Evaluating the Multifunctional Resilience of River Health to Human Service Demand: A Comparison among Fuzzy Logic, Entropy and AHP Based MCDM Models

RAJ BHATTACHARYA (✉ rajgeovu10@gmail.com)

Vidyasagar University

Nilanjana Das Chatterjee

Vidyasagar University

Kousik Das

Vidyasagar University

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Title:

Evaluating the multifunctional resilience of river health to human service demand: A comparison among fuzzy logic, entropy and AHP based MCDM models

Dr. Raj Kumar Bhattacharya

PhD

Department of Geography

Vidyasagar University

Midnapore, West Bengal, India

Pin: 721102

Phone: +917797232031

Email: rajgeovu10@gmail.com

ORCID- <https://orcid.org/0000-0002-1102-0088>

Other authors

Dr. Nilanjana Das Chatterjee

Professor

Department of Geography

Vidyasagar University

Midnapore, West Bengal, India

Pin: 721102

Email: nilanjana_vu@mail.vidyasagar.ac.in

ORCID- <https://orcid.org/0000-0001-9436-2173>

Mr. Kousik Das

PhD Research Scholar (JRF)

Department of Geography

Vidyasagar University

Midnapore, West Bengal, India

Pin: 721102

Email: kousikvugeo@gmail.com

ORCID- <https://orcid.org/0000-0001-9948-1577>

Abstract

Ecosystem services of river for human beings are guided by harmonious relationship; however over growing human service demands (HSDs) are leading to deteriorate the river health connotation. In this study, an assessment index system of monsoonal quarried river health including twenty indicators consisting of riparian, morphological, hydroecological and social structure were established to detect the multifunctional threshold of river system integrity in respect to HSDs at upper (US), middle (MS), lower segments (LS) of Kangsabati River

using fuzzy logic, AHP and entropy based multi-criteria decision matrix (MCDM) methods i.e. vlseKriterijumska optimizacija I Kompromisno Resenje (VIKOR), simple additive weighing (SAW), complex proportion assessment of alternatives (COPRAS), weighted aggregated sum product assessment (WASPAS), technique for order preference by similarity to ideal solution (TOPSIS). The results revealed that overall indicators performance is generally healthy in MS, medium health level in US but mostly unhealthy in LS; and AHP and fuzzy MCDM methods assigned as high priority rank to MS, medium rank to US and least rank to LS, while entropy MCDM methods gives highest rank to US, medium rank to MS and least rank to LS, respectively. According to model validation performances, fuzzy and AHP MCDM methods are signified to HSDs, and results are closer to real problems, whereas entropy MCDM methods are rationalized to harmonic relationship of riverine system. With the acceptability of AHP SAW and WASPASS, it can be concluded that over HSDs is main culprit for river health degradation, and research results are identified the sick sites for ecological restoration.

Keywords: Harmonious relationship, Human service demands (HSDs), River health connotation, Multifunctional threshold, Multi-criteria decision matrix (MCDM)

Introduction

River health is one kind of metaphor likes human health and veterinary health, which is indicated to overall status of a river in particularly ecological function and biodiversity required to meet enough expectation of burgeoning human social needs along with sustainable development (Meyer 1997; Ma et al. 2019). Contrastingly, human satisfaction, response and physical, chemical, biological resilience capacities are controlled the river's well being state (Fairweather 1999; Sadat et al. 2019). During twenty first century, river health including river ecology and its environment has become prime concern caused by abruptly socio-economic development, and several constructions across the river for flow regulation likes dam, reservoir, barrages, bridges, weirs etc.(Gain and Glupponi 2015; Restrepo et al. 2018). Based on socio-economic and cultural functions of rivers, association of river health has become more accelerated from river ecosystem to include of socio-economic and cultural factors with the following of river ecosystem integrity and human service demand (HSD) (Von et al. 2017; Cheng et al. 2018; Vollmer et al. 2018). Many research works have been already done about the river health connotation (RHC), which indicates river ecosystem as a more dynamic process involving more constant changes after the crossing of autogenic level, and then turned to socialize with the corresponding of HSDs (Luo et al. 2018). With the understanding of harmonious relationship between dynamic river ecosystem and HSDs, assessment techniques play big role to determine the resilience of connotation of the river health with the ensuring of scientific management of rivers. In this context, several theory and methods are employed with continuously revised and enriched to measure the RHC (Alemu et al. 2018). Entire assessment approaches are based on three different studies i.e. (1) single based studies like biological, floral species and faunal species, (2) river ecological function based studies like plant respiration, evapo-transpiration and photosynthesis rates, and (3) composite indices based studies like water quality index, macro invertebrate indices (Sing and Saxena 2018; Sadat et al. 2019). Recently, several indices like biological integrity (Petesse et al., 2016; Wellemeyer et al. 2018; Yang et al. 2018), pollution overall index (Sargaonkar and Deshpande 2003), river pollution index (Mupenzi et al. 2017), multi-metric assessment index (Shi et al. 2017), ecological quality index (Sing and Saxena 2018) were widely used to assess the RHC.

Moreover, various methods such as index of stream condition assigning from five crucial components i.e. physical form, hydrology, streamside zone, aquatic life and water quality in Australian (Ladson et al. 1999), rapid bio assessment protocols in USA (Oliveria et al. 2011), river habitat survey method in England (Cunha et al. 2015) and EU water framework directive (Baatrup-Pedersen et al. 2018; Richter et al. 2016) were effectively adopted to determine the river ecological integrity in many developed country in respect to individual national condition (Luo et al. 2018). On the other hand, several mathematical approaches like multivariate analysis (Chau and Muttill 2007), analytic hierarchy process (Saaty 1980), artificial neural network (Xie and Cheng 2006), data envelopment analysis (Zhao et al. 2006), fuzzy comprehensive assessment (Zhao and Yang 2009) were already applied for river health assessment. It is point that all these methods have such significant role for evaluating the multi-dimensional diversity, reliability, structural and functional complexity of river ecosystem as well as RHC. However, these methods could not effectively determine the multi-index assessment and multi-object decision making (Deng et al. 2015). Thus, due to the complex multifunctional threshold state of resilience factors of the RHC, single evaluation method cannot trustfully performed and has not provided the effective results. Consequently, RHC approach has been integrated with multi-dimensional human demands; hence non linear and indeterminate methods are applied to measure this obscure multifunctional relationship (Karr 1999; Norris and Thomas 1999). Therefore, application of fuzzy membership function with assessment evaluation methods has been used in different perspectives such as comprehensive evaluation, scientific decisions, pattern recognition etc. (Jing et al. 2000; He et al. 2011) that are helps for scientific and rational utilization to get more effective evaluation results (Liu and Zou 2012). Based on fuzzy membership function, multi-criteria decision making (MCDM) like fuzzy matter element method (FME) for scientific and comprehensive decision making, combining grey relational analysis method (GRA) for theoretical explanation of uncertain information and incomplete data samples (Chiang and Hsieh 2009), harmony degree evaluation method (HDE) for the analysis of dynamic equilibrium in between HSDs and river ecosystem integrity (Zuo et al. 2016; Luo et al. 2018), were successively used for achieving the different goals i.e. analysis the overall performance of every attributes under river health, integration between river health and water resources management, and comparison and validation amongst the model (Sadat et al. 2019).

Nevertheless, some MCDM models are incorporated either various uncertainties of criteria performance values or uncertainties of criteria weights for river health assessment. Accordingly, most of the models cannot properly detect the multifunctional threshold state of hydroecological and social attributes in respect to HSD especially in RHC. Moreover, in particular of river ecosystem integration, MCDM models have not identified the attribute performance in against the various environmental stresses. In this regard, this research has analyzed the several hydroecological, social and geomorphic river health assessment criterion and indices in Kangsabati River by aforementioned five MCDM models using fuzzy membership function, AHP and entropy evaluation method i.e. VIKOR, TOPSIS, SAW, CORPAS, and WASPASS. The objectives in this study are: (1) to assess the reliability-resilience of hydroecological and social dimensions on RHC in respect to HSD, (2) to quantify the multifunctional threshold state amongst the river health indicators at different course, (3) validation and comparison of five MCDM models as well as selected to best fit methods for assessing the overall RHC status, (4) to find out the sick health sites for ecological restoration.

Study area

The Kangsabati River (21°45'N-23°30'N, 85°45'E-88°15'E), which originates from southeast of Chhota Nagpur plateau fringe in Jharkhand, is one of the main water feeds channel in the south Bengal, lower Gangetic basin. The Kangsabati River has a basin area of 9658km² (Fig. 1). Main stream length of this seasonal alluvial river is approximately 465.23km, and average width-depth ratio in this river ranges from 35.61m to 1208.01m under the significant changes of elevation as 2m-656m above mean sea level (MSL). Maximum rainfall is occurred during monsoon season (June to October) with the average of 1200mm/year. However, several surface characteristic changes such as Mukutmonipur dam construction (1956) near confluence point at Kansai and Kumari River, barrages, artificial embankments, weirs, cross bridges, instream and floodplain sand mining, altering riverine land cover and land use, human beings have strongly interrupted in many aspects of Kangsabati River i.e. flow regime, sediment inflow and outflow, channel morphology, habitat degradation, etc. (Das et al., 2020). After the construction of Mukutmonipur dam, sand mining is one of the prime anthropogenic activities removing huge volume of sand (588155 ton/y) than natural replenishment (1413112 ton/y) from Kangsabati River (2002-2016) (District Land and Land Reforms office of Paschim Midnapore and Bankura, India 2002–2016) (Bhattacharya et al., 2019a). In terms of sand mining in Kangsabati River, natural replenishment (76644 ton/y) is far better than mining (13956 ton/y) in Dherua segment, but rate of mining (161308 ton/y) is exceeds than replenishment (20096 ton/y) in Kapastikri segment. In Lalgargh segment, annual replenishment (529325 ton/y) always crossed the over growing sediment removing (75058 ton/y) (Bhattacharya et al. 2019a, b). As a result, maximum water quality deterioration, channel wideness, bed level lowering, reducing of channel meandering, habitat destruction or transformation, fragmentation of biodiversity indices are occurred in the entire Kapastikri segment while these consequences are restricted in mining and pit sites but sandbar sites are fully free from those affects in Dherua and Lalgargh segments (Bhattacharya et al. 2019a, b, c; 2020b).

Materials and methods

Selection of river health indicators and indices

Determination of assessment criteria plays crucial role because all those criterions have great influences on scientific nature as well as higher effectiveness of river health assessment (Deng et al. 2015); however standard consistent value has not properly set up caused by relatively changes of human demand over the periods (Karr 1991; Sadat et al. 2019). In this study, river health estimation procedure comprises mainly twenty indicators under five layers i.e., riparian zone feature (A), river water condition (B), morphology and its planform (C), ecological structure (D), and social structure (E) using fuzzy, entropy and AHP based MCDM methods. Riparian zone feature included as human activity index (A1), vegetation buffer width (VBW) (A2) and bank erosion degree (A3), while river water condition (B) contained mainly three indicators, namely water flow condition (B1) and mean flow velocity (B2). Substrate compositions (C1), average channel width (C2), average channel depth (C3) are fall under river morphology and its planform, whereas area with human activity (E1), groundwater depletion level (E2) and developmental work (E3) are included under social structure. Moreover, habitat complexity (D5) is contained in ecological structure. On the other hand, some indexes like Simpson index of biodiversity (D1), Simpson reciprocal index (D2), Shannon-Wiener index (D3), species richness index (D4), and species evenness as Pielou index (D5) are considered for the analysis of ecological feature but water quality index (B3) and pollution index (B4) both are taken for river water condition. In addition, river meandering degree (C4) is only index of river morphological structure.

Riparian zone feature (A)

Assessment criteria for riparian zone features are determined using of eco-environmental conditions in the entire Kangsabati River (Bhattacharya et al. 2019b) and followed by previous researches about the river health assessment indicators in tropical river (Sing and Saxena 2018; Sadat et al. 2019). In A indicators, A1 is assigned as five different class i.e. very well (>25), well (25-15), critical state (15-10), poor (10-5), and very poor (<5) based on Ding et al (2015), Yang et al (2018). A2 is estimated as

$$A_2 = \left\{ \left(\frac{\text{Riparian width}}{\text{River width}} \right) \times \text{Tree and shrubs coverage} \times \text{vegetation level} \right\} \quad (1)$$

In this study, A2 is considered up to 200m across the right and left riparian zones from thalweg line; hence assessment class ranges of >200m, 200-100, 100-50, 50-0, and <0 corresponded to very well, well, critical state, poor, and very poor, respectively. A3 comprises with five classes ranges of >60%, 60%-45%, 45%-30%, 30%-10%, and 10% corresponded to very poor, poor, critical state, well and very poor, respectively (Yang et al. 2017; Yang et al. 2018).

River water condition (B)

Nine cross profiles were taken to determine the indicators of river water condition following the flow regime and sediment transport during pre monsoon, monsoon and post monsoon (2016-2017). Sandbar, mining and pits are considered for selection of cross section at Lalgarrh (upper), Dherua (middle), and Kapastikri (lower) segment of Kangsabati River (Fig. 2a, b, c). In B, B1 is computed as follows (Sadat et al. 2019):

$$WFC = \left[\frac{Q_d}{Q_{avg}} \right] \quad (2)$$

Where Q_d denotes daily runoff and Q_{avg} indicates average annual runoff

Nine water samples from Lalgarrh (upper), Dherua (middle), and Kapastikri (lower) segment were collected for measuring the water quality index (WQI) using the assigned weightage value of conductivity (5), DO (5), TDS (4), p^H (4), salinity (4), BOD (2) and Mg^{2+} (2) (Alobaidy et al. 2010). Therefore, sub-indices (SI) of nine samples are calculated to obtain the WQI based on following equations (Sharma et al., 2014)

$$WQI = [\sum SI] \quad (3)$$

$$SI = R_w \times Q_{rs} \quad (3.1)$$

Where R_w means relative weight, Q_{rs} denotes quality of rating scale; SI means sub-indices of water samples.

On the other hand, in B4, comprehensive pollution index is used to determine the pollution along with find out the major pollutants for the nine cross section, which is computed based on DO (mg/L), NH_3-N (mg/L), and p^H as follow (Yang et al., 2018)

$$P = \frac{1}{n} \sum_{i=1}^n \frac{C_i}{C_o} \quad (4)$$

Where C_i denotes concentration amount of i -th pollutant (mg/L), C_o indicates evaluation standard value of i -th pollutant (mg/L).

River morphology and its planform (C)

Sediment samples, cross section and Google Earth image were used to measure the morphological structure including substrate composition in Lalgarrh (upper), Dherua (middle), and Kapastikri segment (lower) (Fig. 2a,b, c). Moreover, extensive field work and qualitative interview with local people are helped to access river morphological structure. In C1, grain size distribution of sediment is considered to measure the particle size of substrate composition ranges as >0.50, 0.50-0.25, 0.25-0.10, 0.10-0.05, and <0.05, respectively (Yang et al.,

2018). Based on Maddock (1999) and Dutta et al. (2017), C2 and C3 are calculated with the taken of nine cross section from sandbar, mining and pit sites of three segments. Sinuosity index (P) is applied to determine the meandering degree (C4) in different segments using Friend and Sinha's method (1993) as follow

$$P = \frac{L_{cmx}}{L_R} \quad (5)$$

Where, L_{cmx} stated curvature distance along the thalweg line or mid channel length in single or widest or mid-channel channel, L_R indicates the straight distance in measuring segment following the thalweg line.

River ecological structure (D)

Total one hundred fifty four species were collected from nine cross sectional sites during 2016-2017. After the collection of species samples, species diversity, species richness, species evenness are calculated using several biodiversity indices. Simpson's index (D) is employed for measuring the relative abundance of each species diversity variation (D1, D2) caused by anthropogenic activities (Shannon 1949) as follow

$$\text{Simpson's index of diversity} = 1 - D \quad (6)$$

$$\text{Simpson's index of diversity} = \frac{1}{D} \quad (6.1)$$

$$D = \frac{\{N(n-1)\}}{\{N(n-1)\}} \quad (6.2)$$

Where N denotes total number of all species within a living organism, n indicates entire number of organisms in each species

On the other hand, Shann-Wiener diversity index (H) is employed to find out the species diversity (D3) in a healthy habitat or community as follow (Shannon 1949)

$$H = -\left\{\frac{S}{N} \ln \frac{S}{N}\right\} \quad (6.3)$$

Where S indicates individual number of specific species, N denotes to total number of all individuals in each sample site, and $\ln$ stated logarithm to base e

Species richness (D4) in different segments measured by simple species richness index as Margalef's index (Margalef 1958)

$$\text{Margalef's index} = \frac{S-1}{\ln N} \quad (6.4)$$

Pielou's evenness index (e) is used to determine the relative abundance of different species (D6) as follow (Pielou 1966)

$$e = \frac{H}{\ln S} \quad (6.5)$$

Social structure (E)

Three indicators of social structure have inverse relationship with RHC (Cheng et al. 2018; Luo et al. 2018); however magnitude or intensity of E1, E2, and E3 is considered for assigning the health status into five level health categories i.e. very well, well, critical state, poor and very poor. Moreover, all corresponding assessment criterions are defined and presented in Table 1.

Weight assignment of the river health indicators

AHP based weighting assignment

Analytical hierarchical process (AHP) is more effective practical cum quantitative and qualitative analysis based multi-criteria decision-making method (Saaty 1980), which is originally given by Saaty (1977) to significantly

explain the non-sequential relationship amongst the target criterion. Pair wise comparison is greatly supported to conduct the AHP process with the taking of overall goal to criteria, sub criteria and judgment matrix. Therefore, $W_n \times n$ is expressed as follow Eq. (7)

$$W = \begin{bmatrix} \mathcal{Q}_{11} & \mathcal{Q}_{12} & \mathcal{Q}_{1n} \\ \mathcal{Q}_{21} & \mathcal{Q}_{22} & \mathcal{Q}_{2n} \\ \mathcal{Q}_{n1} & \mathcal{Q}_{n2} & \mathcal{Q}_{nn} \end{bmatrix}_{n \times n} \quad (7)$$

Where, $\mathcal{Q}_{ij}$ stated the relative importance between two indicators following linguistic term based fuzzy number i.e. equal important (1), weakly more important (3), strongly more important (5), very strongly more important (7), absolutely more important (9) and median value between two adjacent judgements (2, 4, 6, 8). Finally, $\mathcal{Q}_{ij}$ is secured the following conditions according to Eq. (7.1)

$$X(x_{ij}) = \begin{cases} x_{ij} > 0 & (i, j = 1, 2, \dots, n) \\ x_{ii} = 1 & (i = 1, 2, \dots, n) \\ x_{ij} = 1/x_{ji} & (i, j = 1, 2, \dots, n) \end{cases} \quad (7.1)$$

Then, maximum eigenvalue and eigenvector of matrix is to be calculated after the computation of root mean square as follow Eqs. (7.2)- (7.3)

$$y_j = \left(\prod_{i=1}^n \mathcal{Q}_{ij} \right)^{\frac{1}{n}} \quad (i, j = 1, 2, \dots, n) \quad (7.2)$$

$$W_j = \frac{b_j}{\sum_{k=1}^n b_k} \quad (7.3)$$

Therefore, it can be said that judgement matrix is greatly influenced by expert knowledge and performance (Si et al. 2020), however consistence test is most effectively used to check the matrix for ensuring the credibility in each indicators according to Eq. 7.4. Moreover, in case of C.R < 0.1, judgement matrix is more acceptable but C.R > 0.1, judgement matrix must be needed to reassign until the passing of consistence check.

$$C.R = \frac{\lambda_{max}}{(n-1)R.I} \quad (7.4)$$

Where, C.R. means consistency ratio, λ_{max} denotes maximum eigenvalue of the judgement matrix, as computed based on Eq. 7.5, n stated order number of matrix, R.I. indicates average value of random consistency indicator ranges 0, 0.513, 0.893, 1.119, 1.249, 1.345 corresponded with order number of 2, 3, 4, 5, 6, 7, respectively.

$$\lambda = \frac{1}{n} \sum_{i=1}^n \left(\sum_{j=1}^n \frac{\mathcal{Q}_{ij} W_j}{W_i} \right) \quad (i, j = 1, 2, \dots, n) \quad (7.5)$$

Entropy based weighting assignment

Entropy information is first introduced in the thermodynamics theory for accurately assigning the weight of each indicator, and later this is used in information theory given by Shannon (1948). In recent past, entropy evaluation process is widely applied in the field of engineering, economy, finance, etc. (Zou et al. 2006; Zhu et al. 2020). Entropy weighting assignment has three basic steps of calculation i.e. (Zhu et al. 2020)

(1) Relational matrix normalization

Relational matrix normalization is a process of transformation from analogous to normalization, which is very significant to conduct the process of entire performance values for ensuring the conversion from every alternative into specific comparability sequence (Kuo et al. 2008). According to Eq. (8), relational matrix (R_{mn}) is to be translated into comparability sequence matrix (Q_{mn}).

$$R_{mn} = (A_{ij})_{(m \times n)} \text{ converted to } Q_{mn} = (B_{ij})_{(m \times n)} \quad (8.1)$$

Where, $R_{mn} = (A_{ij})_{(m \times n)}$ denotes average indicator matrix; $Q_{mn} = (B_{ij})_{(m \times n)}$ indicates normalized matrix; i is considered as 1, 2..., n; j is expressed as 1, 2... n

$$B_{ij} = \begin{cases} \frac{A_{ij} - \min(a_j)}{\max(a_j) - \min(a_j)} & \text{for efficiency indicator} \\ \frac{\max(a_j) - a_{ij}}{\max(a_j) - \min(a_j)} & \text{for cost indicator} \end{cases} \quad (8.2)$$

(2) Entropy computation of each indicator

Based on entropy information analysis, m indicators and n assessment value of entropy information is calculated as (Sadat et al. 2019)

$$H_j = -\frac{1}{\ln(n)} \sum_{i=1}^m f_{ij} \times \ln(f_{ij}) \quad (8.3)$$

Where, H_j means entropy value of j^{th} indicator and $f_{ij} = \frac{B_{ij}}{\sum_{j=1}^n B_{ij}}$ (Qiu, 2011)

If, $f_{ij}=0$, $\ln(f_{ij})$ is regarded as no mathematical meaning; therefore f_{ij} can be redefined after rearrangement as:

$$f_{ij} = \frac{B_{ij} + 0.0001}{\sum_{j=1}^m (B_{ij} + 0.0001)} \quad (8.4)$$

(3) Weight assessment of each indicator

Eq. (8.5) is used to determine the entropy weight of j^{th} as follow

$$W_j = \frac{1 - H_j}{m - \sum_{i=1}^m H_j} \quad (0 \leq W_j \leq 1) \quad (8.5)$$

Where, $\sum_{j=1}^m W_j = 1$, W_j denotes weight of j^{th} indicator, m means number of the indicator

River health assessment methods

Fuzzy set theory for river health assessment

Fuzzy set theory is applied when decision faces several problems like uncertain knowledge, incomplete, vague, etc., which is originally arranged as crisp setup to considerable value range of 0 and 1 (Wang et al. 2019). In this setup, 1 denotes full membership function whereas 0 indicates non-membership function. In respect of fuzzy situation, triangular fuzzy number (TFNs) is applied to take a decision in multiple purpose and situation (Shukla et al. 2014). Linguistic scale of importance is employed to assign the TFNs rating scale in multi criteria decision making (MCDM) problems as follow equal (1,1,1), weak (1/2, 1, 3/2), fairly strong (3/2, 2, 5/2), very strong (5/2, 3, 7/2), absolute (7/2, 4, 9/2), respectively (Fig. 3a). Generally, a fuzzy number $\tilde{a}$ is expressed through trio $X = (x, y, z)$; therefore membership of TFNs is calculated according to Eq. 9 (Kaganski et al. 2018)

$$\mu_x(X) = \begin{cases} 0, & x < 1 \\ \frac{x-x}{y-x} & x \leq x \leq y \\ \frac{z-x}{z-y} & y \leq x \leq z \end{cases} 0, \quad x > 0 \quad (9)$$

(1) Fuzzy Analytical Hierarchy Process (FAHP)

Fuzzy based AHP is very effective comprehensive MCDM evaluation approach for spoiling the decision problem, and converted into a very small problem (Solangi et al. 2019). TFN is constructed to make a pair wise comparison matrix, which is easily determined the multifunctional threshold state amongst the river health

indicators at different segments (Fig. 3b). With the following of qualitative health indicators, four different levels are considered i.e. very high, high, general, low as corresponding value of $f(1)=1$, $f(2)=0.75$, $f(3)=0.5$, $f(4)=0.25$. According to expert feedback, all those values are converted into fuzzy numbers as

$$y_{ij} = [d(1)_{ij}, d(2)_{ij}, d(3)_{ij}, d(4)_{ij}, d(5)_{ij}] \quad (9.1)$$

Where, $d(x)_{ij}(x=1, 2, 3, 4, 5)$ denotes to the expert feedback proportion at different levels Qualitative health indicator value is determined based on weighted average method as follow

$$r_{ij} = \sum_{x=1}^5 [d(X)_{ij} f(X)] \quad (i = 1, 2, \dots, n) \quad (9.2)$$

TFN is employed to measure the membership function of the river health quantitative indicators according to Eq. 9. Subsequently, fuzzy relation matrix (W) is expressed as

$$R = \begin{bmatrix} RIX_1 \\ RIX_2 \\ RIX_3 \end{bmatrix} W = \begin{bmatrix} r_{11} & r_{12} & r_{1p} \\ r_{21} & r_{22} & r_{2p} \\ r_{n1} & r_{n2} & r_{np} \end{bmatrix}_{n \times p} \quad (9.3)$$

Where r_{ij} denotes the membership degree of every evaluated object in respect of fuzzy subset from indicators X_i . Then, W and R matrix both are combining used to evaluate the vector B with the following of appropriate fuzzy operator

$$B \triangleq (b_1, b_2, \dots, b_p) = W \circ R = (w_1, w_2, \dots, w_n) \circ \begin{bmatrix} r_{11} & r_{12} & r_{1p} \\ r_{21} & r_{22} & r_{2p} \\ r_{x1} & r_{x2} & r_{xp} \end{bmatrix} \begin{bmatrix} r_{11} & r_{12} & r_{1p} \\ r_{21} & r_{22} & r_{2p} \\ r_{n1} & r_{n2} & r_{np} \end{bmatrix} \quad (9.4)$$

At the final stage, best alternative is selected based on maximum membership principle as follow Eq. 9.5

$$b_r = \max_{1 \leq k \leq p} \{b_k\} \quad (9.5)$$

(2) Fuzzy TOPSIS (F TOPSIS)

In spite of imprecise information, Fuzzy TOPSIS as an extension version of TOPSIS is easily solved the problems of decision making in uncertainty data using fuzzy number from triangular membership function (Krohling and Campanharo 2010; Nadaban et al. 2016). With the following of fuzzy set, weighted normalized fuzzy-decision matrix of $\dot{P} = [\dot{P}_{ij}]_{m \times n}$ where $i = 1, \dots, m$, and $j = 1, \dots, n$ both are constructed by the multiplying of normalized fuzzy-decision matrix with its associated weights. Therefore, weighted fuzzy normalized value of $\dot{P}_{ij}$ is computed according to Eq. 9.6

$$\dot{P}_{ij} = w_i \times \dot{P}_{ij} \quad (9.6)$$

F-TOPSIS is consists of the following steps:

Step 1: In this step is involved to identify the positive ideal solution A^+ (benefits) and negative ideal solution A^- (cost) as given by:

$$A^+ = (\dot{P}_1^+, \dot{P}_2^+, \dots, \dot{P}_m^+) \quad (9.7)$$

$$A^- = (\dot{P}_1^-, \dot{P}_2^-, \dots, \dot{P}_m^-) \quad (9.8)$$

$$\text{Where } 1_{\dot{P}_j^+} = (\max 1_{\dot{P}_{ij}.j \in J_1}; \min 1_{\dot{P}_{ij}.j \in J_2}) \quad (9.7.1)$$

$$1_{\dot{P}_j^-} = (\min 1_{\dot{P}_{ij}.j \in J_1}; \max 1_{\dot{P}_{ij}.j \in J_2}) \quad (9.8.1)$$

Where J_1 and J_2 represent the criteria benefit and cost, respectability

Step 2: Second step is comprises to calculate the distance of every alternative in respect to various members. To identify the distance of A_i alternative from the positive ideal solution of the group member M_l , ${}^1d_i^+$ is obtained by:

$${}^1d_i^+ = \sum_{j=1}^n d(1\dot{p}_{ij}, 1\dot{P}_j^+), \text{ with } i = 1, \dots, m; l = 1, \dots, L \quad (9.9)$$

As like positive ideal solution distance, the distance of A_i alternative is obtained negative ideal solution of member M_l , ${}^1d_i^-$ is obtained by:

$${}^1d_i^- = \sum_{j=1}^n d(1\dot{p}_{ij}, 1\dot{P}_j^-), \text{ with } i = 1, \dots, m; l = 1, \dots, L \quad (9.10)$$

Where, distance of $d(\dot{P}_{ij}, \dot{P}_j^+)$ in between two fuzzy members is measured as follow Eq. 9.11

$$d(\tilde{a}, \tilde{b}) = \sqrt{\frac{1}{3}[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2]} \quad (9.11)$$

Step 3: To determined the relative closeness for every alternative A_i based on positive ideal solution follow as

$$\delta_i = \frac{di^-}{di^+ + di^-} \quad (9.12)$$

Step 4: Relative closeness is used to assign the rank of alternatives; hence higher value of δ_i is selected for best alternative. Moreover, this alternative selection is based on closing distance to the positive ideal solution.

Step 5: Final step is comprises to priority the rank amongst the entire health indicators according to order of δ_i value as well as helps to select the best indicator.

Multi-criteria decision making models

(1) VIKOR method

Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR) is crucial approach for multi-criteria decision making through the solving of problems with the associated of incompatible and incompatible standards (Opricovic and Tzeng 2004). Health indicators are assigned as ranking order, and then best indicator is selected using Eq. (10)

$$Q_j = \frac{V(S_j + S^+)}{(S^- + S^+)} + \frac{(1 - V)(R_j - R^+)}{(R^- - R^+)} \quad (10)$$

Where, S^+ means minimum value, $\text{Min}_j S_j$; S^- means maximum value, $\text{Max}_j S_j$; R^+ means minimum value, $\text{Min}_j R_j$; R^- means maximum value, $\text{Max}_j R_j$; V means weight which is measured by the maximum agreement of the group.

(2) SAW method

Simple Additive Weighting (SAW) is effective MCDM method, and is assigned the score in every indicators obtained by aggregating value in different criteria. After the construction of decision matrix, every criteria score is assigned with the taken of relative weights (Hwang and Yoon 1981; Sargaonkar et al. 2011). Final data integration process is completed acquiring from final score value of every option (K_i) follow as Eq. (11) (Ameri et al. 2018; Bhattacharya et al. 2020a)

$$K_i = \sum P_{ij} \times W_j \quad (11)$$

(3) COPRAS method

Complex proportion assessment of alternatives (COPRAS) is regarded as new effective MCDM technique given by Kaklauskas et al (2006), which is used to find out the superiority of one alternative over another along with makes a comparison in the alternatives (Zavadskas et al. 2009). COPRAS is very use full technique to easily evaluate the ranks of alternatives from one step to another step with respect their importance and utility degree in one hand (Kaklauskas et al. 2010), and this method is more sophisticated to apply in maximum and minimum criteria assessment for considering the one criteria in other hand (Podvezko 2011).

To estimate the final weights of all alternative according to Eq. (12)

$$C_i = S_j^+ + \frac{S_{\min}^- \sum_{j=1}^n S_j^-}{S_j^- \sum_{j=1}^n \frac{S_{\min}^-}{S_j^-}} = S_j^+ + \frac{\sum_{i=1}^n S_j^-}{S_j^- \sum_{i=1}^n \frac{1}{S_j^-}} \quad (12)$$

Where, $S_{\min}^-$ means minimum value; S_j^- means maximum index; S_j^+ means minimum index, respectively

(4) WASPAS method

WASPAS method is new scientific method based on weighted sum model (WAS) and weighted product model (WPM), which is proposed by Zavadskas, Turskis, Antucheviciene and Zakarevicius (2012). Innovators are successfully established the better accuracy of this aggregated methods in comparing to accuracy of others MCDM method (Zolfani et al. 2013). Final calculation for assessment and sorting alternatives as follow:

$$WPS_i = 0.5 \sum_{j=1}^n \bar{x}_{ij} + 0.5 \prod_{j=1}^n \bar{x}_{ij} \quad i = \overline{1, m}; \quad j = \overline{1, n} \quad (13)$$

Integration of river health proposed methods

Borda is a technique for combining the proposed ranking method or integrating the proposed method, which is implemented after the construction of diagonal matrix as $m \times m$ to express the row to column in respect to number of wires (Ghaleno et al. 2020). Based on matrix arrangement, boards are encoded with M if number of this technique is high, while boards are encoded with X if number of votes is equal or column is in line. Moreover, row number of boards in every row is assigned based on ranking order that means higher number belongs to win, and higher rank is calculated using copywriting method following not only bets number but also taken losses number for every indicator (segment). Thus, ranking order can be reduces the difference between boards (Opricovic and Tzeng 2004).

On the other hand, root square method is applied to obtain the closest method for getting the final result as follow Eq. (14)

$$RSS = \sum_{i=1}^n (y_i - f(x_i))^2 \quad (14)$$

In this context, y_i refers the final rank and $f(x_i)$, which rank is obtained through the applying of every multi-index decision-making method.

Validation of application models

In this research, percentage change and intensity change both are considered to validate the river health assessment methods as well as find out the best suitable method amongst them (Badri 2003; Ameri et al. 2018; Bhattacharya et al. 2020a).

(1) Percentage change

This method is employed for assigning rank order in different section of river segment with the respect of different methods as follow

$$\Delta P = \frac{N - NN_{constant}}{N} \times 100 \quad (15)$$

Where, ΔP means percentage of changes, N indicates total alternative number, and $N_{consistent}$ stated the alternative numbers of same rank

(2) Intensity change

To make a comparison amongst the using techniques, intensity change find out the actual rank of every indicator in different sections as obtained by Eq. (16)

$$\Delta I = \frac{\sum_{i=1}^N \frac{rank\ i\ (r1)}{rank\ i\ (r2)}}{N} \quad (16)$$

In this context, ΔI refer intensity change, $r1$ represent 1st method of alternative rank, and $r2$ indicate 2nd method of alternative rank

Finally, it can be stated that the entire methodological framework helps to determine the resilience capacity of river health for ecological restoration (Fig. 4).

Result

Score of river health indicators

All the indicators of river health were measured using the specific calculation methods subsequently; corresponding weights are assigned for each sub and major assessment indicators given by AHP and entropy methods to reveal the distinct attribute significance of the river.

Riparian zone feature (A)

In this group, maximum values of human activity index ranges of 5km-25km (A1) fall in poor and critical state than well health level; however average value of this index (9.56m) denotes unhealthy level in the entire Kangsabati River. Vegetation buffer width (A2) reveal that vegetation buffer in all sample sites has much lower except Kapastikri sandbar sites. While in the case of bank erosion degree (A3) magnitude, maximum section sites are faces critical to unhealthy situation in particularly middle and lower segments of Dherua and Kapastikri (Fig. 5). Average value of erosion degree in each segment indicates that bank erosion is more sensitive in abandoned mining or pit sites than non mining or sandbar sites. It is point that indicators of riparian zone are more susceptible to healthy ecosystem in the entire river.

River water condition (B)

Water flow condition (B1) in this river ranges from 0.60 to 0.15 with the average of 0.32, which is highly dominated in sandbar sites than mining and pit sites. Flow condition is not satisfied to ecological demand; hence low water flow creates the hindrance to well health level. Maximum value of mean water velocity (B2) concentrated in upper segment, and it continues downing towards the lower segment. Average flow velocity provides the healthy level in the entire river; however monsoonal peak flow during July to October and low base flow during December to April are hampered the velocity requirement to ecological flow satisfaction. In term of water quality, WQI (B3) demonstrated that very well health status concentrated in GH and IJ section sites, while very poor level observed in AB and OP sections (Fig. 6a). This index is more deteriorated to river health in Kapastikri segment but average index value stayed to well status that is more reasonable to health connotation in Lalgah and Dherua segment. In case of pollution level of water, unhealthy pollution index (B4) is highly concentrated in GH, IJ and EF sections whereas only KL section belongs in well healthy level and OP and MN sections are faces the critical state to health level. Moreover, average pollution index value revealed that poor

quality health status dominated in Kangsabati River. On the other hand, Pearson correlation matrix denoted that physiochemical properties are effectively deteriorated the water quality and increased the pollution level in mining and pit sections (Fig. 6b). Moreover, BOD, salinity, TDS, turbidity, conductivity, DO, Mg⁺ are highly fluctuated as 25%-75% (range within 1.51 quartile from median) in middle and lower course while only p^H is maximum fluctuated in upper course, respectively (Fig. 7a, b, c, d, e, f, g, h). Contrastingly, value of conductivity, salinity, TDS and Mg⁺ are increases but BOD, DO and p^H are decreases in mining sites, while the status of these physiochemical parameters are inversely stayed in sandbar sites. It is point that high intensity human activities in particular intensive sand mining changes the several indicators of river water condition.

River morphology and structure (C)

Substrate composition (C1) in Lalgargh segment (0.30mm) signified the well healthy level but this composition gradually reduces the health level towards the Dherua (0.18mm) and Kapastikri (0.08mm) segment. In term of composition intensity, dense substrate generally forms in sandbar sections than mining and pit sections in each segment of river. Average width (C2) is increases the health assemblage in Dherua (314 m) than Kapastikri (258m) and Lalgargh (257m) segments, while maximum width is recorded in mining sections of GH (495m) followed by MN (361m) and CD (305m), respectively (Fig. 8a). Therefore, instream mining enhanced the spatial extant of river habitat perimeter but huge sedimentation in sandbar section is narrowing the habitat realms. With the following of depth indicator (C3), all the values in selected sections revealed that depth is increases in mining and pit sections but shallow depth is occurring in sandbar sites. In addition, average depth value (1.20m) being at the poor healthy level, which is ineffective role to ecological restoration throughout the river (Table 2).

Based on hydraulic geometry; relationship amongst the flow velocity (v), flow discharge (Q), water depth (d) and channel width (w) in different sections are obtained based on Eq. 17 as follow (Navratil and Albert 2010; Yang et al. 2018):

$$v = kQ^m, \quad d = cQ^f, \quad w = aQ^b \quad (17)$$

According to flow equation of $Q = vwd$, coefficient value of hydraulic geometry of the Kangsabati River can be estimated as follow:

$$b + f + m = 1, \quad a \times c \times k = 1 \quad (18)$$

In accordance to hydraulic geometric results, all highest values of b/f concentrated in mining and pit sections than sandbar sections, which are depicted that wide-deep channel forms in mining sites but narrow-shallow channel forms in sandbar sites (Fig. 8b). Another coefficient of m/f is used to determine the relationship amongst the flow velocity, trend of channel modification and water depth from upstream segment to downstream segment, and mining sites to sandbar sites. In this study, all highest values of m/f in every segment observed in sandbar sections, and least values are recorded in mining and pit sections (Fig. 8c). In terms of channel modification, most of the hydraulic changes are occurred from mining sites to pit sites than course change (Fig. 8d). Thus, flow discharge and water depth both are drastically increase in mining and pit sections with the generating of critical flow velocity due to occurring of wide-deep channel while discharge, depth and velocity gradually decreases in sandbar sites caused by huge sedimentation (Bhattacharya et al. 2019b).

In respect to planform change, average value of meandering degree (C4) is increased the well health level in Kapastikri segment, while this degree is slightly lower than that of well wealth in Lalgargh segment. In Dherua segment, meandering degree is so poor that means its health level is morbid. Therefore, the results of substrate

composition, hydraulic geometry of width and depth, and planform status as meandering degree are all staying in critical state to poor class, which are significant factors leading to morbid status of river geomorphologic health.

River ecological structure (D)

Through the 154 number of species collection from these three segments of the Kangsabati River during 2016-2017, with the applying of Eq. 6, Simpson index of biodiversity values (D1) in nine sections are all at the unhealthy level while Simpson reciprocal index (D2) values in eight sections are all at the critical state to poor level except AB section for reasonable health status. The Shannon-Wiener index (D3) values in all sections are situated at the unhealthy level whereas species richness index (D4) is very poor than that of sustainable health level in mining sections but richness is increases the potentiality at the health level in pit and sandbar sections (Table 2). Overall level of richness index is not as good as well as propagated towards the critical state to unhealthy level in the entire river. The value of habitat complexity (D5) is much lower than healthy level in mining and pit sections while complexity is slightly lower than that of critical state in sandbar sections; however average complexity value denotes unhealthy situation dominated over the course. In term of species evenness (D6), unhealthy level is founds in AB (1.21) and IJ (1.20) sections of Lalgah and Dherua pit sites and well health level is observed in QR (0.82) section of Kapastikri sandbar site (Fig.9a). Average value of species evenness stated that health level reaches at the critical to poor class throughout the segments. In contrary, correlation graph revealed that biodiversity indices have not signified the relationship with healthy river ecosystem (Fig. 9b). Therefore, it is point that all biodiversity indices and habitat complexity are suffered as unhealthy level that means habitat parameters are crossed the resilience state throughout the courses.

Social structure (E)

In the response of social structure, area engaged with human activity (E1) is much higher in Kapastikri segment than Lalgah and Dherua segment. This result demonstrated that overgrowing intensive human activities including dense population degraded the standard health level along the downstream, and low construction rate with sparse population maintained the threshold state of the health connotation along the upstream. Recently, intensive mining, ongoing urban population, industrial activities are creates moderate pressure on river health along the middle stream (Table 2). Groundwater level (E2) is not enough for healthy river state in the entire Kangsabati River; in particular Lalgah segment is much lower than that of potential level (Fig. 10). Overall value of groundwater level is not acceptable for healthy river system. Developmental work (E3) is progressively grown up in Kapastikri segment than Lalgah and Dherua segment, which result indicates very poor health status dominated along the lower course. Therefore, average values of human activity, groundwater level and development work are reaches at the critical state to unhealthy level that means ecological restoration must be needed throughout the river.

Relative weight assignment of indicators

Based on Eq. 7, the weighting of the AHP method is determined for every indicators of Kangsabati River health in Figure 11 where weight score of riparian zone feature (A), river water condition (B), river morphology and structure (C), ecological structure (D), and social structure (E) are given of 0.176, 0.333, 0.098 and 0.266, respectability. Consistency index (CI) in comparison matrix table of A, B, C, D and E groups are of 0.010, 0.020, 0.050, 0.000 and 0.010; thus incompatibility rate of final matrix (0.090) is acceptable, because this rate is lower than 0.1 (Saaty 1977). In line with results of Yang et al. (2018), Zhao et al. (2018), Sadat et al. (2019),

Wang et al (2019); high weight score is assigned to water quality (0.163), bank erosion degree (0.111) and pollution index (0.102) for their greatest effect on river health whereas low score is assigned to river meandering degree (0.015), groundwater level (0.015) and Simpson reciprocal index (0.019) for their least impact on health level (Fig. 11).

On the other hand, with the applying on Eq. (8), entropy based weight of twenty indicators for nine sample sites are estimated separately as shown in Figure 11 to denote the every attribute significant role to the rivers. Maximum weight values are given to development work (0.091), groundwater level (0.0695) and area with human activity (0.0656) for their much controlled role on health connotation (Table 3). Contrastingly, minimum values are considered to substrate composition (0.035), bank erosion degree (0.041) and Simpson reciprocal index (0.0413) for their less controlling capacity to health level. Therefore, it is interest that two weighting methods of AHP and entropy given contradictory score for responsible indicators of river health. For this reason, AHP and entropy based MCDM methods including two fuzzy techniques are applied to estimate the proper rank of indicators along with find out the threshold limit of indicator responses.

Fuzzy, AHP and entropy based MCDM methods for the assessment of river health threshold

After the weighting of AHP assignment, twenty indicators were computed for the preparation of decision matrix and data normalization, which are much needed for priority rank of VIKOR, SAW, COPRAS, WASPAS, and TOPSIS. Linear vector method is effectively applied to determine the data normalization for TOPSIS model using Eqs. (9.6) – (9.12), whereas data normalization for VIKOR, SAW, COPRAS, WASPAS models were calculated using Eqs. (10) - (13). In Table 4, positive and negative value of TOPSIS method including Euclidean distance between them are computed using Eqs. (9.6) - (9.12) while best and worst values of VIKOR method are calculated using Eqs. 10. Contrastingly, final weights of normalized matrix row in each section were calculated for COPRAS, SAW and WASPASS methods using Eqs. (11) – (13).

In order to validate the improved of fuzzy set theory in this research, we employed two effectively used comprehensive assessment methods of fuzzy AHP and fuzzy TOPSIS to detect the threshold level of indicators performance on river health for nine sections of Kangsabati River. As shown in Table 5, computation result of fuzzy AHP and fuzzy TOPSIS are revealed to almost same consistent rank order of the health status of every site using Eqs. (9.1-9.5) and (9.6-9.12). In fuzzy method, highest score is assigned as higher priority in terms of weight and health index of each indicators and lowest score is given as lower priority. In case of fuzzy AHP, maximum compound score of IJ (0.1270), EF (0.1195), KL (0.1189) sections are given highest rank as 1 to 3 for their high health level, whereas minimum compound score of QR (0.09), MN (0.1046), AB (0.107) sections are given lowest rank as 9 to 7 for unhealthy level (Fig. 12). Based on positive relation between final score and health connotation, assessment results of fuzzy TOPSIS demonstrated that maximum compound score of IJ (1.417), EF (0.567), KL (0.540) sections are assigned highest rank as 1 to 3 and minimum score of QR (0.380), GH (0.421), AB (0.428) assigned lowest rank as 9 to 7, respectively (Table 5). It is point that, fuzzy based rank assignment is same rank order in all sections except OP, MN and GH; however except sections fall under unhealthy level predicted by fuzzy AHP and fuzzy TOPSIS.

The result of rank prioritizing the river health status and its potential level of sections in three segments of Kangsabati River by using AHP weight based VIKOR, SAW, COPRAS, WASPAS and TOPSIS models are presented in Table 5. In VIKOR model, based on negative relation between compound score and health level, least compound score of KL (0), IJ (0.21), EF (0.25) sections are given highest rank as 1 to 3 for their potential

health level while more compound score of OP (0.809), AB (0.727), MN (0.665) sections are assigned lowest rank as 9 to 7 for their unhealthy level (Table 5). Based on positive relation between final score value and health level, AHP weight based COPRAS, SAW, WASPASS and TOPSIS denoted that highest final score of KL, IJ, EF, GH sections are evaluated to best rank around 1 to 4 for their high habitat potential level but, least final score of MN, OP, QR, AB sections are assigned around 9 to 6, respectively. In addition, SAW and WASPASS models have same assigned rank order in nine sections except OP and QR sections while CORPAS and TOPSIS models have slightly changes of rank order; however all AHP weight based MCDM models gives the well health level to KL, IJ and EF sections and lowest rank or unhealthy level to MN, OP and QR out of nine sections. Therefore, it can be said that sandbar sections of Dherua and Lalgah segment are sustained their potential health level but, mining and pit sections of Kapastikri are not survived their health level in the entire segment. In spite of mining pit section as IJ, health potentiality is high caused by huge natural replenishment than sediment removing over the Dherua segment.

With the applying of entropy weighting in MCDM models, based on negative relation between final score value and river health in VIKOR model, least final score of CD, AB, EF sections are given highest rank as 1 to 3, signifying to more health potentiality whereas maximum final score of MN, OP, QR sections are assigned lowest rank as 9 to 7, implying to unhealthy level. Based on negative relationship between compound score and health connotation in COPRAS, SAW, WASPASS and TOPSIS models, maximum final score of CD, AB, EF, KL sections are evaluated highest rank order around 1 to 4 for good health condition while MN, QR, OP sections are given lowest rank as 9 to 7 due to having poor health connotation (Table 5). Rank assignment in all entropy based MCDM models demonstrated that entire Lalgah segment and sandbar sites of Dherua segment have high health potentiality including enough healthy connotations but entire Kapastikri segment has low health potentiality including fragmented connotations. This result denoted that enough replenishment of sediment over the sand mining maintained the health status in Lalgah and Dherua segments but over mining than replenishment degraded the health level in mining, pit and even sandbar sites of Kapastikri segment.

Assessment of models validation

With the following of integrating the order of proposed techniques results; IJ, AB, EF sections are considered as highest priority rank order (1-3) for maintaining their potential health level while QR, OP, MN sections are regarded as lowest priority rank order (9-7) for unhealthy level (Table 6). It can be said that Lalgah and Dherua segments has much better health level than Kapastikri segment; however sand mining and others anthropogenic activities are not intensively affected along the upper and middle course, but these are massively consequences along the lower course. On the other hand, RSS results revealed that entropy based VIKOR and SAW models has lowest value of 2, 2.01 in terms of maximum accuracy and efficiency against the fuzzy and others MCDM models as their RSS calculation was presented in Table 7. Therefore, entropy VIKOR and entropy SAW model predicted rank prioritization is more acceptable than others in terms of potential river health level.

Contrastingly, percentage change of every method in compared to each and other is showed in Table 8. Low percentage change is obtained in AHP SAW (63.88) than AHP WASPASS (67.59), entropy SAW (69.44), entropy WASPASS (69.44), entropy COPRAS (72.22), entropy TOPSIS (72.22), entropy VIKOR (73.14), AHP COPRAS (73.15), AHP VIKOR (80.55), AHP TOPSIS (84.26), fuzzy TOPSIS (87.03) and fuzzy AHP (88.88), respectively. Amongst the twelve methods, AHP SAW with the least value of percentage change is considered as more efficiency and accuracy method for prioritizing the sections in terms of potential health level and its

connotations (Badri 2003; Ameri et al. 2018). On the other hand, pair wise comparison method is used to determine the intensity change of each method presented in Table. 9. Maximum rate of changes are observed in AHP WASPASS (20.65) than entropy WASPASS (20), fuzzy TOPSIS (16.84), AHP VIKOR (16.70), entropy SAW (16.55), entropy TOPSIS (16.43), entropy COPRAS (16.37), AHP TOPSIS (16.30), entropy VIKOR (16.23), AHP COPRAS (16.11) and AHP SAW (16.01), respectively. Therefore, AHP WASPASS with highest intensity change is regarded as much efficient and accuracy method than others. According to both change for fuzzy logic, AHP and entropy MCDM validation test, it is true that AHP SAW and AHP WASPASS methods are more accurate than others, for having their best efficiency and accuracy values. In contrary, AHP SAW and AHP WASPASS methods have same priority ranking order amongst the sections.

Discussion

The results of fuzzy techniques and MCDM models in Table 5 shown that rank order of the river health condition in each sections of Kangsabati River is not of same level; however these models help to detect the resilience capacity of river health indicators (Deng et al., 2015; Sadat et al., 2019). Moreover, rank order of entropy weight based MCDM methods were not always same assigned as given by AHP weight based MCDM methods. With the harmonious relationship between river and river ecosystem, entropy weighting MCDM approaches are employed to synthesize the evaluation of indicators (Sadat et al., 2019; Xue et al., 2020). On contrary, considering HSDs, comprehensive processes of AHP weighting MCDM methods are used to assess the actual RHC (Luo et al., 2018). In respect to MCDM validation performance; entropy based MCDM methods given as high priority to upper segment than middle segments for healthy physical setup while AHP based MCDM methods are assigned as maximum priority to middle segment than upper segment for optimum HSD; however both weighting methods stated to low priority to lower segment for over human demand, respectively (Fig.12).

Low riparian vegetation buffer zone, moderate bank erosion and pollution level, narrow channel width, low habitat complexity reduces habitat potential level in sandbar sites of upper segment as EF section; but huge sediment deposition increases the resilience level of damaged indicators with the increase of substrate composition, water quality, species diversity and richness as well as reducing the human activity near riparian sites. In mining pit sites of upper segment as AB section, widen vegetation buffer zone, wide and deep channel, meandering channel, rich biodiversity indices, numerous species and high habitat complexity are sustained potential habitat level; however, lack of sediment in pit sites leads to massive bank erosion, thin substrate composition, polluted water quality and species evenness; thus health suitability gradually decrease over the time. In spite of floodplain sand mining, low species diversity indices; moderate riparian vegetation buffer zone, widen channel, meandering channel, low species evenness, meagre human activity and development work including low groundwater deterioration level are provided as medium standard habitat level in CD section of upper course mining sites. Therefore, following the overall model results, Lalgah segment fall in medium river health level but indicators in this segment are relatively changes from sandbar sites to mining and pit sites.

In sandbar section of middle segment as KL, entropy MCDM methods are clarified the moderate bank erosion, poor water quality, narrow with shallow channel and low vegetation complexity for hindrance of health standard, whereas AHP MCDM methods are signified the less human activity index near riparian zone, widen riparian vegetation buffer, long water flow condition, moderate water velocity, slightest pollution level, thick substrate composition, meandering channel, rich biodiversity indices, moderate species evenness and meagre

development work for enhancing the health potentiality. Despite the wide and deep channel and restricted bank erosion in mining section of middle segment as GH; narrow riparian vegetation buffer, low water flow condition, variable flow velocity, high pollution level (more fluctuated physicochemical parameters), straight channel pattern, least biodiversity indices and species richness are damages the healthy level. In addition, sediment deficiency causes the intense bank erosion, high pollution level, thin substrate composition, massive human activity near riparian sites; but wide riparian vegetation buffer, good water quality, wider with deep channel, rich biodiversity, high species richness and vegetation complex are maintained to suitable health level in pit section of middle segment as IJ. Therefore, it can be said that overall river health status in Dherua segment reaches at standard level in Kangsabati River. Contrastingly, regardless of wide riparian vegetation buffer and meandering channel pattern; massive bank erosion, least water flow condition and water velocity, poor water quality, meagre thickness of substrate composition, low biodiversity and species richness, slight habitat complexity and dense human activity including over growing development work are helped to cross the resilience capacity of health potentiality in mining, pit and sandbar sections of lower course as MN, OP and QR. Through the analysis of ecosystem indicators in Kapastikri segment, health deterioration level is more progressed in mining and pit sites than sandbar sites, as a result ecological restoration must be needed in this entire segment. In order to riverine integrity and HSDs at section level; AHP based MCDM methods like AHP SAW and AHP WASPASS are more fittest to successfully detect the maximum and minimum influence values from twenty river health indicators using normalized matrix, weighted normalized matrix and exponentially weighted matrix, along with assessment of final preference value from effective health indicators. On the other hand, some major limitations are observed in this study i.e. certain degree of subjectivity and uncertainty in indicators assessment, none uniformly dealing, less cross section selection; hence indicator system cannot provide the details information about the river health in the Kangsabati River as well as assessment methods are incapable to actual estimate the indicator role in decision process. However, the finding in this research also helps to identify the sick health sites where most of the indicators are crossed their resilience capacity in one hand, and applied MCDM methods are provided the threshold status of indicator for policy maker to take proper management for ecological restoration.

Conclusion

This study entrusted to establish the extent of river health sensitivity to riparian structure, water flow condition, river morphological structure and its planform, ecological connotation and social structure of the Kangsabati River with the considering of twenty indicator indexes from state of riverine integrity and HSDs. Fuzzy MCDM, AHP based MCDM and entropy based MCDM methods are used to assess the significant role of indicators on river health status along the upper, middle and lower course at segment level, in particular monsoonal alluvial river. The results were revealed that lower course segments are at an unhealthy level but middle and upper course segments are maintained their health level. In this study, segment-wide indicators depicted that high human activity index like sand mining, overgrowing development works as dam construction, industrial set up, urban expansion are the main reasons for beyond the resilience capacity of riverine system through the intense bank erosion, interrupted flow condition and its alteration, deteriorated water quality, thin substrate composition; as a result health level including species diversity, richness and habitat complexity are drastically degraded especially in mining sites. We found that HSDs are crossed the tolerate level of natural integrity of river hydraulics, morphology and ecology in the entire Kangsabati River.

With the following of river health prioritization at section level, entropy based MCDM methods are comprehensively assess the state of natural integrity indicators to acquire the harmonium relationship while fuzzy set theory and AHP based MCDM methods are accurately determined the anthropogenic pressure and its response indicators to find out the real situation. According to validation performance, RSS suggested the entropy based VIKOR models for least error as well as most compatibility within the results of integrating priority as obtained by proposed methods, whereas percentage change and intensity change are validated the AHP based SAW and WASPASS methods amongst the MCDM methods to accurately assign the priority rank for healthy connotation. In respect to over growing HSDs, AHP based MCDM methods are more acceptable for river health assessment index system; therefore prioritization rank as suggest by AHP based SAW and WASPASS helps to take effective ecological restoration in unhealthy sections throughout the river.

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Reference

Alemu T, Bahrndorff S, Pertoldi C, Hundera K, Alemayehu E, Ambelu A (2018) Development of a plant based riparian index of biotic integrity (RIBI) for assessing the ecological condition of highland streams in East Africa. *Ecol. Indic.* 87, 77–85

Ameri A A, Pourghasemi HR, Cerda A (2018) Erodibility prioritization of subwatersheds using morphometric parameters analysis and its mapping: a comparison among TOPSIS, VIKOR, SAW, and CF multi-criteria decision making models. *Sci. Total Environ.* 613, 1385–1400. <https://doi.org/10.1016/j.scitotenv.2017.09.210>

Badri SA (2003) Models of rural planning. Pamphlets Practical Lesson in Geography Rural Planning. 2. Payame Noor University, p. 126 (299-312)

707 Bhattacharya R, Dolui G, Chatterjee ND (2019a) Effect of instream sand mining on hydraulic variables of
708 bedload transport and channel planform: an alluvial stream in South Bengal basin, India. *Environmental Earth*
709 *Sciences*, 78(10), pp.1-24

710 Bhattacharya RK, Chatterjee ND, Das K (2019b) Geomorphic response to riverine land cover dynamics in a
711 quarried alluvial river Kangsabati, South Bengal, India. *Environmental Earth Sciences*, 78(22), pp.1-18

712 Bhattacharya RK, Chatterjee ND, Dolui G (2019c) Consequences of sand mining on water quality and instream
713 biota in alluvial stream: a case-specific study in South Bengal River, India. *Sustainable Water Resources*
714 *Management*, 5(4), pp.1815-1832

715 Bhattacharya RK, Chatterjee ND, Das K (2020a) Sub-basin prioritization for assessment of soil erosion
716 susceptibility in Kangsabati, a plateau basin: A comparison between MCDM and SWAT models. *Science of the*
717 *Total Environment*, 734, p.139474

718 Bhattacharya RK, Chatterjee ND, Das K (2020b) Impact of instream sand mining on habitat destruction or
719 transformation using coupling models of HSI and MLR. *Spatial Information Research*, 28(1), pp.67-85

720 Chau K, Muttill N (2007) Data mining and multivariate statistical analysis for ecological system in coastal
721 waters. *J. Hydroinf.* 9, 305–317 <https://doi.org/10.2166/hydro.2007.003>

722 Cheng X, Chen LD, Sun RH, Kong PR (2018) Land use changes and socio-economic development strongly
723 deteriorate river ecosystem health in one of the largest basins in China. *Sci. Total Environ.* S616–617, 376–385

724 Chiang Y, Hsieh H (2009) The use of the Taguchi method with grey relational analysis to optimize the thin-film
725 sputtering process with multiple quality characteristic in color filter manufacturing. *Comput. Ind. Eng.* 56, 648–
726 661 <https://doi.org/10.1016/j.cie.2007.12.020>

727 Cunha A, Gonçalves P, Barreira J, Trigo A, Hughes SJ (2015) Mobile RHS: a mobile application to support the
728 “river habitat survey” methodology. *Procedia Comput. Sci.* 64, 87–94

729 Das B C, Ghosh S, Islam A, Roy S (Eds.) (2020) *Anthropogeomorphology of Bhagirathi-Hooghly River System*
730 *in India*. CRC Press

731 Deng X, Xu Y, Han L, Yu Z, Yang M (2015) Assessment of river health based on an improved entropy-based
732 fuzzy matter-element model in the Taihu Plain, China. *Ecol. Indic.* 57, 85–95
733 <https://doi.org/10.1016/j.ecolind.2015.04.020>.

734 Ding Y, Shan B, Zhao Y (2015) Assessment of river habitat quality in the hai river basin, northern
735 China. *International journal of environmental research and public health*, 12(9), pp.11699-11717

736 Dutta V, Sharma U and Kumar R (2017) Assessment of river ecosystems and environmental flows: Role of flow
737 regimes and physical habitat variables. *Climate Change and Environmental Sustainability*, 5(1), pp.20-34

738 Fairweather PG (1999) State of environment indicators of “river health”: exploring the metaphor. *Freshw. Biol.*
739 41, 211–220. <https://doi.org/10.1046/j.1365-2427.1999.00426.x>.

740 Friend, P.F. and Sinha, R., 1993. Braiding and meandering parameters. *Geological Society, London, Special*
741 *Publications*, 75(1), pp.105-111

742 Gain AK, Giupponi C (2015) A dynamic assessment of water scarcity risk in the Lower Brahmaputra River
743 Basin: an integrated approach. *Ecol. Indic.* 48, 120–131 <https://doi.org/10.1016/j.ecolind.2014.07.034>

744 Ghaleno MRD, Meshram SG, Alvandi E (2020) Pragmatic approach for prioritization of flood and
745 sedimentation hazard potential of watersheds. *Soft Computing*, 24, pp.15701-15714.

746 He Y, Dai A, Zhu J, He H, Li F (2011) Risk assessment of urban network planning in china based on the matter-
 747 element model and extension analysis. *Int. J. Electr. Power Energy Syst.* 33, 775–782
 748 <https://doi.org/10.1016/j.ijepes.2010.12.037>
 749 Hwang CL, Yoon K (1981) Multiple Attributes Decision Making Methods and Applications. Springer, Berlin
 750 Heidelberg, p. 225
 751 Jing J, Li L, Lv G (2000) Comprehensive evaluation on environmental pollution by fuzzy matter-element
 752 method. *J. Southwest Petroleum Inst.* 11 (4), 70–73
 753 Kaganski S, Majak J, Karjust K (2018) Fuzzy AHP as a tool for prioritization of key performance indicators. In
 754 *Procedia CIRP* <https://doi.org/10.1016/j.procir.2018.03.097>
 755 Kaklauskas A, Zavadskas EK (2011) COPRAS based comparative analysis of the European country
 756 management capabilities within the construction sector in the time of crisis AU - Kildienė, Simona. *J. Bus.*
 757 *Econ. Manag.* 12, 417–434
 758 Kaklauskas A, Zavadskas EK, Raslanas S, Ginevicius R, Komka A, Malinauskas P (2006) Selection of low-e
 759 windows in retrofit of public buildings by applying multiple criteria method COPRAS: a Lithuanian case.
 760 *Energy and Buildings* 38, 454–462
 761 Karr JR (1981) Assessment of biotic integrity using fish communities. *Fisheries* 6, 21–27
 762 Karr JR (1999) Defining and measuring river health. *Freshw. Biol.* 41, 221–234
 763 Krohling RA and Campanharo VC (2011) Fuzzy TOPSIS for group decision making: A case study for accidents
 764 with oil spill in the sea. *Expert Systems with applications*, 38(4), pp.4190-4197
 765 Kuo Y, Yang T, Huang GW (2008) The use of grey relational analysis in solving multiple attribute decision-
 766 making problems. *Comput. Ind. Eng.* 55, 80–93 <https://doi.org/10.1016/j.cie.2007.12.002>
 767 Ladson AR, White LJ, Doolan JA, Finlayson BL, Hart BT, Lake PS, Tilleard JW (1999) Development and
 768 testing of an index of stream condition for waterway management in Australia. *Freshw. Biol.* 41 (2), 453–468
 769 Liu D, Zou Z (2012) Water quality evaluation based on improved fuzzy matter-element method. *J. Environ. Sci.*
 770 (China) 24, 1210–1216 [https://doi.org/10.1016/S1001-742\(11\)60938-8](https://doi.org/10.1016/S1001-742(11)60938-8)
 771 Luo Z, Zuo Q and Shao Q (2018) A new framework for assessing river ecosystem health with consideration of
 772 human service demand. *Science of the Total Environment*, 640, pp.442-453
 773 Ma D, Luo W, Yang G, Lu J and Fan Y (2019) A study on a river health assessment method based on ecological
 774 flow. *Ecological modelling*, 401, pp.144-154
 775 Maddock I (1999) The importance of physical habitat assessment for evaluating river health. *Freshwater*
 776 *biology*, 41(2), pp.373-391
 777 Margalef RAMON (1958) Temporal sucession and spatial heterogeneity in Phytoplankton In; Perspective in
 778 marine Biology. *University of California press. USA*
 779 Meyer JL (1997) Stream health: incorporating the human dimension to advance stream ecology. *Journal of the*
 780 *North American Benthological Society*, 16(2), pp.439-447
 781 Mupenzi C, Li L, Al LNE (2017) Spatial pattern assessment of lake kivu basin rivers water quality using
 782 national sanitation foundation water quality and rivers pollution indices. *Desalin. Water Treat.* 95, 128–143
 783 Nădăban S, Dzitac S, Dzitac I (2016) Fuzzy TOPSIS: a general view. *Procedia Computer Science*, 91, pp.823-
 784 831
 785 Navratil O, Albert MB (2010) Non-linearity of reach hydraulic geometry relations. *J Hydrol* 388:280–290

786 Norris R.H. Thoms MC (1999) What is river health? *Freshw. Biol.* 197–209

787 Oliveira RB, Mugnai R, Castro CM, Baptista DF (2011) Determining subsampling effort for the development of
788 a rapid bioassessment protocol using benthic macroinvertebrates in streams of southeastern Brazil. *Environ.*
789 *Monit. Assess.* 175 (1–4), 75–85

790 Opricovic S, Tzeng GH (2004) Compromise solution by MCDM methods: a comparative analysis of VIKOR
791 and TOPSIS. *Eur. J. Oper. Res.* 156 (2), 445–455 [https://doi.org/10.1016/S0377-2217\(03\)00020-1](https://doi.org/10.1016/S0377-2217(03)00020-1)

792 Petesse ML, Siqueira-Souza FK, de Carvalho, Freitas CE, Petrere, M (2016) Selection of reference lakes and
793 adaptation of a fish multimetric index of biotic integrity to six amazon floodplain lakes. *Ecol. Eng.* 97, 535–544

794 Pielou EC (1966) The measurement of diversity in different types of biological collections. *Journal of*
795 *theoretical biology*, 13, pp.131-144

796 Podvezko V (2011) The comparative analysis of MCDA methods SAW and COPRAS. *Inzinerine Ekonomika-*
797 *Engineering Economics* 22, 134–146

798 Restrepo JD, Escobar R, Tosic M (2018) Fluvial fluxes from the Magdalena River into Cartagena Bay,
799 Caribbean Colombia: trends, future scenarios, and connections with upstream human impacts. *Geomorphology*
800 302, 92–105 <https://doi.org/10.1016/j.geomorph.2016.11.007>

801 Richter J, Fettig I, Philipp R, Jakubowski N, Panne U, Fiscaro P, Alasonati E (2016)
802 Determination of tributyltin in whole water matrices under the European Water Framework Directive. *J.*
803 *Chromatogr. A* 1459, 112–119

804 Saaty TL (1980) *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*. McGraw-
805 Hill, New York, NY

806 Sadat MA, Guan Y, Zhang D, Shao G, Cheng X, Yang Y (2020) The associations between river health and
807 water resources management lead to the assessment of river state. *Ecological Indicators*, 109, p.105814

808 Sargaonkar A, Deshpande V (2003) Development of an overall index of pollution for surface water based on a
809 general classification scheme in Indian context. *Environ. Monit. Assess.* 89 (1), 43–67

810 Sargaonkar AP, Rathi B, Baile A (2011) Identifying potential sites for artificial groundwater recharge in sub-
811 watershed of river Kanhan, India. *Environ. Earth Sci.* 62 (5), 1099–1108. [https://doi.org/10.1007/s12665-010-](https://doi.org/10.1007/s12665-010-0598-z)
812 [0598-z](https://doi.org/10.1007/s12665-010-0598-z)

813 Shannon CE (1949) *The mathematical theory of communication*. CE Shannon and Warren Weaver, Urbana.

814 Sharma P, Meher PK, Kumar A, Gautam YP, Mishra KP (2014) Changes in water quality index of Ganges river
815 at different locations in Allahabad. *Sustainability of Water Quality and Ecology*, 3, pp.67-76

816 Shi X, Liu J, You X, Bao K, Meng B, Chen B (2017) Evaluation of river habitat integrity based on benthic
817 macroinvertebrate-based multi-metric model. *Ecol. Model.* 353, 63–76.

818 Shukla R K, Garg D, Agarwal A (2014) An integrated approach of Fuzzy AHP and Fuzzy TOPSIS in modeling
819 supply chain coordination. *Production and Manufacturing Research*, 2(1), 415–437.
820 <https://doi.org/10.1080/21693277.2014.919886>

821 Si T, Wang C, Liu R, Guo Y, Yue S, Ren Y (2020) Multi-criteria comprehensive energy efficiency assessment
822 based on fuzzy-AHP method: A case study of post-treatment technologies for coal-fired units. *Energy*, 200,
823 p.117533

824 Singh PK, Saxena S (2018) Towards developing a river health index. *Ecol. Indic.* 85, 999–1011
825 <https://doi.org/10.1016/j.ecolind.2017.11.059>

Solangi YA, Shah SAA, Zameer H, Ikram M and Saracoglu BO (2019) Assessing the solar PV power project site selection in Pakistan: based on AHP-fuzzy VIKOR approach. *Environmental Science and Pollution Research*, 26(29), pp.30286-30302

Vollmer D, Shaad, K, Souter NJ, Farrell T, Dudgeon D, Sullivan CA, Fauconnier I, Von Schiller D, Acuña V, Aristi I, Arroita M, Basaguren A, Bellin A, Boyero L, Butturini A, Ginebreda A, Kalogianni E and Larrañaga A (2017) River ecosystem processes: A synthesis of approaches, criteria of use and sensitivity to environmental stressors. *Science of the Total Environment*, 596, pp.465-480

Wang Y, Xu L and Solangi YA (2020) Strategic renewable energy resources selection for Pakistan: Based on SWOT-Fuzzy AHP approach. *Sustainable Cities and Society*, 52, p.101861

Wellemeyer JC, Perkin JS, Fore JD, Boyd C (2018) Comparing assembly processes for multimetric indices of biotic integrity. *Ecol. Indic.* 89, 590–609

Xie J, Cheng C (2006) A hybrid adaptive time-delay neural network model for multistep- ahead prediction of sunspot activity Kwok-Wing Chau Yong-Zhen Pei 28, 364–381

Xue C, Shao C and Chen S (2020) SDGs-Based River Health Assessment for Small-and Medium-Sized Watersheds. *Sustainability*, 12(5), p.1846

Yang T, Liu J, Li X and Zhao X (2017) Plain river habitat assessment of Haihe River basin. *Environmental Science & Technology (China)*, 40(3), pp.190-197

Yang W, You Q, Fang N, Xu L, Zhou Y, Wu N, Ni CY, Liu Y, Liu GH, Yang T, Wang Y (2018) Assessment of wetland health status of Poyang Lake using vegetation-based indices of biotic integrity. *Ecol. Indic.* 90, 79–89

Zavadskas EK, Kaklauskas A, Vilutiene T (2009) Multicriteria evaluation of apartment blocks maintenance contractors: Lithuanian case study. *International Journal of Strategic Property Management*. 13(4):319- 338. doi:10.3846/1648-715X.2009.13.319-338

Zavadskas E K, Turskis Z, Antucheviciene J, Zakarevicius A (2012) Optimization of weighted aggregated sum product assessment. *Electronics and Electrical Engineering*, 6(122), 3–6

Zhao YW, Yang ZF (2009) Integrative fuzzy hierarchical model for river health assessment: a case study of Yong River in Ningbo City, China. *Commun. Nonlinear Sci. Numer. Simul.* 14, 1729–1736 <https://doi.org/10.1016/j.cnsns.2007.09.019>

Zhu Y, Tian D and Yan F (2020) Effectiveness of entropy weight method in decision-making. *Mathematical Problems in Engineering*, 2020

Zolfani SH, Aghdaie MH, Derakhti A, Zavadskas EK and Varzandeh MHM (2013) Decision making on business issues with foresight perspective; an application of new hybrid MCDM model in shopping mall locating. *Expert systems with applications*, 40(17), pp.7111-7121

Zou Z, Yun Y, Sun J (2006) Entropy method for determination of weight of evaluating indicators in fuzzy synthetic evaluation for water quality assessment. *J. Environ. Sci. (China)* 18, 1020–1023 [https://doi.org/10.1016/S1001-0742\(06\)60032-6](https://doi.org/10.1016/S1001-0742(06)60032-6)

Zuo QT, Luo ZL, Ding XY (2016) Harmonious development between socio-economy and river-lake water system in Xiangyang City, China. *Water* 8 (11), 1–19

866 **Table 1** Assessment criteria of river health evaluation indicators

Indicators	Attribute	Unit	Very well	Well	Critical state	Poor	Very poor
A1	ve+	Meter	<25	15-25	10-15	10-5	<5
A2	ve+	Meter	<200	100-200	50-100	0-50	0
A3	ve-	%	>10%	10-30%	30-45%	45-60%	<60
B1	ve+	/	<0.8	0.8-0.6	0.6-0.4	0.4-0.2	>0.20
B2	ve+	m/s	0.60-0.75	0.40-0.50	0.30-0.40	0.20-0.30	>0.20 - <0.75
B3	ve-	%	<25	25-50	50-70	70-100	>100
B4	ve-	/	<0.9	0.9-1.0	1.0-1.1	1.1-1.2	>1.2
C1	ve+	Millimetre	<0.50	0.25-0.50	0.10-0.25	0.05-0.10	>0.05
C2	ve+	Meter	<500	500-400	400-300	300-200	>200
C3	ve+	Meter	<1.7	1.7-1.5	1.5-1.3	1.3-1.0	>1.0
C4	ve+	Number	<2.00	1.60-2.00	1.40-1.60	1.20-1.40	>1.20
D1	ve+	Number	<0.8	0.8-0.6	0.6-0.4	0.4-0.2	>0.20
D2	ve+	Number	<10	10-8	8-6	6-4	>4
D3	ve+	Number	<1.8	1.8-1.6	1.6-1.4	1.4-1.2	>1.2
D4	ve+	Number	<4.5	4.5-3.5	3.5-2.5	2.5-1.5	>1.5
D5	ve+	/	<0.8	0.8-0.6	0.6-0.4	0.4-0.2	>0.20
D6	ve-	Number	<0.8	0.8-1.0	1.0-1.2	1.2-1.5	>1.5
E1	ve-	/	<0.1	0.1-0.3	0.3-0.6	0.6-0.8	<0.8
E2	ve-	Meter	<0.5	0.5-1	1-1.5	1.5-2	<2
E3	ve-	/	<1	5-1	10-5	15-10	>15

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Table 2 Actual values of river health indicators for different sections of the rivers

Indicators	CD	AB	EF	GH	IJ	KL	MN	OP	QR
A1	0.35	0.30	0.45	0.50	0.30	0.45	0.40	0.40	0.30
A2	0.45	0.55	0.15	0.20	0.30	0.35	0.32	0.40	0.70
A3	0.50	0.40	0.45	0.50	0.40	0.45	0.40	0.30	0.30
B1	0.30	0.25	0.50	0.25	0.30	0.60	0.20	0.15	0.35
B2	1.77	1.65	1.70	0.91	0.82	0.87	0.82	0.81	0.83
B3	62.49	82.29	41.69	23.85	23.16	34.61	63.70	83.34	48.11
B4	1.20	1.31	1.38	1.39	1.36	0.51	1.03	0.89	1.23
C1	0.30	0.25	0.35	0.25	0.10	0.20	0.08	0.10	0.05
C2	305.00	247.00	221.00	495.00	281.00	165.00	361.00	226.00	187.00
C3	1.23	1.35	0.83	1.06	1.21	0.95	1.85	1.21	1.13
C4	1.50	1.80	1.40	1.20	1.20	1.40	1.42	1.85	1.40
D1	0.84	0.87	0.86	0.79	0.87	0.87	0.77	0.84	0.81
D2	6.29	9.19	7.17	4.89	7.73	7.47	4.42	6.18	5.22
D3	1.53	1.36	1.53	1.34	1.52	1.66	1.15	1.51	1.18
D4	2.94	3.55	3.62	3.23	3.95	3.53	3.01	3.13	2.78
D5	0.25	0.35	0.15	0.30	0.40	0.20	0.45	0.60	0.35
D6	0.90	1.21	1.11	0.86	1.20	0.98	1.15	0.94	0.82
E1	0.20	0.20	0.20	0.23	0.23	0.23	0.57	0.57	0.57
E2	0.03	0.03	0.03	2.20	2.20	2.20	1.01	1.01	1.01
E3	1.32	1.32	1.32	3.47	3.47	3.47	16.41	16.41	16.41

Table 3 Estimation of weight assignment of the river health indicators using entropy method

Indicators	eij	dij	wij
A1	0.668	0.332	0.045
A2	0.597	0.403	0.055
A3	0.698	0.302	0.041
B1	0.692	0.308	0.042
B2	0.695	0.305	0.041
B3	0.587	0.413	0.056
B4	0.668	0.332	0.045
C1	0.739	0.261	0.035
C2	0.660	0.340	0.046
C3	0.632	0.368	0.050
C4	0.652	0.348	0.047
D1	0.673	0.327	0.044
D2	0.694	0.306	0.041
D3	0.684	0.316	0.043
D4	0.683	0.317	0.043
D5	0.580	0.420	0.057
D6	0.672	0.328	0.044
E1	0.514	0.486	0.066
E2	0.485	0.515	0.070
E3	0.326	0.674	0.091

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885 **Table 4** Positive ideal (f+), negative ideal (f-), maximum (A+) and minimum value (A-) of indicators in
 886 entropy and AHP based VIKOR and TOPSIS models

Indicators	Entropy VIKOR		AHP VIKOR		Entropy TOPSIS		AHP TOPSIS	
	f+	f-	f+	f-	A+	A-	A+	A-
C1	0.019	0.012	0.008	0.005	0.019	0.012	0.008	0.005
C2	0.031	0.007	0.026	0.006	0.031	0.007	0.026	0.006
C3	0.010	0.016	0.027	0.045	0.010	0.016	0.027	0.045
C4	0.024	0.006	0.024	0.006	0.024	0.006	0.024	0.006
C5	0.020	0.009	0.013	0.006	0.020	0.009	0.013	0.006
C6	0.008	0.028	0.023	0.081	0.008	0.028	0.023	0.081
C7	0.006	0.018	0.015	0.040	0.006	0.018	0.015	0.040
C8	0.019	0.003	0.026	0.004	0.019	0.003	0.026	0.004
C9	0.026	0.009	0.014	0.005	0.026	0.009	0.014	0.005
C10	0.025	0.011	0.010	0.004	0.025	0.011	0.010	0.004
C11	0.020	0.013	0.003	0.002	0.020	0.013	0.003	0.002
C12	0.015	0.014	0.021	0.019	0.015	0.014	0.021	0.019
C13	0.019	0.009	0.009	0.004	0.019	0.009	0.009	0.004
C14	0.017	0.011	0.024	0.016	0.017	0.011	0.024	0.016
C15	0.017	0.012	0.013	0.009	0.017	0.012	0.013	0.009
C16	0.031	0.008	0.034	0.008	0.031	0.008	0.034	0.008
C17	0.012	0.017	0.009	0.013	0.012	0.017	0.009	0.013
C18	0.012	0.034	0.015	0.042	0.012	0.034	0.015	0.042
C19	0.001	0.036	0.000	0.008	0.001	0.036	0.000	0.008
C20	0.004	0.051	0.001	0.016	0.004	0.051	0.001	0.016

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Table 5 Prioritization of river health in different river sections using MCDM methods

MCDM Methods	CD	AB	EF	GH	IJ	KL	MN	OP	QR
Fuzzy AHP	0.11	0.11	0.12	0.11	0.13	0.12	0.10	0.11	0.09
RANK	5	7	2	4	1	3	8	6	9
FUZZY TOPSIS	0.50	0.43	0.57	0.42	1.42	0.54	0.50	0.53	0.38
RANK	5	7	2	8	1	3	6	4	9
Entropy VIKOR	0.03	0.11	0.17	0.52	0.48	0.35	1.00	0.81	0.95
RANK	1	2	3	6	5	4	9	7	8
Entropy COPRAS	100	97.78	99.47	78.76	77.7	81.83	67.99	70.21	68.1
RANK	1	3	2	5	6	4	9	7	8
Entropy SWA	0.76	0.77	0.74	0.62	0.61	0.64	0.52	0.56	0.53
RANK	2	1	3	5	6	4	9	7	8
Entropy WASPASS	9.81	9.14	7.27	13.39	8.53	6.15	12.12	9.61	7.63
RANK	2	1	3	5	6	4	9	7	8
Entropy TOPSIS	0.67	0.66	0.62	0.51	0.51	0.51	0.33	0.35	0.36
RANK	1	2	3	5	6	4	9	8	7
AHP VIKOR	0.41	0.73	0.25	0.43	0.21	0.00	0.67	0.81	0.34
RANK	5	8	3	6	2	1	7	9	4
AHP COPRAS	89.37	86.10	93.64	90.66	93.06	100.00	72.93	75.64	78.20
RANK	5	6	2	4	3	1	9	8	7
AHP SAW	0.67	0.67	0.69	0.68	0.70	0.73	0.54	0.60	0.59
RANK	5	6	3	4	2	1	9	7	8
AHP WASPASS	0.65	0.64	0.66	0.65	0.67	0.69	0.51	0.55	0.55
RANK	5	6	3	4	2	1	9	8	7
AHP TOPSIS	0.46	0.39	0.55	0.60	0.62	0.64	0.33	0.33	0.46
RANK	5	7	4	3	2	1	8	9	6

Table 6 Ranking of recommended MCDM methods using BORDA test

Sample sites	Section	Score	Average	Priority
Lalgarh Mining	CD	73	6.083333	4
Lalgarh Mining pit	AB	82	6.833333	2
Lalgarh Sandbar	EF	76	6.333333	3
Dherua Mining	GH	54	4.5	6
Dherua Mining pit	IJ	92	7.666667	1
Dherua Sandbar	KL	62	5.166667	5
Kapastikri Mining	MN	40	3.333333	7
Kapastikri Mining pit	OP	31	2.583333	8
Kapastikri Sandbar	QR	30	2.5	9

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Table 7 Computation of total root mean square for proposing MCDM methods

MCDM Methods	Symbol	RMSE
Fuzzy AHP	A	2.108
Entropy VIKOR	B	1.886
AHP VIKOR	C	2.981
Entropy COPRAS	D	2.211
AHP COPRAS	E	2.357
AHP SAW	F	2.211
Entropy SWA	G	2.055
Entropy WASPASS	H	2.055
AHP WASPASS	I	2.261
AHP TOPSIS	J	2.667
Entropy TOPSIS	K	2.211
Fuzzy TOPSIS	L	2.404

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Table 8 The percentage changes in the twelve MCDM methods compared each and others

	A	B	C	D	E	F	G	H	I	J	K	L	Average
A	100.00	100.00	88.89	88.89	66.67	77.78	100.00	100.00	77.78	66.67	100.00	33.33	88.89
B	100.00	100.00	77.78	44.44	88.89	55.56	44.44	44.44	77.78	100.00	44.44	100.00	73.15
C	88.89	77.78	100.00	100.00	77.78	55.56	88.89	88.89	55.56	55.56	88.89	88.89	80.56
D	88.89	44.44	100.00	100.00	77.78	66.67	33.33	33.33	88.89	100.00	44.44	88.89	72.22
E	66.67	88.89	77.78	77.78	100.00	44.44	88.89	88.89	22.22	77.78	66.67	77.78	73.15
F	77.78	55.56	55.56	66.67	44.44	100.00	55.56	55.56	22.22	66.67	77.78	88.89	63.89
G	100.00	44.44	88.89	33.33	88.89	55.56	100.00	0.00	77.78	100.00	44.44	100.00	69.44
H	100.00	44.44	88.89	33.33	88.89	55.56	0.00	100.00	77.78	100.00	44.44	100.00	69.44
I	77.78	77.78	55.56	88.89	22.22	22.22	77.78	77.78	100.00	66.67	55.56	88.89	67.59
J	66.67	100.00	55.56	100.00	77.78	66.67	100.00	100.00	66.67	100.00	100.00	77.78	84.26
K	100.00	44.44	88.89	44.44	66.67	77.78	44.44	44.44	55.56	100.00	100.00	100.00	72.22
L	33.33	100.00	88.89	88.89	77.78	88.89	100.00	100.00	88.89	77.78	100.00	100.00	87.04

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Table 9 The intensity changes in the twelve MCDM methods compared each and others

	A	B	C	D	E	F	G	H	I	J	K	L	SUM
A	1.00	1.52	1.20	1.44	1.16	1.13	1.64	1.62	1.98	1.17	1.53	1.04	16.42
B	1.44	1.00	1.45	1.02	1.36	1.39	1.06	1.75	1.85	1.44	1.01	1.47	16.24
C	1.14	1.58	1.00	1.50	1.05	1.04	1.76	1.82	1.99	1.05	1.58	1.18	16.70
D	1.49	1.02	1.46	1.00	1.33	1.40	1.13	1.67	1.88	1.45	1.02	1.53	16.37
E	1.16	1.47	1.06	1.40	1.00	1.02	1.53	1.69	2.07	1.04	1.47	1.22	16.12
F	1.10	1.48	1.05	1.43	1.02	1.00	1.54	1.68	2.06	1.02	1.49	1.15	16.01
G	1.53	1.06	1.49	1.09	1.37	1.42	1.00	1.68	1.81	1.47	1.06	1.57	16.55
H	1.81	1.49	2.06	1.53	2.05	2.00	1.59	1.00	1.20	1.95	1.48	1.84	20.00
I	2.01	1.48	2.13	1.56	2.10	2.11	1.36	1.34	1.00	2.11	1.47	1.98	20.65
J	1.14	1.55	1.04	1.49	1.05	1.02	1.66	1.57	2.03	1.00	1.54	1.22	16.31
K	1.53	1.01	1.47	1.02	1.36	1.42	1.06	1.67	1.86	1.45	1.00	1.58	16.44
L	1.05	1.53	1.21	1.47	1.22	1.19	1.67	1.90	1.77	1.26	1.57	1.00	16.84

Fig. 1. Study area

Fig. 2. River segment sites: a Lalgarh, b Dherua, c Kapastikri

Fig. 4. Methodological flow chart in this study

Fig. 5. Actual value of riparian indicators

Fig. 6. Water condition: a actual value of riparian indicators, b water quality index

Fig. 7. Variation of physicochemical parameters along the upper, middle and lower course of Kangsabati River: a BOD (mg/L), b Salinity (PPT), c Turbidity (NTU), d TDS (mg/L), e Conductivity ($\mu\text{S}/\text{cm}$), f p^{H} , g DO, h Mg^{+}

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d

Fig. 8. River morphology: a actual value of morphology indicators; b hydraulic geometry of three segments b/f; c m/f; d hydraulic geometry with respect of flow discharge, width, depth, velocity

a

Fig. 9. River ecology: a actual value of ecological indicators, b species diversity index

Fig. 10. Actual value of social indicators

Fig. 11. Weight estimation in each river health indicator obtaining by AHP and Entropy

Fig. 12. Rank prioritization amongst the nine sample sites using twelve MCM methods

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