

Impact assessment of industrial wastewater discharge in a river basin using interval-valued fuzzy group decision-making and spatial approach

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Received: 28 January 2017 / Accepted: 14 June 2017 / Published online: 19 June 2017
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Abstract Sustainable and integrated river basin planning and management is a complex process involving uncertain data at different stages of decision-making process. Moreover, there are multiple decision makers at different institutions with contrasting interests and objectives, and thus, a collaborative decision making is required to resolve the conflicts. Although the formulation or modeling of such problems under fuzzy framework provides a very strong ground to deal with the uncertain and complex judgments, there is scope to model the problem more accurately. The present study develops a novel approach of dealing with uncertainty associated with group decision making in a river basin, by extending fuzzy Delphi process using interval-valued fuzzy sets. A case study of assessing the impact of industrial wastewaters on the Ganges River basin, India, has also been presented to demonstrate the effectiveness of the proposed methodology. A total of 33 industrial units, mainly paper pulp, tanneries and textiles, discharging massive quantities of wastewater in the Ganges River basin have been chosen for the analysis. These industries are rated by the expert decision makers to represent their objective judgments (and/or subjective preferences) on the basis of ten essential sets of criteria such as impact on river, impact on groundwater, critical pollutants level, impact on public health. The ratings are analyzed and aggregated using modified fuzzy decision-making approach, and industries are ranked accordingly. To enhance the decision-making process, the results are also represented spatially under GIS environment. Analysis of results clearly demonstrates the contribution of crucial indicators/criteria in ensuring the sustainable use of water resources with respect to environmental, social and economic dimensions. The results obtained are compared and validated with the recent research works and reports of pollution control boards. The study recommends several policy implementations, primarily revision in prescribed effluent discharge standards of the industries. The model developed herein can be

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an efficient and productive tool for complex group decisions in water resources planning by facilitating participation and knowledge sharing among the experts.

Keywords Sustainability · Water · Industrial wastewater · Interval-valued fuzzy sets · Fuzzy decision making

1 Introduction

Rivers have been playing a significant role in the development of human civilization, agricultural production, industrialization, power generation and urbanization since time immemorial. However, overexploitation and indiscriminate usage of water resources owing to growing demands have led to degradation and contamination of the river ecosystems across the globe. These days, majority of the rivers act as a recipient of heavy quantities of wastewaters generated from industrial, domestic and agricultural sectors. This has not just affected flora and fauna of the river water bodies, but also posed serious risks to the human health. Keeping in view of the pollution effects, and its risk management to restore the river ecosystem, it is very essential to manage the water resources in a sustainable way. Regular monitoring and management of the industrial effluents entering into the river system can be a primary initiative in this direction. In recent times, integrated water resource planning and management comprising of numerous decision makers has been proven to be an effective approach to manage the river water resources efficiently (Karamouz et al. 2009). It involves development of a systematic plan for a river basin, which simultaneously considers social, economic, ecological and environmental criteria. The performance evaluation of these criteria can be done by incorporating the judgment of the experts belonging to different institutions, having conflicting interests and perceptions in the field of water resource management. The suggestions and guidance of all such group of experts are required to be integrated accurately under a suitable mathematical model in order to arrive at a single, efficient and usable decision. The increasing popularity of such models has attracted the interests of several water resource researchers in the past few decades (Viessman and Smerdon 1990; Loucks 2000). Therefore, a river basin planning is a multi-criteria group decision-making (MCDM) problem. By using MCDM methods, the researchers can develop a decision-making framework based on the suitable criteria considered for a river basin management (Asl Roustia and Araghinejad 2015; Minatour et al. 2015). Among all such methods, analytic hierarchy process (AHP) has been very popular and widely accepted. Once the problem is structured into an AHP hierarchical form, the overall priorities are obtained by integrating the local and global preference weights (Saaty 2001).

Despite the popularity of the traditional MCDM methods such as AHP, one of their major limitations is the inability to deal with limited and uncertain experimental data and human perceptions, and the various complexities associated with the decision variables. The main predicament arises while combining the quantitative measures with linguistic judgments, and incorporating decision maker's perspective toward the risk assessment of the model. One of the effective ways to deal with the uncertainties present in MCDM problems is to represent them using traditional fuzzy sets framework (Zadeh 1965). Such an approach has been achieving tremendous success in the area of water resources in last two decades (Afshar et al. 2011; Razavi Toosi and Samani 2012). Singh et al. (2015) had

applied fuzzy AHP technique based on extent analysis to evaluate the water quality status of River Yamuna, India. Srinivas et al. (2015) had used ‘MATLAB fuzzy expert system’ to analyze the water quality of groundwater wells in the Bikaner region of Rajasthan, India. In order to provide an additional degree of freedom or flexibility to the decision makers for representing the uncertainty with more accuracy, efficient fuzzy sets such as interval-valued fuzzy sets (IVFSs) have been introduced by Gorzalczy (1987). The primary difference between the traditional fuzzy sets and IVFSs is that the membership function of the IVFSs is a fuzzy system within the interval of $[0, 1]$. Figure 1 represents an interval-valued fuzzy set ‘Z’. The membership value at x' corresponding to the set ‘Z’ lies within the interval of $[(\tilde{\mu}_{Z1}), (\tilde{\mu}_{Z2})]$. Very few researchers have enriched the problem-solving ability of multi-criteria decision-making tools based on IVFSs. Some of the popular MCDM techniques such as elimination and choice translating reality (ELECTRE) and technique for order preference by simulation of ideal solution (TOPSIS) have been modified by using interval-valued triangular and trapezoidal fuzzy numbers (Chen and Lee 2010).

As discussed earlier, the decisions pertaining to water resource management, especially the one’s dealing with water quality, are very complex in nature involving several inter-related criteria. Thus, it is always recommended to have a panel consisting of multi-disciplinary experts. Such group decision making can be performed using several methods, most popular being Delphi method (Dalkey and Helmer 1963), which integrates the opinion of group of experts through the medium of questionnaires. Delphi approach has been found to be a potential decision-making tool when combined with the fuzzy MCDM techniques. Minatour et al. (2015) applied the interval-valued fuzzy TOPSIS approach to select the optimal strategy for rural water supply in Nohoor, Iran. Though various investigators have applied the concept of fuzzy multi-criteria in water quality assessment and environmental management (Azarnivand et al. 2015; Singh et al. 2015), there is enough scope to develop systematic models by extending traditional ‘fuzzy AHP-based Delphi approach’ using IVFSs.

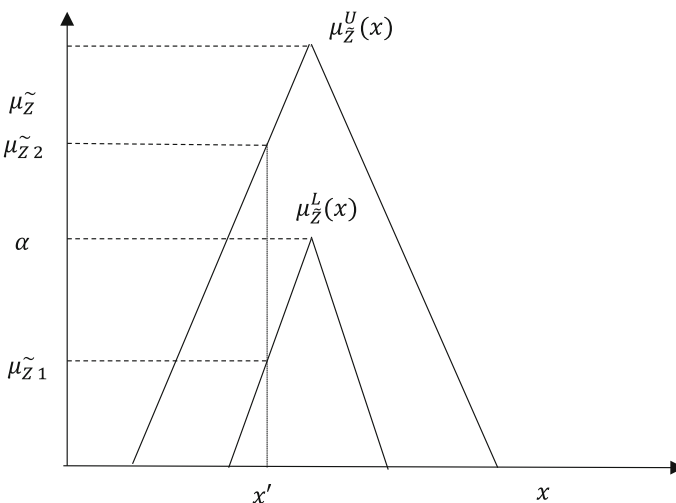


Fig. 1 Representation of interval-valued fuzzy set membership function

Another interesting advancement that has taken place in group decision-making process is the insemination of geographical information system (GIS) in multi-criteria decision analysis (GIS–MCDA). It aggregates geographical data and expert judgments (decision makers' preferences and uncertainties) and provides a flexible framework, where decision makers can explore, understand and redefine a decision problem (Kyem 2004; Boroushaki and Malczewski 2010). The framework can be further enhanced by using fuzzy-based MCDM techniques along with GIS (Pasi and Yager 2006). Fuzzy logic-based GIS modeling has been widely used in the field of water resources. Rather (2012) had used fuzzy-based GIS modeling for identifying groundwater potential zones in Uttar Pradesh, India. Coupling between GIS and fuzzy techniques is found to be particularly useful while modeling fuzzy inputs pertaining to hydrological criteria (Dixon 2005).

The present study develops a modeling framework for group decision making by extending Delphi method using an interval-valued fuzzy AHP approach to rank the 33 industries located in Ganges River basin, India. Ten essential criteria are chosen by deeply studying the impact of industrial wastewater discharge in the river basin. The method is capable of effectively dealing with the complexities of conflict resolution that may arise while group decision making. The outcomes of the model are also represented in GIS environment using ArcGIS to facilitate the interpretation of results in spatial context. The results obtained are also validated using the recent findings of governmental organizations and other secondary sources. Based on the results, revisal of effluent discharge standards and other essential policies is recommended to the controlling agencies.

2 Materials and methods

2.1 Methodology

The proposed methodology is an extension of a very popular group decision-making technique, namely fuzzy Delphi AHP. The modified method addresses the problems concerning sustainable water resource planning and management using the concepts of interval-valued fuzzy sets. The purpose of fuzzy sets is to model ill-defined concepts; therefore, defining membership grades using IVFSs can result in development of an improved model, which can properly represent the uncertainty associated with real-life situations. The application of IVFSs becomes significant when it is not possible for a membership function of the type, $\mu: X \rightarrow [0, 1]$, to assign an exact numerical value within the interval $[0, 1]$ to each element $x \in X$, without losing some information (Gorzalczany 1987). The mathematical representation of IVFSs is as follows:

$$\begin{aligned} Z &= \{x, [\mu_Z^L(x), \mu_Z^U(x)]\}, x \in X \\ \mu_Z^L, \mu_Z^U &: X \rightarrow [0, 1] \forall x \in X, \mu_Z^L \leq \mu_Z^U \\ \bar{\mu}_Z(x) &= [\mu_Z^L(x), \mu_Z^U(x)] \\ Z &= \{(x, \bar{\mu}_Z(x))\}, x \in (-\infty, +\infty) \end{aligned} \quad (1)$$

where $\mu_Z^L(x)$ and $\mu_Z^U(x)$ are the lower and upper limits of the degree of membership, respectively.

In this approach, the predicament of determining the membership function value precisely has been resolved by expressing it within an interval of real numbers. The relative importance of the decision criteria and rating of the decision alternatives corresponding to

each criterion is expressed linguistically to deal with the complexity and vagueness. These linguistic variables are then transformed into interval-valued fuzzy triangular numbers using certain mathematical equations. The judgments of the experts are procured by using a questionnaire, which are then evaluated under fuzzy environment using the proposed approach. The stepwise methodology is described as given below:

Step 1 Selection of decision criteria and alternatives

The expert decision makers are chosen in this step. Based on an extensive literature review and discussion with the experts, potential criteria and alternatives are determined.

Step 2 Hierarchical representation of the problem

The case study is formulated by decomposing appropriate elements at different hierarchical levels. The topmost level deals with the overall objective of the evaluation process of the study. The intermediate levels correspond to criteria. The bottommost level corresponds to sampling alternative sites.

Step 3 Checking the consistency of the experts' judgment

The judgments of the experts are recorded in the form of a questionnaire. The questionnaire is so designed that the experts can assign ratings to the decision criteria or alternatives either qualitatively in linguistic terms or qualitatively by giving a crisp value. For example, the crisp value assigned to the linguistic variable 'very good' is '9'. However, it is important to maintain the consistency in the expert ratings. Therefore, pairwise comparison matrix of the decision criteria/alternatives can be developed based on each experts' opinion, and consistency of the matrix can be checked. In case of inconsistency, the experts are requested to assign the ratings again to achieve the consistency. If a_1, a_2, \dots, a_n denote a set of decision elements (either criteria or alternatives), the pairwise comparison matrix (A) of size $n \times n$ can be defined as follows:

$$A = [\alpha_{ij}] = \begin{matrix} & a_1 & a_2 & a_3 & a_4 \\ \begin{matrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{matrix} & \begin{bmatrix} 1 & \alpha_{12} & \cdots & \alpha_{1n} \\ 1/\alpha_{12} & 1 & \cdots & \alpha_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\alpha_{1n} & 1/\alpha_{2n} & \cdots & 1 \end{bmatrix} \end{matrix} \quad (2)$$

where $\alpha_{ij} = 1$, $(i, j = 1, 2, \dots, n, i = j)$

$$\alpha_{ij} = \frac{\delta_i}{\delta_j}, \quad (i, j = 1, 2, \dots, n, i \neq j)$$

In the above equation, α_{ij} is a crisp mathematical value that expresses the relative importance of element i (δ_i), over the relative importance of element j (δ_j). The δ_i and δ_j are obtained from the linguistic opinions/crisp values assigned by the experts in the questionnaires. Once the matrix is formed, the inconsistency index (II) can be obtained using the following equation:

$$\text{II} = \frac{\delta_{\max} - n}{n - 1} \quad (3)$$

The value of random inconsistency index (RII) for various dimensions is given by Saaty (1980). For matrix dimension ranging from 1 to 10, the corresponding RII values are 0, 0, 0.58, 0.9, 1.12, 1.24, 1.32, 1.41, 1.45 and 1.49, respectively. Then, the inconsistency ratio (IR) values for each matrix are calculated by using Eq. (4).

$$IR = \frac{\Pi}{R\Pi} \tag{4}$$

The consistency of the matrix can be ascertained based on the value of IR. In general, if $IR \geq 0.1$, the experts are required to review their decisions, to ensure that acceptable consistency is achieved.

Step 4 Computation of interval-valued triangular fuzzy numbers (IVTFNs)

Once the pairwise comparison decision matrices satisfy the consistency criteria, the opinions of all the experts are represented together in the form of an IVTFN as defined by Eq. (5). It is composed of three elements, namely pessimistic, moderate and optimistic estimates of the experts about each decision criteria/alternative.

$$\begin{aligned} \tilde{Z}_{ij} &= \left[\left(p'_{ij}, p_{ij} \right); q_{ij}; \left(r_{ij}, r'_{ij} \right) \right] \\ p'_{ij} &= \text{Min} (Z_{ijk}), \quad \forall k = 1, \dots, \gamma \\ p_{ij} &= \text{Min} (Z_{ijk}) + \frac{(\prod_{k=1}^{\gamma} Z_{ijk})^{\frac{1}{\lambda}} - \text{Min} (Z_{ijk})}{2}, \quad \forall k = 1, \dots, \gamma \\ q_{ij} &= \left(\prod_{k=1}^{\gamma} Z_{ijk} \right)^{\frac{1}{\lambda}}, \quad \forall k = 1, \dots, \gamma \\ r_{ij} &= \text{Max} (Z_{ijk}) - \frac{\text{Max} (Z_{ijk}) - (\prod_{k=1}^{\gamma} Z_{ijk})^{\frac{1}{\lambda}}}{2}, \quad \forall k = 1, \dots, \\ r'_{ij} &= \text{Max} (Z_{ijk}), \quad \forall k = 1, \dots, \gamma \end{aligned} \tag{5}$$

where $p'_{ij} \leq p_{ij} \leq q_{ij} \leq r_{ij} \leq r'_{ij}$; Z_{ijk} represents the relative importance of the parameter i over j assigned by the expert k , and λ is the number of experts.

Step 5 Deriving interval-valued fuzzy pairwise comparison matrix

Once all the judgments of the decision makers are integrated and represented in the form of IVTFN as computed in Step 4, a single pairwise comparison matrix, where each element of the matrix is an IVTFN, can be derived and represented as:

$$\tilde{A}^* = \begin{bmatrix} (1, 1); 1; (1, 1) & (p'_{12}, p_{12}); q_{12}; (r_{12}, r'_{12}) & \dots & (p'_{1n}, p_{1n}); q_{1n}; (r_{1n}, r'_{1n}) \\ \left(\frac{1}{r'_{12}}, \frac{1}{r_{12}} \right); \frac{1}{q_{12}}; \left(\frac{1}{p_{12}}, \frac{1}{p'_{12}} \right) & (1, 1); 1; (1, 1) & \dots & (p'_{2n}, p_{2n}); q_{2n}; (r_{2n}, r'_{2n}) \\ \vdots & \vdots & \ddots & \vdots \\ \left(\frac{1}{r'_{1n}}, \frac{1}{r_{1n}} \right); \frac{1}{q_{1n}}; \left(\frac{1}{p_{1n}}, \frac{1}{p'_{1n}} \right) & \left(\frac{1}{r'_{2n}}, \frac{1}{r_{2n}} \right); \frac{1}{q_{2n}}; \left(\frac{1}{p_{2n}}, \frac{1}{p'_{2n}} \right) & \dots & (1, 1); 1; (1, 1) \end{bmatrix} \tag{6}$$

Step 6 Evaluation of relative fuzzy weights

The relative interval-valued fuzzy weights of decisions criteria and alternatives (\tilde{W}_i^*) are calculated by using Eqs. (7) and (8) as follows:

$$\tilde{X}_i^* = [\tilde{z}_{ij} \otimes \cdots \otimes \tilde{z}_{in}]^{\frac{1}{n}} = (x'_{1i}, x_{1i}); x_{2i}; (x_{3i}, x'_{3i}) \quad (7)$$

$$\tilde{W}_i^* = \tilde{X}_i \otimes (\tilde{X}_i \oplus \cdots \oplus \tilde{X}_n)^{-1} = (w'_{1i}, w_{1i}); w_{2i}; (w_{3i}, w'_{3i}) \quad (8)$$

Step 7 Calculation of relative defuzzified weights

The relative defuzzified weights (crisp weights) of the decision criteria/alternatives are obtained using Eq. (9) as given below:

$$W_i^* = \frac{w'_{1i} + w_{1i} + 2w_{2i} + w_{3i} + w'_{3i}}{6} \quad (9)$$

Step 8 Evaluation of final weights and rankings of the alternatives

Finally, the weights of the alternatives are obtained by aggregating the relative weights of each decision criteria, and the alternatives with respect to each criteria using Eq. (10). Based on the weights, the rankings of the alternatives are obtained.

$$W_i^t = \sum_{j=1}^m W_j^* W_{ij}^* \quad (i = 1, 2, \dots, n) \quad (10)$$

where W_i^t is the total weight of i th alternative; W_j^* is the relative weight of j th criterion; W_{ij}^* is the relative weight of i th alternative with respect to criterion j ; m represents the total number of criteria; and n is the number of the decision alternatives.

2.2 Study area and sampling stations monitored for the study

According to Central Pollution Control Board (CPCB 2013), the middle stretch of Ganges River from Kanpur to Varanasi is the most polluted stretch. Unnao District (Fig. 2) situated near Kanpur in the northern side of Ganges River has been chosen as the study area. A total of 33 industrial units (mainly tanneries) distributed primarily at 4 locations, namely Industrial site-1 and Banthar, Industrial site-2, Magarwara-I and Magarwara-II (Table 1), are considered for the analysis. Information pertaining to sampling stations located at Magarwara-I and II is omitted for brevity reasons. Each of these locations has several sources of pollution, which pollutes Ganges River basin either by directly discharging wastewater into the river or by deteriorating the quality of groundwater. There are nine industrial sources/common effluent treatment plants (CETPs) (S1–S9) corresponding to Industrial site-1 and Banthar, and site-2. Similarly, there are eight (S1–S8) and seven (S1–S7) such sources corresponding to Magarwara-I and II, respectively. All these sources serve as the decision alternatives. The effluents discharged by the industries containing huge amount of hazardous content are discharged into the River Ganges after passing through a CETP. The quality of ground water in the adjoining area of these industries is under constant threat of contamination. Uttar Pradesh Pollution Control Board (UPPCB) has collected and monitored 54 wastewater/effluent samples from the industries/effluent

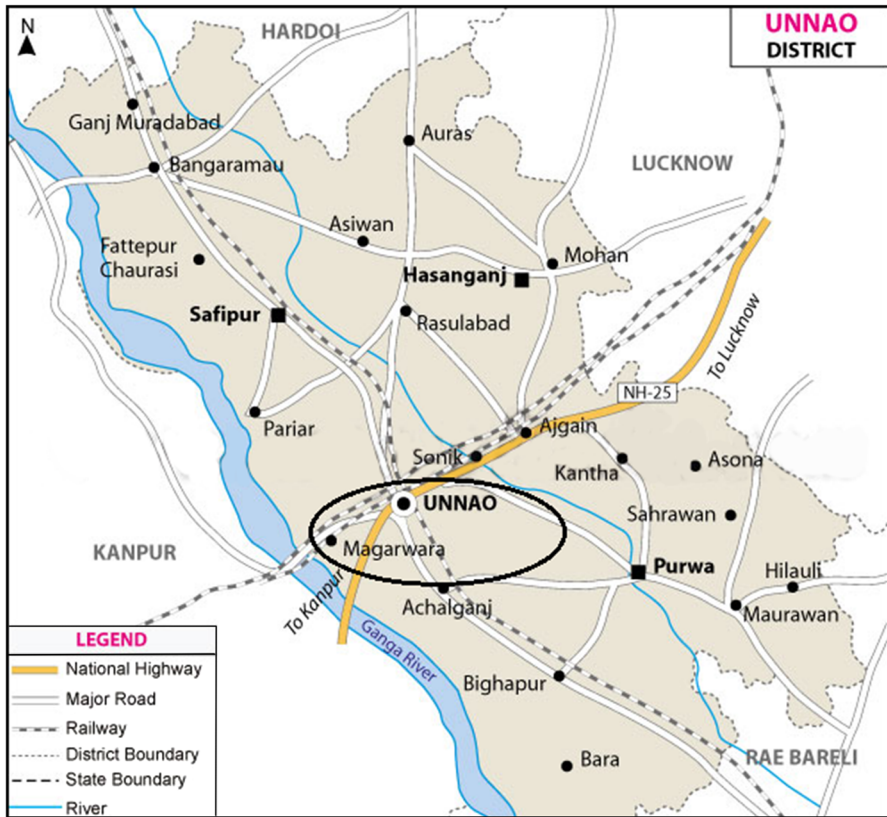


Fig. 2 Map of the Unnao District chosen for the study

treatment plants (ETPs) inlets and outlets. In addition, 55 wastewater samples are also collected and monitored from deep and shallow groundwater aquifers from the surrounding regions covering the entire industrial area. The study was conducted in the pre-monsoon and post-monsoon season during 2012. The line diagram representing all the sampling locations is shown in Fig. 3. The samples are tested for various water quality parameters depending on the type of the industry. For illustration, the effluent characteristics of the CETP located in Industrial site-2, Unnao, are represented in Table 2. The performance of all the industries is evaluated based on the criteria chosen by the experts.

2.3 Experts and criteria considered for the study

As already discussed, the decisions pertaining to water quality modeling require a collaborative decision making of a group of experts; hence, three experts belonging to different institutions are chosen for the study. Expert 1 (E1) belongs to the pollution control board; Expert 2 (E2) belongs to the environmental impact assessment sector located in the study area; and Expert 3 (E3) belongs to a research institute. As the team of experts may have conflicting interests, their judgments are integrated through a modified fuzzy group decision-making technique using interval-valued fuzzy sets. The experts' judgments are recorded by distributing a questionnaire.

Table 1 Sampling stations located at Industrial site-1 and Banthar, and Industrial site-2

S. no.	Symbol	Industrial area site-2 Sampling station	S. no.	Symbol	Industrial area site-1 and Banthar Sampling station
S1	SW-1	CETP Unnao inlet at plant	S1	SW-8	CETP Banthar drain before mixing
	SW-2	CETP Unnao outlet at plant	S2	SW-9	UPSIDC drain
S2	SW-3	U/S of Loni drain at railway bridge before joining of CETP Unnao outlet	S3	SW-10	UPSIDC drain
S3	SW-4	Loni drain after joining of CETP Unnao outlet	S4	SW-11	CETP Banthar inlet at plant
S4	SW-5	UPSIDC drain at bridge near CETP Unnao		SW-12	CETP Banthar outlet at plant
S5	SW-6	Unlined sewage drain at bridge near CETP	S5	SW-25	ETP inlet of M/s AOV Exports Pvt. Ltd.
S6	SW-7	Loni drain D/S of the bridge after joining of UPSIDC drain and sewage drain		SW-26	ETP outlet of M/s AOV Exports Pvt. Ltd.
S7	SW-23	ETP inlet of M/s Indagro Foods Ltd.	S6	SW-31	ETP inlet of M/s Rustom Food Pvt. Ltd.
	SW-24	ETP outlet of M/s Indagro Foods Ltd.		SW-32	ETP outlet of M/s Rustom Food Pvt. Ltd.
S8	SW-27	ETP inlet of M/s Omega International	S7	SW-33	ETP inlet of M/s Falak Enterprises & Asharfi Agri Bioproduct
	SW-28	ETP outlet of M/s Omega International		SW-34	ETP outlet of M/s Falak Enterprises & Asharfi Agro Byoproducts
S9	SW-29	ETP inlet of M/s Allied Leather Finisher Pvt. Ltd.	S8	SW-40	ETP inlet of M/s Bajaj Kagaj Udyog Ltd.
	SW-30	ETP outlet of M/s Allied Leather Finisher Pvt. Ltd.		SW-41	ETP outlet of M/s Bajaj Kagaj Udyog Ltd.
			S9	SW-42	ETP inlet of M/s J S International
				SW-43	ETP outlet of M/s J S International

Authors have identified appropriate criteria after performing a comprehensive literature review based on the earlier work (Singh and Ghosh 2003; Singh et al. 2007), expert guidance, studying the requirements of industries and rivers, and also from few secondary sources (CPCB 2013; UPPCB 2013). These criteria are listed in Table 3. The decision alternatives associated with each industrial location are evaluated with respect to each criterion to obtain crisp scores, which are integrated to derive their final ranking.

3 Application of proposed methodology in the case study

The purpose of this study is to assess the overall impact of the industrial wastewater discharge on Ganges River basin. The methodology discussed in the previous section has been applied to rank the industries located in the industrial areas based on ten criteria (C1–C10). The initial step is to evaluate the importance weights of the ten criteria based on the judgment of the 3 experts. The weights of the alternatives can be derived using the same process.

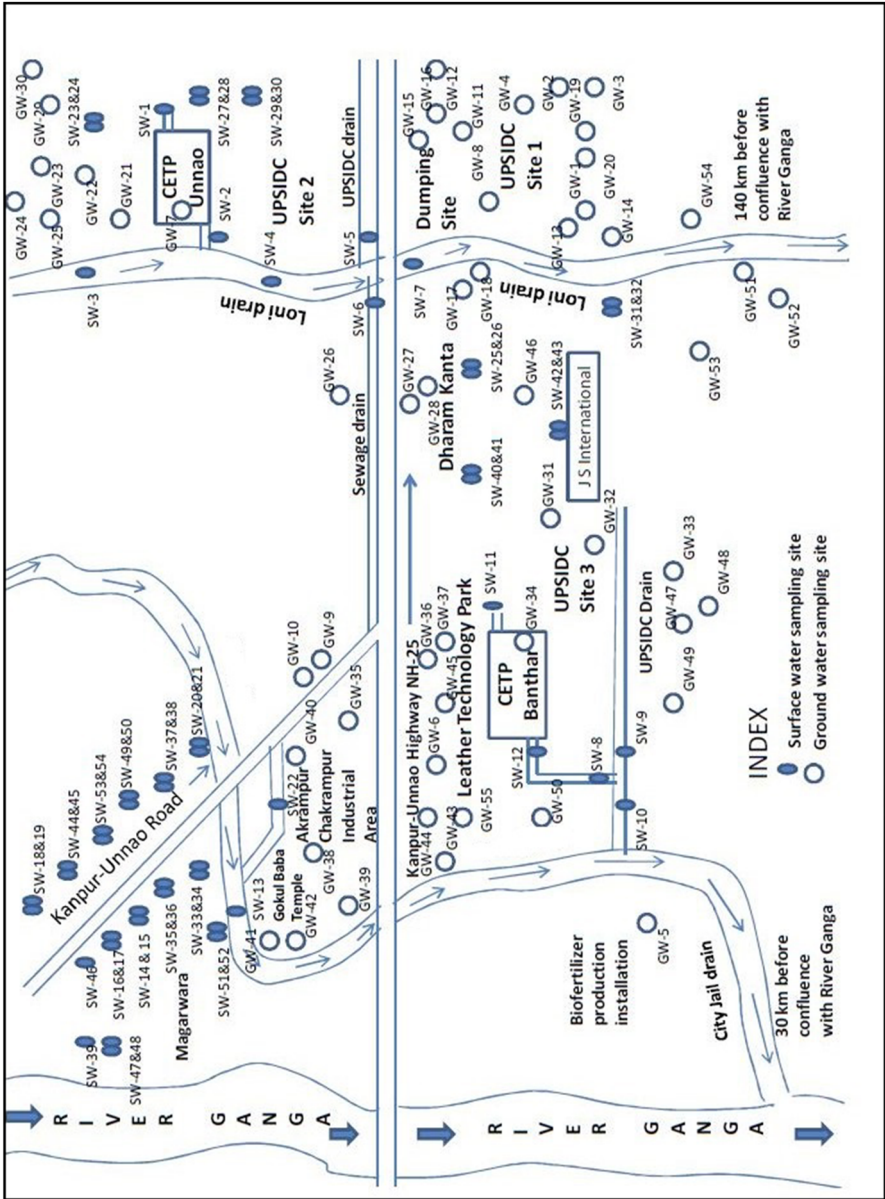


Fig. 3 Line diagram representing the sampling sites located in study area

The problem is represented in hierarchical form (Fig. 4) with three levels. The topmost, second and third levels represent problem definition, decision criteria (C1–C10) and decision alternatives (industries located at different locations), respectively. Then, the questionnaire (Table 4) is designed and circulated among the 3 experts (E1, E2 and E3) to determine the importance weight of each criterion and also to rate the industries with respect to each criterion. The data monitored by UPPCB (2013) served as one of the basis

Table 2 Effluent characteristics of CETP at Industrial site-2, Unnao

S. no.	Parameters	Inlet (SW-1)		Outlet (SW-2)		Effluent standards
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	
1.	pH	7.9	7.6	8	7.7	6.5–8
2.	TDS	12,243	9900	11,226	9500	2100
3.	TSS	390	–	245	–	100
4.	Copper	0.03	0.18	0.02	0.15	3
5.	Nickel	0.15	0.19	0.09	0.06	3
6.	Lead	0.08	0.06	0.05	0.04	0.1
7.	Cadmium	0.01	ND*	0.01	ND*	1
8.	Zinc	0.63	0.16	0.07	0.09	5
9.	Total chromium	3.06	6.87	1.31	3.67	2
10.	Arsenic	–	0.09	–	0.08	0.2
11.	Fluoride	–	1.5	–	1.5	2
12.	COD	3788	2650	1240	850	250
13.	BOD	680	902	98	353	30

Total effluent discharge: 1.6 MLD

All values are in mg/l except for pH, ND*: not detected

Table 3 List of criteria chosen for the study

Criterion	Criterion definition
C1	Effluent discharge from the industry
C2	Efficiency of ETP/CETP with respect to critical elements
C3	Number of critical parameters: pre-monsoon
C4	Number of critical parameters: post-monsoon
C5	Type of effluents/waste released
C6	Impact of critical parameters on River Ganges: pre-monsoon
C7	Impact of critical parameters on River Ganges: post-monsoon
C8	Impact of critical parameters on groundwater: pre-monsoon
C9	Impact of critical parameters on groundwater: post-monsoon
C10	Harmful impact of critical parameter on public health

of expert decision making. The experts expressed their opinion either linguistically or mathematically. A pairwise comparison matrix is formed based on the expert judgments, and their consistency is checked. Table 5 shows the experts' opinion to determine the overall importance of the criteria, and Table 6 shows the ratings given by the experts about the 9 industries (S1–S9) located in industrial site-2 (decision alternatives) with respect to criteria 3 (C3). Similar observations are recorded for industries located in other 3 sites, namely Industrial site-1 and Banthar, Magarwara-I and Magarwara-II.

For illustration, the ratings of the 9 industries (S1–S9) located in Industrial site-2 (decision alternatives) with respect to criteria number 3 (C3—number of critical

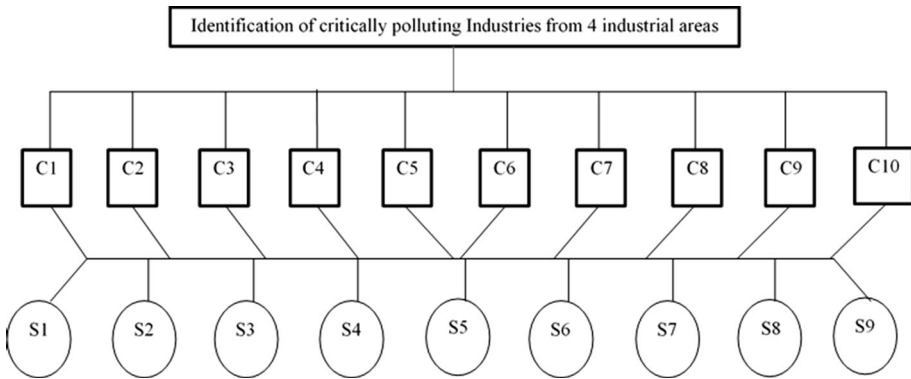


Fig. 4 Hierarchical representation of the case study

Table 4 Questionnaire model used to record the judgments of the experts

Title: Impact of the wastewater discharged from the industries on Ganges River basin

Name	Designation	Academic qualification			Experience
<i>Linguistic variables assigned to rate the importance of the criteria</i>					
VH—very high (9)	H—high (7)	M—medium (5)	L—low (3)	VL—very low (1)	
<i>Linguistic variables assigned to rate the alternatives with respect to each criteria</i>					
With respect to C1, C3, and C4:					
VH—very high (9)	H—high (7)	M—medium (5)	L—low (3)	VL—very low (1)	
With respect to C2:					
VG—very good (9)	G—good (7)	F—fair (5)	B—bad (3)	VB—very bad (1)	
With respect to C5:					
A—less organic (9)	B—recyclable/reusable (7)	C—high organic and less inorganic (5)	D—high organic and high inorganic (3)	E—hazardous (1)	
With respect to C6, C7, C8, C9 and C10					
A—negligible (9)	B—light (7)	C—moderate (5)	D—heavy (3)	E—severe (1)	

parameters, pre-monsoon) have been explained in stepwise manner. In similar lines, the ratings of the industries located in other three sites are determined.

1. The linguistics opinions of experts represented in Table 6 are utilized to obtain a pairwise comparison matrix with respect to each of the experts E1, E2 and E3 as shown in Table 7a, b, c, respectively. The pairwise comparison has been made using expert choice software using Eq. (2).
2. Once the comparison matrices are established, the inconsistency ratios (IRs) are calculated for each matrix using Eqs. (3) and (4). These IRs are represented at the bottom of Table 7a–c. As the values of IR are less than 0.1, the judgments of the

Table 5 Experts' opinion about the criteria

Criterion	Experts		
	E1	E2	E3
C1	VH	H	H
C2	H	H	M
C3	VH	H	H
C4	H	H	H
C5	H	H	H
C6	VH	H	H
C7	M	M	L
C8	H	H	H
C9	M	M	L
C10	VH	VH	VH

Table 6 Experts' opinion about the industries with respect to C3

Industry	Experts		
	E1	E2	E3
S1	VH	H	H
S2	H	M	H
S3	H	M	H
S4	VH	H	H
S5	VH	H	VH
S6	H	M	H
S7	M	L	L
S8	M	L	L
S9	H	M	M

experts are consistent and acceptable. Similar calculations were performed to obtain the comparison matrices of all the criteria using the expert opinions represented in Table 5. Same procedure is adopted to derive the comparison matrices and IR values corresponding to all industries located in other areas (Table 8).

- Using Eq. (5), the interval-valued fuzzy pairwise comparison matrix of industries (alternatives) with respect to C3 is derived and represented in Table 8.
- The relative fuzzy weights of the 9 alternatives with respect to C3 are calculated by using Eq. (7) as given in Table 9.
- The defuzzified relative weights of each alternative with respect to C3 can be obtained using Eq. (8). The alternative obtaining the lowest score is the critical industry, and the one that obtains the highest score is relatively the best industry. The calculations for the same are given below:

$$\begin{aligned}
 W_{s1}^* &= \frac{0.031 + 0.037 + (2 \times 0.044) + 0.057 + 0.070}{6} = 0.047 \\
 W_{s2}^* &= \frac{0.051 + 0.066 + (2 \times 0.083) + 0.097 + 0.114}{6} = 0.082 \\
 W_{s3}^* &= \frac{0.051 + 0.066 + (2 \times 0.083) + 0.097 + 0.114}{6} = 0.082 \\
 W_{s4}^* &= \frac{0.031 + 0.037 + (2 \times 0.044) + 0.057 + 0.070}{6} = 0.047 \\
 W_{s5}^* &= \frac{0.021 + 0.027 + (2 \times 0.033) + 0.038 + 0.043}{6} = 0.032 \\
 W_{s6}^* &= \frac{0.051 + 0.066 + (2 \times 0.083) + 0.097 + 0.114}{6} = 0.082 \\
 W_{s7}^* &= \frac{0.202 + 0.227 + (2 \times 0.258) + 0.298 + 0.345}{6} = 0.265 \\
 W_{s8}^* &= \frac{0.202 + 0.227 + (2 \times 0.258) + 0.298 + 0.345}{6} = 0.265 \\
 W_{s9}^* &= \frac{0.082 + 0.096 + (2 \times 0.113) + 0.142 + 0.173}{6} = 0.120
 \end{aligned}$$

It can be clearly inferred from the defuzzified scores that industries S7 and S8 obtain the highest score of 0.265 on the scale of '0–1'. Hence, these industries release the least number of critical pollutants in the pre-monsoon season. This is in coherence with the monitored data.

The remaining calculations are performed in similar way based on experts' judgments corresponding to importance of criteria and ratings of the alternatives with respect to each criterion for all four industrial sites. The relative defuzzified weight of each 'criterion' and 'alternative with respect to each criterion' for all industrial sites is shown in Table 10. The final weight of each alternative has been obtained using Eq. (9) and is represented in the last column of Table 10. For illustration, the weight of the alternative S1 located in Industrial site-2 is calculated as follows:

$$\begin{aligned}
 W_{s1} &= (0.139 \times 0.037) + (0.072 \times 0.051) + (0.148 \times 0.047) + (0.096 \times 0.060) \\
 &\quad + (0.096 \times 0.060) + (0.139 \times 0.108) + (0.030 \times 0.108) + (0.096 \times 0.128) \\
 &\quad + (0.029 \times 0.044) + (0.235 \times 0.046) \\
 &= 0.066
 \end{aligned}$$

Similarly: $W_{s2} = 0.124$; $W_{s3} = 0.110$; $W_{s4} = 0.080$; $W_{s5} = 0.082$; $W_{s6} = 0.107$; $W_{s7} = 0.204$; $W_{s8} = 0.254$; $W_{s9} = 0.114$.

4 Results and discussion

4.1 Pollution status of industries

The study reveals the presence of high concentrations of hazardous trace metals (Chromium and Fluoride) and organic matter (BOD, COD and TSS) in the industrial wastewater, which imposes a serious threat to the Ganges River basin. The wastewater enters the River Ganges through common drains. The results obtained have been validated by comparing them with the recent works of governmental organizations (CWC 2014; UPJN, UPPCB

Table 7 Pairwise comparison matrix of industries with respect to C3 based on expert opinions

	S1	S2	S3	S4	S5	S6	S7	S8	S9
<i>(a)</i>									
S1	1.000	0.333	0.333	1.000	1.000	0.333	0.200	0.200	0.333
S2	3.000	1.000	1.000	3.000	3.000	1.000	0.333	0.333	1.000
S3	3.000	1.000	1.000	3.000	3.000	1.000	0.333	0.333	1.000
S4	1.000	0.333	0.333	1.000	1.000	0.333	0.200	0.200	0.333
S5	1.000	0.333	0.333	1.000	1.000	0.333	0.200	0.200	0.333
S6	3.000	1.000	1.000	3.000	3.000	1.000	0.333	0.333	1.000
S7	5.000	3.000	3.000	5.000	5.000	3.000	1.000	1.000	3.000
S8	5.000	3.000	3.000	5.000	5.000	3.000	1.000	1.000	3.000
S9	3.000	1.000	1.000	3.000	3.000	1.000	0.333	0.333	1.000
IR = 0.01									
<i>(b)</i>									
S1	1.000	0.333	0.333	1.000	1.000	0.333	0.200	0.200	0.333
S2	3.000	1.000	1.000	3.000	3.000	1.000	0.333	0.333	1.000
S3	3.000	1.000	1.000	3.000	3.000	1.000	0.333	0.333	1.000
S4	1.000	0.333	0.333	1.000	1.000	0.333	0.200	0.200	0.333
S5	1.000	0.333	0.333	1.000	1.000	0.333	0.200	0.200	0.333
S6	3.000	1.000	1.000	3.000	3.000	1.000	0.333	0.333	1.000
S7	5.000	3.000	3.000	5.000	5.000	3.000	1.000	1.000	3.000
S8	5.000	3.000	3.000	5.000	5.000	3.000	1.000	1.000	3.000
S9	3.000	1.000	1.000	3.000	3.000	1.000	0.333	0.333	1.000
IR = 0.01									
<i>(c)</i>									
S1	1.000	1.000	1.000	1.000	3.000	1.000	0.200	0.200	0.333
S2	1.000	1.000	1.000	1.000	3.000	1.000	0.200	0.200	0.333
S3	1.000	1.000	1.000	1.000	3.000	1.000	0.200	0.200	0.333
S4	1.000	1.000	1.000	1.000	3.000	1.000	0.200	0.200	0.333
S5	0.333	0.333	0.333	0.333	1.000	0.333	0.143	0.143	0.200
S6	1.000	1.000	1.000	1.000	3.000	1.000	0.200	0.200	0.333
S7	5.000	5.000	5.000	5.000	7.000	5.000	1.000	1.000	3.000
S8	5.000	5.000	5.000	5.000	7.000	5.000	1.000	1.000	3.000
S9	3.000	3.000	3.000	3.000	5.000	3.000	0.333	0.333	1.000
IR = 0.01									

and CPCB 2017) and few secondary sources (Chaudhary et al. 2017; Paul 2017). For example, recent studies by UPJN, UPPCB and CPCB (2017) on open drains reveal that the concentration of chromium in the wastewater collected from tanneries in Unnao is 1000 times more than the prescribed standard of WHO. In addition, the average concentration of BOD and COD in the Unnao drains is 200 and 400 mg/l, respectively. A very high concentration of chromium and fluoride is also found in the groundwater near the tanneries (Sinha et al. 2016).

The final weights of the industrial units on the scale of zero to 1 (zero indicates most polluting, and 1 indicates least polluting) are represented in Table 10. The Industrial site-1

Table 8 Relative fuzzy weights of the alternatives with respect to criteria C3 (Industrial site-2)

Alternatives (<i>i</i>)	\tilde{X}_i^*	\tilde{W}_i^*
S1	(0.429, 0.469); 0.505; (0.612, 0.699)	(0.031, 0.037); 0.044; (0.057, 0.070)
S2	(0.699, 0.841); 0.963; (1.050, 1.130)	(0.051, 0.066); 0.083; (0.097, 0.114)
S3	(0.699, 0.841); 0.963; (1.050, 1.130)	(0.051, 0.066); 0.083; (0.097, 0.114)
S4	(0.429, 0.469); 0.505; (0.612, 0.699)	(0.031, 0.037); 0.044; (0.057, 0.070)
S5	(0.295, 0.340); 0.379; (0.405, 0.429)	(0.021, 0.027); 0.033; (0.038, 0.043)
S6	(0.699, 0.841); 0.963; (1.050, 1.130)	(0.051, 0.066); 0.083; (0.097, 0.114)
S7	(2.786, 2.887); 2.983; (3.216, 3.429)	(0.202, 0.227); 0.258; (0.298, 0.345)
S8	(2.786, 2.887); 2.983; (3.216, 3.429)	(0.202, 0.227); 0.258; (0.298, 0.345)
S9	(1.130, 1.219); 1.301; (1.533, 1.725)	(0.082, 0.096); 0.113; (0.142, 0.173)

and Banthar has 9 industries/drains, which discharge their wastewater into the Ganges. Some of these industries illegally dump their waste under the ground, leading to groundwater pollution. Rustom Food Pvt. Ltd. (S6) gets the highest score of 0.233, and UPSIDC drain (S3) gets the lowest score of 0.063. According to monitored data, S6 discharges 59 mg/l of BOD, which is slightly higher than prescribed limit of 30 mg/l by CPCB. However, S3 discharges 3 critical parameters, namely TSS, COD and BOD, with concentration of 455, 570 and 160 mg/l, respectively. Also, S6 discharges only 20 KLD of wastewater, whereas S3 discharges more than 100 MLD of wastewater into the Ganges. The observed data also justify that the quality of groundwater near S6 is much better as compared to S3. The high concentration of BOD and COD released from S3 has significantly deteriorated the water quality of River Ganges with BOD value of 12.5 mg/l (CWC 2016). In similar manner, the scores of other industries obtained through experts' opinion are validated.

Industrial site-2 also consists of 9 industries with Omega International (S8) obtaining the highest score of 0.258 and CETP Unnao (S1) getting a lowest score of 0.066. The monitored data indicate that S1 releases more than 100 MLD of wastewater containing 9500, 3.67, 850 and 353 mg/l of TDS, Cr, COD and BOD, respectively. There is an urgent need to increase the capacity of the CETP and the individual ETPs located in the industries. The chromium content in the Ganges is found to be 6.7 mg/l as compared to permissible standard of 0.05 mg/l. On the other hand, S8 releases only 9 KLD of wastewater with 353 mg/l of BOD, which is organic in nature.

Magarwara-I has 8 industries with Sadaf Enterprises Pvt. Ltd. (S4) obtaining the highest score of 0.267 and City Jail Drain (S1) obtaining the lowest score of 0.073. The monitored data indicate that S4 releases 145 mg/l of TDS and 98 mg/l of BOD as compared to their prescribed values of 100 mg/l and 30 mg/l, respectively. Although it is a leather industry, chromium discharge is within the permissible limit of 2 mg/l. S1 releases more than 15 MLD of wastewater with 4 critical parameters, namely TSS, Fe, COD and BOD, having concentrations of 175, 21.6, 640 and 215 mg/l, respectively. S1 contaminate not just the surface water, but also the adjoining groundwater. In addition, most of the drains in Unnao meet the City Jail Drain (UPJN, UPPCB and 2017).

Magarwara-II has 7 industries with ACI Oils (S4) receiving the best score of 0.193, and Global Rimjhim Stainless Steel (S1) gets a lowest score of 0.087. S1 releases 50 KLD of wastewater, which is highly basic (pH 11.2) with high concentration of lead (0.53 mg/l) and fluoride (270 mg/l). Both ground water and surface water are hazardously polluted by

Table 9 Interval-valued pairwise fuzzy comparison matrix of the alternatives with respect to criterion C3 for Industrial site-2

A1		A2			A3			
A1	1.000	1.000	1.000	0.333	0.407	0.481	0.741	1.000
A2	1.000	1.539	2.079	1.000	1.000	1.000	1.000	1.000
A3	1.000	1.539	2.079	1.000	1.000	1.000	1.000	1.000
A4	1.000	1.000	1.000	0.333	0.407	0.481	0.741	1.000
A5	0.333	0.513	0.694	0.847	1.000	0.333	0.334	0.334
A6	1.000	1.539	2.079	2.539	3.000	1.000	1.000	1.000
A7	5.000	4.996	4.992	4.996	5.000	3.552	4.276	5.000
A8	5.000	4.996	4.992	4.996	5.000	3.552	4.276	5.000
A9	3.000	2.998	2.997	2.998	3.000	1.442	2.221	3.000
A4		A5			A6			
A1	1.000	1.000	0.333	0.407	0.481	1.000	1.000	1.442
A2	1.000	1.539	1.000	1.000	1.000	2.079	2.539	2.997
A3	1.000	1.539	1.000	1.000	1.000	2.079	2.539	2.997
A4	1.000	1.000	0.333	0.407	0.481	1.000	1.000	1.442
A5	0.333	0.513	0.333	0.334	0.334	0.694	0.847	1.000
A6	1.000	1.539	1.000	1.000	1.000	2.079	2.539	2.997
A7	5.000	4.996	3.000	3.276	3.552	4.992	4.996	5.292
A8	5.000	4.996	3.000	3.276	3.552	4.992	4.996	5.292
A9	3.000	2.998	1.000	1.221	1.442	2.998	3.000	3.276
A7		A8			A9			
A1	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.334
A2	0.200	0.241	0.282	0.307	0.333	0.241	0.307	0.694
A3	0.200	0.241	0.282	0.307	0.333	0.241	0.307	0.694
A4	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.334

Table 9 continued

	A7			A8			A9								
A5	0.143	0.161	0.179	0.190	0.200	0.143	0.161	0.179	0.190	0.200	0.200	0.241	0.282	0.307	0.333
A6	0.200	0.241	0.282	0.307	0.333	0.200	0.241	0.282	0.307	0.333	0.200	0.241	0.282	0.307	0.333
A7	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	2.998	2.997	2.998	3.000
A8	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	2.998	2.997	2.998	3.000
A9	0.333	0.334	0.334	0.334	0.333	0.333	0.334	0.334	0.334	0.333	1.000	1.000	1.000	1.000	1.000

Table 10 Final weights of the industries (alternatives) located in all industrial areas

Industrial site-1 and Banthar											
Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	
Criteria weight	0.139	0.072	0.148	0.096	0.096	0.139	0.030	0.096	0.029	0.235	
Industries↓										Final weight↓	
S1	0.072	0.138	0.054	0.213	0.167	0.077	0.289	0.162	0.162	0.047	0.115
S2	0.072	0.080	0.054	0.021	0.052	0.077	0.044	0.162	0.162	0.047	0.074
S3	0.057	0.043	0.054	0.049	0.090	0.077	0.078	0.055	0.055	0.047	0.063
S4	0.043	0.043	0.024	0.021	0.025	0.059	0.027	0.107	0.107	0.029	0.046
S5	0.109	0.080	0.099	0.138	0.090	0.147	0.136	0.077	0.077	0.088	0.112
S6	0.382	0.280	0.180	0.213	0.260	0.147	0.186	0.222	0.222	0.145	0.233
S7	0.228	0.043	0.076	0.022	0.069	0.053	0.058	0.107	0.107	0.047	0.088
S8	0.072	0.280	0.283	0.216	0.257	0.215	0.182	0.107	0.107	0.284	0.233
S9	0.043	0.043	0.225	0.140	0.054	0.215	0.044	0.107	0.107	0.284	0.172
Industrial site-2											
S1	0.037	0.051	0.047	0.020	0.060	0.108	0.108	0.128	0.044	0.046	0.066
S2	0.037	0.145	0.082	0.143	0.097	0.108	0.108	0.186	0.205	0.140	0.125
S3	0.037	0.145	0.082	0.143	0.097	0.108	0.108	0.169	0.199	0.084	0.110
S4	0.094	0.051	0.047	0.097	0.060	0.108	0.108	0.034	0.044	0.084	0.081
S5	0.094	0.189	0.032	0.024	0.060	0.108	0.108	0.024	0.030	0.093	0.083
S6	0.057	0.068	0.082	0.044	0.158	0.108	0.108	0.193	0.223	0.093	0.109
S7	0.037	0.273	0.265	0.230	0.302	0.108	0.108	0.128	0.154	0.238	0.206
S8	0.353	0.053	0.265	0.230	0.221	0.220	0.220	0.232	0.256	0.238	0.258
S9	0.290	0.053	0.120	0.097	0.020	0.062	0.062	0.231	0.022	0.037	0.115
Magarwara-I											
S1	0.029	0.042	0.027	0.082	0.078	0.079	0.071	0.127	0.127	0.077	0.073
S2	0.029	0.265	0.135	0.221	0.146	0.132	0.125	0.127	0.127	0.144	0.150
S3	0.246	0.123	0.036	0.082	0.033	0.037	0.071	0.044	0.044	0.029	0.079
S4	0.391	0.201	0.287	0.221	0.251	0.232	0.285	0.127	0.127	0.228	0.267
S5	0.029	0.265	0.287	0.221	0.251	0.232	0.285	0.211	0.211	0.228	0.231
S6	0.045	0.042	0.059	0.034	0.146	0.232	0.071	0.127	0.127	0.228	0.139
S7	0.213	0.034	0.084	0.059	0.055	0.045	0.048	0.127	0.127	0.045	0.089
S8	0.107	0.056	0.104	0.082	0.100	0.045	0.071	0.127	0.127	0.045	0.086
Magarwara-II											
S1	0.062	0.179	0.044	0.044	0.082	0.127	0.127	0.032	0.032	0.091	0.087
S2	0.028	0.179	0.160	0.160	0.109	0.127	0.127	0.161	0.161	0.166	0.147
S3	0.253	0.115	0.160	0.160	0.109	0.127	0.127	0.161	0.161	0.166	0.173
S4	0.056	0.179	0.160	0.160	0.313	0.260	0.260	0.161	0.161	0.166	0.193
S5	0.262	0.115	0.160	0.160	0.174	0.127	0.127	0.161	0.161	0.117	0.169
S6	0.262	0.179	0.160	0.160	0.109	0.127	0.127	0.161	0.161	0.166	0.179
S7	0.139	0.115	0.160	0.160	0.174	0.127	0.127	0.161	0.161	0.166	0.164

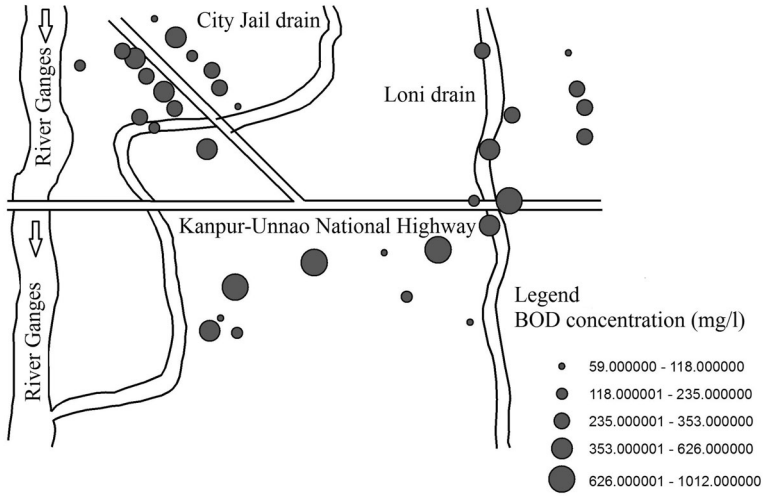


Fig. 5 Spatial representation of BOD

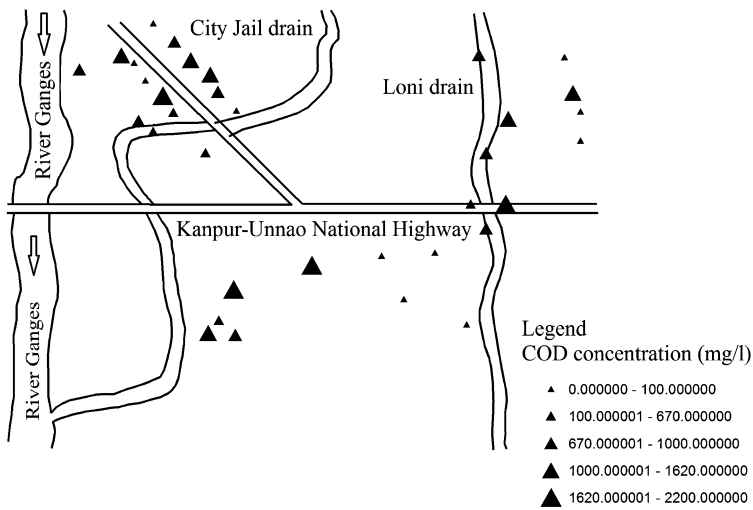


Fig. 6 Spatial representation of COD

these elements. On the other hand, ACI Oils is a small-scale industry releasing only 50 KLD of wastewater with 760 mg/l and 150 mg/l of COD and BOD, which are organic in nature.

The individual weights of all the industries are less than 0.500 indicating their critical condition. The experts' judgments are found to be very close to the actual observed data (UPPCB 2013). The study area has been divided into 4 divisions, and industries are ranked

(Table 1) based on their degree of impact on the river basin. This will help in prioritizing the policies and regulations that are to be enforced upon a particular industry.

It may also be noted that most of these industries have significantly affected the public health. A study conducted by National Cancer Registry Programme (NCRP) supported by the Indian Council of Medical Research (2012) in the study area reveals that 15% of every 10,000 people surveyed were suffering from gall bladder cancer, which is second highest in the world. In addition, 25 people in every one lakh population suffer other types of cancer, such as urinary bladder, kidneys, food pipe, liver and skin cancer. This is due to presence of chromium, arsenic, lead and nickel in the river system. In addition, intake of BOD-rich water causes gastrointestinal diseases. Thus, the tenth criterion (C10) has also significantly contributed in the ranking process.

4.2 Strategies and policies for sustainable development of river basin

The ranking of industries guides the policy makers to make regular amendments in the prescribed standards of effluent discharge for these industries, depending on the status of river system. For example, UPJN, UPPCB and (2017) recommends revision of BOD discharge standards from 30 mg/l to 10 mg/l. The study recommends regular, systematic and vigorous monitoring of industrial discharge and strict law implication. This is essential as the self-purifying capacity of rivers and groundwater aquifers is reducing with time (Singh 2008). One of the primary reasons for reduction in streamflow is the consumption of huge quantity of freshwater by the industries and discharge of untreated wastewater. There is an urgent need to establish efficient effluent treatment plants, and thus, 'zero liquid discharge' policy must be imposed on all major industries. Recently, environment ministry has issued closure of 150 industries (9 paper and pulp units, 28 textile units, 6 slaughter houses, 9 sugar units, 4 distilleries, 68 tanneries, 10 chemical units and 14 other units) in January 2016. Also, a vigilance team regularly carries out the inspection pertaining to water consumption and wastewater generation by the industries. In order to minimize

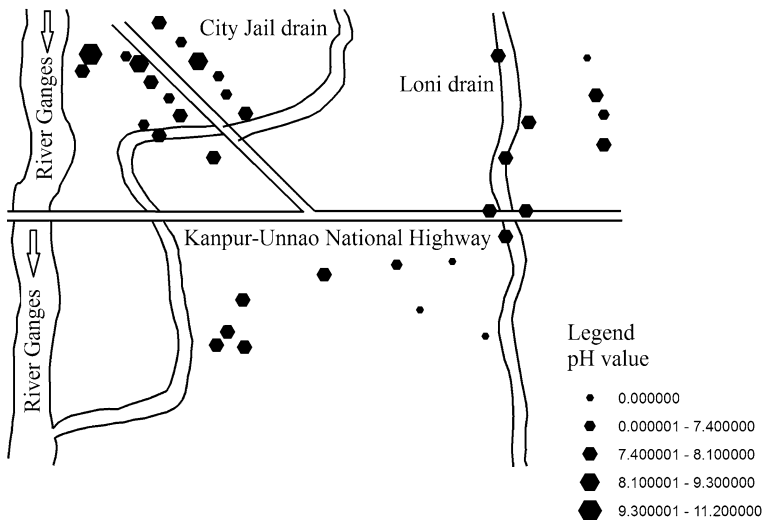


Fig. 7 Spatial representation of Ph

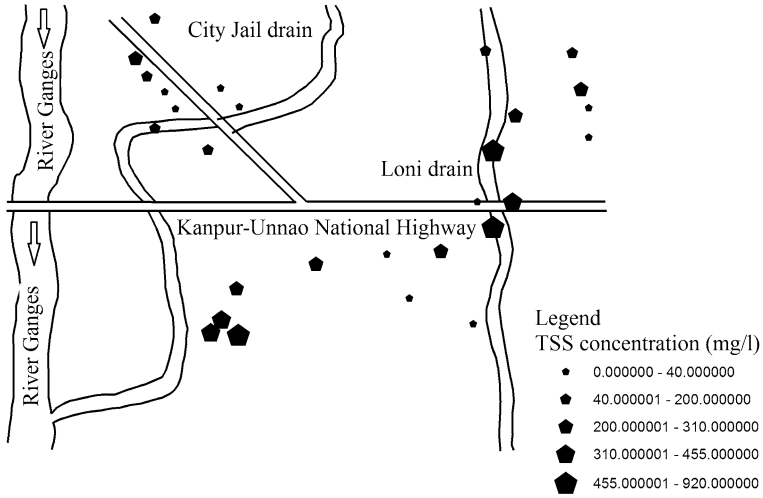


Fig. 8 Spatial representation of TSS

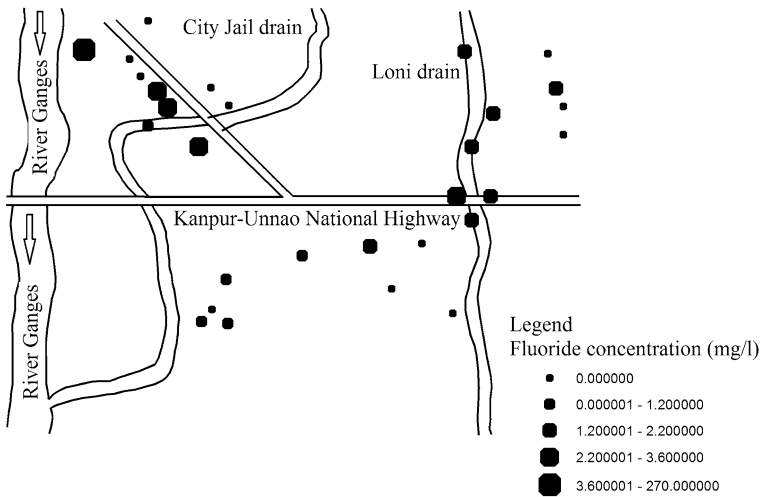


Fig. 9 Spatial representation of fluoride

consumption of freshwater, industries must use recycled water and ‘rain water harvesting’ can be performed. Overdependence on technology without the involvement of local stakeholders is one of the major shortcomings of earlier policies. Involving local stakeholders can lead to effective decision making as demonstrated in this case study. Educating people (especially universities) about the harmful effects of the industries to reduce their dependency on tannery products can be a major initiative toward sustainable river basin management. The effect of wastewater on the biotic community of the River Ganges should also be studied to maintain its ecosystem.

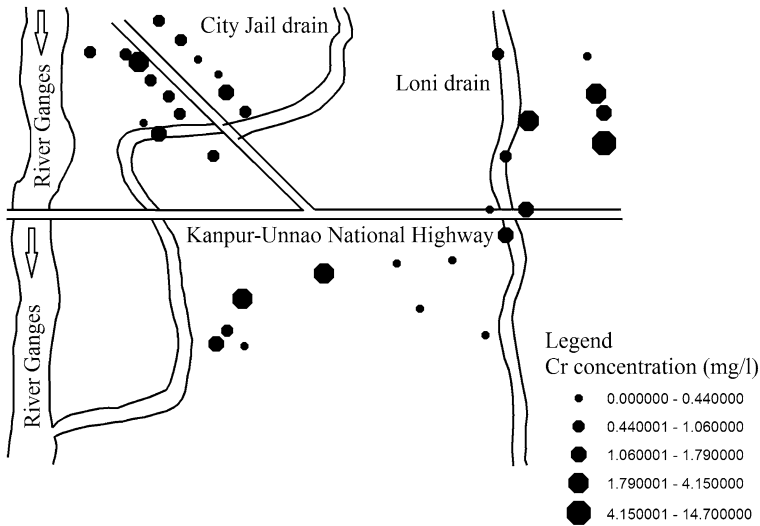


Fig. 10 Spatial representation of chromium

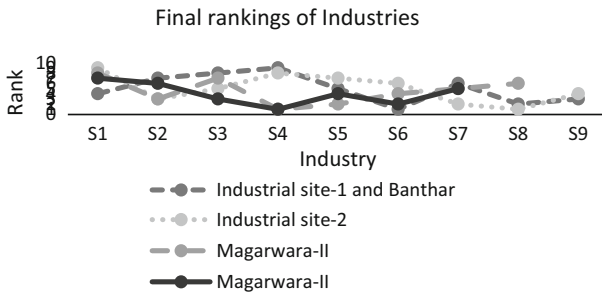


Fig. 11 Final rankings of the industries corresponding to all industrial sites

According to the judgments of experts and monitored data, the critical pollutants discharged by the industries obtaining lowest ranks are biochemical oxygen demand (BOD), chemical oxygen demand (COD), chromium (Cr), total suspended solids (TSS), pH and fluoride (F). These are also represented spatially using ArcGIS tool (Figs. 5, 6, 7, 8, 9, 10) for better accuracy. Since, most of the industries are ‘tannery’ based, high concentration of ‘Cr’ is observed. Solid waste consisting of chromium has been found to be dumped illegally along the National Highway (NH-25). Such practices need to be stopped immediately. Regulatory actions should be taken in areas, where high concentration of chromium in soils/groundwater is found to avoid any further contamination. The Loni Drain and City Jail Drain carry sewage as well as industrial effluents into the Ganges. The stagnation of the City Jail Drain at several places (e.g., Lucknow–Kanpur highway) has seriously deteriorated groundwater, soil and nearby vegetation. A proper underground sewerage system must be laid in all inhabited areas, and all open drains must be lined to enter the river through STPs and ETPs.

5 Conclusions

The present paper proposes a novel mechanism to resolve the uncertainties that may arise due to conflicting interests of the experts in group decision making for sustainable river basin management. Application of interval-valued fuzzy sets also gives a scope to the decision makers to be more precise in their judgments associated with complex problems. The methodology proposed herein is simple, flexible and comprehensive as it considers 33 industries discharging wastewaters in the Unnao District of Ganges River basin, India. Suitable application of the methodology has helped in identifying and ranking the critical industries (Fig. 11) based on their impact on the river basin corresponding to 10 essential criteria. Model incorporates the views of the experts belonging to the different disciplines of water resources. The results obtained have been validated by comparing them with the monitored data and the recent studies. In addition, the results are found to be consistent with the classifications defined by CPCB (2013). In order to enhance the decision-making process and policy implementation, critically polluted areas are identified by spatial representation of critical pollutants. The Ganges River water quality in the Unnao District is severely deteriorated due to an excessive, unorganized and illegal discharge of wastewaters from the industries. The reduced streamflow of the Ganges has decreased its self-purifying capacity, and thus, there is an immediate need to revise the prescribed standard limits of the wastewater effluents released from the industries, and the STPs into the river. The fuzzy group decision making performed in this study takes care of this essential aspect while developing the model and also proposes emphatic policies to the environmental organizations. Thus, model has the potential to become a suitable decision-making tool not just in the area of water resources, but in any field which requires group decision making.

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