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Development of CCME WQI model for the groundwater appraisal for drinking in Basaltic terrain of Kadava River basin, Nashik, India

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In this study, Canadian Council of Ministers of the Environment, Water Quality Index (CCMEWQI) model has been used to ascertain the groundwater suitability for drinking in Kadava River basin located in Nashik district, Maharashtra. Therefore, forty (40) representative groundwater samples were collected from different dug/bore well during Pre (PRM) and Post (POM) monsoon seasons of 2011 and analyzed by standard procedures of APHA. The parameters like pH, EC, TDS, TH, Ca, Mg, Na, K, Cl, F, SO_4 and NO_3 were considered to compute the CCME WQI model. The results of CCME WQI values inferred that 7.5 % in PRM and 17.5 % samples in POM seasons fall in poor category. Moreover, 77.5 % and 60 % samples fall in marginal category in PRM and POM seasons. While, 15 % and 22.5 % samples came under fair category in PRM and POM seasons. Spatial distribution maps illustrated that North, Central and South regions are identified as vulnerable for drinking; hence, unfit for drinking. In a nutshell, groundwater quality is significantly deteriorated because of agricultural practices and anthropogenic activities, therefore appropriate monitoring along with proper remedial measures is essential to sustain the groundwater quality in the river basin.

[Keywords: CCME WQI model; Drinking suitability; Groundwater; Kadava River]

Introduction

Water is important and infinite natural source for the endurance of life and one of the essential components of human health system. The water quality of drinking water is ultimately associated with human health, because of consumption of contaminated drinking water possess many water borne diseases from local to global scale[1]. The water-borne diseases resulted to serious threats to public health and augmented the morbidity and mortality rate particularly in children[2,3]. It is estimated that in developing countries around 250 million populations infected yearly which led to 10-20 million deaths globally[4,5]. Over the period of time, owing to limited fresh water resources, people widely use groundwater for mitigating the needs of drinking, irrigation, industry etc. It is assumed that groundwater is one of the safe and reliable sources of drinking water owing to its natural quality and less susceptibility compared with freshwater resources. In fact one third part of the world population meets their drinking needs from ground water[6]. In general, groundwater quality depends on composition of rock, rock-water interface, water residence time, variability in climate and rainfall, water depth, soil media etc., and anthropogenic inputs from domestic, agricultural and industrial activities[7-16]. Thus, for sustainable water resource management, water quality evaluation is more vital in relation to public health and socio-economic development local to global scale[17-19]. Therefore, water quality monitoring programme is essential for sustainable management of available water resources and mitigate water quality issues in different regions.

Water quality index (WQI) is one of the useful mathematical tools and a complex indicator of water quality that gives relative information based on diverse water quality variables into a single numerical value which can be simply communicated to public[20-23]. The most improvement advantage of WQI is estimation of water quality condition devoid of interpreting the individual water quality variables separately. Nonetheless, more than 20 WQI were formulated and used for water quality assessment worldwide[24-26]. Furthermore, the Canadian Council of Ministers of the Environment (CCME) has designed an index to make simpler the water quality data with no losing its scientific base which is practicable to use over space and time to the public in an easier manner[27,28]. This index is mainly based on number of selected input water quality variables, size of dataset and objectives or standards used for its development. Also, the selection of suitable guidelines or objectives is important towards computing the water quality index values. However, scope (F1), frequency (F2) and amplitude (F3) measures of variance have been considered for computation of index. The scope depicts the proportion of input variables that could not meet their objectives at least through the time under concern (i.e. failed variables). Frequency corresponds to the proportion of individual tests that doesn’t fulfill their objectives (i.e. failed tests) and amplitude stands for the amount through which failed test values could not perform the objectives[28]. Moreover, by the combination of these three variables a single dimensionless number is produced which represents in general the superiority of water. Moreover, the CCME index values varies from 0 to 100; where, 0 correspond to the worst quality and 100 stands excellent quality of water, which conveys the water quality understanding among scientific and non scientific communities. In worldwide, many research scholars have been widely using CCME WQI model to categorize water quality for potable, recreational, irrigational and safeguard of aquatic life[29-38].

In the Kadava River basin, groundwater is mainly used for drinking and agriculture purpose; so, its quality is closely related with local public health. Generally, local populace extract groundwater from dug and bore well for drinking without any prior treatment; therefore, water quality assessment is essential. In the study area, the majority of the population reside in remote areas and farm houses; thus, it is quite hard to provide a central water treatment facility to all of them. However, large area is under intense agriculture due to plentiful water and favorable climate. The groundwater quality may pose serious threats owing to application of chemical fertilizers, pesticides, soil amendments etc[39]. So, it is necessary to investigate the groundwater quality status which may attribute from natural or anthropogenic inputs. Therefore, the main objectives of the study are: i) to evaluate the physicochemical behavior of groundwater for drinking suitability and their influencing factors. ii) to develop CCME WQI model to evaluate the drinking suitability of groundwater. iii) to generate CCME WQI maps to identify the vulnerable sites and know the spatial extent of contamination for remedial strategies in the study area.

Study area

The study area comprises a total area of 1053 km^2 and located between 73^{0}55’ - 74^{0}15’E and 19^{0}55’ - 20^{0}25’N which comes in Chandwad and Niphad Tehsils of Nashik District, Maharashtra (Fig. 1). The

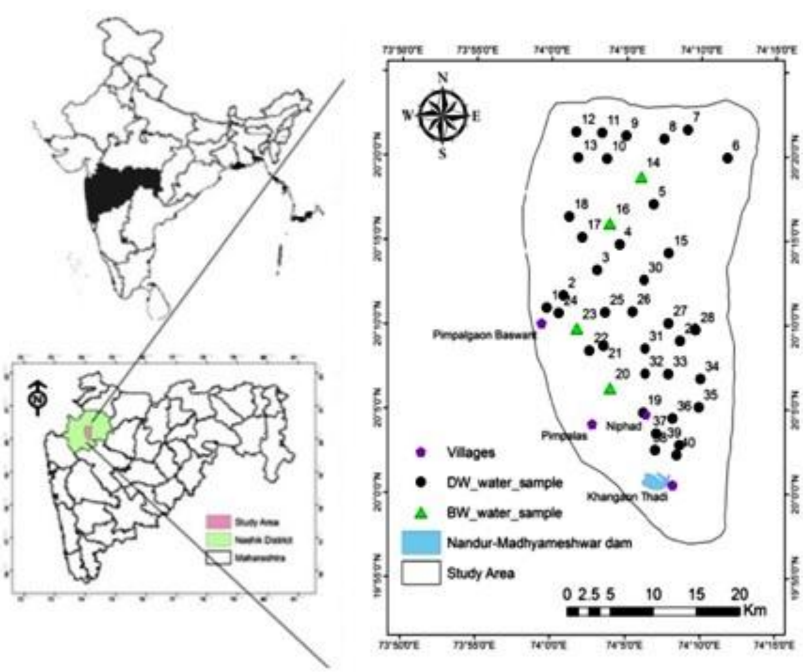

Fig. 1 — Study area map with groundwater sample locations.

River Kadava is foremost tributary of Godavari which originates in Western Ghat locally known as Sahyadri hills in Nashik district and flows in northwest to southeast direction and convergence with Godavari River at Khangaonthadi village of Niphad tehsil. Geologically, it is underlain by basalt of upper cretaceous to lower Eocene age and encompass ‘Pahoehoe’ and ‘Aa’ lava flows. The hard rock (basalt) and soft rock (alluvium) patches dominantly occur in the study area. The groundwater found in unconfined, semi confined to confined conditions, upper weathered and down to 20 - 25 m depth fractured zones[40]. The average rainfall is 700 mm from south-west monsoonal winds (June to September) with semi arid climate. The lowest temperature recorded in winter is 5 ^{0}C; while, highest 40 ^{0}C in summer season[41]. Few alluvium patches (20-25 meter depth) are found along the river flow. The majority of the area is under agricultural practices and principal crops are sugarcane, grapes, onion, vegetables etc.

Materials and Methods

To know the suitability of groundwater for drinking in Kadava River Basin, forty (40) groundwater samples were collected from shallow and deep aquifers during pre - post monsoon seasons of 2011. These groundwater samples were collected in pre-treated 1 litre plastic container; proceeding to water collection the well was subjected to pump for 2-3 minutes to equivocate contamination. Further, water samples containers were labeled properly and transported to the laboratory for further physicochemical analysis. The pH and EC was measured *in situ* by handheld multi-parameter tester and sample coordinates were recorded by GPS. The cations including calcium, magnesium, sodium, potassium, and anions such as carbonate, bicarbonate, sulfate, nitrate and fluoride were analyzed by adopting the procedures defined by American Public Health Association[42]. For analytical precision, ion balance errors are calculated and found in ± 10 % which is accepted worldwide[43]. The base map and water quality index maps of the study area were prepared in ArcGIS. The statistical analysis and CCME calculation were carried out in MS-Excel and CCME WQI calculator[28].

Computational steps of CCME WQI model

The CCME WQI is computed through following steps:

- **Selection of variables**

The twelve variables like pH, EC, TDS, TH, Ca, Mg, Na, K, Cl, F, SO_4 and NO_3 were selected to assess the suitability of groundwater for drinking.

- **Selection of objectives**

The BIS standards (IS10500:2012)[44] of drinking water were considered as an objectives for WQI.

Calculation of index

CCME is mainly based on three measures viz., Scope (F_1), Frequency (F_2) and Amplitude (F_3).

F_1 (Scope):

It is used to depict the proportion of water quality variables that could not fulfill their objectives at the time period under concern (i.e. failed variables)

F_1 = (Number of Failed Variable) / (Total number of Variables) X 100 ... (1)

F_2 (Frequency):

It demonstrates the proportion of individual tests which cannot fulfill their objectives (i.e. failed tests)

F_2 = (Number of Failed tests) / (Total number of tests) X 100 ... (2)

F_3 (Amplitude):

It illustrates the amount by which failed test values could not meet their objectives

(a) If an individual content is greater than (>) or less than (<); when, the objective is at least, the objective is termed as “excursion” and is denoted by equation 3.

When the test value must not surpass the objective

excursion_i = (Failed test value) / (Objective_j) – 1 ... (3)

If the test value found above the objective

Execursion_i = (objective j / Failed test value) – 1 ... (4)

(b) The combined total by which individual tests are out of fulfillment is calculated by Eq. 5

$$nse = \sum_{i=1}^{n} excursioni \Big/ \# \, of \, tests \quad \text{... (5)}$$

nse = normalized sum of excursions.

(c) F_3 is formulated by Eq. 6

F3 = (nse / 0.01nse + 0.01) ... (6)

Finally, the CCME WQI is computed through Eq. 7

$$CCME = 100 - (\sqrt{F_1^2 + F_2^2 + F_3^2} / 1.732) \quad \text{... (7)}$$

The 1.732 is a divisor which uses to normalize the resultant values of range of 0 to 100; 0 indicates the worst and 100 express for the best water quality. Further, it is ranked into five categories viz., 0 to 44 = Poor; 45 to 64 = Marginal; 65 to 79 = Fair; 80 to 94 = Good and 95 to 100 = Excellent [10].

Results and discussion

The statistical summary of physicochemical parameters and their BIS standards are illustrated in Table 1.

Groundwater quality

In groundwater, the pH values vary from 7.8- 8.9 (Avg. 8.3) and 7.7 – 8.6 (Avg. 8.1) in PRM and POM seasons which indicate that groundwater is slightly alkaline, this nature is attributed from CO_2 loss, precipitation and minerals dissolution[45]. Generally, pH doesn't articulate any ill effect on human heath but it amends the water taste and associated with other ionic elements of water[46]. As per the BIS standards, 15 % and 2.5 % groundwater samples surpassed the PL in PRM and POM seasons; thus, restricted for potable use (Table 1). The EC value is soaring in pre monsoon from 816 to 7760 (2508.5 µS/cm) and 718 - 8000 µS/cm in post monsoon (2134.55 µS/cm). Generally, EC value increase with temperature and fluctuates with the amount of dissolved salts contents in groundwater[47]. TDS of groundwater is considered as significant parameter for drinking suitability, which ranged from 530.4 to 5044 mg/l in PRM and 466.7-5200 mg/l in POM seasons (Table 1). Such elevated concentration of TDS is owed to climate, lithology, agricultural and anthropogenic inputs. As per the BIS 27.5 % and 17.5 % samples surpasses the PL in both the seasons due to salt percolation, mineral dissolution in aquifer; however, drinking of such water may lead to gastrointestinal problems.

The content of calcium varied from 12.02-130.40 (avg. 102.45 mg/l) and 15.2-99.86 (avg. 45.86 mg/l) in PRM and POM seasons. According to BIS standards, all groundwater samples were within PL from both the seasons; therefore, suitable for drinking. The magnesium content has wide range fluctuation from 28.32-285.37 and 19.8-265.5 mg/l in PRM and POM seasons. However, 45 % and 17.5 % samples were beyond the PL (100 mg/l) of the BIS standards in PRM and POM seasons. The elevated content of magnesium is contributed from geological setup, composed of Thakurwadi formation with picritic horizons[48]. The total hardness content of 27.5 % and 10 % groundwater samples exceeded the PL (600 mg/l) in the PRM and POM seasons (Table 1). The sodium values vary from 15.6 to 583.4 mg/l (avg. 102.45 mg/l) in PRM and 25.2 - 403.7 (avg. 96.27 mg/l) in POM season. Consumption of elevated sodium containing water increases blood pressure, arteriosclerosis, vomiting, stiffness in cerebral and muscular organs etc[49]. The K concentration varied from 0.9 to 7.5 mg/l and 0.1 – 12.5 mg/l in PRM and POM seasons which is mainly influenced from the application of K rich fertilizers; also, it confirms that most of the samples are suitable for consumption.

Table 1 — Statistical summary of physicochemical parameters and BIS drinking standards

Parameters	Pre monsoon (PRM) 2011		Post monsoon (POM) 2011		BIS (IS10500:2012)	
	Range	Average	Range	Average	Desirable Limit (DL)	Permissible Limit (PL)
pH	7.8-8.9	8.3	7.7-8.6	8.1	6.5	8.5
EC	816-7760	2508.5	718-8000	2134.55	-	-
Ca	12.02-130.43	52.89	15.2-99.86	45.86	75	200
Mg	28.32-285.37	102.79	19.8-265.5	77.6	30	100
Na	15.6-583.4	102.45	25.2-403.7	96.27	-	200
K	0.9-7.5	2.32	0.1-12.5	2.42	-	12
Cl	42.6-1057.9	233.9	49.2-839.4	184.5	250	1000
SO_4	22.61-239.01	130.11	46.7-301.4	117.27	200	400
NO_3	19.31-68.62	48.63	31.4-66.15	49.97	-	45
F	0.1-2	0.43	0.2-0.8	0.39	1	1.5
TH	189.73-1281.79	553.49	182-1204	432.71	300	600
TDS	530.4-5044	1630.53	466.7-5200	1387.46	500	2000

The values of water quality parameters are denoted in mg/l; pH on scale; EC in µS/cm.

The chloride content ranged from (42.6 to 1057.9 mg/l) and (49.2 – 839.4 mg/l) with average values of 233.9 and 184.5 mg/l in PRM and POM seasons respectively. As compared with the BIS limit, most of the samples are within PL (1000 mg/l); thus, fit for drinking. The chloride content increased due to agricultural runoff, domestic waste and animal excreta. The average content of sulphate in PRM (130.11 mg/l) and in POM (117.27 mg/l) seasons is far below the DL (200 mg/l) of BIS; hence, confirms the groundwater fitness for drinking. The values of nitrate content vary from 19.31 to 68.62 mg/l with average value (48.63 mg/l) and 31.37 to 66.15 mg/l with average value (49.97 mg/l) in PRM and POM seasons respectively. According to the BIS standards, 52.5 and 65 % groundwater samples go beyond the PL (45 mg/l) in PRM and POM seasons (Table 1). The drinking of excessive nitrate containing water causes methemoglobinemia and blue baby syndrome in children. The excessive nitrates contents owed from surplus use of NPK complex fertilizers and domestic waste[38]. Fluoride concentration in groundwater above 1.5 mg/l leads to dental and skeletal fluorosis in human; however, in this study all the groundwater samples had fluoride content below the PL, hence, suitable for drinking (except sample number 14) (Table 1).

CCME WQI model

The descriptive statistics of CCME WQI for both the seasons is summarized in Table 2. The CCME WQI value ranges from 37 to 69 in PRM and 27 to 74 in POM seasons of 2011. It is illustrated that there is no significant variation in the average values of CCME WQI but the minimum and maximum values deviated widely (Table 2). The overall classification suggested that in POM season the groundwater quality is slightly deteriorated as evaluated with PRM season which may be due to the mixing of contaminants along with recharge water into aquifer system.

Table 2 — Statistical summary of CCME WQI values in PRM and POM seasons of 2011

Season	Pre monsoon (PRM)	Post monsoon (POM)
Minimum	37 .00	27.00
Maximum	69.00	74.00
Average	55.38	55.10

CCME WQI values classified into five different classes to evaluate the drinking suitability of water are illustrated in Table 3. It is inferred that, 7.5 and 17.5 % groundwater samples comes under poor class (0-44) for drinking in PRM and POM seasons. Figure 2, corroborates that few samples (sample numbers 13 and 38) in PRM and (sample number 16, 34 and 37) POM seasons are on the edge of poor class; hence, it signifies that these samples are not contaminated as rest of the samples belonging to poor category. The sample numbers 1, 3, 6, 9, 34 and 37 came under marginal class in pre monsoon season but shifted to poor class in post monsoon season due to percolation of agricultural runoff and mineralization into aquifer. The marginal class (45-64) encompassed majority of the samples i.e. 77.5 % (PRM) and 60 % (POM) seasons. The sample numbers 2, 4, 11, 12, 14, 17, 18, 19, 20, 22, 23, 24, 29, 35, 36, and 39 showed similar trend in water quality as marginal for drinking in both the seasons; while, few samples shifted from marginal to poor class due to anthropogenic impacts. It also depicted that many samples (< 60) were very close to fair category in both the seasons, which would increase the fair water quality percentage in future with proper measures. Still, 6 (15 %) and 9 (22.5 %) groundwater samples belong to fair class in PRM and POM seasons (Table 3). In nutshell, there was no uniform trend in groundwater quality, but most of the samples fell in marginal to fair for drinking in both the seasons of 2011.

Spatio-temporal variation of CCME WQI

Geographic information system based interpolation technique i.e. Inverse Distance Weightage (IDW) is utilized to exemplify the spatio-temporal variation in

Table 3 — Classification of groundwater samples for drinking based on CCME WQI values

Class (Range)	PRM Sample Numbers	Samples %	POM Sample Numbers	Samples %
Poor (0-44)	13, 16, 38	7.5 %	1, 3, 6, 9, 16, 34, 37	17.5
Marginal (45-64)	1-6 , 9-12, 14, 15, 17-27, 30, 32, 34-37, 39, 40	77.5 %	2,4,7, 8, 11-14, 17-20, 22-24, 28-31, 33, 35, 36, 38, 39	60.0
Fair (65-79)	7, 8, 28, 29, 31, 33	15.0 %	5, 10, 15, 21, 25, 26, 27, 32, 40	22.5
Good (80-94)	-	-	-	-
Excellent (95-100)	-	-	-	-

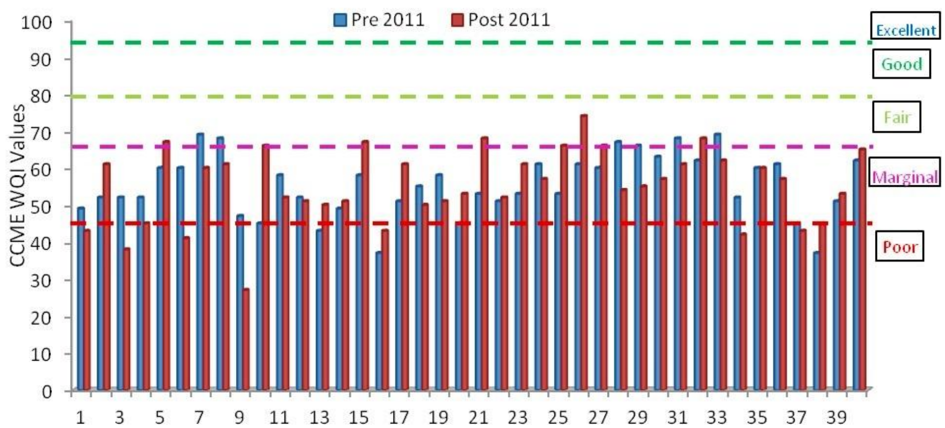

Fig. 2 — Graphical representation of CCME WQI for groundwater samples

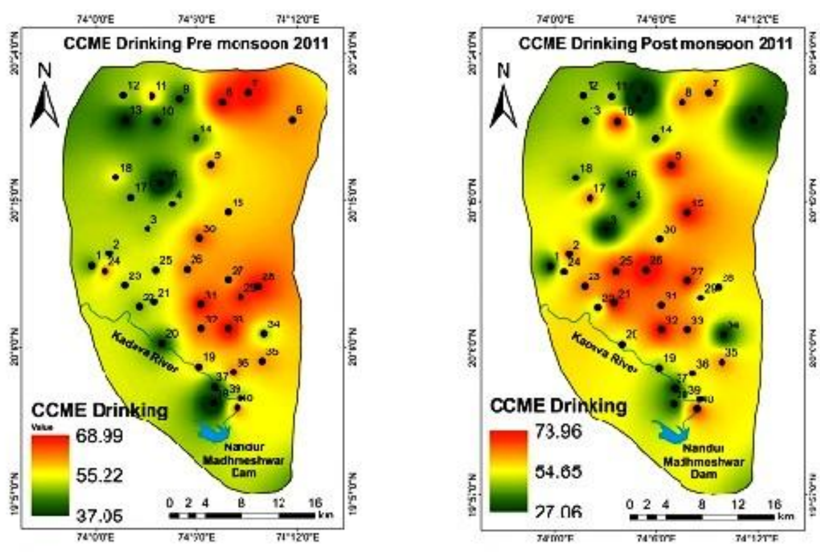

Fig. 3 — (a-b) Spatial distribution of CCME for Drinking in pre and post monsoon seasons of 2011

Fig. 3 — (a-b) Spatial distribution of CCME for Drinking in pre and post monsoon seasons of 2011

groundwater quality and to measure the spatial extent of contamination at each sample location (Fig. 3a-b). In pre monsoon season, almost half part of the study area i.e. western side is polluted; hence, restricted to use of groundwater for drinking. Few groundwater samples (sample numbers 9, 10, 13, 16, 20, 37 and 38) were highly polluted due to prolonged agriculture and anthropogenic pressure. However, in POM season many water samples were found vulnerable in North region and few samples from Central and South region. The samples located along the surface water flow direction (sample numbers 20, 37 and 38) were affected in both the season due to the mixing of agricultural runoff and domestic waste as these samples are in the vicinity of the settlement. It is confirmed that intense agriculture and anthropogenic inputs are the prime contributors of declining groundwater quality in both the seasons. These maps help to recognize the seasonal variation in water quality and also help to identify the vulnerable sites for effective implementation of remedial strategies to restore water quality.

Conclusion

Hydro-chemical analysis inferred that groundwater was moderately alkaline and hard to very hard category at few locations. The elevated content in few parameters like EC, TDS, Cl and NO_3 owed to impact of agricultural and anthropogenic inputs, percolation of salts, dissolution of minerals, agricultural runoff and domestic waste. Sodium, potassium, sulfate and fluoride were within the permissible limits, hence, confirmed their fitness for drinking. CCME classification depicted that 7.5 % and 17.5 %; 77.5 % and 60 %; 15 and 22.5 % groundwater samples came under poor, marginal and fair categories in PRM and POM seasons, respectively. It is exhibited that overall groundwater quality was significantly deteriorated due to amalgamation of contaminants which leached into aquifer system from agricultural and anthropogenic inputs. Also, groundwater wellhead inspection and groundwater management plans should be developed to mitigate the issues of water quality degradation.

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