66.14 mg/l and 3.1 and 79.69 mg/l before and after monsoon season. It has been determined that the post monsoon samples with excess values are 11.66% and 21.66%. Animal faeces and nitrogen-rich fertilisers are the main sources of nitrate (Panaskar *et al.*, 2014).Utilizing water that is high in nitrates results in methemoglobinemia and impairs blood oxygenation (Mukate *et al.*, 2017; Sunitha *et al.*, 2012). The nitrate spatial variation maps show that regions of the north east with intensive agricultural operations have high nitrate concentrations. Winter has more of it than summer does (Fig. 2i, j). In the pre-/post-monsoon season, the bicarbonate concentration ranges from 125-825 mg/l (avg. 385.88 mg/l) and 100-1325 mg/l (avg. 442.74 mg/l) (Table 3).

Water Quality Index (WQI)

The five categories of Water Quality Index are: excellent (0-50), good (50-100), poor (100-200), extremely poor (200-300) and >300 which is unfit for drinking. (Table 4). In the pre-/post-monsoon season, the WQI value ranges from 53.84 to 218.79 and 33.19 to 210.48 respectively. The average WQI result 98.36 and 77.50 shows that the Jam river basin's overall water quality is good. Table 4 shows that 13.33% samples have excellent water quality during post monsoon. 65 and 68.33% of samples have good water quality, 30 and 16.66% have poor water quality, and 5 and 1.66% of samples have very poor water quality during the pre- and post-monsoon seasons. Because of low hydraulic gradient and rock-water interaction, the average groundwater quality is affected. Figure 3 shows that most groundwater samples fall into the good water, while a small number of samples fall into the poor and few samples are very poor category.

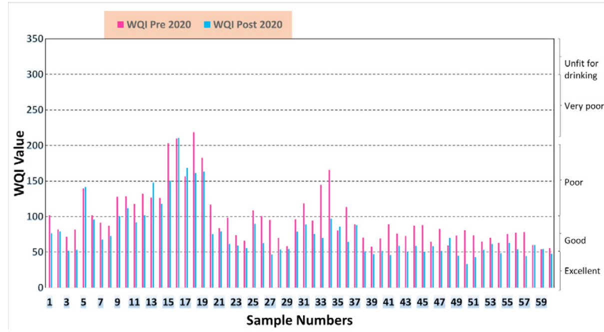


Fig. 3. Graphical representation of WQI values

Spatial variation of WQI

The water quality for various locations was shown on the spatial variation map of WQI (Fig. 4) along with a confirmation that it was safe to drink. With the exception of the north-east study region, it is noted that the groundwater quality is good. Samples 1, 6, 11, 20, 25, 26, 31, 33, and 34, which had low quality in the pre-monsoon, improved in quality in the post-monsoon; this change may have been caused by the dilution effect. Due to the deteriorating water quality in both seasons, the samples (15, 16, and 18) that are located in the north-eastern region are recognised as hot spots. This region is continuously irrigated, and the area's primary crops, sugarcane and onions, require constant fertilisation, which causes nitrate and chloride enrichment in both surface water and groundwater.Numerous groundwater sources in the north-eastern region have been identified to be susceptible and should not be used for drinking. The varied cropping patterns, rock weathering, the predominance of evaporation, and other factors contribute to the variety in

Table 4. Water quality categorization based on WQI range

Range	Category	Pre-monsoon 2020		Post-monsoon 2020	
		Number of samples	% of samples	Number of samples	% of samples
0-50	Excellent	0	0.00	8	13.33
50-100	Good	39	65	41	68.33
100-200	Poor	18	30	10	16.66
200-300	Very poor	3	5	1	1.66
>300	Unfit for drinking	0	0.00	0	0.00

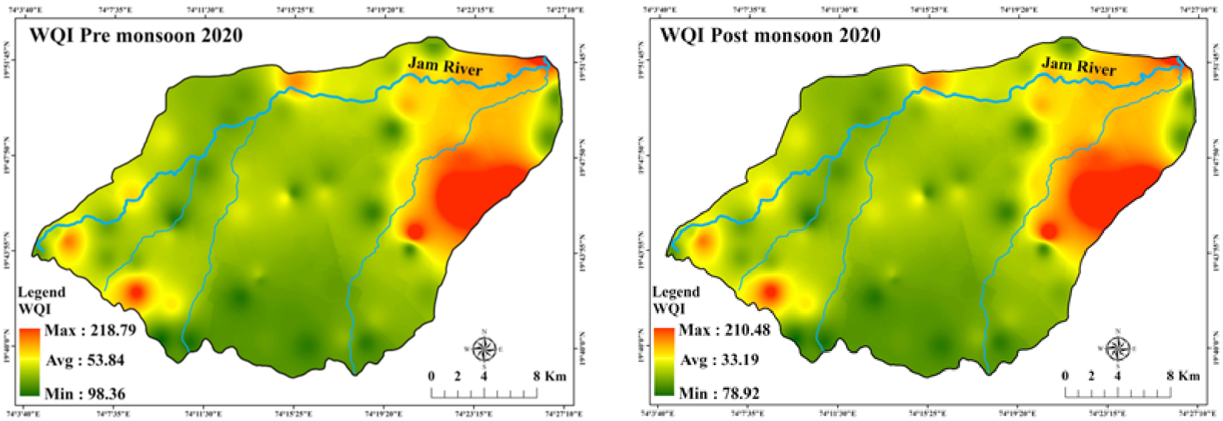


Fig. 4. Spatial variation maps of WQI

groundwater quality over the entire basin.

Conclusion

This study uses the WQI approach and the governing principles of hydro-chemistry to determine if groundwater is suitable for drinking. The factors, including pH, Ca, Mg, Na, Cl, NO_3, TH, and TDS, that eventually led to worsening groundwater quality exceeded the desired and allowed limits specified by the BIS, (2012). According to hydro-chemical study, groundwater is permanently hard and alkaline. The groundwater inorganic pollution load and salt dissolving are responsible for the elevated EC. The intense agriculture and local anthropogenic inputs are responsible for the high amount of Cl, NO_3 and TDS. The persuasion of agricultural runoff, excessive application of chemical fertilizer, percolation and dissolving of salts in aquifer, and excessive application of fertilizer are all observed to have a major negative impact on groundwater quality in the post-monsoon season. According to WQI data, 13.33% of samples collected after the monsoon fall into the excellent category, 65 and 68.33%, 30 and 16.66%, 5 and 1.66%, are good, poor and very poor samples collected before and after the monsoon respectively. The north-eastern region's groundwater quality is heavily impacted by anthropogenic inputs, primarily agriculture. To show the good, marginal and vulnerable places for efficient management of water resources, WQI maps display the category of water. The results of the study could help local government officials in Nashik and Ahmednagar district (Jam river basin) identify eligible and vulnerable groundwater resource management areas.

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