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Chapter- 20

Evaluation of frequently used water quality indices (WQIs) depending on their effectiveness in measuring river pollution: A case study on River Churni, West Bengal

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Keywords: Water quality Parameters, index, pollution, River Churni, monitoring

Abstract:

Water quality is highly dynamic attribute of any water body that varies depending on time and space. It is a complex measurable character calculated based on various water quality parameters. The parameters maybe physical parameters (Colour, temperature, turbidity, odour etc.), chemical parameters (pH, hardness, alkalinity, chloride, phosphate, nitrates etc.), and biological parameters (nutrient, virus and microorganisms). Individually, these parameters are not adequate to provide clear idea about water quality of any water body thus, a reporting tool of water quality is very much needed to consolidate the impact of all parameters into a single number. Water quality index (WQI) does the same job. Many researchers have used several WQIs to validate the researches but these indices differ in their effectiveness as well as in construction procedure. The main objective of the present study is to evaluate the usefulness of some frequently used WQIs in measuring the pollution level of a river. River Churni, a river of Nadia district of a West Bengal is selected for the case study. Our findings suggest that water quality index given by Canadian council of ministers of the environment (CCMEWQI) is the most valuable mathematical tool with high potentiality and flexibility having highest power of interpretation of pollution level in a river. This finding may be useful to many researchers and stakeholders for monitoring and testing the water quality of any river over the time.

Introduction:

Water is very crucial component for living on this planet and also for the sustainability of the environment. However, groundwater and surface water quality have long been deteriorating due to various natural and anthropogenic activities (Fortes et al., 2023). Water quality is highly dynamic to study and cannot be quantified using one or two parameters. A set of physical, chemical and biological parameters should be checked to determine the quality of water (Santra et al., 2003; Boyacioglu, 2007, 2010; Panigrahi et al., 2015; Bhattacharya et al., 2016; Mukate et al., 2019; Chakraborty et al., 2019). Measuring each of these parameters requires high knowledge of their interrelationship and interdependence with other external conditions (Iticescu et al., 2019). Theoretically, reports of water quality parameters need to be presented in such a manner that can be understood by various stakeholders engaged in water quality

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evaluation, assessment and monitoring. Water quality indices (WQIs) have been found to be efficient strategy for collecting information with aggregation of many indicators or water quality parameters which could be difficult to interpret separately (Fortes et al., 2023). WQIs help to translate technical facts facilitating overall water quality reporting and interpretation despite the fact that this indices provide a preliminary view of water quality, they have limitations associated to their modeling method, together with information loss due to aggregation and subjectivity inherent to the parameter (Abtahi et al., 2015; Boyacioglu, 2010; Hurley et al., 2012; Rickwood and Carr, 2009). WQIs are mathematical tools or formulations that enable the aggregation and conversion of a experimental dataset with selected water quality parameters into a dimensionless single value (Akter et al., 2016; Brown, 1972; Hurley et al., 2012; Lumb et al., 2011; Mukate et al., 2019).

River Churni, an important source of the surface water of district Nadia of West Bengal (India), is an important tributary of river Bhagirathi- Hooghly. According to Das and Chakrabarty (2007), approximately two-thirds of the total fish species appeared to have been eliminated from this river since 1983 due to the huge pollution load. Besides several local source of pollutions, the river ecology mainly gets disturbed by the effluent of the sugarcane mill complex of Darshana (Bangladesh) several times throughout the year making its water very much polluted (Bakshi et al., 2016; Panigrahi and Bakshi 2016; Bakshi and Panigrahi 2015; Panigrahi et al. 2015; Sarkar and Islam 2019; Roy et al., 2022). The main objective of the study was to evaluate the water quality index of the river water using different water quality indices (WQIs). On the other hand, the present study was also aimed to identify the suitable water quality index among the commonly used indices to evaluate their benefits and limitations based on SOWT analysis (analysis of strengths, weaknesses, opportunities and threats). The result obtained from this investigation will surely be helpful to the future researchers in applying WQI in River Churni and other similar streams.

Materials and methods

The study area and data sources

The investigation was carried out for 12 months and started with data collection in March 2022 and ended in February 2023. River Churni is one of the major distributaries of river Mathabhanga. The river originates at Pabakhali village (Majhdia) of Nadia District. It pours its content into River Bhagirathi-Hooghly near Shibpur (Nadia). Three sampling sites are selected throughout the stretch of river Churni (Table 1) in such a manner that S-1, S-2 and S-3 sites are situated at the upper, middle and lower stretch respectively. Sampling and evaluation of water quality parameters are done according to APHA (1995) guidelines. Dissolved Oxygen, Total Solid, pH and Electrical conductivity have been evaluated using digital meters at the sampling site. Data have been collected from each sampling sites four times a year *i.e.*, pre-monsoon, monsoon, post monsoon and winter. Three commonly used water quality indices have been incorporated to evaluate the water quality of river Churni. The selected water quality indices are The National Sanitation Foundation Water Quality Index (NSF WQI), the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI), Oregon Water Quality Index (OWQI).

Table 1. Sampling sites name and details.

Sampling Site	Latitude	Longitude	Site Code
Krishnaganj	23.403965ºN	88.709667ºE	S-1
Ranaghat	23.263231 ºN	88.6008545ºE	S-2
Aranghata	23.177679ºN	88.558168ºE	S-3

To evaluate the three selected water quality indices on the basis of their strengths, weaknesses, opportunities and threats, SWOT analysis is applied. Data regarding this have been collected, from science research journals of repute, published reports from renowned national or international agencies and doctoral thesis. Weight has been given to the reproducible articles, indexed in journal database like Scopus, Pubmed, Copernicus etc to make the evaluation utmost consolidated and extensive.

Selected parameters for different WQIs

For the calculation of NSF WQI, 9 parameters are incorporated viz., DO, BOD, pH, turbidity, total solids, Water temperature, nitrate total Phosphorus and fecal coliform. Each parameter is meticulously weighted depending on the magnitude of its importance on water quality following the classification by Brown et al. (1970). The Canadian Council of Ministers of the Environment Water Quality Index Model (CCMEW QI) was developed in Canada in 2001 (Fortes et al. 2023). The parameters used in calculating th e CCME-WQI values are not adjusted, allowing for easy use of water quality. In this study, pH, water temperature, Electrical conductivity, DO, BOD, nitrate, phosphate, total solid and fecal coliform are taken into consideration. To evaluate OWQI, the selected water quality parameters are as follows: water temperature, Electrical conductivity, DO, BOD, ammonia and nitrate, total phosphate, total solid and fecal coliform (Table 2).

Table 2. Parameters used to calculate index and their units

Sl. No.	NSF-WQI	CCME-WQI	OWQI
1.	pH	pH	Water Temperature (ºC)
2.	Water Temperature (ºC)	Water Temperature (ºC)	Electrical Conductivity
3.	Turbidity (NTU)	Electrical Conductivity(µS/cm)	DO (ppm)
4.	DO (ppm)	DO (ppm)	BOD (ppm)
5.	BOD (ppm)	BOD (ppm)	Ammonia and Nitrate (ppm)
6.	Nitrate (ppm)	Nitrate (ppm)	Total Phosphate (ppm)
7.	Total Phosphate (ppm)	Total Phosphate (ppm)	Total Solid (ppm)
8.	Total Solid (ppm)	Total Solid (ppm)	Fecal Coliform (MPN/L)

9.	Fecal Coliform (MPN/L)	Fecal Coliform (MPN/L)	

WQI assessment methods

The first water quality index has been developed by Horton in 1965 in USA using 10 water quality parameters (Akter et al., 2016). Among these 10 water quality parameters temperature and pollution level have been treated as adjustment factor and other eight selected parameters are pH, dissolved oxygen, total coliform count, total carbon, alkalinity, chloride and sewage treatment percentage (Lumb et al., 2011; Sarkar and Abbasi, 2006). The NSF WQI has been proposed by Brown (1970) from the National Sanitation Foundation or NSF as a modification of Horton Water Quality Index or HQI. The calculating formula of NSF WQI is as follows.

$$WQI = \sum_{i=1}^{n} Q_i W_i$$

Here Q_i is the sub index value for i-th parameter whereas W_i is the weight of that water quality parameter. Here, 'n' stands for number of evaluated water quality parameters.

Based on individual weight established by Sutandian et al. (2016) and Brown (1970) the weight used for each parameter are as follows: DO (0.17), Fecal Coliform (0.15), pH (0.12), Biological Oxygen Demand or BOD (0.10), Nitrates (0.10), Phosphates (0.10), Water temperature (0.10), Turbidity (0.08) and Total dissolved Solid (0.08).

The Canadian Council of ministers of the environment model of water quality index (CCME-WQI) happen developed in Canada in 2001 (Fortes et al. 2023). The parameters used to calculate the CCME-WQI value are not fixed as it allows flexibility regarding the adoption of water quality parameters. However, a minimum of four water quality parameters must be incorporated to determine the value. The calculation formula is as follows:

$$CCME\ WQI = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}$$

The above mentioned formula have three major components *viz.*, F_1, F_2 and F_3. Here, F_1 is the percentage of the total selected parameters that do not meet the standard value (or BIS value). Whereas, F_2 is the percentage of the performed tests that do not meet the standard value. The calculation of F_1 and F_2 are as follows:

$$F_1 = \frac{Number\ of\ failed\ parameters}{Total\ number\ of\ parameters} \times 100$$

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

F_3, the amount of relativity by which the test values fail to meet the standard value, is calculated following the equation.

$$F_3 = \frac{nse}{(0.01 \times nse + 0.01)}$$

Here, *nse* stands for the collective amount by which the test values fail to meet the standard value. The *nse* value can be calculated by the incorporation of excursion value. Here, excursion value means the number of times the individual tests failed to meet the standard value. The formula for calculating *nse* and excursion are as follows:

$$nse = \frac{\sum_{i=1}^{n} excursion_i}{total\ number\ of\ tests}$$

$$excursion_i = \left(\frac{Failed\ test\ value}{water\ quality\ standard\ of\ the\ i^{th}\ parameter}\right) - 1$$

The calculation of OWQI or Oregon water quality index can be done by incorporating 8 selected parameters, i.e., pH, water temperature, DO, BOD, total solid, ammonia and nitrate, total phosphate and faecal coliform. Each parameter is meticulously weighted equally because unequal waiting is only appropriate for the assessment of WQI developed in a particular manner. The determination of sub-indices value for each parameter is done on the basis of the equations established by Cude (2001). The formula for calculating OWQI value is given below.

$$OWQI = \sqrt{\frac{n}{\sum_{i=1}^{n} \frac{1}{(Q_i)^2}}}$$

Here, Q_i stands for the sub index value for the i-th water quality parameter. And 'n' is the number of investigated water quality parameters.

The water quality status qualification (given in table 3) have been incorporated according to the classification developed by Sutandian et al. (2016) and Dunnate (1979). The interpretation of different WQI values can be useful to understand the qualitative status of water at the three sampling sites.

Table 3. Water quality qualification depends upon index value.

NSF WQI		CCME WQI		OWQI	
Index Value Range	Quality Status	Index Value Range	Quality Status	Index Value Range	Quality Status
91-100	Very Good	95-100	Very Good	90-100	Very Good
71-90	Good	80-94	Good	85-89	Good
51-70	Fair	60-79	Fair	80-84	Fair
26-50	Bad	45-59	Marginal	60-79	Bad
0-25	Very Bad	0-44	Bad	0-59	Very Bad

Determination of most fitted WQI for River Churni

To determine the best fitted WQI model to evaluate the overall pollution status of River Churni, West Bengal, the logical structure of SWOT analysis is applied. SWOT analysis is performed to strategically evaluate the WQIs. The analysis provides the possibility of determining and evaluating the interrelationship between the strengths, weaknesses, threats and opportunities of certain subjects. The analysis comprises two dimensions, viz., external and internal. The internal component comprises the strengths and weaknesses of the subject, whereas the external component comprises the opportunities and threats of the particular subject (Fortes et al., 2023).

Result and Discussion

River Churni and its pollution load

River Churni, an important river of the Nadia district of West Bengal (India), provides livelihood for a huge number of fishermen in the four blocks of Nadia district (Krishnaganj, Hanskhali, Ranaghat I and Ranaghat II). The river originates as a distributary of river Mathabhanga near Krishnaganj. After flowing about 54 kms the river pours its content into the river Bhagirathi Hooghly near Shibpur, Nadia. The river has been facing the problem of ecological degradation since the 1980s (Das and Chakrabarty, 2007; Panigrahi et al., 2015) mainly due to the effluent of sugar mill factories and wine factories situated at Darshana (Bangladesh). A huge number of fish species, plankton groups, and macrobenthic invertebrates have been reported to be eliminated from the river in the last few decades (Bakshi and Panigrahi, 2015). There are two main types of pollution sources: point sources and non-point sources. The point sources of the pollution are the sugarcane mill of Bangladesh, the wine factory of Bangladesh, municipal sewage from Birnagar and Ranaghat municipality, thread dyeing houses of Ranaghat, etc. Whereas the non-point sources are brick kilns, agricultural lands, jute retting, etc., situated at various places on both sides of the river.

Water quality of the river is receiving pollutants from various sources throughout the stretch. The effluent from sugarcane mill complex lowers the dissolved oxygen value, alters pH, increases BOD value. The prominent impact of this effluent is majorly noticed in the upper stretch. Whereas in the middle and lower stretches of the river, water quality remained disturbed for a few days. Regular tidal flow in the lower and middle part of the stretch minimize the effect of the pollutant very quickly. The major pollution sources of middle and lower part of the river are municipal wastes increasing the contamination of fecal Coliform in the water. Electrical conductivity remains high in the lower part of the river due to the dumping of solid wastes and brick kilns. The level of dissolved oxygen is very low throughout the stretch, whereas BOD values range high throughout the stream. The average and standard deviation values are given in Table 4 for all the evaluated parameters.

Application of different WQI methods to calculate the quality of the water

Different water quality parameters show that the river water remains better in the monsoon period. The higher rainfall could cause a better condition of river water quality because it dilute the pollutant naturally. The result of the WQI assessment shows that water quality is better at the lowest rate of the river regardless of the method applied. In all three calculation methods it is shown that the river water quality is either poor or very poor quality. The data of WQI is obtained sampling site wise. Though calculation of NSF-WQI can be done seasonally or monthly. DO, BOD, pH, turbidity, total solids, Water temperature, nitrate total Phosphorus and fecal coliform are assessed seasonally and meticulously weighted according to Sutandian et al (2016). The value of NSF-WQI ranges from 41.2 to 46.9 which means that overall pollution level of each sampling site is 'Bad'.

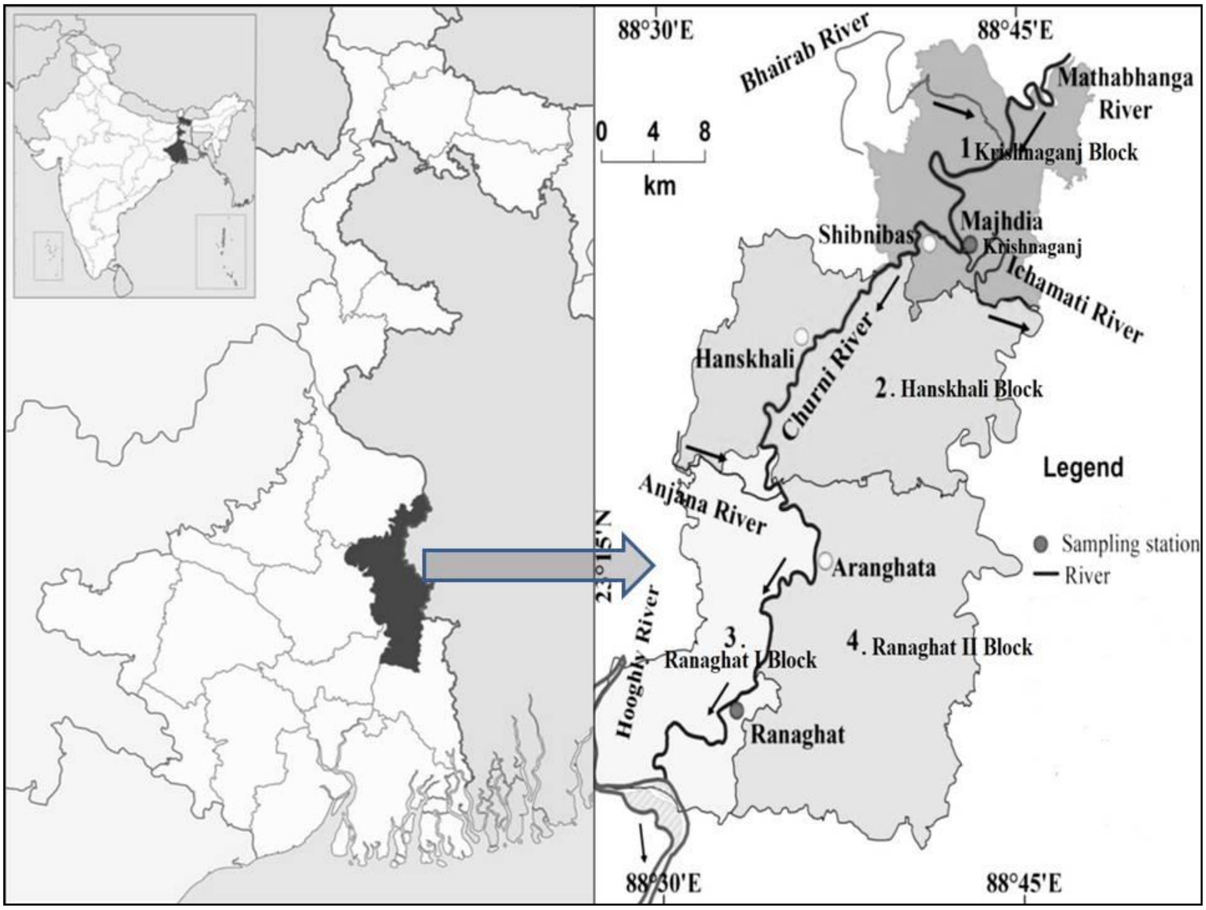

Figure 1. River Churni and position of sampling sites.

Table 4. Water quality Parameters of different sampling sites.

Sites	Values	Temp(°C)	pH	Turbidity (NTU)	DO (ppm)	BOD (ppm)	Nitrate (ppm)	Total Phosphate (ppm)	Total Solid (ppm)	Fecal Coliform (MPN/100 ml)	EC (µS/cm)
S-1	Avg	17.397	3.8 6602	4.52548	1.87842	4.38389	0.90066	0.2863	410.184	43648.5	342.408
	SD	12.2	3.8 953	4.0876	1.28	3.31	0.159	0.14879	335.71	11956.2	115.

		107	2	6	029	618	23		1		718
S-2	Avg	27.8875	7.075	7.74167	2.575	8.1375	0.975	0.3675	649.695	34362.5	421.75
	SD	6.47178	0.49917	1.02477	0.9535	1.94567	0.67777	0.15327	100.686	33261.5	241.432
S-3	Avg	28.05	7.4	8.375	3.325	6.185	1.045	0.455	747.255	58025	461.5
	SD	7.1789	0.4899	0.96047	0.66018	1.26737	0.90486	0.16941	143.099	48944.9	244.951

The CCME WQI assessment is done using 8 parameters excluding water temperature as no standard values have been found for this parameter. The number of field parameter in S-1 is 6. Number of tests is 32 among which 19 tests fail to meet up the standard value. F1 and F2value for sampling site 1 (S-1) and sampling site 2 (S-2) remain same because the number of failed parameters number of taste and number of failed tests are equal for both sampling sites (Table 5).

Table 5. Calculated values of different components of CCME WQI

Sites	No. of Parameters	No. of failed parameters	No. of Tests	No. of Failed Tests	F1	F2	F3	CCME WQI
S-1	8 (excluding Water Temperature)	6	32	19	75	59.375	97.4337	21.16542
S-2	8(excluding Water Temperature)	6	32	19	75	59.375	98.3342	20.79329
S-3	8 (excluding Water Temperature)	4	32	13	50	40.625	99.7208	31.45452

Various research have been performed to confirm the contradiction visible when the usage of unique WQIs. In truth, the end result can be explained by using aggregation of the indices. but, the unparalleled of the water parameters varies in step with the spatio-temporal dimensions of its direction all through the cycle and in line with allocations and makes use of. The latter determines the selection of water excellent variables, the analytical approach, and the sampling period (Kachroud et al. 2019).

Table 6. Values of different WQIs and interpretation

NSF WQI		CCME-WQI		OWQI	
Index Value	Quality of water	Index Value	Quality of water	Index Value	Quality of water
41.2	Bad	21.16542	Bad	11.51	Very Bad
44.97	Bad	20.79329	Bad	11.43	Very Bad
46.9	Bad	31.45452	Bad	11.17	Very Bad

SWOT analysis to evaluate the best fitted WQI method

According to Sarkar and Abbasi (2006), selection of large number of parameters poses weakness because greater number of aggregated data leads to greater loss of information confirming inaccurate calculation of water quality index. But in case of river Churni the pollution sources are diffused. So, incorporation of incorporation of multiple water parameter is recommended. According to Nabizadeb et al. (2013), weighting of the water quality parameters is considered to be subjective allowing another weakness. To be very precise, weighting of water quality parameters is highly dependent on users' expertise and judgement (Dash and Kalamdhad 2021). So, we selected CCME-WQI for assessment of water quality of river Churni. Though, NSF-WQI is a very good reporting tool but due to average measurability and low flexibility it is not treated as the most appropriate WQI assessment method (Table 7). OWQI is is very strict in selection of parameters and with low flexibility. The weighting method is also ambiguous, thus it is not the ideal tool to evaluate the pollution level of river Churni.

Table 7. SWOT analysis and interpretation on the basis of River Churni

WQI methods	SWOT analysis				Remark on the basis of Churni River
	Internal forces		External forces		
	Strengths (+)	Weaknesses (-)	Opportunities (+)	Threats (-)	
NSF-WQI	Good reporting tool. Spatio-temporal comparison can be assessed easily.	Limited use of parameters. Chances of eclipsing (weighted geometric and arithmetic mean subject to over – estimation of quality) is	Recommended by many researchers for assessing overall water quality with special reference to drinking purpose. Data aggregation model	Absence of monitoring data of selected parameters.	Good reporting tool for surface water assessment but limited number of parameters can be incorporated.

		there. Low flexibility and average measurability.	becomes more flexible by incorporating sub-index value from pre-existing literature.		
CCME-WQI	Good reporting tool. Spatio-temporal comparison can be assessed easily. No limitation in parameter selection. High flexibility. High measurability. Non-linear data aggregation without weight calculation.	Non-linear, complex to calculate, data aggregation is done without weighting.	Recommended by many researchers for assessing overall water quality. Use is universal in context of measured limitations.	Absence of monitoring data of selected parameters	Ideal for river Churni as it allows more parameters to be incorporated. As the pollution is of diffused type evaluation of multiple parameters is essential.
OWQI	Good reporting tool.	Limitations in selecting parameters. Weighting is ambiguous. Low flexibility.	Surface and ground water for drinking purposes can be assessed.	Absence of monitoring data of selected parameters	Not ideal due to low flexibility and ambiguous weighting method.

Flexibility is identified as a weakness in SWOT analysis by Fortes et al. (2023). But they also conclude that it is desirable WQI characteristics in assessment of pollution. Thus flexibility is given importance to avoid the restrictions in selecting the parameters to prepare a well defined modelling.

Conclusion and Future approaches

The results of the study indicate that the Churni River is experiencing a huge pollution load from some point and some nonpoint sources. It is measured that the water quality is below the standard level throughout the stretch. Application of different water quality indices generates different WQI values to interpret the pollution level. All three WQIs (viz., NSF-WQI, CCME WQI, OWQI) validate the fact that sampling site 1 (S-1) is more highly affected by the pollution than the other two sampling sites (S-2 and S-3). Sampling site-3 (S-3) shows little higher value of CCME WQI than the others depicting the fact that the pollution level is slightly less in the lower stretch of the river. This may be due to the tidal effect of the river, which has no influence on the upper stretch of the river. SWOT analysis proved that CCME WQI method is the most suitable WQI assessment method in case of river Churni mostly due to its universal approach and high flexibility. In this study, all over pollution index has been studied on the basis of different sampling sites. There are more opportunities for the future researchers to study extensively considering monthly data instead of seasonal data of any river. Incorporation of more WQI analysing methods can make the study more reliable scientifically.

Conflict of Interests

Author wants to announce that there is no conflict of interest with anybody or any institution regarding this research work.

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