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ORIGINAL ARTICLE

Risk characterization and surface water quality assessment of Manas River, Assam (India) with an emphasis on the TOPSIS method of multi-objective decision making

Kunwar Raghvendra Singh[1] · **Rahul Dutta**[1] · **Ajay S. Kalamdhad**[1] · **Bimlesh Kumar**[1]

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Abstract

The present study centers on the investigation of surface water quality with the aid of quality indices and explores the application of a multi-objective decision-making method (TOPSIS) in arranging decisions for policy makers on the basis of overall ranking of the sampling locations. A case study has been performed on the Manas River, Assam (India). Water Quality Index (WQI) involving physico-chemical parameters, and heavy metal pollution index (HPI) and contamination index (CI) involving heavy metal influences were employed for water quality assessment. WQI graded two sampling locations "very poor" and all other locations "poor". HPIs of all the locations were below the critical value of 100, but the CI depicted that two locations were "moderately contaminated". Risk assessment to human health was done using hazard quotient and hazard index. Cluster analysis (CA) demonstrated site similarity by grouping the relatively more polluted and less polluted (LP) sites into two major clusters. However, there surfaced difficulty in discerning the overall water quality, as all the three quality indices included different parameters and contradicted each other. A multi-objective decision-making tool, TOPSIS was therefore employed for ranking the locations on the basis of their relative pollution levels. The novelty of the study reflects in the identification of the relatively more or relatively less polluted sites within the same cluster in CA by the application of TOPSIS. The study justifies the effectiveness of TOPSIS method in prioritizing decisions in complex scenarios for policy makers.

Keywords Water quality · Manas River · TOPSIS · WQI · HPI · CI · Risk assessment · Cluster analysis

Introduction

Adulteration of surface water quality as a consequence of natural or man-made activities has garnered global attention for their conservation and protection (Carpenter et al. 1998). The expulsion of untreated municipal and industrial waste, agricultural run-offs, leaching from landfills, mining and other activities have not only been hostile to aquatic ecosystems but also have introduced various trace elements such as toxic metals which have a persisting and non-biodegradable character (Carpenter et al. 1998; Sin et al. 2001). Extensive programs for water quality monitoring and assessment have thus surfaced worldwide so as to counter any activity causing the degradation of such resources.

Monitoring programs evaluate a broad array of physical, chemical and biological water quality parameters as well as the concentration of heavy metals in water. This necessitates the integration of these large and complex data sets into meaningful results that can represent the overall water quality status of a water body and can also be presented to planners and decision makers to take remedial action during an event of pollution. This led to the evolution of Water Quality Indices (WQIs) which aggregate a large set of measured parameters into a single numeric value (Zandbergen and Hall 1998). Nowadays, heavy metal contamination has turned out to be an area of major focus for water quality researchers due

✉ Kunwar Raghvendra Singh
s.kunwar@iitg.ac.in

Rahul Dutta
rahul.dutta@iitg.ernet.in

Ajay S. Kalamdhad
kajay@iitg.ernet.in

Bimlesh Kumar
bimk@iitg.ernet.in

1 Department of Civil Engineering, Indian Institute of Technology Guwahati, Guwahati 781039, India

to its toxicity and abundance (Sin et al. 2001). Heavy metals can cause fatigue and damage the operations of brain, lungs, liver, kidney, blood composition and other important organs. Chronic exposure to heavy metals can damage the neural system paving the way for multiple sclerosis, Parkinson's disease, and muscular dystrophy (Järup 2003; Harmanescu et al. 2011). Ingestion of lethal doses can cause cardiovascular collapse and renal tubular damage. These effects emphasize the need for quantification of heavy metals by quality indices such as the Heavy Metal Pollution Index (HPI) given by Mohan et al. (1996) and the Contamination Index (CI) developed by Rapant et al. (1995) and refined at Geological Survey of Finland. These assessments are necessary not only for evaluating the heavy metal contamination as a numerical score but also for assessing the scope of potability of water.

Apart from WQIs, the potential of multi-objective decision-making methods in stream restoration efforts has been evaluated by researchers in modifying WQI ranking, redressing management issues such as storage system, performance assessment, demand response and renewable energy sources (Aalami et al. 2010; Sianaki and Masoum 2013; Zahedi 2017; Yousefi et al. 2018). Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is an effective methodology for ranking a number of conceivable alternatives by gauging their Euclidean distances (Sianaki et al. 2018). The TOPSIS method based on information entropy tries to arrive at a positive ideal solution (PIS) and a negative ideal solution (NIS), and then finds the scenario nearest to the PIS and farthest from the NIS (Sianaki et al. 2018).

WQIs are used for assessing the water quality with respect to physico-chemical parameters and heavy metal contamination is quantified by HPI and CI, as conventional WQIs do not include them in their computations. This necessitates the need for the TOPSIS method for not only providing an overall ranking of the sites by taking into account both the physico-chemical parameters and heavy metals but also prioritizing decisions in time of contingencies.

In this study, water quality of Manas River in Assam (India) has been assessed. Its water quality has been represented in terms of WQI. Heavy metal contamination was evaluated using HPI and CI. Health hazard due to heavy metals was expressed as hazard quotient (HQ), developed by U.S. Environmental Protection Agency (US EPA). Overall ranking in terms of pollution level of each sampling site was decided by TOPSIS and verified by cluster analysis (CA). Although, earlier studies have focused on modifying expected conflicts between drinking water quality index and irrigation water quality index, and validation of groundwater quality indices and its classes by the application of TOPSIS (Zahedi 2017; Zahedi et al. 2017; Yousefi et al. 2018), no study has identified relatively less polluted sites and relatively more polluted sites by removing conflicts between drinking water quality index and heavy metal pollution indices. Also, this study depicted the utility of the TOPSIS method in identification of relatively less polluted and relatively more polluted sites within the same cluster in cluster analysis.

Materials and methods

Study area

The Manas River has its origin in the Himalayan foothills between southern Bhutan and India. It is regarded as the largest river system of Bhutan and debouches into India through western Assam. It covers a distance of 104 kilometers in the state of Assam (India) before discharging into the Brahmaputra River at Jogihopa. The Manas River flows through the outskirts of Bongaigaon which is a major city in the state of Assam. As per Indian census of 2011, the population of the city is more than 1,00,000. The climate is humid sub-tropical in the region and it experiences the highest rainfall during the months of June and July (more than 350 mm). It receives less rainfall during winter (November to February). The average temperature of the city varies from 10 to 35 °C. The study area has been depicted in Fig. 1.

Sample collection, preservation and analysis

The collection of water samples was done from nine sampling locations located along the stretch of the river (Fig. 1). All water samples were taken at 0.5 m below the surface of the river in triplicates. A total of 15 physico-chemical parameters were analyzed. pH and dissolved oxygen (DO) were measured in situ. Titrimetric method was done for the analysis of total hardness (TH) and total alkalinity (TA). Sodium (Na^+), calcium (Ca^{2+}), and potassium (K^+) were analyzed using flame photometer. Anions were analyzed by ion chromatograph (IC). A total of six metals namely iron (Fe), manganese (Mn), chromium (Cr), copper (Cu), lead (Pb) and zinc (Zn) were measured in all the sampling sites by atomic absorption spectroscopy (AAS). Analytical procedures of Standard Methods for the Examinations of Water and Wastewaters 20th edition, published by APHA (2012) have been followed throughout the analysis.

Water Quality Index (WQI)

The method adopted for the calculation of WQI was in accordance with Alobaidy et al. (2010) and proceeds as follows:

Step 1 A total of 15 parameters were taken and each parameter was allotted a definite weightage (W_a) according to its relative influence on the entire water quality varying from 1 to 5 (Table 1). Parameters which influenced more ominously

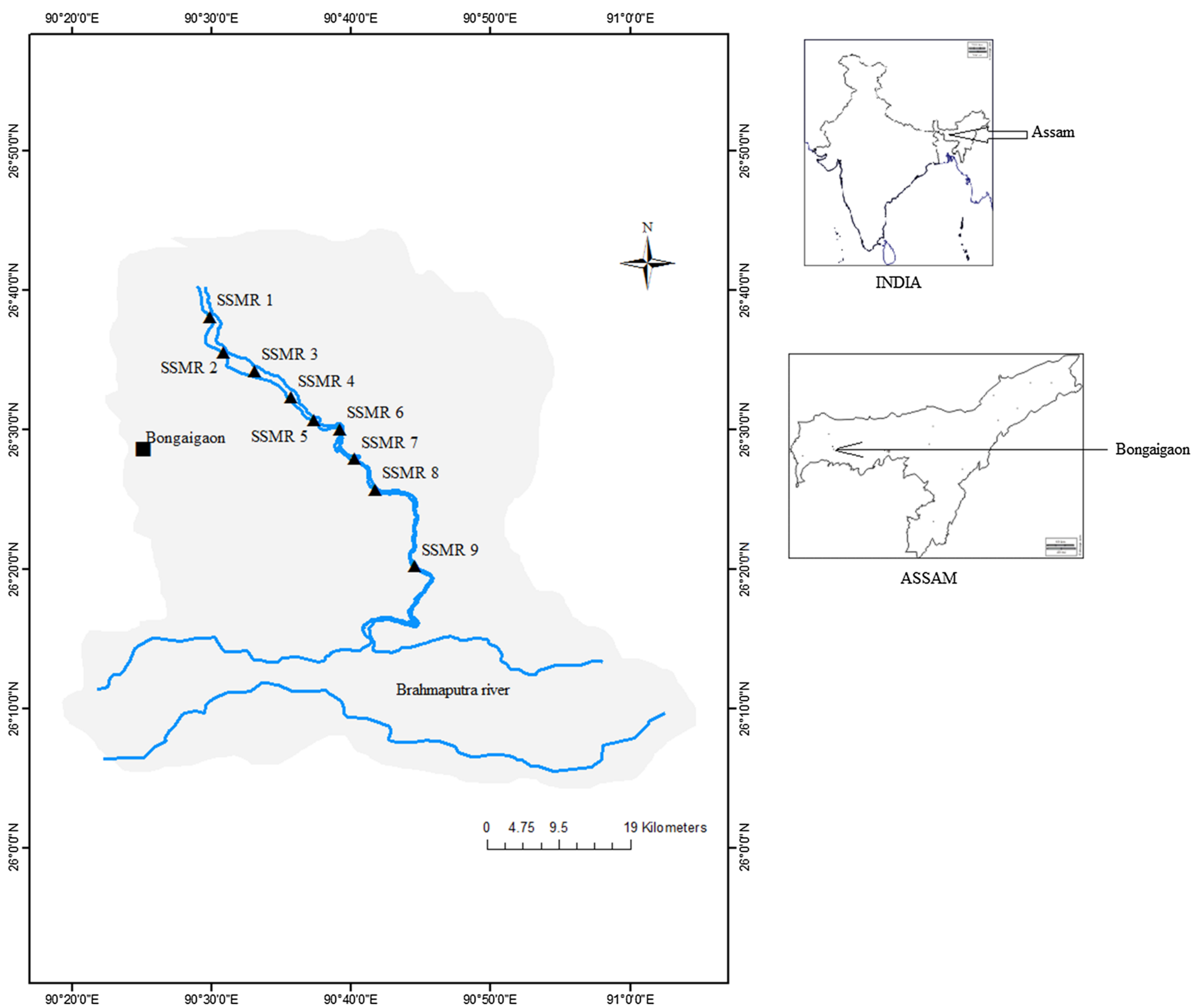

Fig. 1 Map of water sampling sites in the Manas River

the water quality were assigned a weight of 5 and the least influencing parameters were assigned a weight of 1 (Sharma et al. 2014). Relative weights (W_r) were worked out using the formula given below:

$$W_r = W_{ai} / \sum_{i=1}^{n} W_{ai} \quad (1)$$

where W_r and W_{ai} denote the relative weightage and assigned weightage to each parameter, n indicates the number of parameters considered for the computation of WQI. The calculated value of W_r for each parameter is given in the Table 1.

Step 2 A quality rating scale (Q) was calculated as:

$$Q_i = \left[C_i / S_i \right] \times 100 \quad (2)$$

In calculating the Q for the dissolved oxygen (DO) and pH, a different method was engaged such that the ideal values (V_i) of pH (7.0) and DO (14.6) were subtracted from the measured values in the samples (Hameed et al. 2010).

$$Q_{i\mathrm{pH,DO}} = \left[(C_i - V_i)/(S_i - V_i) \right] \times 100 \quad (3)$$

where Q_i denotes the quality rating scale, C_i denotes measured concentration of each parameter, and S_i denotes the drinking water standard values for each parameter according to Bureau of Indian Standards (BIS 2012).

Step 3 Sub-indices (SI) were determined to calculate the overall WQI.

$$\mathrm{SI}_i = W_r \times Q_i \quad (4)$$

$$\mathrm{WQI} = \sum \mathrm{SI}_i \quad (5)$$

Table 1 Relative weight of chemical parameters and their permissible limits

Parameters	Indian standards	Weight (W_a)	Relative weight (W_r)
pH	6.5–8.5	4	0.078
Dissolved oxygen (DO)	≥ 5 mg/L	5	0.098
Alkanity	200 mg/L	2	0.039
Hardness	300 mg/L	2	0.039
Total dissolved solids (TDS)	500 mg/L	4	0.078
Electrical conductivity	250µS/cm	5	0.098
Na^+	200 mg/L	1	0.020
Ca^{+2}	75 mg/L	2	0.039
Mg^{+2}	30 mg/L	2	0.039
Fe	0.3 mg/L	4	0.078
Mn	0.05 mg/L	4	0.078
F^-	1 mg/L	4	0.078
Cl^-	250 mg/L	3	0.058
SO_4^{2-}	200 mg/L	4	0.078
NO_3^-	45 mg/L	5	0.098

The computed WQI values were categorized in agreement with the suggested categorization of water quality (Yadav et al. 2010) as shown in Table 2.

Heavy Metal Pollution Index (HPI)

The heavy metal pollution in both the rivers have been evaluated by two major indices (HPI and CI). HPI has been evaluated using the weighted arithmetic average method of indexing and was developed by Mohan et al. (1996) as follows:

Step 1 A unit weightage with a value inversely proportional to the recommended S_i of the evaluated parameter was assigned.

Step 2 The HPI model proposed is given as:

$$\text{HPI} = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \tag{6}$$

where W_i represents the unit weightage of ith parameter; Q_i denotes sub-index of the ith parameter and n indicates number of parameters included in the evaluation.

Table 2 Water quality scale (Yadav et al. 2010)

Water quality	WQI
Excellent	0–25
Good	26–50
Poor	51–75
Very poor	75–100
Unsuitable	Above 100

Step 3 Sub-index of the ith parameter was calculated as:

$$Q_i = \sum_{i=1}^{n} \frac{|X_i - C_i|}{(S_i - C_i)} \times 100 \tag{7}$$

where X_i and C_i denote the monitored and ideal values of the ith heavy metal and S_i denotes standard value of the ith heavy metal.

The numerator of the above equation (Eq. 7) indicates the numerical difference between the two values disregarding the algebraic sign. The critical value of HPI for drinking water is 100 (Prasad and Bose 2001).

Contamination Index (CI)

Individual components or parameters exceeding their upper permissible limits are aggregated for the calculation of CI for a sampling site. The combined effects of the toxic metals are thus summarized to a single numeric value. The scheme for calculation is as follows (Backman et al. 1998):

$$CI = \sum_{i=1}^{n} C_{fi} \tag{8}$$

where,

$$C_{\text{f}i} = \frac{C_{\text{a}i}}{C_{\text{n}i}} - 1 \tag{9}$$

and $C_{\text{f}i}$ signifies the contamination factor of the ith parameter and $C_{\text{a}i}$ represents the analyzed value of the ith parameter. $C_{\text{n}i}$ is the upper permissible limit of the ith parameter.

Analytical values of components lower than their upper permissible limits were not taken into account. The grade scale of contamination index has been tabulated in Table 3.

Risk assessment on human health

The exposure, toxicity and risk assessment on human health included two major pathways namely ingestion and dermal absorption (US EPA 2004; Wu et al. 2009). The average daily dose (ADD) received from each individual pathway has been determined using equations modified from the US EPA.

$$\text{ADD}_{\text{ingestion}} = \frac{C \times \text{IR} \times \text{EF} \times \text{ED}}{B_{\text{w}} \times \text{AT}} \tag{10}$$

Table 3 CI scale (Backman et al. 1998)

Heavy metal contamination	CI
Low	< 1
Medium	1–3
High	> 3

$$\mathrm{ADD_{dermal}} = \frac{C \times \mathrm{SA} \times K_{\mathrm{p}} \times \mathrm{ET} \times \mathrm{EF} \times \mathrm{ED} \times 10^{-3}}{B_{\mathrm{w}} \times \mathrm{AT}} \quad (11)$$

where average daily dose ingestion ($\mathrm{ADD_{ingestion}}$) and dermal absorption ($\mathrm{ADD_{dermal}}$) is calculated in μg/kg/day. The description of parameters involved in the calculation of $\mathrm{ADD_{ingestion}}$ and ($\mathrm{ADD_{dermal}}$) has been given in Table 4.

Risk characterization was enumerated by potential non-carcinogenic concerns calculated by hazard quotient (HQ). The estimation involved comparing the ADD of contaminants from each exposure pathway with the corresponding reference dose ($R_{\mathrm{f}}D$). The $R_{\mathrm{f}}D$ values have been given in Table 5. Values of HQ exceeding 1 indicated concern of non-carcinogenic effects. The hazard index (HI) which is the summation of HQs from all possible pathways evaluates the total potential of non-carcinogenic risk from the water source.

$$\text{Hazard Quotient (HQ)} = \frac{\mathrm{ADD}}{R_{\mathrm{f}}D} \quad (12)$$

$$R_fD_{dermal} = R_fD \times ABS_{GI} \quad (13)$$

The values used in the equations have been obtained from the US EPA and the $R_{\mathrm{f}}D$ values originate from the risk-based concentration table, US EPA (2004).

Cluster analysis

Cluster analysis (CA), a multivariate statistical technique groups objects on the basis of some particular characteristics they possess (Shrestha and Kazama 2007). Each and every object belonging to the same cluster possess some identical characteristics. Hierarchical clustering is the most common method of clustering and the resulting representation is done with the use of a dendrogram. In the present study, CA was executed on the data to evaluate the similarity among the sampling sites with respect to physico-chemical parameters as well as heavy metals. Hierarchical CA was implemented on the data by the means of Ward's method and Euclidean distances were used as a measure of similarity (Güler et al. 2002; Yidana et al. 2008). The data sets were also standardized by 'z scores' so as to avoid any errors occurring from differences in data dimensionality and units of measurement. All the statistical analysises have been accomplished using the statistical package SPSS® (version 20.0 for Windows).

Table 5 Reference dose of heavy metals

Metal	$R_{\mathrm{f}}D_{\mathrm{ingestion}}$	$R_{\mathrm{f}}D_{\mathrm{dermal}}$
Fe	700.00	140.00
Mn	24.00	0.96
Cr	3.00	0.075
Pb	1.40	0.42
Cu	40.00	8.00
Zn	300.00	60.00

Technique for order preference by similarity to ideal solution (TOPSIS)

TOPSIS methodology based on information entropy aims at arriving at an alternative which is closest to the PIS and farthest from the NIS. It serves as an effective tool in decision-making processes and may be implemented as follows (Hwang and Yoon 1981):

Step 1 The "alternatives" (sampling locations) and the "criteria" (parameters) were specified for both the rivers to which the ranking was to be allocated according to their contamination status. Assuming the presence of "m" possible alternatives called $A = \{A_1, \ldots, A_m\}$ which are to be evaluated alongside "c" criteria $C = \{C_1, \ldots, C_c\}$.

Step 2 A matrix X was employed in assigning ratings to the criteria where x_{ij} indicated the value of alternative A_i for criterion C_j

Table 4 Assumption parameters to derive the average intake values

Exposure parameters	Description	Value	References
C	Concentration of heavy metal in mg/L	Observed value	–
B_{W}	Body weight expressed in kg	52 for average Indian man	Jain et al. (1995) and Dang et al. (1996)
EF	Exposure frequency in days/year	350	US EPA (2004)
ED	Exposure duration in years	24	US EPA (2004)
SA	Skin surface area in cm^2	18,000	US EPA (2004)
AT	Averaging time	ED × 365 for non-carcinogenic risks	US DoE (2011)
IR	Ingestion rate in L/day	4.05	Dang et al. (1994)
ET	Exposure time in h/day	0.6	US EPA (2004)
K_{p}	Dermal permeability coefficient in cm/h	Varies for each metal	US EPA (2004)

$$X_{m\times c} = \begin{bmatrix} x_{11} & x_{12} \dots . & x_{1c} \\ \vdots & \dots \ .x_{ij} & \vdots \\ x_{m1} & \dots & x_{mc} \end{bmatrix}$$

Step 3 Criteria weights were calculated on the basis of information entropy techniques as follows:

$$q_{ij} = \frac{x_{ij}}{x_{1j} + \cdots + x_{mj}} \ ; \ \forall j \in \{1, \dots, c\} \tag{14}$$

And,

$$E_j = -\frac{1}{\ln m} \sum_{i=1}^{m} q_{ij} \ln q_{ij}; \forall j \in \{1, \dots, c\} \tag{15}$$

where $0 \le E_j \le 1$ where index with higher entropy has greater variation. Therefore, the weight of the criteria may be calculated as:

$$w_j = \frac{d_j}{d_1 + \cdots + d_c} \tag{16}$$

And, $d_j = 1 - E_j$. All the weights were aggregated to a matrix $w_{c\times c}$.

Step 4 A normalized decision matrix was constructed ($N_{m\times c}$) using vector normalization method as follows:

$$r_{ij} = \frac{x_{ij}}{\sqrt{x_{ij}^2 + \cdots x_{mj}^2}} \tag{17}$$

Thus, $N_{m\times c} = \left[r_{ij}\right]_{m\times c}$.

Step 5 A weighted normalized decision matrix was constructed (V) as follows:

$$V = N_{m\times c} \times w_{c\times c}$$

Step 6 The PIS and the NIS of the alternatives were computed as:

$$\text{PIS} = \{\max v_{ij} | v_{ij} \in V\} = (v_1^+, \dots, v_c^+) \tag{18}$$

$$\text{NIS} = \{\min v_{ij} | v_{ij} \in V\} = \left(v_1^-, \dots, v_c^-\right) \tag{19}$$

Step 7 The Euclidean distance of each alternative from the PIS (d_i^+) and NIS (d_i^-) were calculated as:

$$d_i^+ = \sqrt{\sum_{j=1}^{c} \left(v_{ij} - v_j^+\right)^2} \tag{20}$$

$$d_i^- = \sqrt{\sum_{j=1}^{c} \left(v_{ij} - v_j^-\right)^2} \tag{21}$$

Step 8 Proximity or closeness coefficients (CC) of each and every alternative was calculated as:

$$\text{CC}_i^+ = \frac{d_i^-}{d_i^- + d_i^+} \tag{22}$$

Step 9 The alternatives were finally ranked according to their closeness coefficients.

Results and discussions

Descriptive statistics of monitored parameters

The descriptive statistics of the monitored physico-chemical parameters at a total of nine sampling locations of the Manas River have been shown in Table 6. From Table 6, it was observed that the pH of the river was within the guidelines provided by BIS of 6.5–8.5. A significant amount of chemical reactions occurring in nature are pH-sensitive, and there is a high influence of pH on the biotic compositions of aquatic systems. DO concentrations of the river were considerably high which may be ascribed to temperature variations and phytoplankton growth. TDS of the river was within the permissible limits of BIS guidelines (500 mg/L). The presence of high concentration of ions capable of carrying electrical charge contribute mainly to high EC values in rivers. TH and TA of the river were in their desirable limits. According to BIS guidelines, the desirable limits of both the parameters are 200 mg/L. The BOD_5 values at majority of the locations were found to be within the desirable limits except in SSMR 5 (12.75 mg/L). The major cations and anions analyzed have been depicted in Table 6 for the river.

Water Quality Index

The WQI adopted for the evaluation of water quality of river was in accordance with Hameed et al. (2010). The results of the evaluation showed the fairly different grades of water quality along the stretch of both the rivers. The gradation of water quality of river has been done as per the quality scale given by Yadav et al. (2010). The evaluation of the WQI yields significant results which have been shown in Fig. 2. The calculated WQIs of the Manas River was found to be in the range of 54.3–91.1. The sampling locations SSMR 5 and SSMR 6 of the Manas River were graded as "very poor" by the quality scale of Yadav et al. (2010). The remaining sampling locations along the river were of "poor quality".

Table 6 Descriptive statistics of physico-chemical parameters of water samples collected from Manas River

	pH	DO	BOD5	TS	TDS	TSS	EC	TH	TA	Na^+	K^+	Ca^{2+}	Mg^{2+}	F^-	Cl^-	NO_3^-	SO_4^{2-}
Max	7.86	7.48	12.75	915.00	285.00	730.00	0.41	182.20	150.00	4.91	7.74	24.95	30.20	0.35	14.10	2.40	36.42
Min	7.37	7.10	3.00	260.00	185.00	55.00	0.26	120.42	62.00	3.30	2.25	5.70	25.89	0.06	4.57	0.29	17.44
Mean	7.59	7.30	5.52	493.33	232.78	260.56	0.35	159.83	113.67	4.03	4.98	16.94	28.73	0.14	9.46	1.27	23.95
SD	0.17	0.14	3.14	223.20	32.24	230.99	0.05	20.43	30.78	0.55	2.21	6.13	1.58	0.09	3.42	0.69	6.91
Kur	− 1.03	− 1.52	2.04	− 0.66	− 0.88	0.14	− 0.55	− 0.33	− 0.59	− 1.46	− 2.28	− 0.72	0.23	1.39	− 1.64	− 1.38	0.16
Skew	0.46	− 0.15	1.66	0.88	0.40	1.19	− 0.55	− 0.81	− 0.79	0.26	0.07	− 0.37	− 1.29	1.51	− 0.32	0.13	1.29
Cov	0.02	0.02	0.57	0.45	0.14	0.89	0.14	0.13	0.27	0.14	0.44	0.36	0.05	0.67	0.36	0.54	0.29

Quantification of heavy metal contamination and risk assessment on human health

The concentration of heavy metals at the sampling locations for the Manas River have been depicted in Table 7. The results obtained from evaluating both the indices (HPI and CI) have been depicted in Table 8. The HPI of the sampling locations in the Manas River were in the range of 23.93–55.39. The water quality at all the nine sampling locations was graded to be suitable for human consumption, as the HPI values at all the locations were below the critical limit (≥ 100). The highest HPI value (55.39) was noted at the sixth sampling location of the Manas River which is located near Bongaigaon (Assam). At this location, the concentrations of the heavy metals were in the order of Fe > Cu > Zn > Mn > Cr > Pb. The results on evaluation of the contamination index of each location depicted that the fifth and the sixth sampling location of the Manas River having CI values of 2.32 and 2.07 were "moderately contaminated" or "medium polluted".

From Table 8, it was observed that the indices (HPI and CI) contradicted each other. The HPI indicated that the water quality at all the locations of the Manas River was suitable for human consumption and the CI graded the fifth and the sixth sampling location of the river as moderately contaminated. This initiated the need for assessing the risk of heavy metal contamination on human health so as to provide a transparent picture of the potential risk of heavy metal intake to communities depending on the water of the Manas River for their day to day activities. The $ADD_{ingestion}$, ADD_{dermal}, HQ and HI presented in Table 9 evaluates a comprehensive risk assessment to the human population residing along the stretches of the Manas River. The HQ ingestion and HQ dermal of all the heavy metals were below unity suggesting that the metals posed little or no health hazards when they enter through both the pathways. Furthermore, the overall hazard index (HI) of all the heavy metals came out to be well below unity suggesting the same. Although the risk characterization and assessment in this study has been done with utmost precision, there exist several uncertainties associated with the risk assessment which was emphasized by US EPA and other references. However, the results form a foundation on which several thorough investigations can be built upon for better assessments.

Cluster analysis and TOPSIS

In the study, WQI included the physico-chemical parameters and the HPI and CI included the heavy metal concentrations. However, characterization of the sampling locations became difficult as the results of the three indices contradicted each other. A weak correlation was found among them. Hierarchical cluster analysis (HCA)

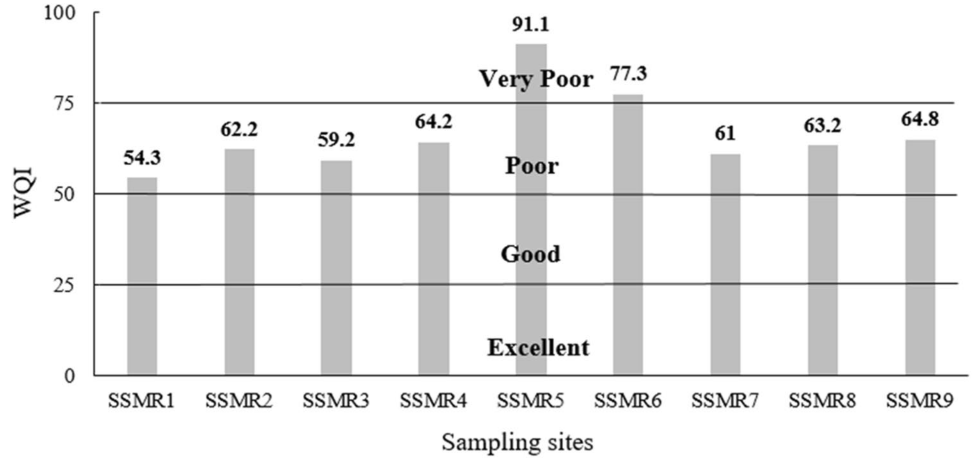

Fig. 2 Variation of WQI at all sampling locations

Table 7 Descriptive statistics of heavy metals of water samples collected from Manas River

	Fe	Mn	Cr	Pb	Cu	Zn
Max	0.99	0.02	0.01	0.01	0.07	0.06
Min	0.09	0.00	0.00	0.00	0.03	0.02
Mean	0.42	0.01	0.01	0.00	0.05	0.04
SD	0.29	0.01	0.00	0.00	0.01	0.01
Kur	− 0.15	0.26	− 1.51	0.02	1.89	− 0.28
Skew	0.98	0.95	0.11	0.09	1.19	− 0.13
Cov	0.70	0.88	0.26	0.35	0.19	0.25

Table 8 HPI and CI of Manas River

Sampling sites	HPI	CI
SSMR1	43.45	0.55
SSMR2	27.89	0.08
SSMR3	24.45	0.00
SSMR4	37.84	0.00
SSMR5	23.93	2.32
SSMR6	55.40	2.07
SSMR7	30.42	0.00
SSMR8	37.97	0.02
SSMR9	34.36	0.71

implemented on the data included both the physico-chemical parameters and heavy metals to group the sampling locations possessing similar characteristics. The visual representation of the clusters in the form of a dendrogram has been depicted in the Fig. 3. The consequence of the cluster analysis resulted in two major clusters. The first cluster represented the relatively less polluted sites (LP) and the second cluster grouped the more polluted sites (MP). The second cluster included the fifth and the sixth sampling locations (SSMR 5 and SSMR 6, respectively) which had the highest WQI as well as the highest CI. The overall ranking of the sampling locations given by the TOPSIS methodology has been shown in the Table 10. The TOPSIS method also ranked these locations as the most polluted sites by giving them an overall rank of 8 and 9, respectively. The first cluster had two sub-clusters containing the remaining sampling locations. The identification of the relatively more polluted sub-cluster or the relatively less polluted sub-cluster becomes difficult in

Table 9 Hazard quotient and hazard index of Manas River

Metal	C_w	ADDing	ADDder	$HQ_{ingestion}$	HQ_{dermal}	HI
Fe	0.418	31.235	0.083	0.045	0.001	0.045
Mn	0.008	0.630	0.002	0.026	0.002	0.028
Cr	0.006	0.434	0.001	0.145	0.015	0.160
Pb	0.004	0.265	0.000	0.189	0.000	0.189
Cu	0.047	3.492	0.009	0.087	0.001	0.088
Zn	0.044	3.311	0.005	0.011	0.000	0.011

Fig. 3 Dendrogram of CA of Manas River

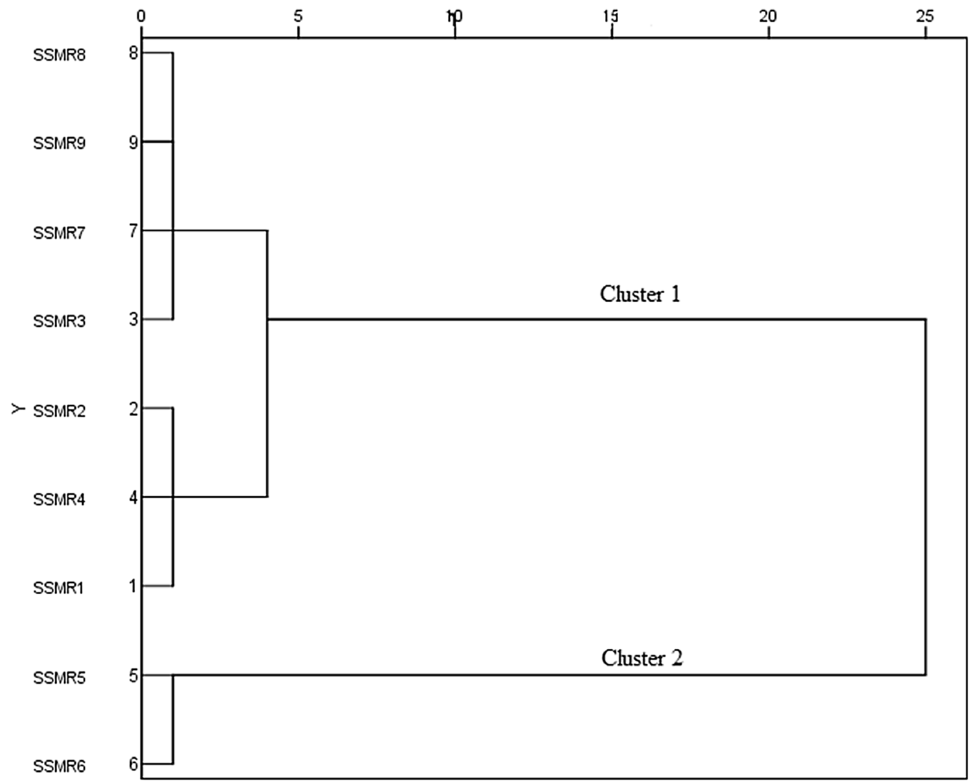

Table 10 Closeness coefficients (CC) and TOPSIS ranks of all the locations of Manas River

SS	SSMR1	SSMR2	SSMR3	SSMR4	SSMR5	SSMR6	SSMR7	SSMR8	SSMR9
CC	0.81	0.84	0.63	0.92	0.32	0.16	0.75	0.62	0.73
RANK	3	2	6	1	8	9	4	7	5

such circumstances where WQI, HPI and CI are in dispute among themselves. However, in such a complicated scenario, the TOPSIS method clearly identifies the relative pollution level by giving them their overall ranks. The first sub-cluster including the sites SSMR 7, SSMR 9, SSMR 3 and SSMR 8 were ranked 4, 5, 6 and 7, respectively. The second sub-cluster including sites SSMR 4, SSMR 2 and SSMR 1 were ranked 1, 2 and 3, respectively. It can be inferred that the first sub-cluster is relatively more polluted than the second sub-cluster. The TOPSIS method provided an overall ranking to the sampling sites of both the clusters as well as proved efficient in ranking the sites within the sub-clusters.

Conclusions

In this study, the surface water quality assessment of Manas River, Assam has been done using three quality indices, Hameed's WQI, HPI and CI. The WQI graded two sampling locations near Bongaigaon as "very poor" and all other locations as "poor". HPI of all the locations were below the critical value of 100, but the CI depicted that the two locations near Bongaigaon are "moderately contaminated". Cluster analysis grouped the sampling locations in two major clusters LP and HP. TOPSIS was performed including all the measured parameters for characterization of sampling locations and provided an overall ranking of the sampling locations on the basis of their relative pollution levels. Furthermore, TOPSIS also served efficient in prioritizing sampling locations within the same cluster which was not possible to discern from the numerical scores of WQI based on physicochemical parameters, and HPI and CI which included only the heavy metals. It was concluded that TOPSIS served as an effective tool in prioritizing decisions for policy makers based on these overall ranks for better water resources management and effective implementation of stream restoration strategies.

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