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Human risk assessment of Panchet Dam in India using TOPSIS and WASPAS Multi-Criteria Decision-Making (MCDM) methods

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ABSTRACT

Every river dam activity has definite beneficial effects but cannot circumvent its negative impact in the long run. The Panchet dam has been commissioned as a multipurpose river valley project under the authority of Damodar Valley Corporation (DVC) across the river Damodar at the border of West Bengal and Jharkhand states of India in 1959 to overcome some problems like flood control, supply of irrigation, domestic and industrial water, hydro-electric power generation etc. But it has now become a threat to the surrounding people, due to rapid sedimentation and reduction in its water holding capacity. Human risk assessment of the dam thus claims importance and such an effort is executed in this work using Delphi Questionnaire and two Multi-Criteria Decision-Making (MCDM) methods viz. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Weighted Aggregated Sum Product Assessment (WASPAS). At first 9 human risk alternatives (A1-A9) of the dam are identified using Delphi Questionnaire and rated them in order to prioritize using TOPSIS and WASPAS methods. Risk prioritization results of TOPSIS and WASPAS show somewhat differences. The integrated 'Mean-Rank' method is applied to provide final priority ranking of the risk alternatives and the result is: A3 > A9 > A8 > A4, A6 > A1 > A7 > A5 > A2 (when WASPAS parameter $\lambda = 0$); A3 > A9 > A4, A8 > A2 > A6 > A1 > A5, A7 (when WASPAS parameter $\lambda = 1$); A3 > A9 > A8 > A4, A6 > A1 > A2 > A5 > A7 (when WASPAS parameter $\lambda = 0.5$). In all cases, A3 (Population Displacement) alternative ranks first and is identified as the top most risk prone alternative among all. The risk of displacement of people due to further inundation of land is rising gradually. This has motivated us for assessment of other human risks of the dam in the work.

1. Introduction

More than 45,000 large dams have been built in many places of the world, and nearly half of the world's rivers are obstructed by large dam (World Commission on Dams, 2000; Siddique and Bid, 2017; Fu et al., 2018). This type of project is recognized as multipurpose river valley development project and provides a number of benefits like generation of hydroelectric power, provision of irrigation facility, flood control, fishing activities etc. (Seyed Ali and Maryam, 2014; Siddique and Bid, 2017). Though damming activity has some beneficial aspects, it brings several kinds of threat to the people settled near the dam. The Panchet Dam has been built in 1959 across the river Damodar at the border of West Bengal and Jharkhand states of India. Within 60 years of its inception, human risk assessment has become essential as it brings certain damages to life and properties of people almost in each monsoon season when rainfall continues for almost 24 hours in the upper catchment area of the river Damodar ((Bid, 2016; Siddique and Bid, 2017; Issa et al., 2017). Seasonal monsoon rain and consequent run off has been proved most effective risk factor of the dam because it causes silting of the reservoir (Seyed Ali and Maryam, 2014; Siddique and Bid, 2017; Issa et al., 2017). Hence, human risk assessment of damming activities is considered as an important tool for reduction and mitigation of risk of the people settled near the dam. The main objective of the current study is the identification of human risk alternatives of the Panchet dam which have been set with the use of Delphi Questionnaire and assessment of human risk through prioritization of all risk-generating factors using two MCDM (Multi-Criteria Decision-Making) methods - TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) and WASPAS (Weighted Aggregated Sum Product Assessment).

Brief summary about the organization of sections of the present work is as follows: Section 1 is introduction part and section 2 represents literature review. Section 3 outlines the materials and methods adopted for the work including study area (3.1), the Panchet dam (3.2), sampling design and field survey (3.3), concept of risk and risk assessment (3.4),

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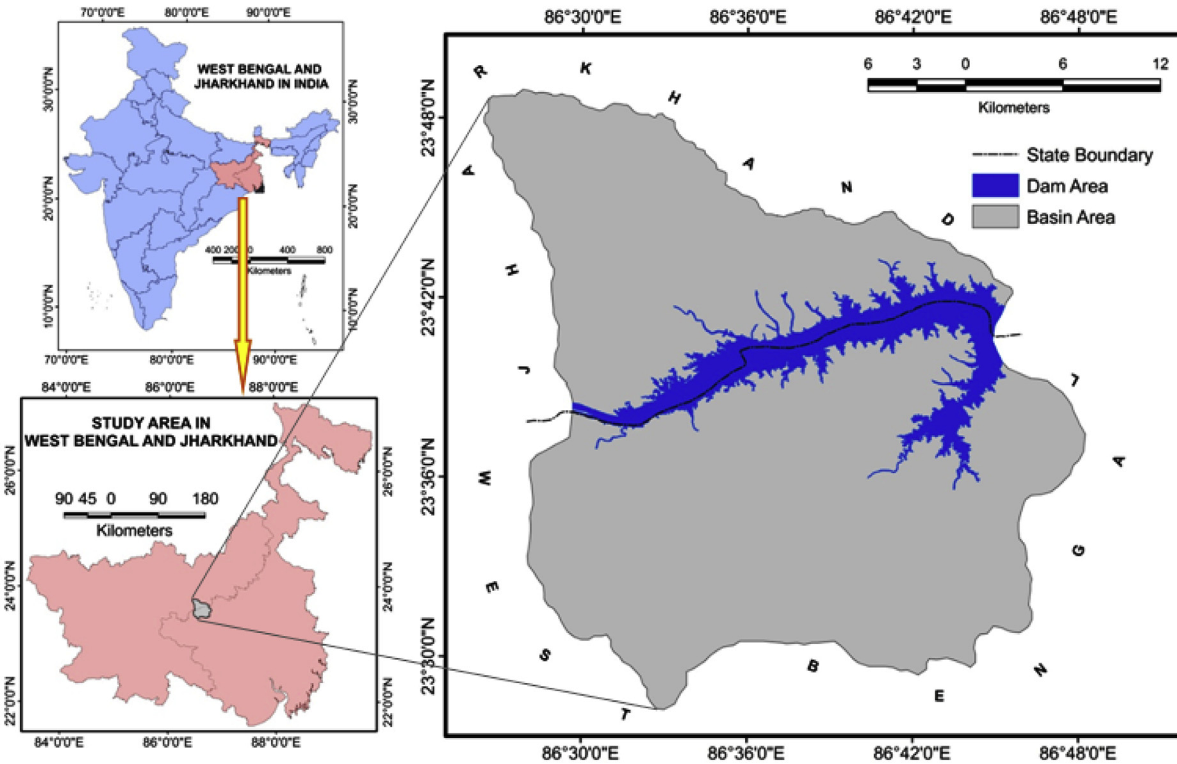

Fig. 1. Location of the Panchet dam.

identification of risk alternatives (3.5), TOPSIS method (3.6), WASPAS method (3.7). Result and discussion has been placed in section 4 which incorporates prioritization result based on TOPSIS (4.1), prioritization result based on WASPAS (4.2), final prioritization result based on Mean-Rank Method (4.3), analysis of risk alternatives (4.4) and section 5 deals with conclusion.

2. Methodology

The TOPSIS method was postulated by Yoon (1980) and was further developed by Hwang and Yoon (1981) (Srikrishna et al., 2014). The technique is well-known in various Multi-Criteria Decision-Making (MCDM) methods and is commonly used to assess prioritization of risk alternatives through weightage system among a set of risk alternatives (Lai et al., 1994; Dong et al., 2010; Yari and Chaji, 2012; Baecher, 2016; Yang and Nataliani, 2017). A study was carried out by Srdjevic et al. (2004) to assess water management system in Brazil where the TOPSIS method was used. Similarly WASPAS method was postulated by Zavadskas et al. in 2012 with a robust utility in the field of Multi Criteria Decision Making Approach. It is a combination of two well known MCDM methods such as Weighted Sum Method (WSM) and Weighted Product Method (WPM). Zavadskas et al. (2013b) used WASPAS to verify

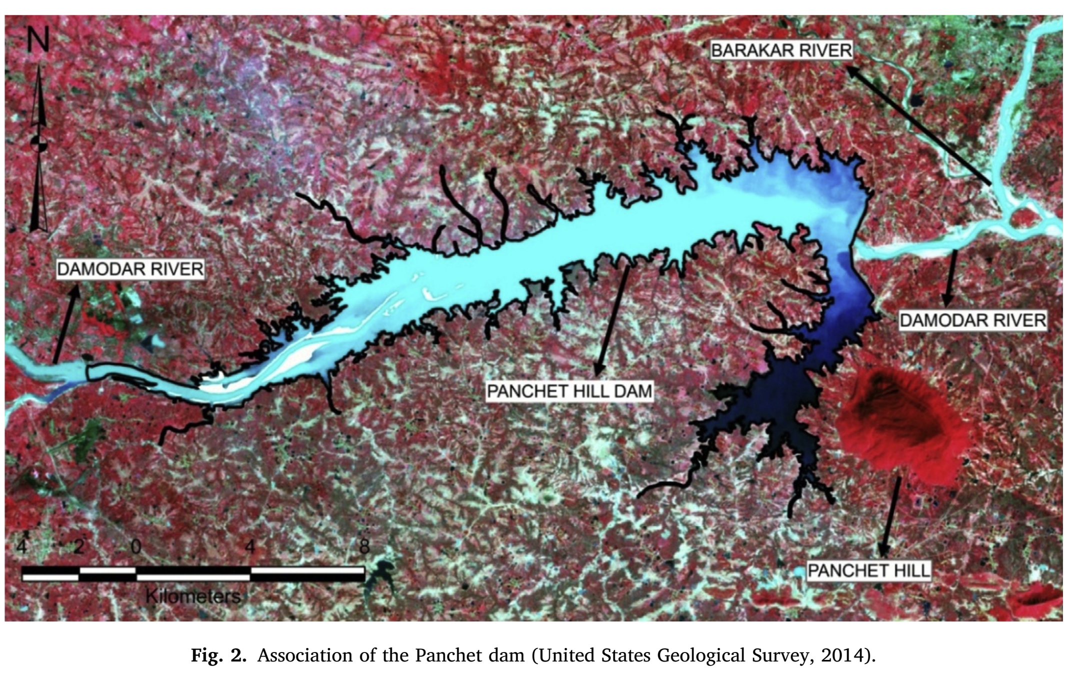

Fig. 2. Association of the Panchet dam (United States Geological Survey, 2014).

Table 1
Basic information about the Panchet Dam.

Construction started	1952
Year of opening	6/12/1959
Impounds	Damodar river
Types of dam	Earthen dam with concrete spillway
Height	45 Metres
Width (in base)	10.67 Metres
Length	6777 Metres
Surface area	27.92 k.m.^{2}
Catchment area	10,961 k.m.^{2}
Average annual basin rainfall	114 c.m.
Gross storage capacity	1497.54 million m^3
Dead storage capacity	170.37 million m^3
Average annual run off volume	4540 million m^3
Irrigated land	28 Lakh hectares
Power generation capacity	2 × 40 MW

Source: www.dvc.gov.in.

robustness of the approach for the assessment of alternative solutions. Dejus and Antuchevičiene (2013) applied it for assessing health and safety solutions for any construction site. A number of researchers namely Zavadskas et al. (2013a), Chakraborty and Zavadskas (2014), Hashemkhani et al. (2013), Bagočius et al. (2013), Staniunas et al. (2013) have applied the method for various project management. Tosun and Seyrek (2010); Sun et al. (2014); Seyed Ali and Maryam (2014); Mohsen et al. (2015); Srivastava and Babu (2016); Chen and Lin (2018) are some notable researchers who used the methods for assessment of human risks in respect to dams.

Table 2
Reservoir classification according to shape factor 'M' (Borland and Miller, 1958).

Types of Reservoir	Classification	Shape factor 'M'
I	Lake	3.5–4.5
II	Flood plain - foot hill	2.5–3.5
III	Hill	1.5–2.5
IV	Gorge or normally empty	1.0–1.5

3. Materials and methods

3.1. Study area

The eastern part of the Chotanagpur plateau is extended into the Jharkhand State and western periphery of the West Bengal. This area has been taken as the area under study for the present research work. The whole area slants from north-west to south-east direction (Chatterjee et al., 1970). Climatically the area is dry and wet sub-humid tropical climate, dominated by south west monsoon. The tract lies under the '*Aw*' type of climate (Spate and Farmer, 1954) as per Koppen's climatic classification. Temperature ranges from 3.8 °C in winter to 52 °C in summer while annual rainfall fluctuates from 1100 mm to 1500 mm. The area is covered by red lateritic residual type of soil. Hills and undulating lands create a unique feature of topography. *Sal (Shorea robusta) and Palas (Butea frondosa)* are the main plant species of the area. 643.5 meters high and 5 kms long Panchakot or Panchet Hill is situated to the north-east portion of the area which is basically formed of Upper Gondwana sedimentary rocks (Bhattacharya et al., 1985; Siddique and Bid, 2017). Location and association of the Panchet dam are shown in the Fig. 1 and Fig. 2 respectively.

3.2. The Panchet Dam

The Panchet Dam is one of the most important strategic dams and multipurpose projects of India, which is maintained by the Damodar Valley Corporation (DVC). Different aspects of the dam are highlighted in the Table 1. Based on nature and shape factor (M), reservoirs are classified into four categories (type I to IV). The Panchet reservoir is very close to type II, which is recognized as 'flood plain-foot hill type' of reservoir (Table 2 and Fig. 3). The shape factor (M) represents the reciprocal slope of the straight line that can be calculated from plotting the water depth at the dam site in the Y-axis against the storage capacity in the X-axis on a logarithmic scale (Borland and Miller, 1958; Mohammadzadeh-Habili and Heidarpour, 2010; Kaveh et al., 2013).

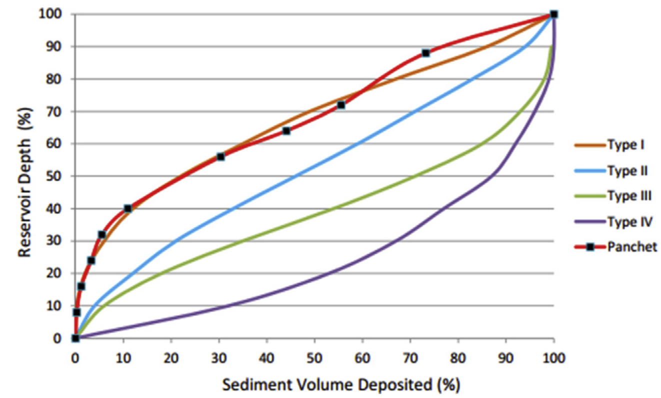

Fig. 3. Type curves of reservoirs for area reduction method (Central Water Commission, 2015).

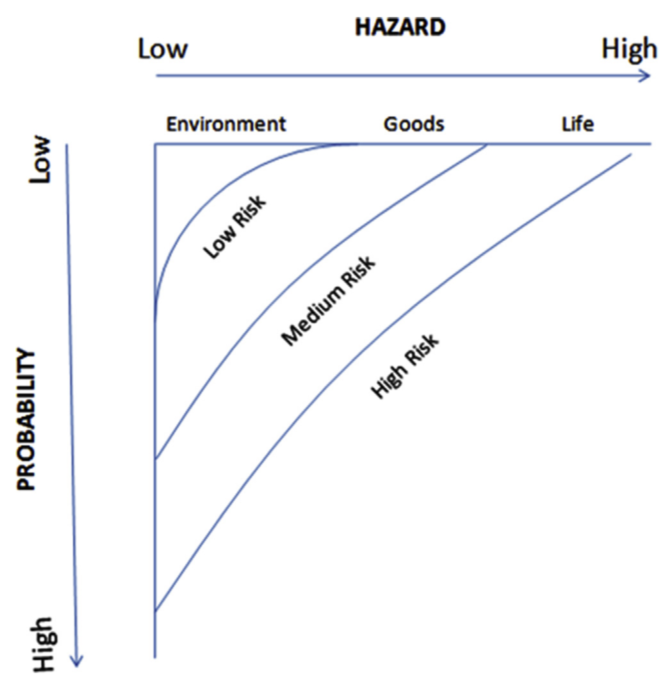

Fig. 4. Relationship between hazard and its probability to risk.

3.3. Sampling design and field survey

A reconnaissance survey was conducted in 2015 and field observations for two times have been completed from 2016 to 2017. The first observation was conducted in the pre monsoon period (first week of May) and another at the near end of the monsoon season (second week of August). A buffer zone of 1 km area from high level of the dam water was created where 92 villages are located. Villages were verified by the Google earth map and GPS (Geographical Positioning System) coordinates on the ground. Among those 92 villages, 8 remain substantively under water condition, 22 possess the location between the high and low water level and 62 villages are located in the range of high water level

Table 3
Alternatives of human risks and their codes.

Symbols of Alternatives/indexes	Description of Alternatives/Indexes
A1	Dam induced flood
A2	Inundation of settlement
A3	Population displacement
A4	Employment and income
A5	Loss of properties
A6	Loss of agricultural land
A7	Dam safety risk
A8	Human health risk
A9	Stress and strain

and 1 km buffer zone. 40 villages were selected for survey through questionnaire schedule. 5 households from each village have been surveyed. Thus the total number of sample is 200 (n = 40 x 5 = 200) and the sample villages are selected on the basis of clustering method.

3.4. Concept of risk and risk assessment

In broader term, risk is the probability of a hazard occurring and creating loss but this risk can be increased and decreased by human action (Quarantelli, 1998; Jozi and Malmir, 2014; Chen and Lin, 2018).

Risk can be conceptualized by the formula of Fournier d'Albe, 1979 (Eq. 1).

$$Risk = \frac{Hazard\ (probable)\ x\ Loss\ (expected)}{Preparedness\ (loss\ mitigation)} \tag{1}$$

The relationship between hazard and its probability (Fig. 4) can be examined to determine the overall degree of risk. The risk assessment is a preliminary stage intended to expose major problems. According to Kates and Kasperson (1983), McGrath (2018), risk assessment comprises three distinct steps viz. identification of risks associated with the event, estimation of risks of such event and evaluation of social consequences of the derived risk.

3.5. Identification of risk alternatives (A1 – A9)

Risk-generating factors of Panchet Dam are identified in this study usingthe Delphi method. The Delphi panel was consisted of 4 experts having vivid knowledge and experience of more than 10 years in the concerned field. They were renowned field personnels and good academicians in the field of risk assessment of dam. Delphi questionnaires were distributed among the panelists. High-priority risk-generating factors were obtained at the second round of Delphi polling. The questionnaires were scored by the experts on a 9 point weightage scale. The data obtained from the questionnaire surveys were analyzed by Excel software. Out of 13 risk alternatives, 9 are accepted in the identification step. The symbols of alternatives are A1, A2 … A9 (Table 3). These risks are rated by the TOPSIS and WASPAS method. Some alternatives were probabilistic in nature and therefore verification of the given weightage was made through focus group discussion with the local people. Overall procedure of human risk assessment of the Panchet Dam is represented in Fig. 5.

3.6. TOPSIS method

The TOPSIS method has different stages to identify the solution from several alternatives. The entire procedure of this method is completed through a series of seven interlinking steps (Sen and Yang, 1998; Abo--Sinna and Amer, 2005; Yang and Hunng, 2007; Tosun and Seyrek, 2010; Sun et al., 2014; Chen and Lin, 2018) as shown below:

Step 1: Formation of Decision Matrix (DM)

First step of the TOPSIS method is related with the construction of Decision Matrix (DM). The basic structure of the DM may be represented with the following equation (Equation 2):

$$DM = \begin{bmatrix} & C_1 & C_2 & \dots & C_n \\ L_1 & x_{11} & x_{12} & \dots & x_{1n} \\ L_2 & x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ L_m & x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \tag{2}$$

Where i is the criterion index (i = 1. . . m); m is the number of potential sites and j is the alternative index (j = 1. . . n). The elements $C_1, C_2\dots, C_n$ refer to the criteria; while $L_1, L_2\dots, L_n$ refer to the alternative locations. The elements of the matrix are related to the values of criteria i with respect to alternative j.

The m × n decision matrix is formulated for human risk assessment of the Panchet dam. Four experts engaged in this work declared their decisions on 9 risk factors and ultimately a 4 × 9 matrix is made. The quantitative values acquired from the experts' opinion are shown in Table 4, while the experts are represented with N1, N2,. . ., N4 symbols,

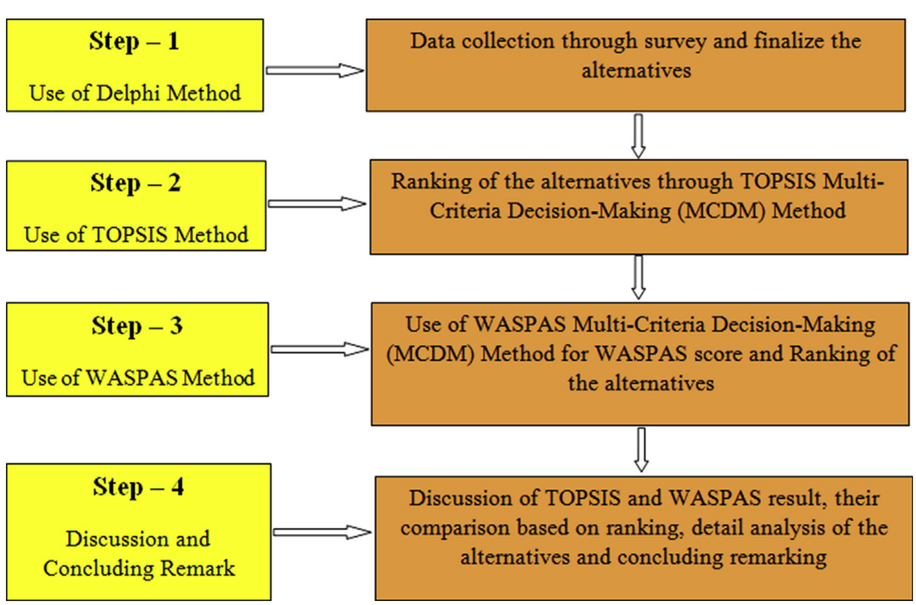

Fig. 5. Complete procedure of human risk assessment of the Panchet dam.

Table 4
Decision matrix.

	A1	A2	A3	A4	A5	A6	A7	A8	A9
N1	7	8	9	2	1	6	4	5	3
N2	5	7	9	6	2	5	3	6	4
N3	6	7	8	3	1	5	5	6	5
N4	6	6	9	4	2	4	3	4	5

and the risk factors are expressed with A1, A2,. . ., A9 symbols.

Step 2: Normalized Decision Matrix (NDM)

Normalized Decision Matrix (r_{ij}) is obtained through Eq. (3) which helps to convert dimensionless values of the decision matrix:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad i = 1, 2\ldots, m \qquad j = 1, 2, \ldots, n \tag{3}$$

Normalized Decision Matrix (r_{ij}) of the current study is shown in Table 5.

Step 3: Weighted Decision Matrix

In this stage, weight of each alternative (W_i) is calculated by the 'expert survey method' which is a familiar weighted method in the group of subjective fixed weight methods. Certain weightage was given by each expert for every alternative and then averaged. Computed average weight for A1 to A9 alternatives are 10%, 20%, 30%, 7.5%, 2.5%, 7.5%, 5%, 10% and 7.5% respectively. Table 6 represents outcomes of the weighted normalized decision matrix for the present study obtained through multiplication of the normalized decision matrix by the weighted vector. Eq. (4) is used to calculate weighted dimensionless matrix.

$$V = N_D{}^{*}\, W_{n\ X\ n} \tag{4}$$

Where, V is the weighted dimensionless matrix and W is a diagonal matrix of theweights obtained for indices.

Step 4: Identification of Positive Ideal (A^+) and Negative Ideal (A^-) Solution

In fourth stage, positive and negative ideal solutions are determined using Eqs. (5) and (6) respectively. Symbol A^+ represents positive ideal solution which indicates the lowest risk, whereas A^- points out the negative ideal solution that highlights the highest risk. The values of A^+ and A^- of the present research work have been shown in Table 7.

$$A^+ = \{V_1^+, \ldots, V_n^+\} = \{(MAX\ i_{v_{ij,}}\ j\ \varepsilon\ J)(MIN\ i_{v_{ij,}}\ j\ \varepsilon\ J)\} \qquad i = 1, 2, \ldots, m \tag{5}$$

$$A^- = \{V_1^-, \ldots, V_n^-\} = \{(MIN\ i_{v_{ij,}}\ j\ \varepsilon\ J)(MAX\ i_{v_{ij,}}\ j\ \varepsilon\ J)\} \qquad i = 1, 2, \ldots, m \tag{6}$$

Where, J is associated with benefit criteria, and J' is associated with cost criteria. Risk alternatives are determined as benefit or cost criteria on the basis of the role played in the event of human risk of the Panchet dam. In the present research A4 is the only benefit criteria because it checks the event positively while A1, A2, A3, A5, A6, A7, A8 and A9 are considered as cost criteria because they run the system negatively.

Step 5: Separation Measures from Positive and Negative Ideal Solutions

The deviation of each alternative (D^+) from the positive ideal solution (A^+) is measured with the following equation (Eq. 7):

$$D_i^+ = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^+\right)}^{2} \qquad i = 1, 2, \ldots, m \tag{7}$$

The deviation of each alternative (D^-) from the negative ideal solution (A^-) is calculated with the help of the following equation (Eq. 8) using Euclidean method, the results are presented in Table 7.

$$D_i^- = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^-\right)^2} \qquad i = 1, 2, \ldots, m \tag{8}$$

Step 6: Measure of the Relative Closeness to the Ideal Solution

Eq. (9) is used to calculate the relative closeness of each location to the ideal solutions (C_i), the result of which is given in Table 8.

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \qquad i = 1, 2, \ldots m \tag{9}$$

Table 5
Normalized decision matrix.

	A1	A2	A3	A4	A5	A6	A7	A8	A9
N1	0.5793	0.5685	0.5136	0.2480	0.3162	0.5940	0.5207	0.4703	0.3464
N2	0.4138	0.4974	0.5136	0.7442	0.6324	0.4950	0.3905	0.5644	0.4618
N3	0.4965	0.4974	0.4565	0.3721	0.3162	0.4950	0.6509	0.5644	0.5773
N4	0.4965	0.4264	0.5136	0.4961	0.6324	0.3960	0.3905	0.3762	0.5773

Table 6
Weighted normalized decision matrix.

	A1	A2	A3	A4	A5	A6	A7	A8	A9
N1	0.0579	0.1137	0.1540	0.0186	0.0079	0.0445	0.0260	0.0470	0.0259
N2	0.0413	0.0990	0.1540	0.0550	0.0158	0.0371	0.0197	0.0564	0.0346
N3	0.0496	0.0990	0.1369	0.0279	0.0079	0.0371	0.0325	0.0564	0.0432
N4	0.0496	0.0852	0.1540	0.0372	0.0158	0.0297	0.0197	0.0376	0.0432

Table 7
Positive (A^+) and Negative (A^-) Ideal Solutions, as well as their deviations (D^+ and D^-).

	A1	A2	A3	*A4	A5	A6	A7	A8	A9
A^+	0.0413	0.0852	0.1369	0.0550	0.0079	0.0297	0.0197	0.0376	0.0259
A^-	0.0579	0.1137	0.1540	0.0186	0.0158	0.0445	0.0325	0.0564	0.0432
D^+	0.0203	0.0345	0.0290	0.0487	0.0111	0.0181	0.0142	0.0282	0.0259
D^-	0.0203	0.1155	0.0171	0.0419	0.0111	0.0181	0.0192	0.0210	0.0193

* A4 is the only benefit criteria or positive criteria.

Table 8
Relative closeness to the ideal solutions.

	C1	C2	C3	C4	C5	C6	C7	C8	C9
Ci	0.5000	0.7700	0.3709	0.4624	0.5000	0.5000	0.5700	0.4268	0.4269

Table 9
Ranking (R) of the risk alternatives.

	A1	A2	A3	A4	A5	A6	A7	A8	A9
R	5	7	1	4	5	5	6	2	3

Table 10
Symbol and description of criteria used in WASPAS.

Symbol of Criteria	Description of Criteria
*C1	Supply of sediment
*C2	Filling of reservoir
*C3	Over topping
**C4	Water holding capacity
**C5	Monitoring and repairing of dam

*indicates non benefit or cost criteria and ** indicates benefit criteria.

The value of *Ci* lies between 0 and 1 and when it is close to 1, the alternative will have less risk (Olson, 2004).

Step 7: Rank of the Preference Order

Finally, the risk alternatives (R) are rated according to the *Ci* values (Table 9). In descending order of *Ci*, the available alternatives can be ranked on the basis of their importance. According to the value of *Ci,* higher value of the relative closeness refers to the higher ranking order and thus it represents better performance of the alternative. Ranking of the preference in descending order thus allows relatively better performances (Hwang and Yoon, 1981; Socorro García-Cascales and Teresa Lamata, 2012; Seyed Ali and Maryam, 2014; Jozi et al., 2015). Though the TOPSIS method is very useful technique under MCDM methods, but it has some flaws that occur in many cases, such as rank reversal condition, total rank reversal condition, condition of inclusion and exclusion of alternatives etc. (Socorro García-Cascales and Teresa Lamata, 2012).

3.7. WASPAS method

The whole procedure of WASPAS method is completed through different stages as shown below (Ghorabaee et al., 2016):

Step 1: Development of Decision/Evaluation Matrix

The basic structure of the decision matrix used in WASPAS method is represented by the following equation (Eq. 10):

$$\begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \tag{10}$$

Where, m is the number of alternative and n is the number of criteria. X_{ij} is the performance of i^{th} alternative with respect to j^{th} criteria.

Risk alternatives taken in WASPAS method are same which are used in the TOPSIS method (A1 to A9). Experts, engaged in the field survey have suggested 7 factors responsible for different risk alternatives and we have finalized 5 factors known as risk criteria (C1 – C5) to assess human risks of the dam. The list of risk criteria and decision matrix are given in Tables 10 and 11 respectively.

Step 2: Normalization of the Decision Matrix

Normalized value of decision matrix is represented in Table 12 which is computed using two equations (Eqs. (11) and (12)):

The equation for benefit criteria is

Table 11
Decision matrix.

Alternative	Criteria				
	C1	C2	C3	C4	C5
A1	7.00	6.00	8.00	5.00	7.00
A2	6.00	7.00	7.00	4.00	4.00
A3	2.00	5.00	6.00	4.00	8.00
A4	2.00	6.00	2.00	2.00	2.00
A5	3.00	5.00	5.00	1.00	6.00
A6	3.00	5.00	5.00	4.00	4.00
A7	6.00	6.00	6.00	3.00	9.00
A8	4.00	5.00	4.00	2.00	6.00
A9	4.00	5.00	6.00	4.00	8.00

Table 12
Normalized decision matrix.

Alternative	Criteria				
	C1	C2	C3	C4	C5
A1	0.2857	0.8333	0.2500	1.0000	0.7778
A2	0.3333	0.7143	0.2857	0.8000	0.4444
A3	1.0000	1.0000	0.3333	0.4000	0.8889
A4	1.0000	0.8333	1.0000	0.4000	0.2222
A5	0.6667	1.0000	0.4000	0.2000	0.6667
A6	0.6667	1.0000	0.4000	0.8000	0.4444
A7	0.3333	0.8333	0.3333	0.6000	1.0000
A8	0.5000	1.0000	0.5000	0.4000	0.6667
A9	0.5000	1.0000	0.3333	0.8000	0.8889
w_{ij}	0.3000	0.2000	0.1000	0.2000	0.2000

$$\bar{x}_{ij} = \frac{x_{ij}}{max_i x_{ij}} \tag{11}$$

and, the equation for non-benefit criteria is

$$\bar{x}_{ij} = \frac{min_i x_{ij}}{x_{ij}} \tag{12}$$

Step 3: Computation of WSM and WPM

Total relative importance of i^{th} alternative is computed on the basis of Weighted Sum (WS) and Weighted Product (WP) method which are calculated on the basis of Eqs. (13) and (14) respectively.

$$WSM = Q_i^{(1)} = \sum_{j=1}^{n} \bar{x}_{ij} w_j \tag{13}$$

$$WPM = Q_i^{(2)} = \prod_{j=1}^{n} \left(\bar{x}_{ij}\right)^{w_j} \tag{14}$$

Where, $Q_i^{(1)}$ and $Q_i^{(2)}$ denote the relative importance of i^{th} alternative in relation to the j^{th} criterion which are based on WS and WP method respectively, and w_j is the weightage of criteria. Weightage of every criterion given by each expert then is averaged. The averaged weightage of C1 to C5 criteria are 30%, 20%, 10%, 20% and 20% respectively shown in Table 12. Detail computation of WSM and WPM for the Panchet dam is represented in Tables 13 and 14 simultaneously.

Step 4: Calculation of total relative importance for each alternative

Joint generalized criterion of weighted aggregation of additive and multiplicative methods (Zavadskas et al., 2013a, 2013b) is calculated on the basis of the following equation (Eq. 15):

Table 13
Weighted sum method (WSM).

Alternative	Criteria						
	C1	C2	C3	C4	C5	Preference Score	Rank
A1	0.0857	0.1667	0.0250	0.2000	0.1556	0.6329	7.0000
A2	0.1000	0.1429	0.2857	0.1600	0.0889	0.7775	2.0000
A3	0.3000	0.2000	0.0333	0.0800	0.1778	0.7911	1.0000
A4	0.3000	0.1667	0.1000	0.0800	0.0444	0.6911	4.0000
A5	0.2000	0.2000	0.0400	0.0400	0.1333	0.6133	9.0000
A6	0.2000	0.2000	0.0400	0.1600	0.0889	0.6889	5.0000
A7	0.1000	0.1667	0.0333	0.1200	0.2000	0.6200	8.0000
A8	0.1500	0.2000	0.0500	0.0800	0.1778	0.6578	6.0000
A9	0.1500	0.2000	0.0333	0.1600	0.1778	0.7211	3.0000

Table 14
Weighted product method (WPM).

Alternative	Criteria						
	C1	C2	C3	C4	C5	Preference Score	Rank
A1	0.6867	0.9642	0.8706	1.0000	0.9510	4.4724	7
A2	0.7192	0.9349	0.8822	0.9564	0.8503	4.3430	9
A3	1.0000	1.0000	0.8959	0.8326	0.9767	4.7052	1
A4	1.0000	0.9642	1.0000	0.8326	0.7402	4.5370	4
A5	0.8855	1.0000	0.9124	0.7248	0.9221	4.4448	8
A6	0.8855	1.0000	0.9124	0.9564	0.8503	4.6046	3
A7	0.7192	0.9642	0.8959	0.9029	1.0000	4.4822	6
A8	0.8123	1.0000	0.9330	0.8326	0.9221	4.5000	5
A9	0.8123	1.0000	0.8959	0.9564	0.9767	4.6413	2

Table 15
Rank of alternatives when WASPAS parameter λ = 0, 0.5 and 1.

Alternative	Criteria							
	WSM	WPM	λ = 0.5		λ = 0		λ = 1	
			WASPAS Score	Rank	WASPAS Score	Rank	WASPAS Score	Rank
A1	0.6329	4.4724	2.5527	7	4.4724	7	0.6329	7
A2	0.7775	4.3430	2.5603	6	4.3430	9	0.7775	2
A3	0.7911	4.7052	2.7482	1	4.7052	1	0.7911	1
A4	0.6911	4.5370	2.6141	4	4.5370	4	0.6911	4
A5	0.6133	4.4448	2.5291	9	4.4448	8	0.6133	9
A6	0.6889	4.6046	2.6468	3	4.6046	3	0.6889	5
A7	0.6200	4.4822	2.5511	8	4.4822	6	0.6200	8
A8	0.6578	4.5000	2.5789	5	4.5000	5	0.6578	6
A9	0.7211	4.6413	2.6812	2	4.6413	2	0.7211	3

$$Q_i = 0.5\, Q_i^{(1)} + 0.5\, Q_i^{(2)} = 0.5 \sum_{j=1}^{n} \bar{x}_{ij} w_j + 0.5 \prod_{j=1}^{n} (\bar{x}_{ij})^{w_j} \tag{15}$$

More generalized equation for determining the total relative importance of i^{th} alternative is calculated on the basis of Eq. (16) (Šaparauskas et al., 2011; Zavadskas et al., 2012):

$$Q_i = \lambda\, Q_i^{(1)} + (1-\lambda) Q_i^{(1)} = \lambda \sum_{j=1}^{n} \bar{x}_{ij} w_j + (1-\lambda) \prod_{j=1}^{n} (\bar{x}_{ij})^{w_j} \tag{16}$$

Where, λ is the parameter of the WASPAS method. The value of λ ranges from 0 to 1. When λ = 1, then the WASPAS method behaves like WSM, and, when λ = 0, it transforms into WPS. Table 15 represents the rank of alternatives where λ values are minimum (λ = 0), medium (λ = 0.5) and maximum (λ = 1).

4. Result and discussion

4.1. Prioritization results based on TOPSIS

Fig. 6 represents the relative closeness value (*Ci*) of each alternatives derived from TOPSIS method. The second alternative, 'Iundation of

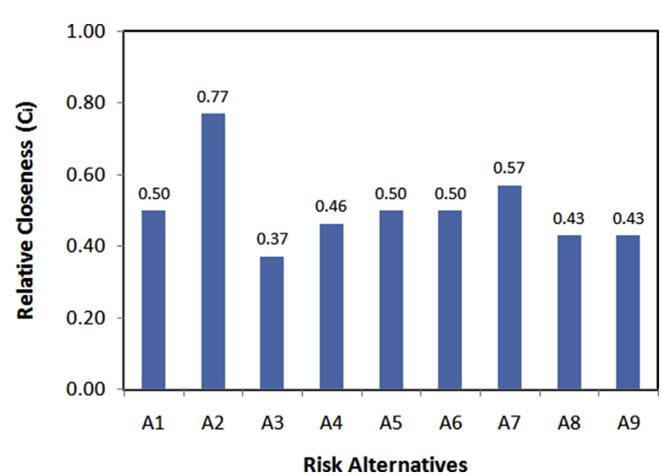

Fig. 6. Relative Closeness (C_i) of risk alternatives derived from TOPSIS method. Low value of C_i represents high risk alternative while high value indicates alternative of low risk.

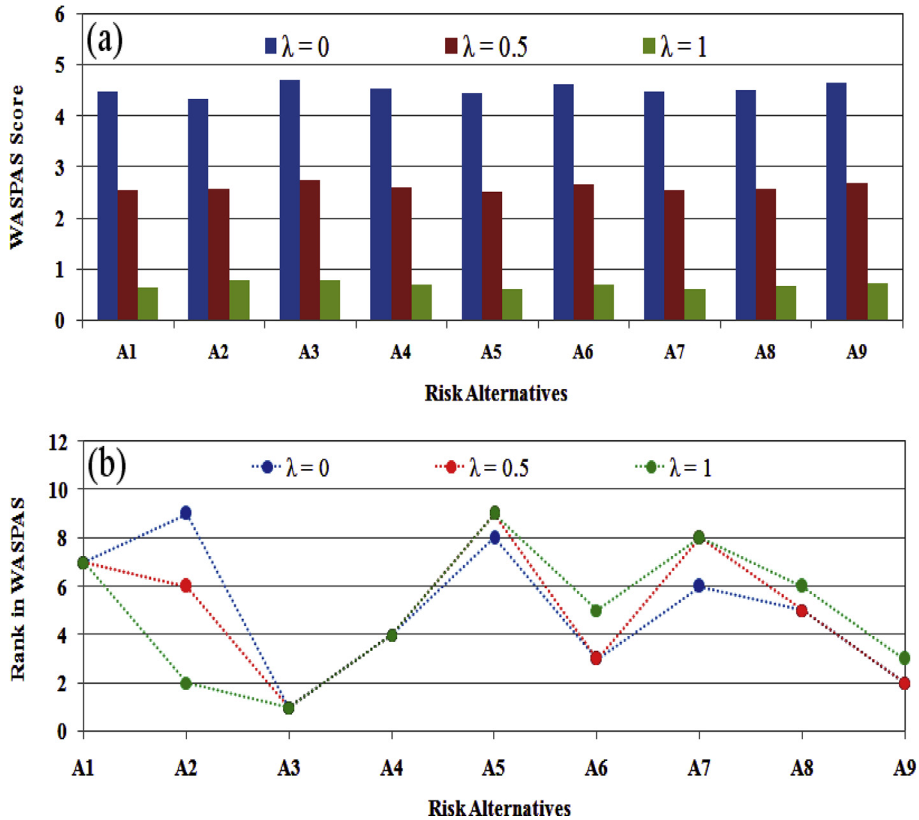

Fig. 7. a. WASPAS score and b. Rank of alternatives derived from WASPAS method. High WASPAS score represents high risk alternative whereas low value indicates low risk alternative.

settlement' (A2) acquires maximum relative closeness value ($Ci = 0.77$) from the ideal solutions that indicates minimum risk factor in the case of Panchet dam and it obtains 7th rank among the risk alternatives. The third alternative, 'Population displacement' (A3) gets minimum *Ci* value ($Ci = 0.37$) from the ideal solution which indicates maximum risk factor in the case of Panchet dam, and thus it obtains 1st rank among the alternatives. The second priority risk generating alternative is 'human health risk' (A8) with 0.43 Ci value. The third and fourth priority alternatives are 'Stress and strain' (A9) and 'Employment and income' (A4) respectively. *Ci* value of Alternatives A1 (dam induced flood), A5 (loss of properties) and A6 (loss of agricultural land) is same ($Ci = 0.50$) and all obtain fifth priority rank. The sixth risk priority alternative is 'dam safety risk' (A7) with 0.57 Ci value. In TOPSIS method, the priority of risk alternative is as follows:

A3 > A8 > A9 > A4 > A1, A5, A6 > A7 > A2

Population displacement > Human health risk > Stress and strain > Employment and income > Dam induced flood, Loss of properties, Loss of agricultural land > Dam safety risk > Inundation of settlement.

In the TOPSIS method, A3 (population displacement) alternative obtains the first rank because it is the most crucial problem of people surrounding the dam. People have suffered from displacement since the day of inception of the dam. A number of villages were compelled to abandon because the dam authority occupied the land for constructing the dam in the decade of 1950. At present, the problem is emerging as a threat for the surrounding villagers due to quick inundation of land by the dam water. The current research investigates that 30% area of the reservoir is totally blocked due to high rate of siltation on the bed of reservoir. The upper catchment of the dam is composed of sedimentary rock easily erodible in nature and helps to supply ample volume of sediment to the reservoir through surface runoff. Water holding capacity of the dam is decreasing rapidly due to filling up of its space. In rainy season, the reservoir turns into almost filled up condition after receiving continuous rain in the upper catchment area through tributary streams. In this circumstance, a number of villages are inundated in the upper catchment area of the dam. The present research has explored 8 villages that are completely under water of the dam, 22 villages are situated between the high and low water level of the dam water, while 62 villages are located within the 1 km buffer area of the dam. The people of these villages live with threat of inundation and, as a result, A3 alternative gets more weightage in the TOPSIS. It also obtains first rank in TOPSIS that highlights more risk prone factor than the others. The problem may be overcome with enhancement of the water holding capacity of the dam through its reclamation. Plantation of indigenous vegetation species in the upper catchment area may be an essential solution to check the enormous supply of sediment to the reservoir. Removal of sediments deposited in the bed of reservoir is an effective way to check the problem albeit it's high cost effectiveness. Diversion of water channels in different directions at the time of peak flow condition of the dam is another effective solution of the problem. According to TOPSIS result, A2 alternative (inundation of settlement) acquires last rank and indicates relatively less risk prone factor as a number of people of the villages have abandoned the settlements surrounding the dam in search of occupation and sustenance of life.

4.2. Prioritization results based on WASPAS

The result obtained from WASPAS method varies with the deviation in WASPAS parameter (λ), which varies from 0 to 1. When we consider λ value as 0, the A3 alternative acquires maximum WASPAS score (4.7052) and gets 1st rank that represents it as the highest risk alternative among all. A2 alternative achieves 4.3430 WASPAS score and obtains 9th rank that represents it as a minimum risk factor. When λ value is considered as 0.5, the A3 (WASPAS score = 2.7482) and A5 (WASPAS score = 2.5291)

Table 16
Mean rank of risk alternatives.

Symbols of Alternatives/ Indexes	Description of Alternatives/ Indexes	MCDM Methods		Mean-Rank	MCDM Methods		Mean-Rank	MCDM Methods		Mean-Rank
		Ranking in TOPSIS	Ranking in WASPAS (λ = 0)		Ranking in TOPSIS	Ranking in WASPAS (λ = 0.5)		Ranking in TOPSIS	Ranking in WASPAS (λ = 1)	
A1	Dam induced flood	5	7	6	5	7	6	5	7	6
A2	Inundation of settlement	7	9	8	7	6	6.5	7	2	4.5
A3	Population displacement	1	1	1	1	1	1	1	1	1
A4	Employment and income	4	4	4	4	4	4	4	4	4
A5	Loss of properties	5	8	6.5	5	9	7	5	9	7
A6	Loss of agricultural land	5	3	4	5	3	4	5	5	5
A7	Dam safety risk	6	6	6	6	8	7	6	8	7
A8	Human health risk	2	5	3.5	2	5	3.5	2	6	4
A9	Stress and strain	3	2	2.5	3	2	2.5	3	3	3

risk alternatives hold 1st and 9th rank simultaneously. When λ value is 1, A3 (WASPAS score = 0.7911) alternative again holds 1st rank and A5 (WASPAS score = 0.6133) alternative obtains 9th rank. It indicates that A3 is the most risk prone alternative whereas A5 is low risk prone alternative of the Panchet dam.

WASPAS score and WASPAS rank obtained from WASPAS method for risk alternatives are represented in Figs. 7a and 7b respectively. Maximum WASPAS score represents top priority risk alternative while minimal score indicates least priority of risk alternative. The top-priority alternative coming out from WASPAS result is 'Population displacement' (A3) in all cases when the λ value is minimum (0), medium (0.5) and maximum (1). In the WASPAS method the priority of risk alternatives is as follows:

λ = 0: A3 > A6 > A9 > A1 > A4 > A7 > A8 > A5 > A2

Population displacement > Loss of agricultural land > Stress and strain > Dam induced flood > Employment and income > Dam safety risk > Human health risk > Loss of properties > Inundation of settlement.

λ = 0.5: A3 > A9 > A6 > A4 > A8 > A2 > A1 > A7 > A5

Population displacement > Stress and strain > Loss of agricultural land > Employment and income > Human health risk > Inundation of settlement > Dam induced flood > Dam safety risk > Loss of properties.

λ = 1: A3 > A2 > A9 > A4 > A6 > A8 > A1 > A7 > A5

Population displacement > Inundation of settlement > Stress and strain > Employment and income > Loss of agricultural land > Human health risk > Dam induced flood > Dam safety risk > Loss of properties.

According to the result of WASPAS method A3 (population

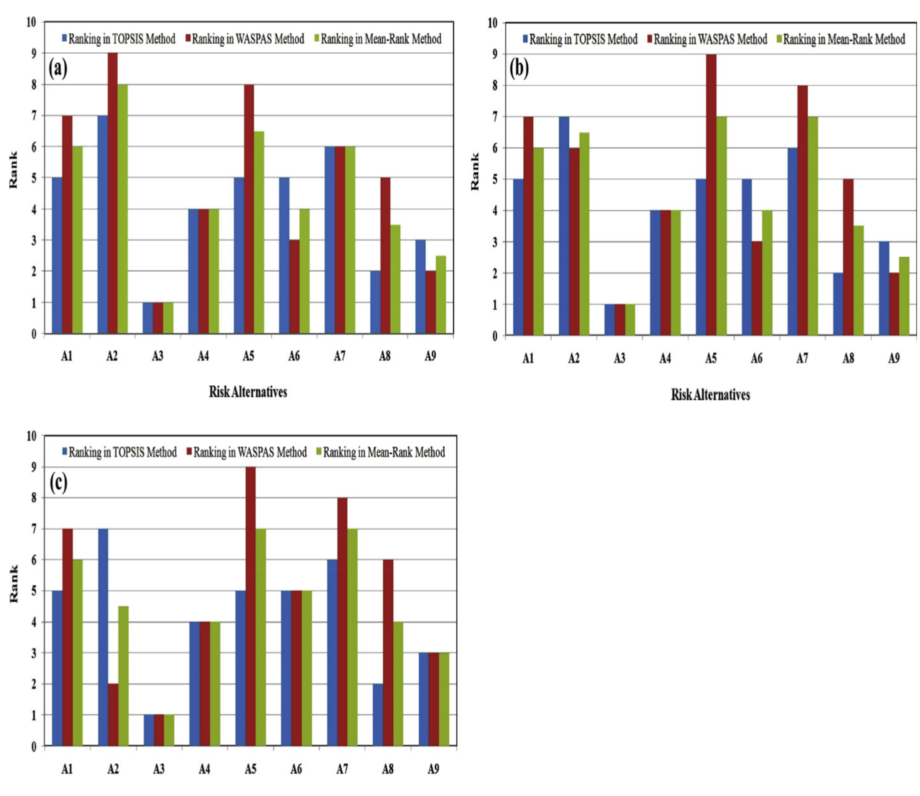

Fig. 8. Ranking of Risk Alternatives (A1-A9) on the basis of results derived from TOPSIS, WASPAS and Mean-Rank methods when (a) WASPAS parameter λ = 0, (b) WASPAS parameter λ = 0.5, (c) WASPAS parameter λ = 1.

displacement) risk alternative has obtained first rank among the risk alternatives in all three cases when WASPAS parameter λ value is 0, 0.5 and 1. The experts give more weightage to the A3 alternative because it is the crucial problem of the people settling near the dam and obviously it appears as the prominent risk factor while the A2 alternative is emerging as comparatively less problematic risk factor when $\lambda = 0$ and A5 alternative appears as low risk factor in the both cases when $\lambda = 0.5$ and 1. Causes and remedies of the top ranking risk factor are discussed in the previous section.

4.3. Final prioritization results based on Mean-Rank Method

Two different MCDM methods (TOPSIS and WASPAS) give some similar and some dissimilar ranks among the nine identified risk criteria of the Panchet dam. In this circumstance, it is essential to apply a reliable method to obtain a unified result of risk criteria ranking. We select 'Mean-Rank' method as a combined method and apply it to eliminate the conflicts in the ranking result obtained from both TOPSIS and WASPAS method. In this method, ranking is calculated through Mean-Rank method on the basis of results obtained from TOPSIS and WASPAS. Though the result of TOPSIS and WASPAS is quite differing, it is the more reliable method than approximate Median-Rank method for more accuracy of the technique. The technique is able to render more accurate result in the case of smaller sample (Yu et al., 2007; Liao et al., 2011). Average ranking of nine risk alternatives is represented in Table 16. Final risk priority ranking of nine risk alternatives may be stated as:

A3 > A9 > A8 > A4, A6 > A1 > A7 > A5 > A2 when WASPAS parameter $\lambda = 0$

(Population displacement > Stress and strain > Human health risk > Employment and income, Loss of agricultural land > Dam induced flood > Dam safety risk > Loss of properties > Inundation of settlement).

A3 > A9 > A8 > A4, A6 > A1 > A2 > A5 > A7 when WASPAS parameter $\lambda = 0.5$

(Population displacement > Stress and strain > Human health risk > Employment and income, Loss of agricultural land > Dam induced flood > Inundation of settlement > Loss of properties > Dam safety risk).

A3 > A9 > A4, A8 > A2 > A6 > A1 > A5, A7 when WASPAS parameter $\lambda = 1$

(Population displacement > Stress and strain > Employment and income, Human health risk > Inundation of settlement > Loss of agricultural land > Dam induced flood, > Loss of properties, Dam safety risk).

Fig. 8 represents the ranking of 9 risk alternatives in TOPSIS, WASPAS and Mean-Rank methods.

4.4. Analysis of risk alternatives

Analysis of risk alternatives is given below -

Population displacement (A3): The event population displacement is closely related to the Panchet dam and maximum displacement takes place at the time of inception of the dam. In the post dam period, due to rapid sedimentation on the bottom of the reservoir, water holding capacity has been reduced and has caused to inundate its contiguous areas. The residents mainly migrate from those villages which are permanently inundated and periodically remain under water of the reservoir. Perception of the local people on displacement and migration of population for such causes has been collected through rigorous field survey. The survey data has been put in Table 17.

Stress and strain (A9): The Panchet village is attached to the dam wall in the downward side of the dam. In monsoon, water level exceeds the 125 meter height and begins to inundate the areas surrounding the dam. Excessive run-off with huge dissolved sediments and bed load carried to the reservoir create tremendous pressure on dam wall with chances of collapse. Water above 135 meters spills over at its fullest capacity of storage. Dam authority became compelled to open all sluice gates in 2013 in such situation and a man-made flash flood occurred in the outlet area of the dam (Siddique and Bid, 2017).

Table 17
Perception of local people about population displacement.

Questions about Population Displacement	Percentage of Respondents (%)
Is there any migration process in your locality for the construction of the Panchet dam?	
Yes	68.5
No	12.5
Don't know	19.0
How many villages were vacated for the construction of the dam?	
>20	5.5
20-30	8.0
30-40	12.0
40-50	18.5
>50	56.0
How many families were evicted from your village/mouza for the construction of the dam?	
>10	22.0
20-Oct	33.0
20-30	21.5
30-40	12.5
>40	11.0

Source: Field Survey, 2015–2017 *n = 200.

Loss of agricultural land (A6): The assumed rate of siltation of the Panchet dam is 2.44 million m^3 whereas the observed rate is 11.75 million m^3 (Irrigation Commission, 1982). A superimposed map (Fig. 9) shows the area covered by water of Panchet dam in peak season (July, 2011) and lean season (March, 2011). Total water covered area in July measured from the map was 49.80 km^2 and in March it was 29.62 km^2. Thus the submerged area in peak season measured for 20.18 km^2. The main reason of encroachment of dam water towards upstream is gradual reduction of water holding capacity of the dam due to rapid silt deposition in the bottom. Fig. 10 gives a vivid picture of land submergence from 1977 to 2014. Paddy fields and orchards become submerged in rainy season, and the crops and vegetables are damaged due to long stagnation of water in the fields.

Dam induced flood (A1): Though the dam has reduced the monsoonal peak discharge and flood frequency but floods reappeared in 1959, 1969, 1978, 1995, 2000 and 2013, of which the 1978 flood was most disastrous one. A dispute between dam authority and West Bengal Government recurs every year in the monsoon period over the release of water from the reservoir because released water creates a flash flood and water logging condition in the lower catchment area of Damodar in West Bengal (Siddique and Bid, 2017).

Employment and income (A4): Local people, mainly the Scheduled Tribes (ST) and the Scheduled Castes (SC) settled in the vicinity of the dam had been compelled to change their occupation and livelihood due to removal of extensive forest area after the commissioning of the dam. At present, they follow the occupation of seasonal labour migrating to the nearest agricultural belt. A few groups of fishermen are engaged in fishing activity in the Panchet Dam. Agricultural activities are possible only where irrigation facilities are available. A survey based on questionnaire schedule in this regard reveals the types of employment and income level of the area (Table 18).

Human health risk (A8): Water logging in contiguous area caused by the dam in monsoon period and retting of paddy plant residues generate huge amount of methane gas. Eutrophication causes abrupt growth of hydrophytes on stagnant water of the reservoir in winter and its decomposition in summer also emits huge methane gas. These are detrimental to human body and people who live in the contiguous area of the dam suffer from such hazard.

Dam safety risk (A7): When reservoir storage reaches its peak capacity after heavy monsoon rain, pressure of huge mass of water on dam walls is increased which causes breaching and break down of the dam wall. Disproportionate load of sediment also create huge pressure on dam wall. In addition, dam safety may fail by the cracks on concrete spillway

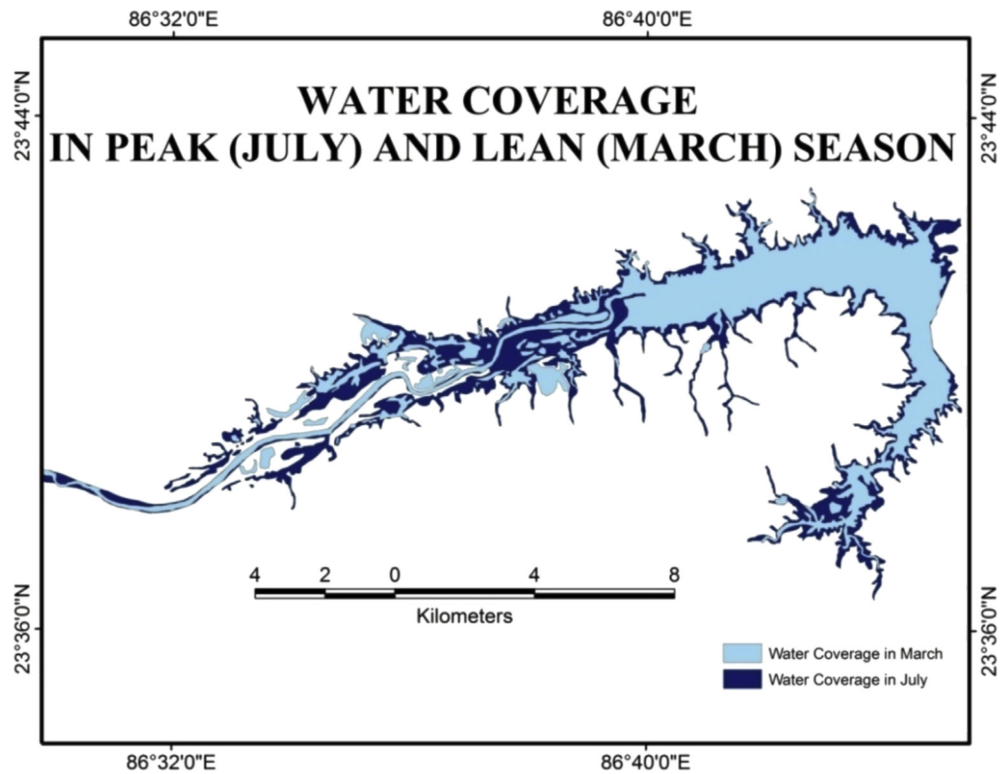

Fig. 9. Spreading of dam water in peak season and inundation of land.

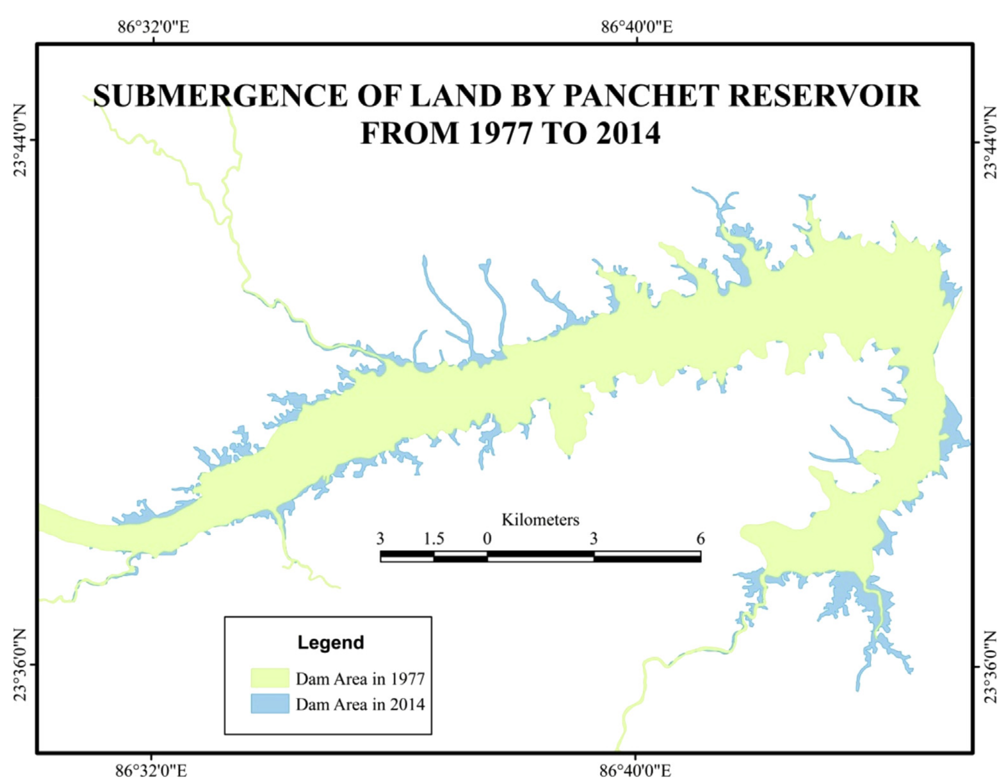

Fig. 10. Inundation of dam surrounding land since1977 to 2014.

or on earthen wall of the dam. Overflow of the dam can also be considered as dam safety risk.

Loss of properties (A5): Inundation of settled and agricultural lands cause loss of life and properties of the people. A large extent of paddy field is damaged in rainy season due to water logging condition. Similarly, houses and other infrastructures are damaged by flood hazards. Fishes of the nearest ponds escape with the overflow of those water bodies. Though the dam authority pays some compensation for the loss

Table 18
Status of employment and income.

Questions about Employment and Income	Percentage of Respondents (%)
What were the major sources of income before the construction of the dam?	10
Services	35
Cultivation	12
Trade and commerce	16
Agricultural Labourer	27
Forest Products	
What are the major sources of income at present?	17
Services	28
Cultivation	15
Trade and commerce	26
Agricultural Labourer	14
Forest Products	
What were the major sources of irrigation before the construction of the dam?	
Jore-bundhs	17
Ponds	12
Wells	19
Tube Well	7
Rivers	41
Canals	4
What are the present major sources of irrigation in your area?	
Jore-bundhs	7
Ponds	13
Wells	16
Tube Well	11
Rivers	32
Canals	21
How many crops were raised in a year in the same plot before the construction of the dam?	
One time in a year	65
Two time in a year	31
Three time in a year	4
How many crops are raised in a year in the same plot after the construction of the dam?	
One time in a year	48
Two time in a year	40
Three time in a year	12
What is the daily wages of a laborer at present?	
Below 100/-	5
100–150/-	12
150–200/-	46
Above 200/-	37
What is the range of monthly income?	
Below 5000/-	36
5000–10000/-	42
10000–20000/-	16
Above 20000/-	6

Source: Field Survey, 2015–2017 *n = 200.

incurred, but this has always been proved insufficient.

Inundation of settlement (A2): 22 villages have been periodically submerged and 8 villages are completely inundated by the reservoir water. Completely inundated villages are Kharbana, Tantloi, Banshjor, Ghatkul, Malancha, Naynakuri, Bharatpur and Telkupi. Villages which are situated between high water and low water level suffer from periodically water logging condition. Occasionally inundated villages are Gopal Chak, Jhaburdi, Kharikabad, Paharudi, Belyak Hajra, Mahuda, Krishtapur, Bathanbari, Shalchura, Belyadanga, Gopal Chak, Chak Mangla, Saltora, Baghadabar, Simpathar, Kalhajpur, Jeratanr, Ankbaria, Hatikundar, Katral, Kalmegha and Rangametya.

5. Conclusion

On the basis of the above analysis and results of different types of human risks from the Panchet Dam, we can conclude that the dam at present has become a threat to the local people living in the contiguous areas of the dam. Priority of the risk alternatives in the TOPSIS method follows A3 > A8 > A9 > A4 > A1, A5, A6 > A7 > A2 sequence and in WASPAS method follows A3 > A6 > A9 > A1 > A4 > A7 > A8 > A5 > A2 (when WASPAS parameter $\lambda = 0$), A3 > A9 > A6 > A4 > A8 > A2 > A1 > A7 > A5 (when WASPAS parameter $\lambda = 0.5$), A3 > A2 > A9 > A4 > A6 > A8 > A1 > A7 > A5 (when WASPAS parameter $\lambda = 1$). Though risk prioritization results have some similarity, but there are some mismatches too. To avoid this conflict, we have used final rank of risk alternatives by 'Mean-Rank' method and the priority result is A3 > A9 > A8 > A4, A6 > A1 > A7 > A5 > A2 (when WASPAS parameter $\lambda = 0$), A3 > A9 > A8 > A4, A6 > A1 > A2 > A5 > A7 (when WASPAS parameter $\lambda = 0.5$), A3 > A9 > A4, A8 > A2 > A6 > A1 > A5, A7 (when WASPAS parameter $\lambda = 1$). Among the set of alternatives, A3 (Population displacement) claims the top-priority human risk factor of the dam with minimum relative closeness value ($Ci = 0.37$) from the ideal solution obtained through the TOPSIS method and maximum WASPAS score (4.7052 when $\lambda = 0$, 2.7482 when $\lambda = 0.5$, 0.7911 when $\lambda = 1$) obtained from the WASPAS method.

The present research work is conducted to assess the human risks resultant of the Panchet dam. The dam authority (DVC) does not emphasize on the loss of the local people who suffered most for commissioning of the dam. They are compelled to tolerate all awful effects of the dam in silence. The result of the work reveals that risk of population displacement has been most prominent on the people surrounding the dam from the very day of its inception. Deposition of disproportionate sedimentation, reduction in water holding capacity and inundation of the area contiguous to the dam site bring threat to the people settled near the dam. The work is essential and relevant for the reduction of dam induced risks. Recently the new idea of 'Decommissioning of Dam' is being accepted worldwide that suggests replacement of large dams with small and check dams for sustainability of both human and environmental ecology. With this viewpoint, the current work has immense potentiality for the future work in the field of decision making process to obtain permission for construction of new dam. The authority can ensure about the human risks of dam construction before issuing permission. The work is very helpful in avoiding any man-made disaster or calamity from the dam as the dam authority has an opportunity to verify the risk factors on the basis of the result obtained from the present work. Complete and effective risk mitigation strategies become very essential to reduce risk factors of the Panchet Dam. It can be checked by different ways such as elimination, diminution, transmission, receiving, resistance, and adaptation of risk etc. whereas continuous monitoring and management are the solutions of various emerging risks of the Panchet Dam.

Declarations

Author contribution statement

Sumanta Bid: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Giyasuddin Siddique: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

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