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Assessment of water quality of Damodar River in South Bengal region of India by Canadian Council of Ministers of Environment (CCME) Water Quality Index: a case study

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ABSTRACT

River Damodar situated in the South Bengal region of India is the main source of water for the surrounding industries and agricultural places. The objective of the present study is to evaluate the water quality of Damodar River in terms of an index under the influence of several physical and chemical parameters by using Canadian Council of Ministers of Environment Water Quality Index (CCME WQI) method as the river has been subjected to enormous contamination in recent times. Water samples have been procured from eight different locations along the river bank in the pre-monsoon, monsoon, and post-monsoon for the entire period of 2012. Immensely complex data were coined into a single term for the sake of convenience using CCME WQI method. This index consists of three elements: scope, frequency, and amplitude. Besides this, the seasonal variation of different water quality parameters like pH, total dissolved solid, total suspended solid, conductivity, turbidity, dissolved oxygen, chemical oxygen demand, biological oxygen demand, chloride, fluoride, chromium, alkalinity, total hardness, calcium and magnesium hardness, oil, grease, and total Coliform were also assessed during the aforementioned time period. The relationships among the eight sampling stations were emphasized by cluster analysis to characterize and evaluate CCME WQI that produces an index value in the range of 0–100 to reflect the worst and best quality water, respectively. Nevertheless, the CCME WQI values obtained from the respective stations depict fair values on an average except the last sampling station Tetul Bagan Gas Canal where the river water is heavily contaminated and thus require pre-treatment before use.

Keywords: Damodar; Water quality; CCME; WQI; Cluster analysis

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1. Introduction

Water is considered to be in abundance as a complimentary gift of Mother Nature. India has been endowed with rich natural resources. While rapid industrialization in India induces overall economic growth, it also causes contamination and over-utilization of the available resources. Continuous industrial effluent discharge tends to elevate the concentration of metal ions in the aquatic ecosystem that arouse the consciousness of the people toward clean technology with the passage of time. This has led to the development of water quality parameters which can be used as a management tool for evaluating water quality. The Damodar River, located in West Bengal state of India largely fulfills various needs of water for irrigation and other domestic uses to the residential areas of the main cities like Durgapur, Panagarh, Bankura, and Rajbandh.

The aim of the present investigation was to assess the water quality of the river system under consideration in terms of Canadian Council of Ministers of Environment (CCME) Water Quality Index. However, the assessment of water quality requires two most important elements (1) measurement of the variables affecting water quality and (2) comparison of measured variables obtained with those of standard limits defined in Indian specifications [1]. However, when a large number of parameters are judged, assessment of water quality in a single unit rather becomes difficult.

A Water Quality Index is a "communication tool for determination of water quality" [2–5]. It can be treated as a management tool that summarizes large amounts of complex data into a single number and yields easily interpretable information for reporting to policy-makers and the public. It is a dimensionless quantity that helps to relate the overall water quality at a specific location and time thereby determining the suitability of water for varied uses. Water quality data can be presented using graphical and numerical integration tools. A large number of standard procedures are available to correlate and classify the water quality indices. However, they are laborious, demands a lot of time, and do not produce easily understandable water quality estimation. Multivariate technique is one such effective method in the recent times that has aided in water quality management. Other statistical techniques such as factor analysis, principle component analysis, and cluster analysis are some of the approaches to determine the spatial and temporal deviations of complex water quality data-set.

Several water quality indices like National Sanitary Foundation Water Quality Index (NSF WQI), Oregon Water Quality Index (OWQI), Delphi WQI, etc. have been developed by the researchers during the previous year's [6–11]. They serve as excellent tools and aid the water managers for framing water policies. The Canadian Council of Ministers (CCME WQI) has been attempted in particular for Damodar River as it has not been previously done.

A novel Water Quality Index was introduced in Canada around mid-1990s by the British Columbia [12–17]. The frequency of water parameter sampling, frequency of failures of water quality parameters, and divergence of the parameter from its specification were combined to calculate WQI. There was an urge to examine the suitability of water for varied uses and thus the Water Quality Guidelines Task Group of the Canadian Council of Ministers of the Environment customized the original British Columbia Water Quality Index and certified it as the Canadian Council of

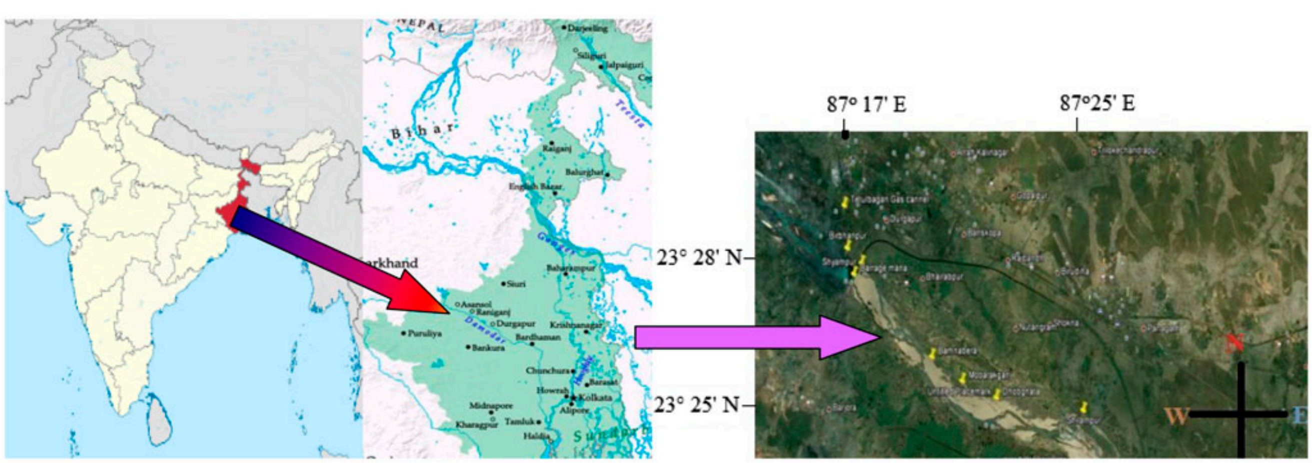

Fig. 1. River Damodar shows the sample stations.

Table 1
The names of the sampling spots

Name of the location	Denotation number	Latitude	Longitude
Shilampur	D_1	23°24′	87°25′
Dhobaghata	D_2	23°25′	87°22′
Mobarakganj	D_3	23°25′	87°21′
Bamnabera	D_4	23°26′	87°20′
Shyampur	D_5	23°28′	87°18′
Barrage mana	D_6	23°28′	87°18′
Birbhanpur	D_7	23°29′	87°17′
Tetul Bagan Gas Canal	D_8	23°30′	87°17′

Ministers of Environment Water Quality Index (CCME WQI) in 2001 [18]. Presently, the CCME WQI is employed by many provincial, territorial environment departments and watershed organizations [19]. Mostafaei et al. [1] studied the spatial and temporal long-term variations of the physical, chemical, and biological parameters over a span of 36 years at ten different places of the Kashkan River to resolve the suitability of water that was rated as average. Lumb et al. [15,16] had examined the water quality of the Mackenzie River basin in Canada using CCME WQI method where he stated that there would be a negative impact on water quality if the parameters exceed their standard values. Efficacy of CCME WQI index to evaluate the drinking water was performed [20]. Water of River Yamuna was assessed by CCME WQI at four locations for pre-monsoon, monsoon, and post-monsoon during a period of 10 years [21].

Samples were collected at eight different locations of Damodar River mainly the downstream part of Durgapur city in West Bengal for the pre-monsoon, monsoon, and post-monsoon season as depicted in Fig. 1. It had been found that people belonging to these areas, who do not have proper access to clean water, use this river water to fulfill their basic needs like washing, bathing, cleaning, and for irrigating agricultural lands. Thus, the prime objective of this study is to evaluate the water quality of River Damodar in terms of CCME to judge its suitability for use.

The names of corresponding sample collection sites along with their geographical location have been mentioned in Table 1.

2. Materials and methods

2.1. Study area and sampling sites

Fig. 1 shows the location of Damodar River or the Deonad Nadi (latitudes 23°30′N and 24°19′N; longitudes 85°31′E and 85°21′E) which is a sub-system of the Ganges River system of India [22]. Damodar River is 592 km long with a drainage area of 22,015 km^2. It flows along the southwest direction and enters the deltaic portions of the plain below Raniganj. It separates into two channels before merging with Hooghly. Being featured as a rocky river, it is named as Antasira which means difficult to encounter. The word Damodar has originated from the word *"udar"* or a womb full of fire. It is a high flashy rain-fed river having an average annual rainfall of 140 cm annually. The river emerges from the Palamau Hills of the Chota Nagpur watershed (23°37′N and 84°41′E) lying at a height of 610 m above the mean sea level. It flows through the Indian states of Jharkhand and West Bengal and is primarily fed by six major streams like Bokaro, Konar, Jamunia, Gowai, Ijri, Sali, and Barakar, its sub-tributaries being the Gupta and Banerjee [23]. Majher-Mane village is a point where these wastes drain into the river basin [24]. In 1955, Durgapur Barrage was constructed across the River Damodar. People residing in the outskirts of Durgapur, Bankura, Panagarh, Rajbandh, Barakar, Konar, and Jharkhand depend on the river water for their living. However, the sewage wastewater and industrial effluents from various steel, chemical, and cement sectors are being regularly discharged into the river water thus making it unsafe for use. The delta region of Damodar basin is mainly composed of alluvial soil. It ranges from the plateau type of laterite soil to that of alluvial soil in its lower basin. Red and yellow loams of laterite soil can be found in the upper valleys. The climate of the region is characterized by hot and humid summers accompanied by moderate winters.

2.2. Materials

Various water quality parameters were recorded for eight sampling stations during the period of 2012 for pre-monsoon, monsoon, and post-monsoon. Water samples from the river were collected in 1 l HDPE bottles, which were previously washed with distilled

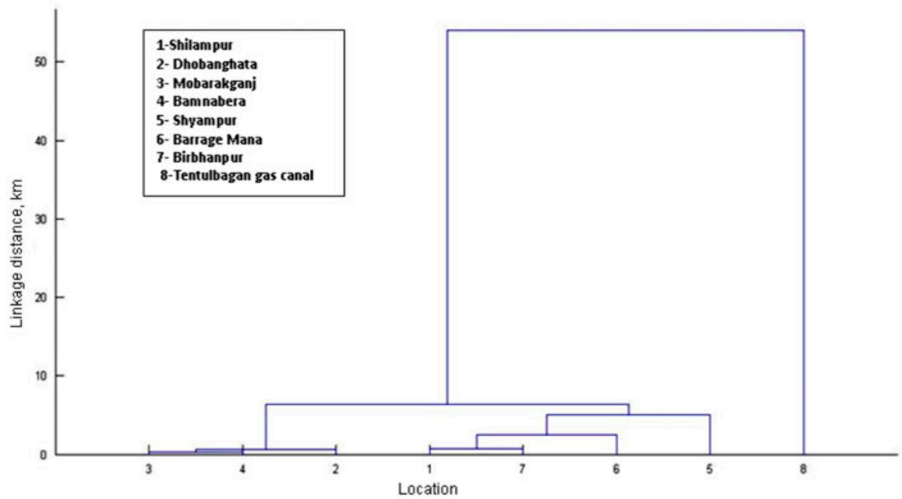

Fig. 2. Similarity Dendogram among stations from cluster analysis.

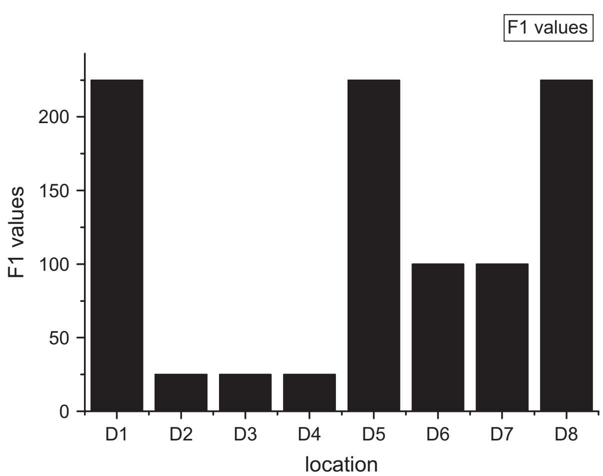

Fig. 3. Histogram showing distribution of F_1 parameter.

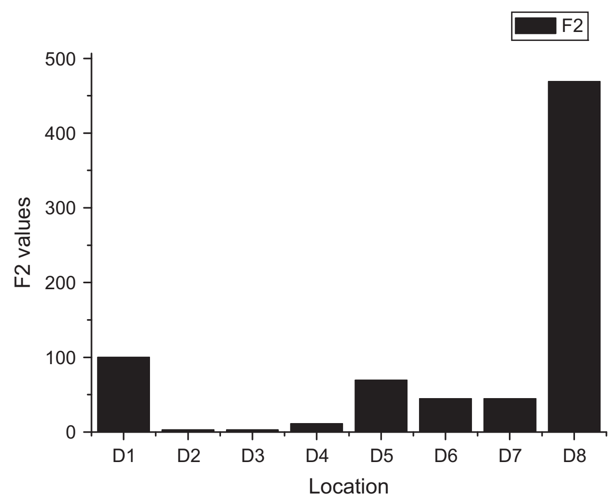

Fig. 4. Histogram showing F_2 (frequency) values against the locations.

water. The map of the area under study has been presented in Fig. 1. These samples were regularly analyzed by standard procedures to determine the concentration of sulfate, phosphate, nitrate, chloride, and chromium ion concentration [25,26]. The concentrations of Ca, Mg, and Na were measured by a flame photometer (Jenway model PFP7) Few selected parameters such as pH, water temperature, total dissolved solids (TDS), and electrical conductivity (EC) were deduced at the site itself by using standard equipment (Merck, German). The pH of the study samples is measured using and pH Meter Metrohm (model 827). Dissolved oxygen (DO) was calculated by oxygen fixation with the required reagent. However, standard measures were adopted for the analysis of parameters like biological oxygen demand (BOD) and chemical oxygen demand (COD). The observations were further compared with the Indian Standards [27,28] as shown in Table 6 [29].

2.3. Methods

2.3.1. Hierarchical cluster analysis

Cluster analysis has been adopted in the present study to classify all the eight sampling stations into similar but distinct groups. This analysis is applicable on various types of data-sets [30]. Hierarchical

Table 2
Classification of CWQI values

WQI value	Interpretation	Remarks
95–100	Excellent	All parameters are meeting the objectives
89–94	Very good	Slight threat to water quality
80–88	Good	Minute threat to quality when parameters seldom vary from the desired range
65–79	Fair	Suitable water quality but variables deviate from the objectives
45–64	Marginal	Almost impairable water quality
0–44	Poor	Water quality departs from its desirable level

clustering is the formation of a cluster tree by grouping the data over a variety of scales. The cluster trees are formed by combining the cluster of one level with the cluster of the next higher level until one cluster remains. Hierarchical cluster analysis was performed by means of Matlab7 (Mathworks. Inc. ver. 7.0.1) in the present analysis and has been shown in Fig. 2 [31].

2.3.2. CCME Water Quality Index

Canadian Council of Ministers of Environment has introduced a universally approved methodology by which the ambient water quality conditions could be determined in terms of an index considering a number of parameters [12,14–16,32]. This index is based on the combination of three factors-scope, frequency, and amplitude to yield a single dimensionless number that can reflect the water quality at the very first instance [29]. It was developed by British Columbia Ministry of Environment, Lands and Parks and was further reshaped by the Alberta Environment. The following factors are:

2.3.2.1. Factor 1 (F_1 – scope). It stands for the percentage by which the variables deviate from their objectives. Here, it has been graphically represented in Fig. 3 and can be numerically expressed as:

$$F_1 = \frac{(\text{Number of failed variables})}{(\text{Total number of variables})} \times 100 \tag{1}$$

2.3.2.2. Factor 2 (F_2 – Frequency). It is the percentage of "failed" tests (tests not fulfilling their objectives) which has been diagrammatically depicted in Fig. 4. It can be represented mathematically as:

$$F_2 = \frac{\text{Number of failed tests}}{\text{Total number of tests}} \times 100 \tag{2}$$

2.3.2.3. Factor 3 (F_3 – Amplitude). It represents the amount by which failed test values deviate from their objectives. It is calculated in three steps:

(i) At the very beginning "excursion" is calculated. Excursion can be defined as the number of times an individual parameter is greater than or less than the objective. It is calculated by the equation given as under when the test value does not exceed the objective.

$$\text{Excursion} = \frac{\text{Failed test value}}{\text{Objective}} - 1 \tag{3}$$

In case the test value exceeds the objective, we can use the equation cited below to obtain the value for excursion:

$$\text{Excursion} = \frac{\text{Objective}}{\text{Failed test value}} - 1 \tag{4}$$

(ii) Normalized sum excursions (NSE) denote the total amount through which each test is out of compliance. It is usually calculated by dividing the summation of all the excursions by the total number of tests.

$$\text{NSE} = \frac{\sum_{i=1}^{n} \text{Excursion}}{\text{Total number of tests}} \tag{5}$$

The above expression gives the sum of excursions from the objectives.

(iii) F_3 signifies the extent by which the failed test value is deviated from the local objectives and is calculated with the help of an asymptotic capping function by scaling of the normalized sum of excursions from the objectives within 0–100.

$$\text{WQI} = \frac{\left[100 - \sqrt{\left(F_1^2 + F_2^2 + F_3^2\right)}\right]}{1.732} \tag{6}$$

Table 3
Observation for the season of pre-monsoon for Damodar

	Parameters																					
Location	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
D_1	8.10	152	0.26	290.0	**14.23**	8.80	5.10	96	145	90	55	124	0.20	33	0.07	35.87	0.89	36.0	22.0	43.32	0.23	0.22
D_2	8.30	161	0.13	320.0	1.48	7.70	3.20	64	125	92	33	100	0.12	17	0.01	30.22	0.74	36.8	13.2	32.63	0.04	0.21
D_3	8.10	149	0.21	223.3	5.23	7.20	4.70	96	115	86	29	115	0.18	22	0.03	27.57	0.62	34.4	11.6	40.44	0.01	0.20
D_4	7.90	150	0.18	330.0	1.34	8.30	5.00	64	135	72	63	134	0.12	6	0.02	32.35	0.54	28.8	25.2	18.50	0.11	0.44
D_5	7.50	140	0.35	163.3	6.05	8.70	5.30	64	125	68	57	112	0.13	28	0.13	15.97	0.88	27.2	22.8	45.12	0.12	0.42
D_6	7.70	135	0.50	227.0	3.15	8.00	4.00	32	125	72	53	104	0.17	6	0.01	13.97	0.86	28.8	21.2	43.44	0.99	0.23
D_7	**8.50**	215	0.50	164.1	1.05	7.30	0.67	96	145	56	89	112	0.26	4	0.00	19.96	0.90	22.4	35.6	50.72	0.04	0.17
D_8	7.90	277	3.90	554.0	**374**	**2.00**	2.01	128	155	64	91	136	0.11	70	0.53	67.88	**1.82**	25.6	36.4	109.3	0.54	0.45

Notes: A = pH, B = TDS, C = TSS, D = conductivity (μs), E = turbidity (NTU), F = DO (2 mg/L), G = BOD (mg/L), H = COD (mg/L), I = total hardness (ppm), J = calcium hardness (ppm), K = magnesium hardness (ppm), L = alkalinity (mEq/L), M = oil and grease, N = Coliform (MPN/mL), O = chromium (mg/L), P = chloride (mg/L), Q = fluoride (mg/L), R = calcium (mg/L), S = magnesium (mg/L), T = sulfate (mg/L), U = phosphate (mg/L), and V = nitrate (mg/L). Values marked with bold indicate the exceedance of the value from permissible limit.

Table 4
Observation for the season of monsoon for Damodar

Location	Parameters																				
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
D_1	7.47	140	0.16	280	**78.20**	**5.36**	2.68	64	130	75	55	112	0.02	34	**0.05**	25.66	0.54	30	22	31.26	0.05	0.19
D_2	7.61	150	0.04	301	2.59	**5.36**	2.01	32	115	75	40	120	0.00	14	0.00	23.09	0.43	30	16	24.37	0.01	0.15
D_3	7.30	113	0.08	226	**25.80**	6.71	3.36	64	100	70	30	96	0.02	17	0.04	17.96	0.37	28	12	12.57	0.12	0.18
D_4	7.56	161	0.06	323	1.83	6.03	0.67	32	130	60	70	120	0.00	2	0.00	28.23	0.33	24	28	6.38	1.00	0.22
D_5	7.58	122	0.10	247	**48.60**	**5.36**	2.01	96	115	35	80	40	0.04	6	**0.17**	15.39	0.52	14	32	34.60	0.09	0.19
D_6	7.55	129	0.10	259	**74.90**	**4.69**	0.67	96	110	60	50	104	0.02	17	**0.05**	17.96	0.50	24	20	13.27	0.06	0.23
D_7	**10.0**	198	0.26	244	**42.10**	14.09	4.03	64	60	45	15	112	0.04	12	**0.06**	17.96	0.57	18	6	13.86	0.13	0.15
D_8	7.76	228	0.72	457	**475**	**4.02**	4.02	128	170	40	130	152	0.08	**50**	**0.39**	48.76	0.89	16	52	19.46	0.32	0.23

Notes: A = pH, B = TDS, C = TSS, D = conductivity (μs), E = turbidity (NTU), F = DO (2 mg/L), G = BOD (mg/L), H = COD (mg/L), I = total hardness (ppm), J = calcium hardness (ppm), K = magnesium hardness (ppm), L= alkalinity (mEq/L), M = oil and grease, N = Coliform (MPN/mL), O = chromium (mg/L), P = chloride (mg/L), Q = fluoride (mg/L), R= calcium (mg/L), S = magnesium (mg/L), T = sulfate (mg/L), U = phosphate (mg/L), and V = nitrate(mg/L). Values marked with bold indicate the exceedance of the value from permissible limit.

Table 5
Observation for the season of post-monsoon for Damodar

Location	Parameters																				
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
D_1	8.13	68.7	0.033	136.9	**13.97**	9.26	2.81	64	112	100	12	272	0.004	0.18	0.004	25.99	0.702	40	1.44	35.29	0.039	0.278
D_2	7.84	98.6	0.050	197.3	7.84	6.04	3.62	96	136	104	32	224	0.004	0.11	0.004	29.99	0.404	41.6	3.84	26.64	0.003	0.083
D_3	7.82	84.9	0.016	169.9	7.31	6.44	3.22	64	180	108	72	224	0.001	0.15	0.001	29.99	0.368	43.2	8.64	36.96	0.010	0.021
D_4	**8.78**	80.8	0.016	177.1	**17.76**	10.8	5.24	64	148	92	56	176	0.004	0.11	0.004	31.99	0.276	36.8	6.72	34.60	0.014	0.108
D_5	**8.77**	63.8	0.016	127.1	1.70	11.2	5.64	32	144	80	64	192	0.010	0.09	0.010	15.99	0.606	32	7.68	27.52	0.017	0.075
D_6	**8.85**	48.9	0.016	99.0	2.05	12.0	5.24	96	132	76	56	176	0.006	0.15	0.006	13.99	0.631	30.4	6.72	25.16	0.016	0.037
D_7	8.26	70.2	0.033	157.2	2.66	8.85	3.22	64	112	80	32	192	0.008	0.17	0.008	13.99	0.626	32	3.84	27.52	0.018	0.192
D_8	**9.09**	98.3	0.716	213.3	**387**	**4.83**	4.03	96	180	96	84	432	0.037	0.20	0.037	101.96	1.12	38.4	10.1	60.06	0.502	0.292

Notes: A = pH, B = TDS, C = TSS, D = conductivity (μs), E = turbidity (NTU), F = DO (2 mg/L), G = BOD (mg/L), H = COD (mg/L), I = total hardness (ppm), J = calcium hardness (ppm), K = magnesium hardness (ppm), L= alkalinity (mEq/L), M = oil and grease, N = Coliform (MPN/mL), O = chromium (mg/L), P = chloride (mg/L), Q = fluoride (mg/L), R= calcium (mg/L), S = magnesium (mg/L), T = sulfate (mg/L), U = phosphate (mg/L), and V = nitrate (mg/L). Values marked with bold indicate the exceedance of the value from permissible limit.

Ultimately, the CWQI is determined from the equation given above.

It is worth noting that 1.732 is a scaling factor which brings the index between 0 and 100 [8]. Interpretation of WQI for each location along with the remarks has tabulated below. Values are further compared with the interpretation Table 2 [24].

3. Results and discussion

The present work has dealt with various physicochemical parameters, which have shown temporal and spatial variations over the year of 2012. The results for the seasonal variations of few selected parameters for pre-monsoon, monsoon, post-monsoon have been represented in Tables 3–5, respectively. Prepared by considering all the eight sampling sites based on the calculated Water Quality Index of Damodar River for the year 2012. The observed parameters have definite fluctuation according to the location and season. pH is an important parameter to comment on the health status of water from a specific river (whether it is acidic or basic). It was found that the pH value was within neutral to alkaline or slightly alkaline range throughout the year as represented by Figs. 5(a), 6(a), and 7(a). D_7 location has been found to possess maximum pH

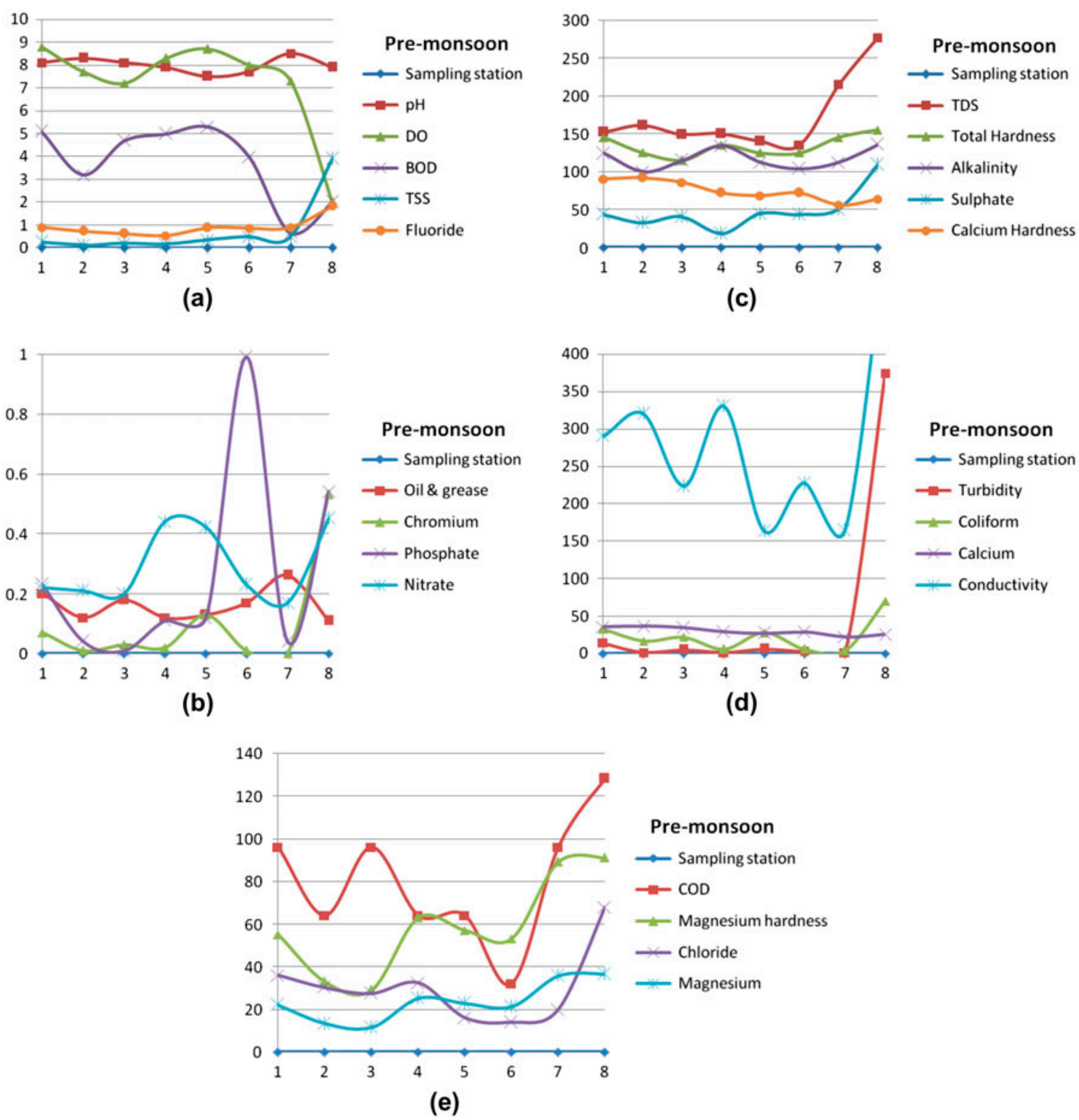

Fig. 5. Water quality parameters for pre-monsoon.

of 10 during monsoon compared with other locations as shown by Fig. 6(a). Presence of various kinds of minerals in water is denoted by TDS whose value was found within its acceptable limit as depicted in Table 6. The observation of Fritsch [33] stated that alkaline water has more total solids than acidic water, which is true for the present study as evident from the graphs shown in Figs. 5(c), 6(c), and 7(c). EC defined as the capability of an ionic solution to conduct current can vary if subjected to the change in composition of water. Change in the conductivity was observed for every season and location with a maximum limit of 554 μS/cm as depicted through Figs. 5(d), 6(d), and 7(d), respectively, during the season of pre-monsoon. The cloudy appearance of water is reflected by its *turbidity* expressed in NTU unit. Turbidity for the first and last location was observed as 14.23 and 374 NTU, respectively, which exceeded the permissible limit as depicted in Figs. 5(d), 6(d), and 7(d). In the season of monsoon, most of the location is seen to have exceeded permissible limit of turbidity as shown in Fig. 6(d). DO is yet another important parameter that acts as an input to compute WQI. Presence of sufficient amount of DO facilitates a healthy environment for the survival of aquatic organisms. DO has been shown in Figs. 5(a), 6(a), and 7(a), respectively, for the three consequent seasons. High chloride level leads to the reduction of DO level and increase in BOD level. Further with addition of domestic sewages along with the stream, microbial activity and BOD of the aquatic system gets increased accompanied by depletion of DO in river water. It was observed that DO level was

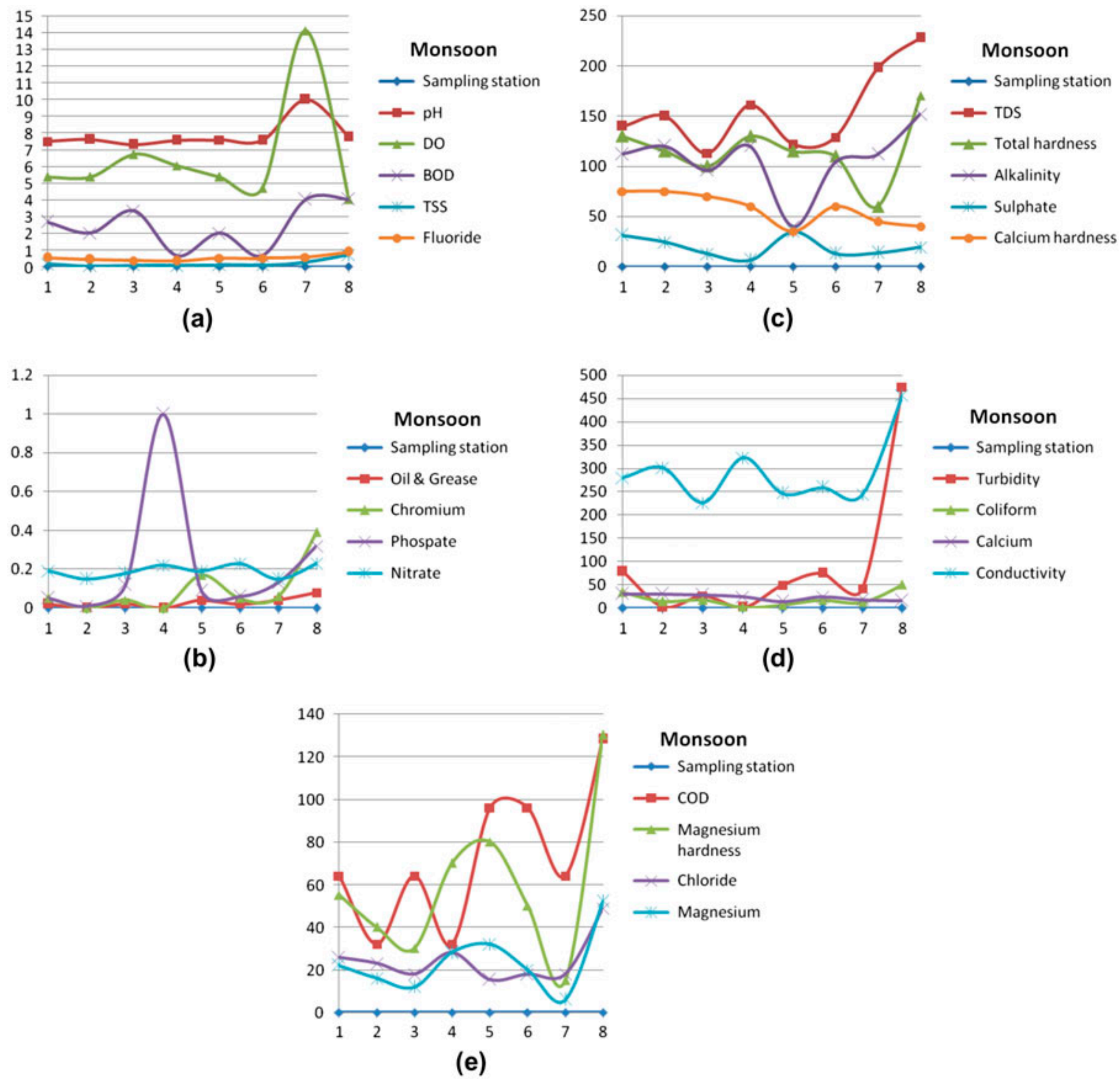

Fig. 6. Water quality parameters for monsoon season.

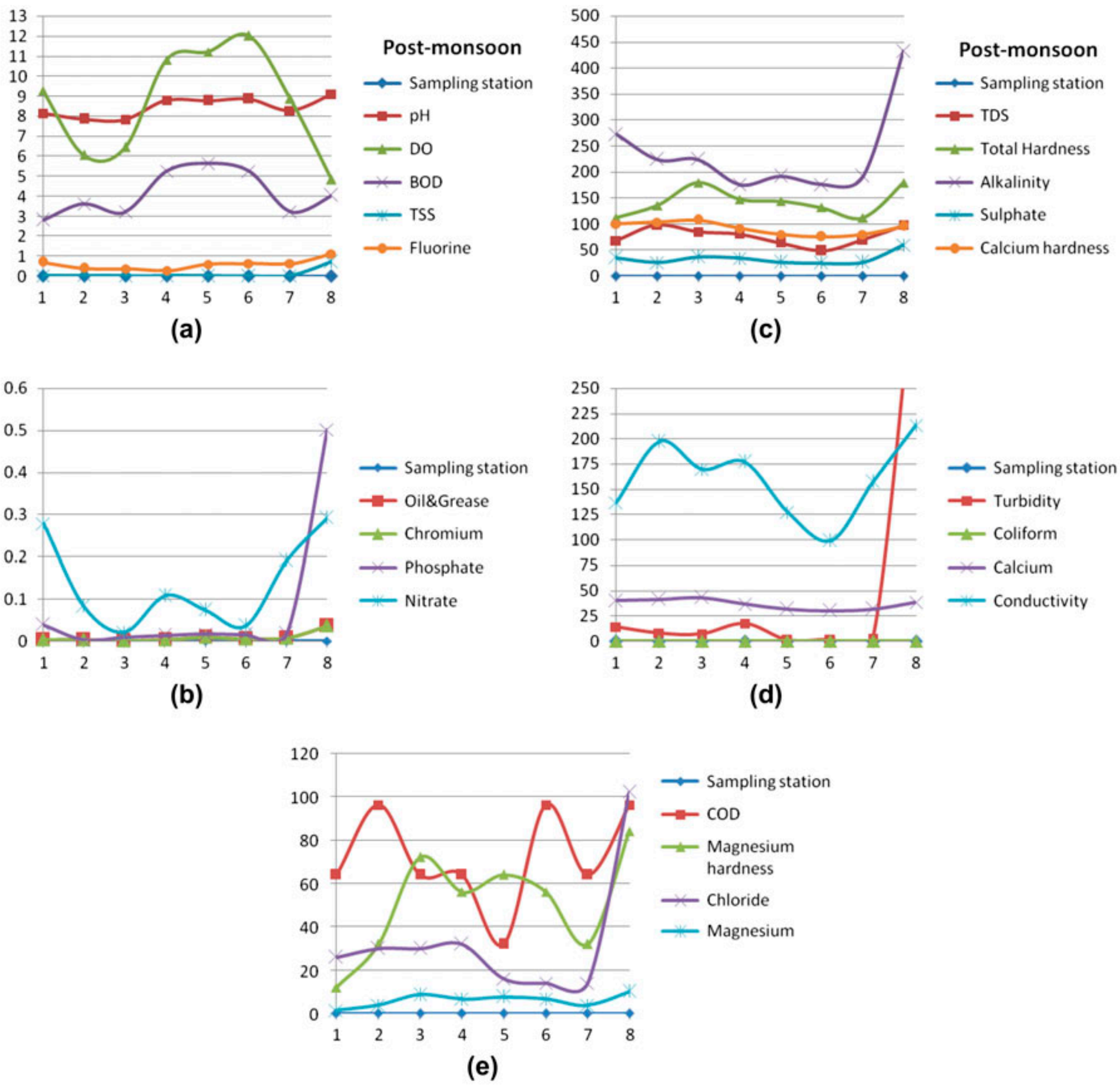

Fig. 7. Water quality parameters for the period of post-monsoon.

within the comfort level to support aquatic life in contrary to the last location with a DO value of 2 mg/l. In the season of monsoon it was found that DO level for most of the locations remained below the permissible limit. This may be due to heavy sewage contamination at different stations. Apart from DO and turbidity, the concentration of chromium has contributed greatly to CCME WQI. For few sampling points, the chromium concentration has diverted copiously from its permissible value of 0.05 mg/l as represented in Figs. 5(b), 6(b), and 7(b). This particular finding of chromium may be due to the activity of few surrounding tannery industries. Finding of chromium in Damodar River is a subject of interest for researchers to their further analysis. The concentration of sulfate, phosphate, nitrate, total hardness, alkalinity remained within their safe limits consistently for all of the three seasons. Fluoride which is a dangerous element in terms of its ability to cause dangerous human disease such as fluorosis was within its permissible value of 1.5 mg/l for all the sampling stations. Only a fluctuation was observed in the season of pre-monsoon for the last location (D_8) with an alarming fluoride level of 1.82 mg/l as shown in Fig. 5(a).

The load of total Coliform bacteria present in water was determined with most probable number (MPN). Presumptive test determines the number of Coliforms present in a water sample. In the season of pre-monsoon, monsoon, and post-monsoon the number of Coliform bacteria for the last location was observed

Table 6
Indian standards for drinking water specifications

Sl No.	Parameter	Desirable limit
1	Turbidity	1–5
2	pH	6.5–8.5
3	Total Hardness	200–600
4	Calcium	75–200
5	Magnesium	30–100
6	Chlorides	250–1,000
7	Sulfates	150–400
8	Nitrate	45 (no relaxation)
9	Fluoride	0.6–1.2
10	Chromium (Cr^{+6})	0.05
11	Alkalinity	200–600
12	BOD	30–100
13	TDS	500–2000
14	Oil and grease	0.5 (no relaxation)

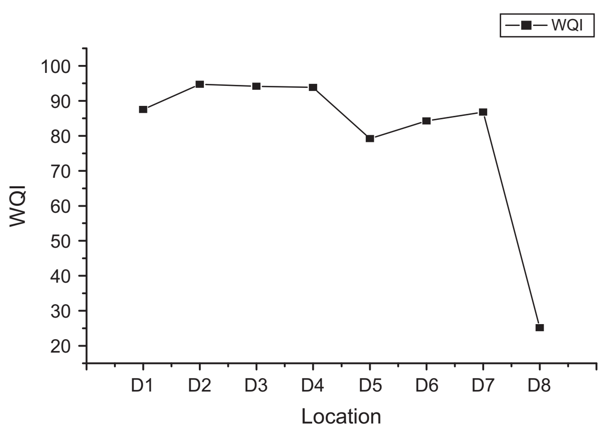

Fig. 8. WQI of all locations of Damodar River.

to be 70, 50, and 55 MPN/100 ml, respectively. The cause can be attributed to the mixing of industrial wash out with the addition of sewage contamination in this location which creates a healthy condition for the micro-organism to live in the long run.

The results represented in Fig. 8 have shown that the WQI values for almost all the locations are within good to excellent range as per the CCME WQI methodology except D_5 and D_8. The last location (D_8) exhibited a poor WQI value of 25.14 as it carried more effluents into the river for being severely influenced with discharges of Tamlanallah. More pollutants from local sources were also carried down for which the WQI value for D_5 was found to bear a fair value of 79. Thus, it is summarized that with an increase in the pollutant parameters, WQI value decreased and vice versa.

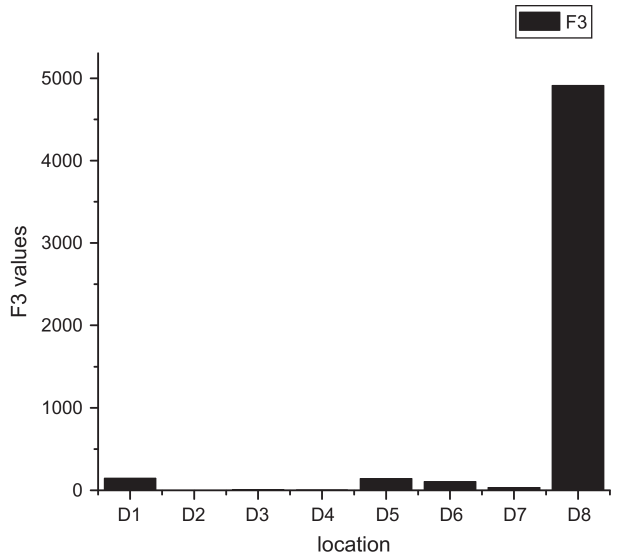

Fig. 9. Histogram showing F_3 (amplitude) values for all the locations.

In addition, F_1, F_2, and F_3 have been calculated from the measurements and represented in Figs. 3, 4, and 9, respectively. Cluster analysis is a reliable technique that has been applied to enable us to design a future spatial sampling strategy in an optimal way by classifying Water Quality Index in the whole region across the river basin. Thus, the number of sampling sites for the evaluating network gets eventually reduced. Eight sampling stations along the stretch of Damodar River have been considered for cluster analysis to obtain a single index equation for each group, rather than having an equation for every station. Thus, a considerable load of work is reduced. In Fig. 2, cluster 1 and cluster 2 are categorized as low pollution and high pollution station, respectively. Cluster 1 consists of locations 1–7. Two groups are closely associated with cluster 1. First group includes locations 3, 4, and 2 and the second group from cluster 1 consists of location 1, 7, 6, and 5. Both are significant in terms of linkage distance. Cluster 2 consists of location 8 only. Since D_8 is a lone element, it would have different characteristics from the rest of the sampling stations. The WQI has been calculated for individual location with the help of F_1, F_2, and F_3 for all the eight locations collected during three consecutive seasons of pre-monsoon, monsoon, post-monsoon. The calculated values of WQI have been represented graphically in Fig. 8.

4. Conclusion

Simple analysis of physicochemical parameters could not produce Water Quality Index. Hence, CCME

Water Quality Index was evaluated in the present investigation by considering the physicochemical and microbial parameters. After detailed observation, it was inferred that the activities of local inhabitants and wash out from municipal discharge along with the disposal of industrial effluents were mainly responsible for adversely affecting the water quality. The WQI for most of the sampling stations had assured the suitability of this water for irrigation and other domestic purposes. However, the water is still not fit for drinking without any mild pretreatment. Climatic condition has an obvious effect on water quality as deduced from the results which show that the water quality during post-monsoon was better than that for pre-monsoon and monsoon. The last location (D_8) of Damodar River was found to be heavily polluted either due to domestic sewage discharges, disposal of industrial effluents, garbage, and such other anthropogenic activities. This necessitates more precautions and regulatory measures by means of continuous monitoring to prevent the pollutants from exceeding their acceptable limits.

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