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Water-level fluctuation (WLF) of Panchet dam in India and assessment of its human risk using AHP method

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Abstract This paper is an endeavor to probe into the temporal and seasonal water-level fluctuation (WLF) of Panchet dam in India since 2005–2016 and analysis of its risk to the dam-surrounding people, using analytical hierarchy process (AHP). The present study specifies that 30% storage capacity of the reservoir has been reduced within 60 years because of rapid sedimentation, while the trend analysis indicates that 50% and 100% storage capacity will be blocked within 130 years and 250 years respectively, if the present state continues. Thus it reveals a 250 years' active life span of the dam. Average temporal WLF of the dam is 12 mts and significant at the 5% level of significance ($p < 0.05$) whereas, seasonal WLF is 8 mts and also significant at the 1% level of significance ($p < 0.01$). This temporal and seasonal WLF leads to significant rise and fall of water level that poses threat to the people of 92 villages situated within 1 km buffer area of the dam. Nine human risk alternatives (A1–A9) resulted from the WLF of the dam are identified using Delphi Questionnaire then rated and prioritized them using AHP method. Risk prioritization result varies from 9.90 to 10.29 calculated on the basis of consistency measure (CM) value. It indicates that 'Population displacement' (A3) and 'Inundation of settlement' (A2) are the highest (CM 10.29) and lowest (CM 9.90) vulnerable among the risk alternatives obtaining maximum and minimum CM values respectively.

Keywords Panchet dam · Water budget · Sedimentation · WLF · Human risk assessment · AHP

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Introduction

Dams are constructed to serve as water reservoir first and then for other benefits like flood control, irrigation, hydropower generation, supply of domestic and industrial water etc. but most of the dams fail due to fluctuation of water level (Fathani 2011; Siddique and Bid 2017; Maimunah et al. 2019; Bid and Siddique 2019a, b). According to an estimate, overtopping is responsible for 34% of the world's dam failure events (Graham 1995; Augutis et al. 2004). Water level fluctuation (WLF) in dam depends on in-and-outflow condition and unstable budget of water that affects the process of human ecology (Junk and Wantzen 2004; Wantzen et al. 2008; Hofmann et al. 2008; Leira and Cantonati 2008). Most of the world's reservoirs lose their natural water level regime with controlling water regulation (Marttunen et al. 2006). Water level of a hydroelectric power generating dam depends on discharge of water through turbine and storage of water in reservoir. Generation of power from such reservoirs controls the water level (Zohary and Ostrovsky 2011; Hirsch et al. 2014). Natural WLF of a dam varies within a few centimeters to a maximum of 3 mts, whereas it varies up to 100 mts in artificially regulated WLF (Zohary and Ostrovsky 2011).

The Panchet dam, one of the most important dams of Damodar Valley Corporation (DVC), was installed in 1959 across the river Damodar and its nature is very close to 'flood plain-foot hill type' of dam. Variation of water level in such dams is significant as the recharge of the reservoir depends on inflow from uncertain monsoon rain and discharge of water depends on the range of multipurpose activities such as hydroelectric power generation, supply of water for domestic, industrial and irrigation purpose etc. that lead to fluctuation of the water level. Temporal variation differs within 12 meters whereas seasonal variation ranges up to 8 meters. Generation of hydroelectric energy plays havoc on the WLF of the dam that causes peripheral displacement and threat to the people of all 92 villages located within 1 km buffer area of the dam. Among them 30 villages are situated in the most vulnerable condition. This study is an endeavor to probe into the WLF of the Panchet dam and analysis of its risk to the dam-surrounding human communities using Analytical Hierarchy Process (AHP). AHP method was developed by Saaty (1980) to analyze and support decisions in the complex problems. It is based on structuring the problem in a hierarchical form that reduces complex processes in decision making and helps to obtain the best decision (Mahmoodzadeh et al. 2007). AHP was introduced in the 73rd Annual Meeting of the International Commission of Large Dams (ICOLD) held in 2005 as an effective method for risk assessment of hydraulic structures and dams (Dongjian et al. 2005). The principal objectives of the research work are the analysis of relationship between sedimentation and water holding capacity of the Panchet dam for measurement of its active life, explanation of both temporal and seasonal WLF and its impact on 1 km buffer area as well as the assessment of its human risk using AHP method.

Literature review

Valdiya (2016a, b) explains all aspects of Indian geology in his work. A detail account on origin, evolution and characteristics of Panchet and Raniganj formations are incorporated. The work of Bagchi (1972) has given emphasis on geological framework of Bhagirathi-Hooghly Basin, sedimentation in the Ajay Damodar river, sediment-transport characteristics in western plateau fringe of West Bengal and the effects of upland discharge, tectonic landforms of South Bengal. It discusses the different agricultural aspects in Damodar-Hooghly interfluves and urban industrial pattern of Bhagirathi-Hooghly Basin. Bhattacharyya (2011) explains entire geographical aspects such as geology, physiography, soil, socio-cultural, economic etc. of the lower Damodar river in India. Formation and detail history of the DVC has been discussed here. It includes a vast data set regarding all dams of the DVC. The work has significantly focused upon the human role in changing fluvial environment. The work of Klingensmith (2007) is a good document about twentieth century's large dams, displacement and development in India, and unseen politics behind the large dam. It attempts to explain how dams have played a significant role in development efforts in one side and political effort on other with special emphasis on Damodar Valley Corporation (DVC). The author has raised his voice against the imitation of Tennessee Valley Authority (TVA) plan to Damodar Valley Corporation (DVC) though Indian and American political history, ideological history of development, environmental issues was not similar. It vividly portrays a chronological explanation of dams and development in India since 1960s.

The work conducted by McCully (2001) is similar to the theme of the present work. It is a complete book about dam where concept, types, nature of dam and numerous data about large dam are recorded. Environmental effects and consequences of dams are also highlighted in detail. Failure and economic consequences of large dams are discussed. Some evidences of international anti-dam movements are mentioned. Sedimentation of dam, flood situation and proper management of flood are also elaborated. Graf (1999) has worked on geographic census of American dams and their large-scale hydrologic impacts. It explains the effects of dam on fluvial system of the continental United States and their impact on river discharge.

Wijesundara and Dayawansa (2011) have done a work on the construction of the Victoria reservoir in Sri Lanka and its impacts on cultural landscape of the dam surrounding area. Baghel (2014) has focused on environmental, social and economic impacts of river control in India. The risk analysis and approaches to river control are also explained. Bengtsson et al. (2012) give emphasis on all aspects of lakes and reservoir in their work. Dam failures—impact on reservoir safety legislation in Great Britain; dams and reservoirs in Macedonia; dams classification; dams, flood protection, and risk; large dams and environment; reservoir and lake trap efficiency; reservoir capacity; reservoir sedimentation; sedimentation processes in lakes; water quality in lakes and reservoirs etc. are elaborated in this work. Erskine (1985) explains the downstream geomorphic impacts of large dams (Glenbawn Dam) in the Australia. Kirchherr et al. (2016) highlights the social impacts of dams for a time period of 50 years. Wiejaczka et al. (2018) examine the local residents' perceptions of a dam and reservoir construction project in the Teesta River catchment basin (Darjeeling Himalayas).

Liuyong et al. (2018) have discussed about the global trend of dam removal. It reveals that dam removal largely occurred in the North America and Europe, and most of the removed dams were small and old dams. Hart et al. (2002) have analyzed the risk assessment framework of dam removal and have explained how is it varies with the variation of different types of dam and watershed characteristics. It has also explained the challenges and opportunities for ecological research and river restoration in the case of dam removal. It predicts the ecological responses to dam removal.

Research works on impact of water level fluctuation on environment and littoral ecology of different lakes and reservoirs have been undertaken by several scholars like (Hunt and Jones 1972; Guganesharajah and Shaw 1984; Stephens 1990; Coe and Foley 2001; Usmanova 2003; Coops et al. 2003; Augutis et al. 2004; Junk and Wantzen 2004; McGowan et al. 2005; Naselli-Flores and Barone 2005; Wantzen et al. 2008; Hofmann et al. 2008; Leira and Cantonati 2008; Fathani 2011; Zohary and Ostrovsky 2011; Hirsch et al. 2014; Logez et al. 2016; Ye et al. 2017; Pipitone et al. 2018; Maimunah et al. 2019) etc., but literature on impact of WLF on human ecology is very meager, therefore, the current scheme of research must have potentialities to contribute adequate knowledge in this particular field of research.

Study area

The Panchet basin, a part of the catchment area of the Damodar River and located at the border of West Bengal and Jharkhand states of India, has been considered as an area under investigation for this research scheme. The area under study encompasses Purulia district of West Bengal and Dhanbad district of Jharkhand state in terms of its composition with district level administrative units. The location and environs of the area is shown in Fig. 1. The area is formed of the metamorphic rocks of Proterozoic and sedimentaries of Gondwana ages. The rocks of Gondwana age include only Quaternary sediments mixed with residual soils at places and are confined to the narrow drainage basin of the Damodar River. The Panchet hill area is formed of coarse-grained feldspathic sandstones with thin greenish brown shale and red claystone (Geological Survey of India 1991; Valdiya 2016a, b; Siddique and Bid 2017; Bid and Siddique 2019a, b). The area is an eastern extension of the Chotanagpur plateau and is recognized as the western margin of Bengal plain and Chotanagpur plateau. The Panchet hill (643.5 m) is situated at the south-east portion of the area. The Damodar River runs a distance of 26 km along this basin area. The elevation of the area at the entry point of the River is 175 m while at the exit it lowers down to 100 m. The slope in this is about 10°/km (Siddique and Bid 2017; Bid and Siddique 2019a, b). It is characterized by dry and wet sub-humid tropical climate under the regime of south-west monsoon. The tract falls under the '*Aw*' type of climate as per Koppen's scheme of climatic classification. Temperature varies from 3.8 in winter to 52 °C in summer and annual rainfall varies from 1100 to 1500 mm. (Spate and Learmonth 1954; Bid and Siddique 2019a, b). Damodar is the main river which flows from north-west to south-east direction along the basin. The number of streams ($N\mu$) in different stream order (μ) and Bifurcation ratio (R_b) of the basin is shown in Table 1. The dominant plant species of the area are *Sal* (*Shorea robusta*) and *Palas* (*Butea frondosa*). A drastic change in the vegetal cover has been observed since last two decades. Total vegetation cover of the area was 172.94 km^2 in 1990

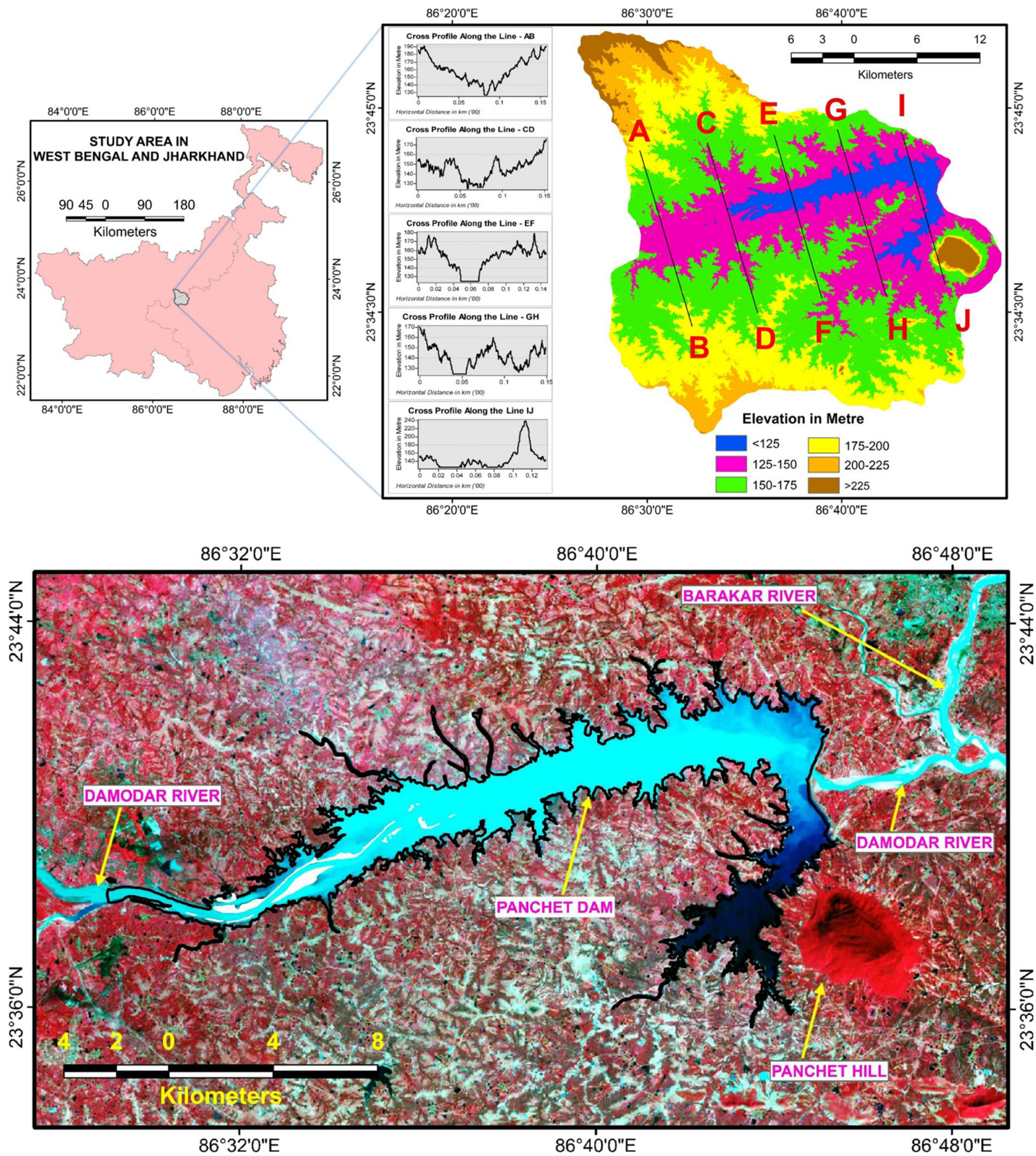


Fig. 1 Location of Panchet basin and association of the Panchet dam. Cross-sectional profile is prepared on the basis of ASTER DEM data of 30-m resolution, acquired from the link of http://glcf.umd.edu/data/aster/ using the ArcGis software of 10.2.1 version

but it has been reduced to 51.64 km^2 in 2014 (Bid 2016; Siddique and Bid 2017). Figure 2 shows the geological formation (Fig. 2a), climatic features (Fig. 2b), surface drainage and stream ordering (Fig. 2c) and vegetation cover (Fig. 2d) of the basin area. The crucial information about the dam is furnished in the Table 2.

The sedimentary formation of the Panchet dam basin area is easily erodible in nature, as a result the reservoir has been receiving ample volume of

Table 1 Stream ordering and Bifurcation ratio of the Panchet basin

Stream order (μ)	Number of streams (Nμ)	Bifurcation ratio (R_b)
1	136	4.5
2	30	3.7
3	8	2.6
4	3	3
5	1	–

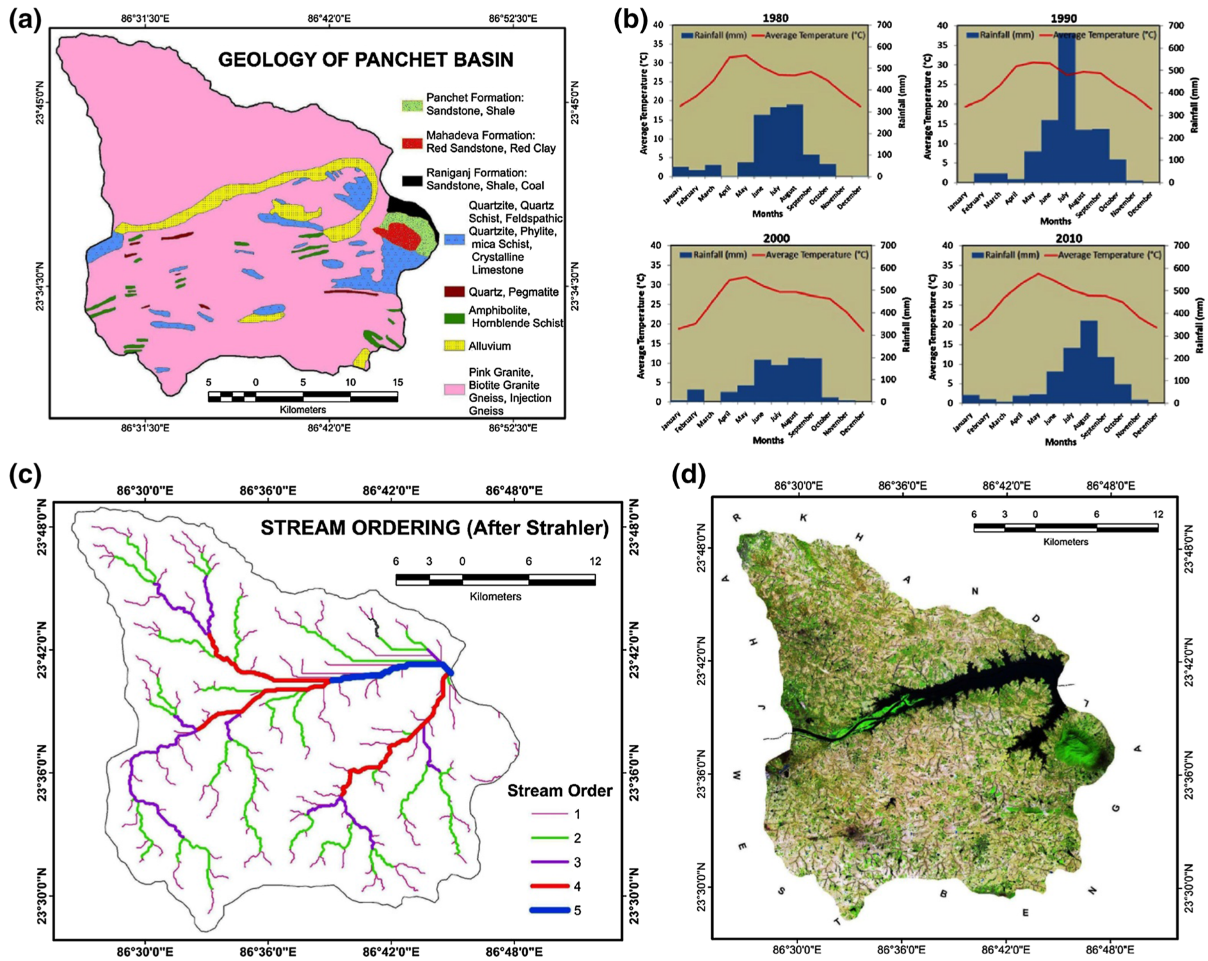


Fig. 2 Physical elements of the Panchet basin area: **a** Geological structure, **b** 10 years average temperature and rainfall graphs from 1971 to 2010, **c** stream ordering and surface hydrology, **d** vegetation cover

sediment in every year. It blocks the reservoir space and reduces the water holding capacity. Water level of the dam remains within 125 mts throughout the year except the monsoon period. In the monsoon period due to excessive supply of surface run-off, water level tends to rise and the event of water level fluctuation begins to emerge. This temporal and seasonal fluctuation of the water level deeply impacts on the people who are living surrounding the dam and become vulnerable for their life. In this context we take an attempt to analyze the water level fluctuation of the Panchet dam and assessment of its human risk using AHP method.

Table 2 Basic information about the Panchet Dam. Source: www.dvc.gov.in

Construction started	1952
Year of opening	6/12/1959
Impounds	Damodar river
Types of dam	Earthen dam with concrete spillway
Height	45 m
Width (in base)	10.67 m
Length	6777 m
Surface area	27.92 km^2
Catchment area	10,961 km^2
Average annual basin rainfall	114 cm
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

Materials and methods

Sampling design

Field work for this study was commenced a priori with reconnection survey in 2015. Household survey has been completed in 2017. On the basis of the reconnection survey, a 1 km buffer zone from the high water level of the dam was demarcated. 92 villages are located within this 1 km buffer area. Locations of these villages were verified by the Google earth map and GPS (Geographical Positioning System) coordinates. 40 villages were selected through clustering method for the questionnaire survey and 5 households were surveyed from each village. Thus total number of sample taken counts to 200 (n = 40 × 5 = 200).

Research methodology

The research problems and objectives have been finalized after selection of the study area. The entire methodology is divided into two broad groups—(1) systematic analysis and related factors, and (2) risk analysis using AHP method. The first group is the assemblage of 6 consecutive steps like sampling design, data collection, analysis of different concepts and factors, conversion of daily water level into monthly average data, calculation of WLF, and impact of WLF. The 3rd step 'analysis of different concepts and factors' is further discussed on the heads such as sedimentation of the dam, water holding capacity of the dam and different water levels of the dam whereas. The 4th step is divided into analysis of temporal WLF and seasonal WLF. Daily water level data of the Panchet dam for 2005–2016 was provided by the DVC, Maithon Office, Jharkhand. Daily data have been converted into monthly average data, and then annual average temporal and seasonal water level data for that period was computed. Water storage level of the Panchet hydroelectric power generating dam has been verified using water balance equation of reservoir (Peter 2010):

$$S_t = S_{t-1} + i_{t-1} - (W_{t-1} + R_{t-1}); t\epsilon T \quad (1)$$

where S_t = storage level in time t; S_{t-1} = storage level in previous time; i_{r-1} = natural flows between time t and t − 1; W_{t-1} = amount of turbinated water at the time t − 1 and R_{t-1} = residual flow at the time t − 1.

Water level fluctuation is also verified mathematically by calculating changes in the depth of water between period t and t + 1 using the following formula (Hirsch et al. 2014):

$$WLF = H_t - H_{t+1} \quad (2)$$

where WLF = water level fluctuation; H_t = water depth at period t; H_{t-1} = water depth after period t.

The second group is constructed on the basis of 6 sequential steps such as identification of 9 risk alternatives through Delphi questionnaire; categorization of the alternatives into 2 groups (economic-social and cultural risk—6 alternatives; health and safety risk—3 alternatives); scoring them using 9 points weightage scale; averaging the score of 4 experts engaged in Delphi panel; calculation of the risk priority rank of the alternatives through AHP method; human risk analysis based on AHP method. Nine risk alternatives of the dam have been identified using the Delphi method. 4 experts engaged with Delphi panel have efficiency and experience in the concerned field. Delphi questionnaires have been distributed among them and the questionnaires have been scored on a 9 point weightage scale. The symbols of alternatives are A1, A2, …, A9 (Table 3). These alternatives are weighted by the selected experts and the ranks have been computed through pair-wise comparisons matrix in AHP method using Excel software. Some alternatives are probabilistic in nature. A focus group discussion has therefore been conducted with local people at the time of field survey in 2018 to overcome the circumstances that could affect the procedure's robustness. Finally, the human risk of WLF of the Panchet dam has been assessed on the basis of both descriptive and statistical analysis. Flowchart of the research methodology is shown in Fig. 3.

AHP method

AHP method in this study has been used to prioritize the chosen criteria. The problems were simplified in AHP method through a hierarchal structure including goal, criteria and alternatives (Bowen 1990; Ngai 2003; Cimren et al. 2007; Gumus 2009; Jozi and Malmir 2014; Mohsen et al. 2015; Seyed et al. 2015). Figure 4 represents the hierarchal structure of Human Risk Assessment of the Panchet Dam for WLF. 'Human Risk Assessment of the Panchet Dam' is considered at the first level of the hierarchy as basic goal to solve the problem. Two main risk criteria—'economic, social and cultural risk' and 'human health and safety risk' are set up at the second level. These two risk criteria are constituted on the basis of grouping the risk alternatives (A1–A9) by researchers. The third level consists of risk alternatives. The criteria are weighted by pair-wise comparison matrices in accordance with a nine point scale of weightage varying from 1 to 9 (Saaty 1980, 1990; Sarkis and Talluri 2004; Bertolini and Braglia 2006; Gerogiannis et al. 2010).

The pair-wise comparison matrices are entered into Excel Software to compute the relative weight of each risk alternative. After calculating the relative weight, final risk score is calculated by multiplying the relative weights and thus the risk alternatives are prioritized on the basis of their final risk scores. Consistency Measure (CM), Consistency Index (CI) and Consistency Ratio (CR) are calculated on the basis of λ and RI (Random Index). The CR values of 0.1 or < 0.1 confirm accuracy and acceptance of the result. Geometric mean values were computed for each score to convert various ideas that were obtained from pair-wise comparison of 4 experts into a single opinion and reach consensus.

Structure of the pair-wise comparison matrix (P) in this research work for human risk assessment of Panchet Dam is shown in the following equation (Eq. 3):

$$P = \begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} \tag{3}$$

Then each element of a column is divided by the column total in the pair-wise matrix to generate a normalized pair-wise matrix (X_{ij}) using the following formula (Eq. 4):

Table 3 Human risk alternatives and their symbols

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

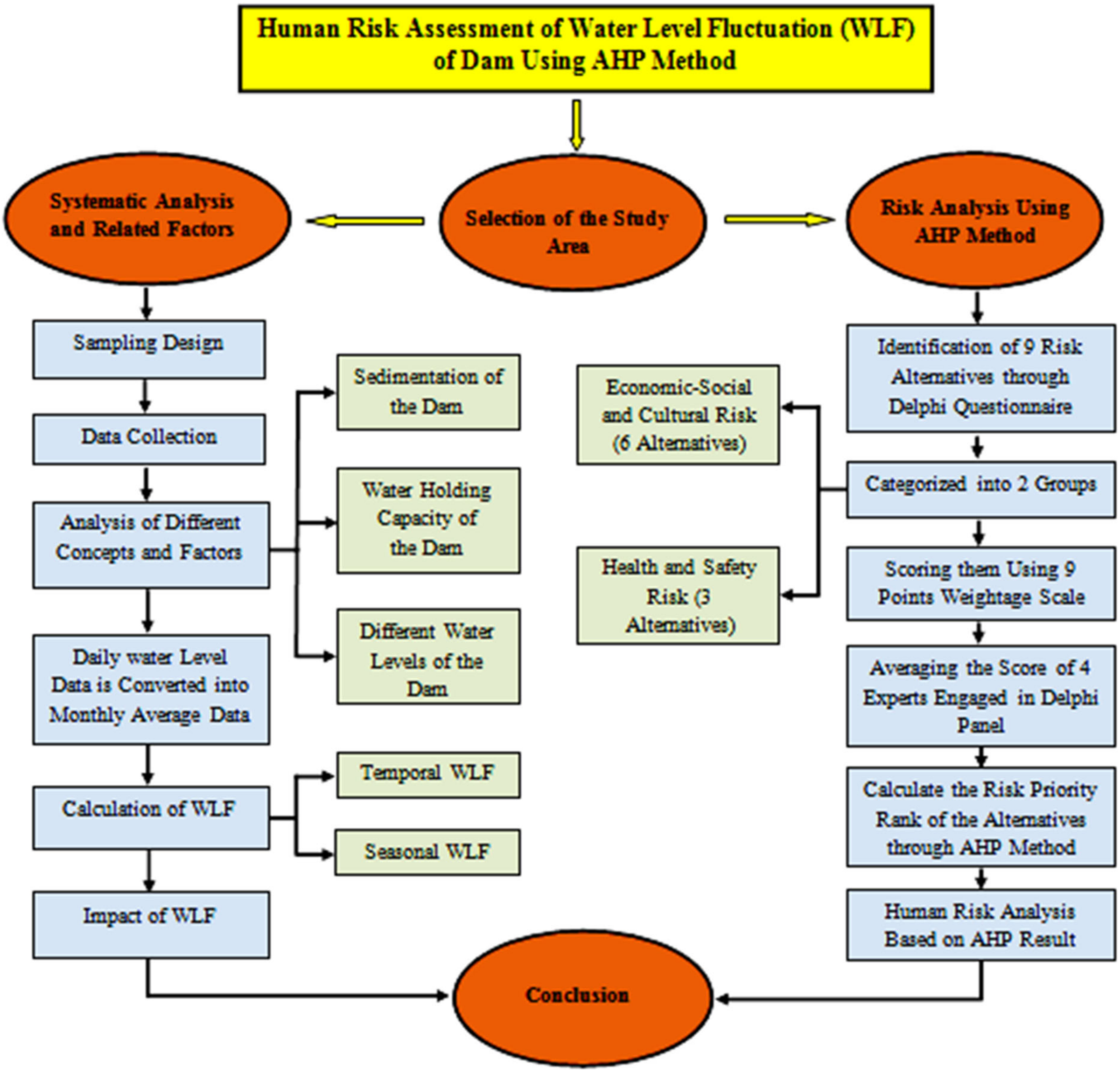


Fig. 3 Flowchart of the research methodology

$$X_{ij} = \frac{C_{ij}}{\sum_{i=1}^{n} C_{ij}} \begin{bmatrix} X_{11} & X_{12} & X_{13} \\ X_{21} & X_{22} & X_{23} \\ X_{31} & X_{32} & X_{33} \end{bmatrix} \quad (4)$$

Then the summation of the normalized column of matrix is divided by the number of criteria used (n = 9) to generate weighted matrix (W_{ij}) using the following formula (Eq. 5):

$$W_{ij} = \frac{\sum_{j=i}^{n} X_{ij}}{n} \quad \begin{bmatrix} W_{11} \\ W_{12} \\ W_{13} \end{bmatrix} \quad (5)$$

In next stage, consistency vector is calculated by multiplying the pair wise matrix by the weight vector using the following formula (Eq. 6) and it is accomplished by dividing the weighted summation vector with criterion weight through following formulae (Eqs. 7–9):

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} * \begin{bmatrix} W_{11} \\ W_{21} \\ W_{31} \end{bmatrix} = \begin{bmatrix} Cv_{11} \\ Cv_{21} \\ Cv_{31} \end{bmatrix} \quad (6)$$

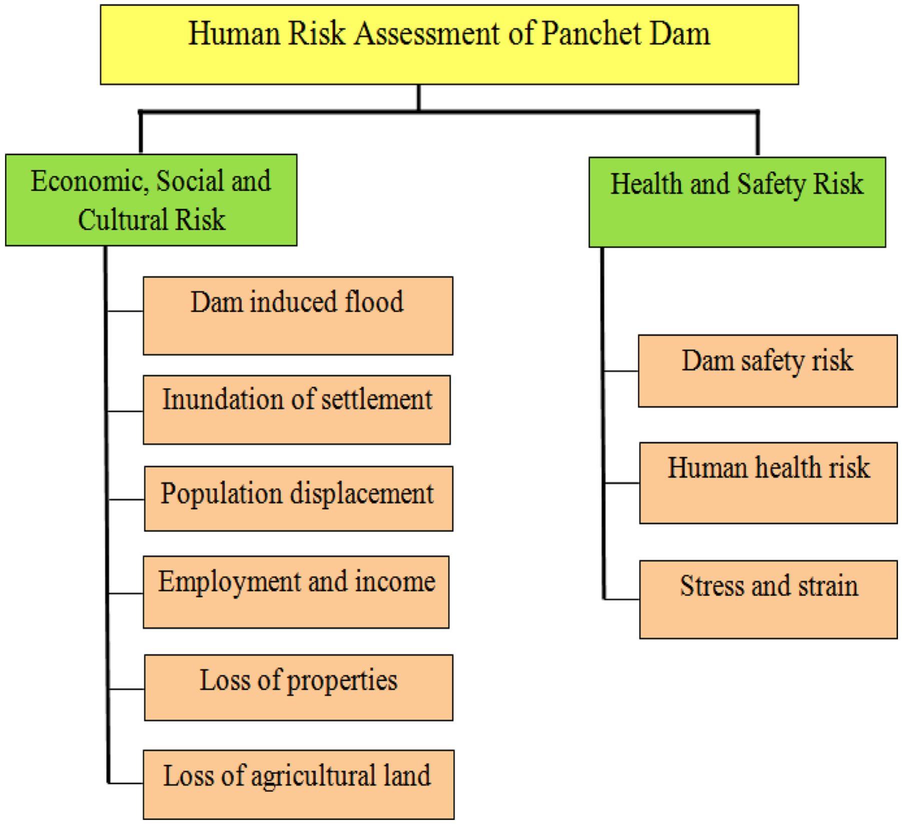


Fig. 4 Hierarchical structure in AHP for human risk assessment of WLF in the Panchet dam

$$Cv_{11} = \frac{1}{W_{11}}[C_{11}W_{11} + C_{12}W_{21} + C_{13}W_{31}] \quad (7)$$

$$Cv_{21} = \frac{1}{W_{21}}[C_{21}W_{11} + C_{22}W_{21} + C_{23}W_{31}] \quad (8)$$

$$Cv_{31} = \frac{1}{W_{31}}[C_{31}W_{11} + C_{32}W_{21} + C_{33}W_{31}] \quad (9)$$

Then λ is calculated by averaging the values of the consistency vector using the following formula (Eq. 10):

$$\lambda = \frac{\sum_{i=1}^{n} Cv_{ij}}{n} \quad (10)$$

After calculating the λ, Consistency Index (CI) and Consistency Ratio (CR) are calculated with the help of Eqs. 11 and 12 respectively.

$$CI = \frac{\lambda - n}{n - 1} \quad (11)$$

$$CR = \frac{CI}{RI} \quad (12)$$

where RI = Random Inconsistency Indices

Pair-wise comparison matrix of the study is represented in Table 4; normalization of the matrix and consistency measure is given in Table 5; Random Inconsistency Indices for N – 10 is given in the Table 6; λ, CI, RI, N and CR are represented in Table 7.

Result and discussion

Sedimentation, water holding capacity and water level of the dam

As mentioned earlier, the upper catchment area of the Panchet dam is formed of sedimentary rock which is easily erodible in nature. Water turbidity of the dam varies seasonally and spatially (Bid and Siddique 2019a, b). Highly turbid water dominates in the monsoon period (July to September) due to supply of adequate sediment carried into the dam by the adjoining streams. These sediments are precipitated

Table 4 Pair wise comparison matrix

Factor	A1	A2	A3	A4	A5	A6	A7	A8	A9
A1	1.00	1.00	0.14	1.00	1.00	0.33	1.00	0.33	1.00
A2	1.00	1.00	0.33	1.00	3.00	0.20	1.00	0.33	0.33
A3	7.00	3.00	1.00	5.00	3.00	3.00	3.00	3.00	1.00
A4	1.00	1.00	0.20	1.00	3.00	0.20	1.00	1.00	0.33
A5	1.00	0.33	0.33	0.33	1.00	0.33	1.00	1.00	1.00
A6	3.00	5.00	0.33	5.00	3.00	1.00	3.00	1.00	1.00
A7	1.00	1.00	0.33	1.00	1.00	0.33	1.00	0.33	1.00
A8	3.00	3.00	0.33	1.00	1.00	1.00	3.00	1.00	3.00
A9	1.00	3.00	1.00	3.00	1.00	1.00	1.00	0.33	1.00
Total	19.00	18.33	4.01	18.33	17.00	7.40	15.00	8.33	9.67

Table 5 Normalizing the matrix and consistency measure

Factor	A1	A2	A3	A4	A5	A6	A7	A8	A9	Total weights	Average relative weights	Consistency measure	Rank
A1	0.05	0.05	0.04	0.05	0.06	0.05	0.07	0.04	0.10	0.51	0.06	10.09	4
A2	0.05	0.05	0.08	0.05	0.18	0.03	0.07	0.04	0.03	0.59	0.07	9.90	9
A3	0.37	0.16	0.25	0.27	0.18	0.41	0.20	0.36	0.10	2.30	0.26	10.29	1
A4	0.05	0.05	0.05	0.05	0.18	0.03	0.07	0.12	0.03	0.64	0.07	10.04	5
A5	0.05	0.02	0.08	0.02	0.06	0.05	0.07	0.12	0.10	0.57	0.06	9.95	8
A6	0.16	0.27	0.08	0.27	0.18	0.14	0.20	0.12	0.10	1.52	0.17	10.28	2
A7	0.05	0.05	0.08	0.05	0.06	0.05	0.07	0.04	0.10	0.56	0.06	10.02	6
A8	0.16	0.16	0.08	0.05	0.06	0.14	0.20	0.12	0.31	1.28	0.14	10.01	7
A9	0.05	0.16	0.25	0.16	0.06	0.14	0.07	0.04	0.10	1.03	0.11	10.25	3
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	–	–	–	–

Table 6 Random inconsistency (RI) indices for N − 10

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.46	1.49

Table 7 Values of λ, CI, RI, N and CR

Measures	Values
λ	10.09
CI	0.136
RI	1.46
N	9
CR	0.093

and accumulated at the bottom of the reservoir that further block the reservoir space and reduces the water holding capacity. A 57% increase in actual siltation rate than the rate assumed at the time of installation, has rapidly blocked the dam reservoir. Such rate of siltation has helped fluctuation of the water holding capacity and also water level of the dam. At the time of installation of the dam, total water holding capacity was estimated to 1600 million m^3 in round figure. The trend line of Fig. 5a represents that almost 30% storage capacity has been blocked at present and that has been happened within 60 years of its inception. Estimation curves shown in Fig. 5b, c explain that 50% and 100% reduction of water holding capacity will be blocked in the year 2090 and 2210 respectively that indicates a 250 years active life span of the dam.

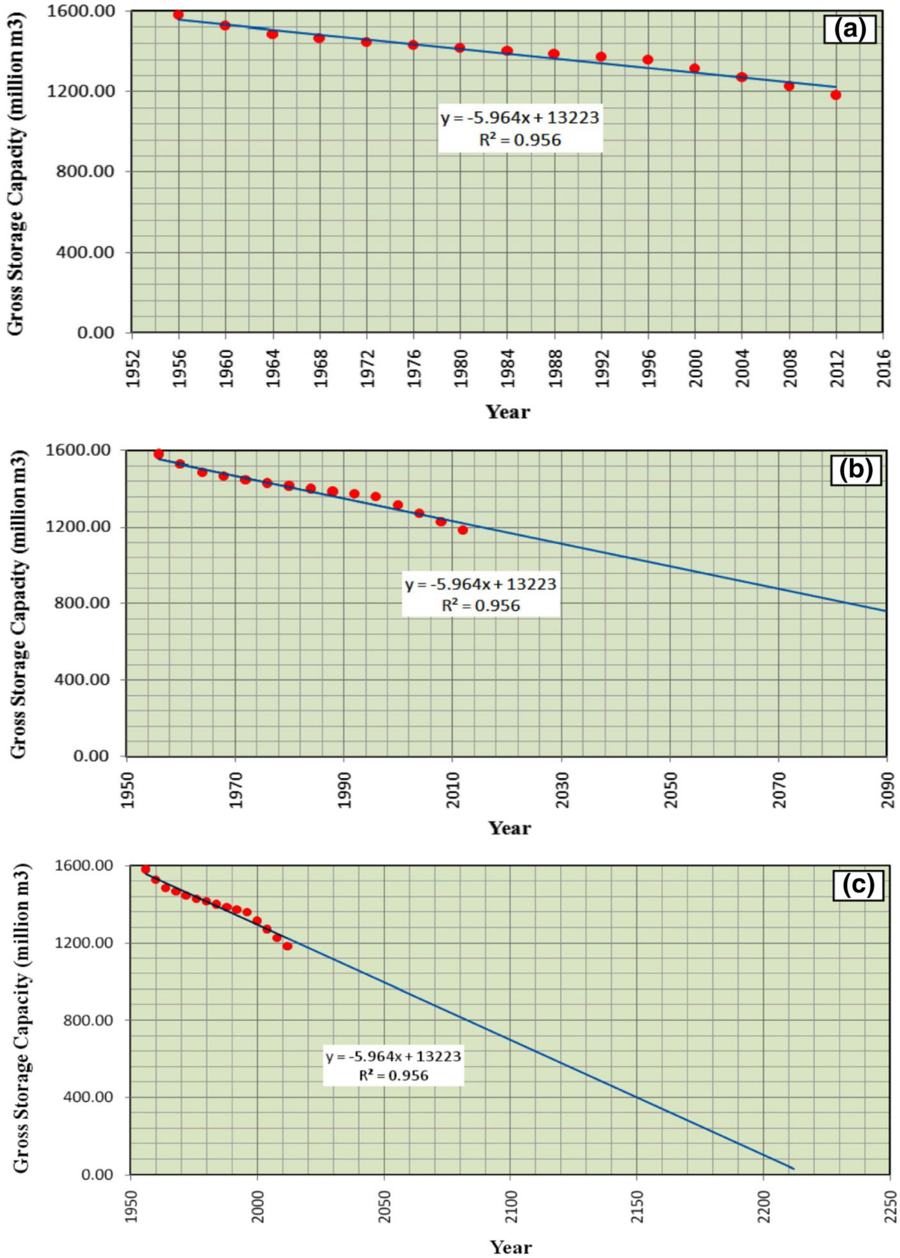


Fig. 5 Life estimation of the Panchet dam **a** present condition, **b** 50% loss of life, **c** 100% loss of life

Figure 6 shows the daily water holding capacity of the dam from 2005 to 2013. The upper limit of water storage remains within 1.8–1.9 billion m^3 in the winter season (January to March) of the years 2007, 2008, 2012 and 2013; in the monsoon period (July to September) of the year 2007; in the post monsoon period (October to December) of the year 2007, 2009, 2011 and 2013. In every year, water storage decreases into less than 0.5 billion m^3 in pre monsoon period (April to June) because it is the severe water crisis phase of Indian climate known as the summer period. 2013 was an exception when water storage remained within 1.8–1.9 billion m^3 throughout the year except the monsoon period. Due to excessive rain in the upper catchment area and supply of excess water, the dam authority became compelled to release surplus water in 2013 that caused a severe flood situation in the lower catchment area. The diagram indicates a

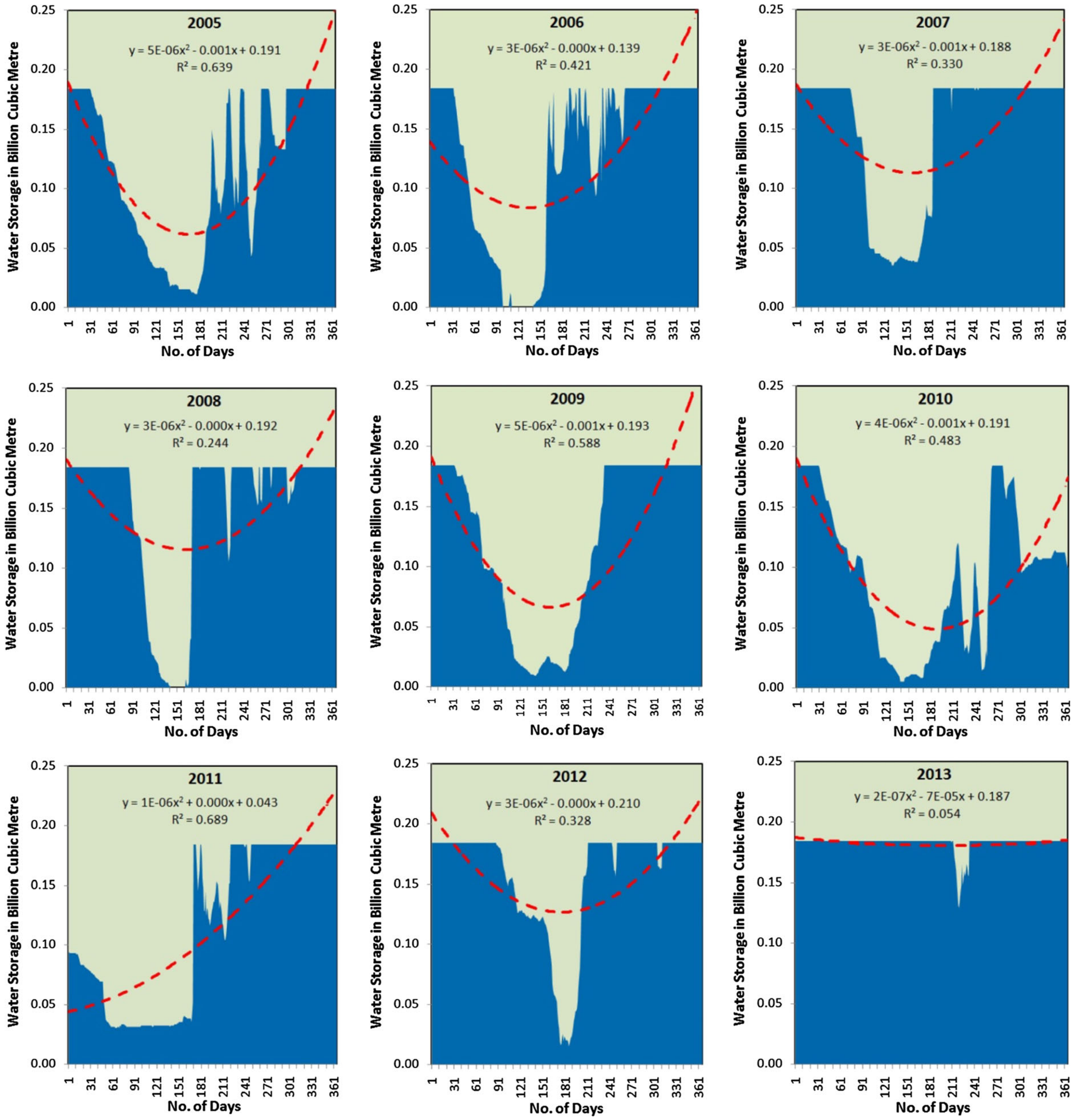


Fig. 6 Water storage capacity of the Panchet dam from 2005 to 2013

significant variation of water storage throughout the year and also responsible for fluctuation of the water level. Figure 7 highlights the everyday water level of the dam from 2005 to 2013. Maximum water level exceeded 130 mts in the year 2006, 2007, 2009 and 2013. Water level < 120 mts remained in the years of 2005, 2006, 2008, 2009, 2010 and 2016. It indicates 10–15 mts annual range of water fluctuation. Minimum water level remained in the pre monsoon period whereas maximum level was achieved in the end of monsoon period.

Temporal and seasonal WLF

Water level of the Panchet dam used to fluctuate within 118 mts to 132 mts and its annual ranges during

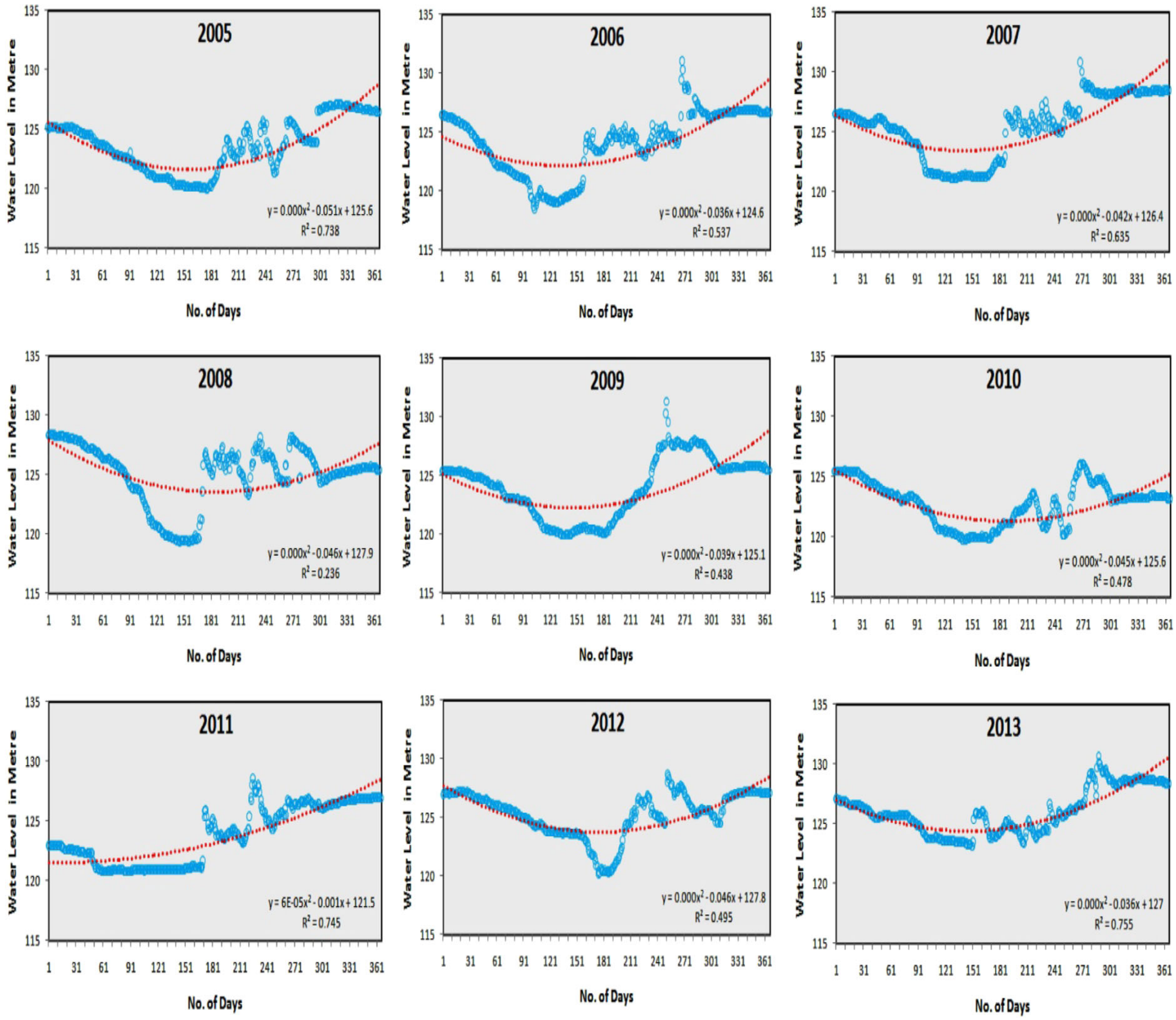


Fig. 7 Water level of the Panchet dam from 2005 to 2013 constructed based on daily water level data

2005–2016 were 7.04 mts, 12.49 mts, 9.69 mts, 9.04 mts, 11.43 mts, 6.32 mts, 7.74 mts, 8.41 mts, 7.56 mts, 5.88 mts, 7.82 mts and 7.6 mts respectively. WLF of the Panchet dam is significant due to uncertain recharge and controlled discharge of water. This fluctuation of water has both temporal and seasonal implications. A box plot and whisker plot diagram (Fig. 8) prepared on the basis of 5 statistical measures—minimum, maximum, quartile-I, median and quartile-III computed using daily water level data of the dam from 2005 to 2016 to analyze WLF status. It explains that maximum WLF has occurred in September of the years 2005, 2006, 2007, 2009 and 2010; in August of the years 2013, 2014, 2015 and 2016; in June of the years 2008 and 2011; and in July of the year 2012 while minimum WLF rises in the month of January of the year 2005, 2009, 2010 and 2012 but it rises in December for rest of the years.

Figure 9a, b represent temporal and seasonal WLF computed on the basis of average annual water level data from 2005 to 2016. Red lines show both temporal and seasonal average WLF from 2005 to 2016. The average annual WLF within this time period varies within 6 to − 6 mts in temporal scale that indicates a 12 mts fluctuation of water level. On the other hand it is reduced in the case of seasonal average annual WLF where fluctuation ranges within 4 to − 4 mts that suggests an 8 mts fluctuation in that level. Maximum

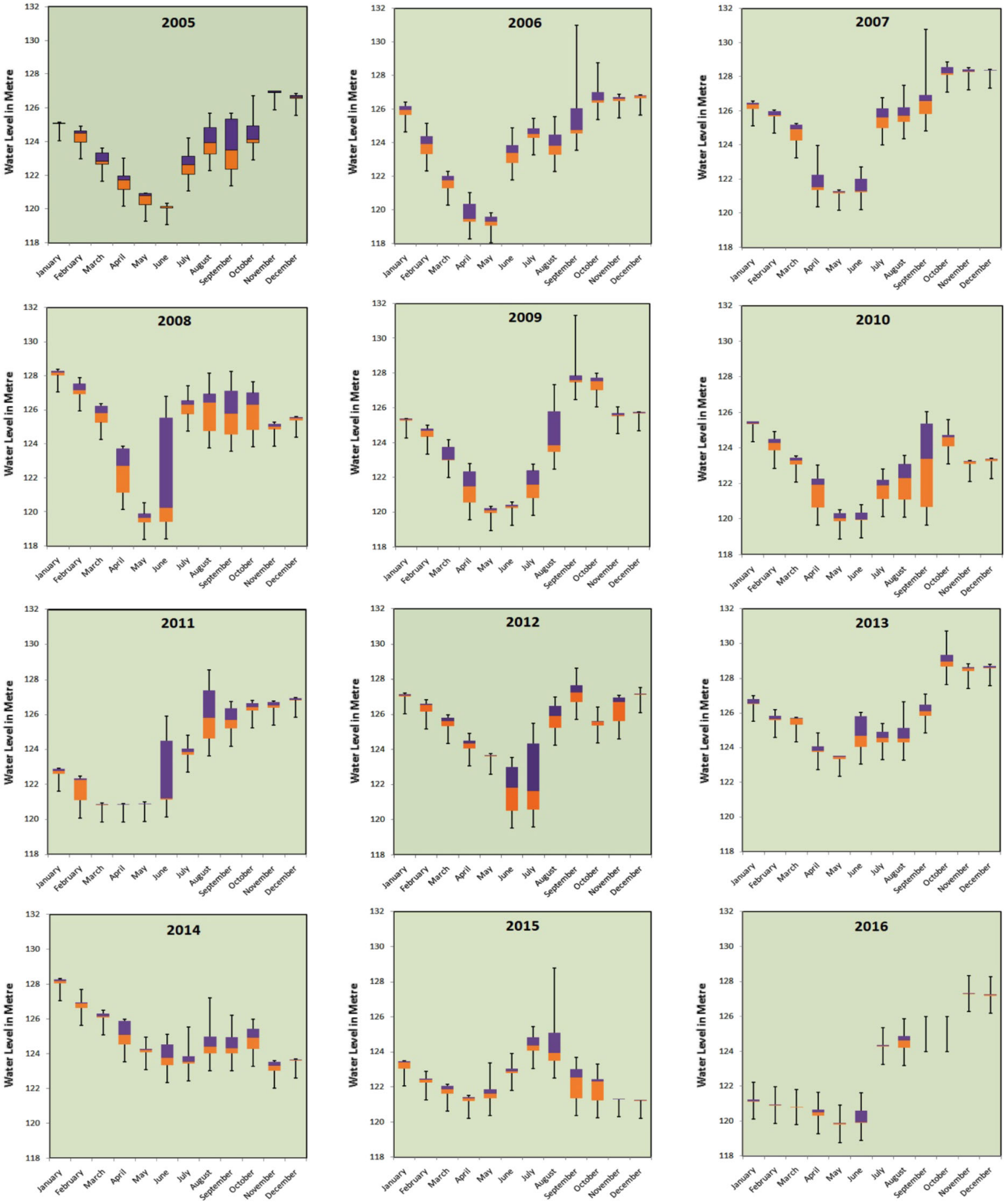
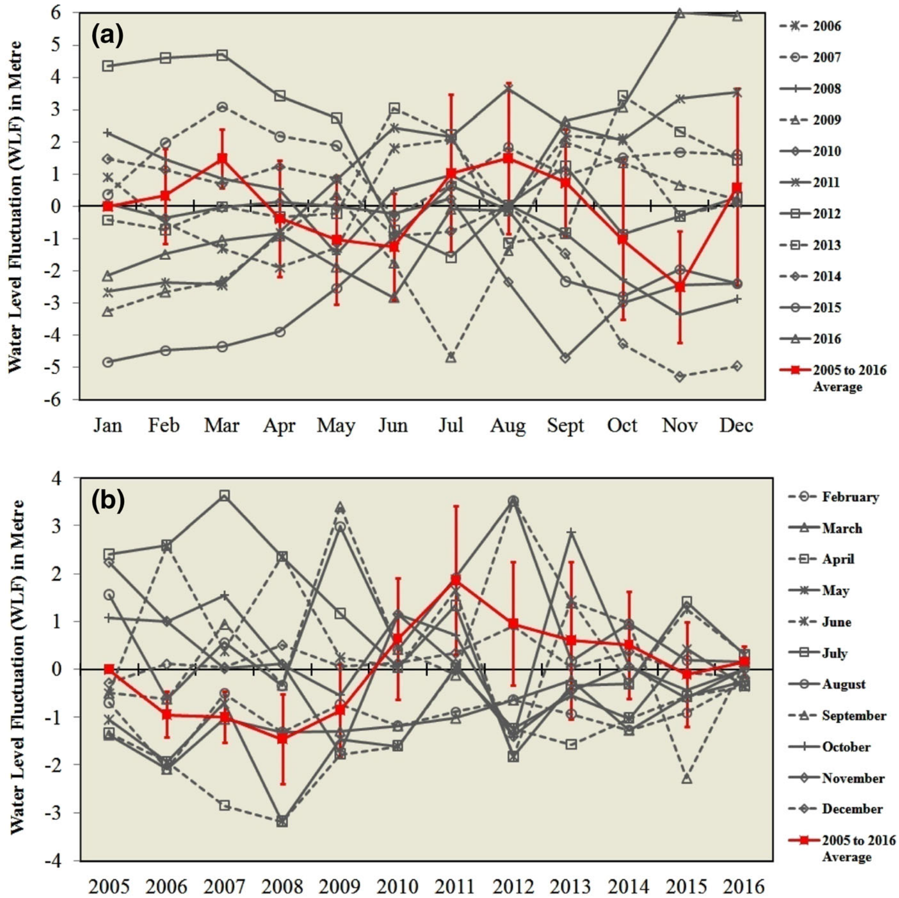


Fig. 8 Box plot and whisker plot based on QD for WLF of the dam ($p < 0.05$)

positive and negative fluctuations have occurred in the year 2016 and 2014 respectively. In terms of seasonal WLF, the highest positive and negative fluctuations have occurred in the month of July and April correspondingly. August and November months have experienced the maximum positive (1.49 mts) and

Fig. 9 **a** Temporal, **b** seasonal water level fluctuation based on average annual data from 2005 to 2016 and error bar plotting based on SD



negative (− 2.5 mts) WLF respectively, whereas, 2011 is highest positive (1.87) and 2008 is highest negative (− 1.45) WLF year for 2005–2016 average temporal fluctuation. Red colour error bars computed on the basis of standard deviation (SD) are placed in both average temporal and seasonal fluctuation curves that brilliantly explain WLF status of the dam. A number of statistical measures such as range (R), mean ($\bar{X}$), median (M), standard deviation (SD), quartile deviation (QD), correlation (r), standard error of estimate (SEE), skewness, kurtosis of each year and the average for the period 2005–2016 are also measured to analyze temporal (Table 8) and seasonal (Table 9) fluctuation of water level. Figure 10 is a box plot and whisker plot prepared on the basis of mean ($\bar{X}$) and standard deviation (SD) to analyze temporal (10a) and seasonal (10b) WLF from 2005 to 2016. Both temporal and seasonal fluctuations are significant in 95% and 99% level of significance respectively ($p < 0.05$ and $p < 0.01$).

Impact of WLF on 1 km buffer area

The research work explores impact of WLF on the dam surrounding human communities. 125 mts water level of the dam is permissible and people remain in a safe condition but when it fits in between 125 and 130 mts, inundation of land and settlement initiates. When the water level of the dam slightly surges from 130 mts and 135 mts, large tracts of agricultural land and settlement get inundated. They become more vulnerable when water level exceeds 135 mts. In such a situation, vast area gets inundated; relief work and rehabilitation needs to be started. Water level fluctuation and human risk condition of the dam surrounding people are given in Table 10. Figure 11 shows the 92 villages located within 1 km buffer area of the dam that are severely affected by the WFL. Among them, 62 villages (Table 11) are located between 1 km buffer area and the high water level, whereas 22 villages (Table 12) are situated in between high and

Table 8 Statistical measures of annual and average temporal water level fluctuation (WLF) of the Panchet dam (mts) from 2005 to 2016

Years	Max	Min	$\bar{X}$	SD	r	Q1	Median	Q3	Range	Inter quartile range	QD	SEE	Skewness	Kurtosis
2005	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2006	2.18	− 1.9	0.32	1.47	0.35	− 0.69	− 0.01	1.87	4.08	2.56	1.28	0.42	0.04	− 1.48
2007	3.09	− 0.32	1.45	0.91	− 0.07	0.89	1.65	1.9	3.41	1.01	0.51	0.26	− 0.35	0.45
2008	2.27	− 3.35	− 0.35	1.8	− 0.17	− 1.68	0.28	0.88	5.62	2.56	1.28	0.52	− 0.43	− 0.99
2009	1.98	− 4.68	− 1.03	2	0.17	− 2.41	− 1.14	0.43	6.66	2.84	1.42	0.58	− 0.22	− 0.72
2010	0.23	− 4.7	− 1.26	1.64	− 0.77	− 2.4	− 0.31	0.01	4.93	2.41	1.21	0.47	− 0.91	− 0.26
2011	3.64	− 2.65	1.02	2.44	0.47	− 1.2	2.09	2.7	6.29	3.9	1.95	0.7	− 0.6	− 1.39
2012	4.69	− 1.57	1.49	2.34	− 0.9	− 0.41	0.76	3.66	6.26	4.07	2.04	0.67	0.27	− 1.7
2013	3.43	− 1.13	0.73	1.65	0.45	− 0.5	− 0.12	2.24	4.56	2.74	1.37	0.48	0.54	− 1.47
2014	1.48	− 5.28	− 1.02	2.48	− 0.68	− 2.17	− 0.38	0.92	6.76	3.09	1.95	0.72	− 0.87	− 0.77
2015	0.63	− 4.83	− 2.5	1.73	0.39	− 4.01	− 2.46	− 1.71	5.46	2.3	1.15	0.5	0.39	− 0.62
2016	6	− 2.83	0.6	3.06	0.16	− 1.58	− 0.5	2.76	8.83	4.34	2.17	0.88	0.9	− 0.52
2005–2016 average	1.49	− 2.5	− 0.05	1.28	− 0.24	− 1.03	0.32	0.88	3.99	1.91	0.96	0.39	− 0.52	− 0.61

Table 9 Statistical measures on annual and average seasonal water level fluctuation (WLF) of the Panchet dam (mts) from 2005 to 2016

Months	Max	Min	$\bar{X}$	SD	r	Q1	Median	Q3	Range	Inter quartile range	QD	SEE	Skewness	Kurtosis
January														
February	− 0.23	− 2.08	− 0.94	0.48	0.33	− 1.19	− 0.89	− 0.67	1.85	0.52	0.26	0.14	− 1.07	2.1
March	− 0.21	− 2.08	− 1.01	0.53	0.76	− 1.29	− 1.1	− 0.61	1.87	0.68	0.34	0.15	− 0.14	0.25
April	0.02	− 3.18	− 1.45	0.94	0.28	− 1.81	− 1.45	− 0.91	3.2	0.9	0.45	0.27	− 0.37	− 0.07
May	0.43	− 3.18	− 1.05	0.96	0.51	− 1.49	− 1.03	− 0.49	3.61	1	0.5	0.28	− 0.7	1.22
June	2.59	− 1.82	0.64	1.27	− 0.22	− 0.05	0.35	1.5	4.41	1.55	0.78	0.37	− 0.17	− 0.14
July	3.63	− 1.82	1.07	1.55	− 0.46	− 0.05	1.26	2.37	5.45	2.42	1.21	0.45	− 0.17	− 0.39
August	3.53	− 0.61	0.96	1.29	− 0.69	0.17	0.5	1.66	4.14	1.49	0.75	0.37	0.94	− 0.02
September	3.53	− 2.27	0.59	1.65	− 0.57	− 0.36	0.29	1.07	5.8	1.43	0.72	0.48	0.52	0.47
October	2.86	− 1.4	0.52	1.12	− 0.51	− 0.11	0.42	1.1	4.26	1.21	0.61	0.32	0.4	0.65
November	2.25	− 1.75	0.04	1.09	− 0.47	− 0.48	0.04	0.34	4	0.82	0.41	0.31	0.33	0.59
December	0.91	− 0.28	0.17	0.32	− 0.46	0.01	0.09	0.35	1.19	0.34	0.17	0.09	1.02	1.36
2005–2016 average	1.87	− 1.45	0.04	1.01	− 0.02	− 0.9	0.16	0.63	3.32	1.53	0.77	0.3	0.16	− 0.67

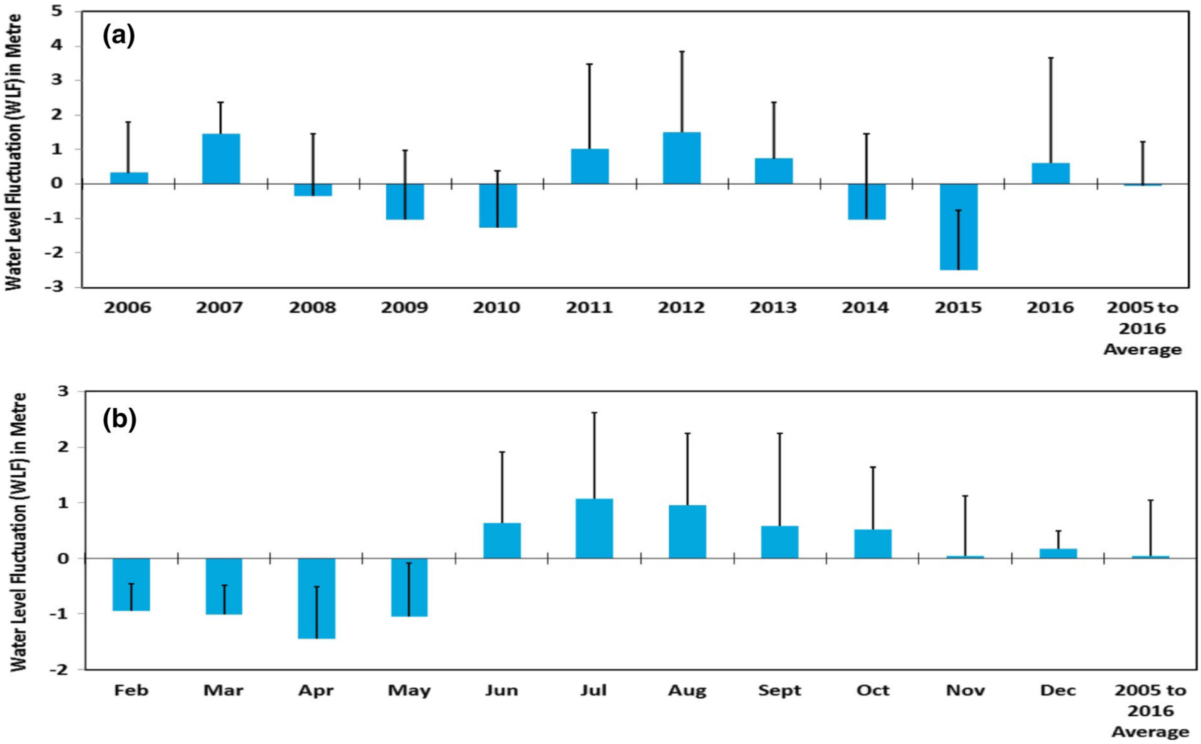


Fig. 10 Box plot and whisker plot based on mean and standard deviation showing, **a** significant temporal ($p < 0.05$), **b** seasonal fluctuation ($p < 0.01$) of water level

Table 10 Water level fluctuation (WLF) and human risk situation

Water level in metre	Risk situation
< 125	No chance of overtopping, no inundation activity of agricultural land and settlement, no risk condition for flood and dam failure, compensation do not give
125–130	Start to inundate agricultural land and settlement, increase pressure on dam wall, chances on dam safety risk and dam failure, displacement starts in dam contiguous area, starts to give compensation for inundation, no chances of overtopping
130–135	Large area of agricultural land and settlement are inundated, emerged flood situation both in upper and lower catchment area, high risk of dam failure due to excessive water and sediment pressure on dam wall and overtopping, displacement, migration, rehabilitation starts, compensation and relief are given
> 135	Highly hazardous situation emerged due to tremendous flood event in the catchment area, vast area is inundated and remain waterlogged, relief work and rehabilitation started, overtopping the dam water and instant wash out of settlement situated on the opposite side of the dam wall

low water level of the dam. 8 villages (Table 13) therefore remain completely under water condition since the construction phase of the dam. Fluctuation rate remains very high in monsoon period (July to September) due to excessive water recharge of the dam received from monsoon rain. It inundates the surrounding lands frequently and people suffered from periodic migration. They are compelled to leave the area in monsoon period as possibility of overtopping and dam failure risks are increased but they come back again in the post monsoon period (October to December) as fluctuation slows down and become

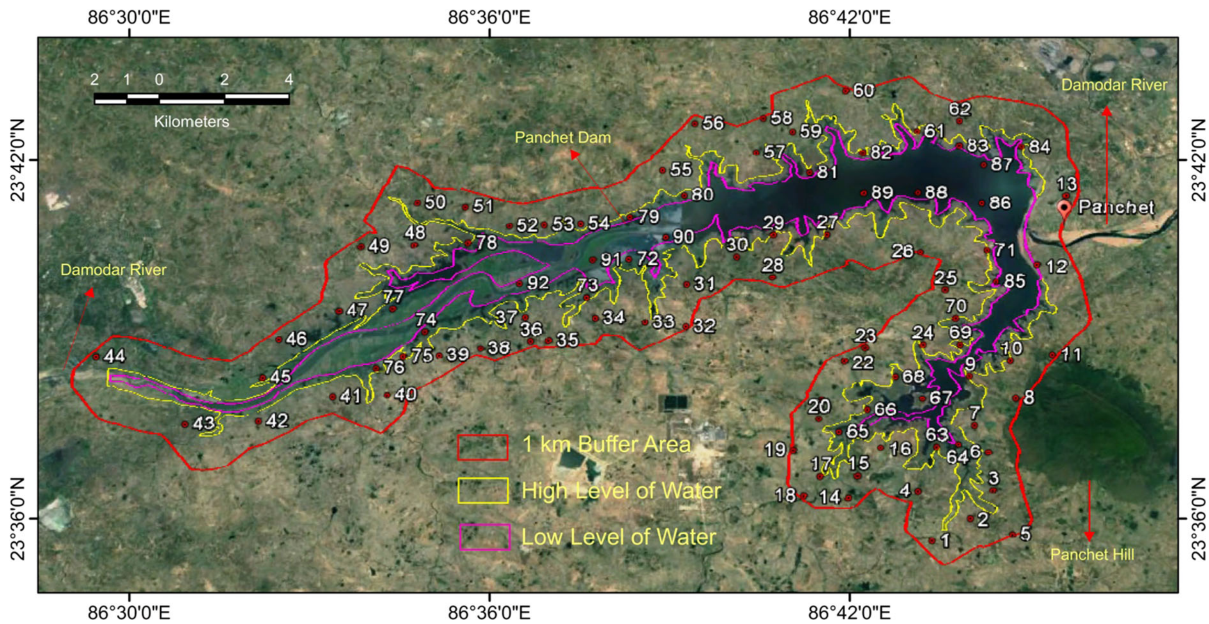


Fig. 11 92 villages located within 1 km buffer area being affected from the WLF of the dam

stable with recession of water to the core and WLF tends to minimize the range that also reduces the human risk.

Human risk analysis based on AHP result

The result obtained from AHP method on the basis of 'average relative weights' (W) and 'Consistency Measure' (CM) shows the final risk score and their priority ranking. W and CM value obtained from AHP method for nine individual risk alternatives is represented in Fig. 12a, b respectively. Maximum CM value represents top priority risk alternative while minimal CM value indicates least priority of risk alternative. The top-priority alternative emerged out of AHP result is 'Population displacement' (A3). W and CM scores of A3 alternative are 0.26 and 10.29 respectively. Alternatives which earn second and third rank are 'Loss of agricultural land' (A6, W = 0.17, CM = 10.28), and 'Stress and strain' (A9, W = 0.11, CM = 10.25). 'Dam induced flood' (A1) holds the fourth rank with W and CM values of 0.06 and 10.09 respectively. 'Employment and income' (A4, W = 0.07, CM = 10.04), 'Dam safety risk' (A7, W = 0.06, CM = 10.02) and 'Human health risk' (A8, W = 0.14, CM = 10.01) justifies the fifth, sixth and seventh risk priority ranks correspondingly. 'Loss of properties' (A5, W = 0.06, CM = 9.95) and 'Inundation of settlement' (A2, W = 0.07, CM = 9.90) demand minimal risk priority and their risk priority ranks are eighth and ninth respectively. The priorities of risk alternatives in the AHP method are as follows:

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

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.

According to the result achieved applying AHP method, A3 (population displacement) and A2 (inundation of settlement) risk alternatives claim the first and the last rank among the risk alternatives. The experts grant more weightage on the A3 alternative because it is the crucial problem of the human communities settling near the dam and obviously it appears as the major risk factor while A2 alternative emerges as relatively less challenging risk factor. The people surrounding the dam site have suffered from displacement since the very beginning of its inception. A number of villages were obligated to leave because of the dam authority got hold of their land for damming purpose. The human communities settled on the periphery of the reservoir now face regular

Table 11 Villages situated between 1 km buffer area and high water level

Part of the dam	Point	Name of the villages	Latitude	Longitude
South-Eestern	1	Jarukhamar	23° 35′ 36.68″ N	86° 43′ 21.96″ E
	2	Namabathan	23° 43′ 21.96″ N	86° 43′ 58.33″ E
	3	Kachbel	23° 36′ 26.13″ N	86° 44′ 21.01″ E
	4	Dhatara	23° 36′ 24.32″ N	86° 43′ 08.64″ E
	5	Haridi	23° 35′ 43.76″ N	86° 44′ 38.99″ E
	6	Pahargora	23° 37′ 03.19″ N	86° 44′ 16.48″ E
	7	Rampur	23° 37′ 29.88″ N	86° 44′ 03.02″ E
	8	Rangadahar	23° 37′ 57.36″ N	86° 44′ 43.52″ E
	9	Lakshanpur	23° 38′ 17.98″ N	86° 43′ 58.58″ E
	10	Shihulibari	23° 38′ 34.67″ N	86° 44′ 39.04″ E
	11	Baghmara	23° 38′ 41.01″ N	86° 45′ 19.80″ E
	12	Mahishnadi	23° 40′ 12.05″ N	86° 45′ 06.24″ E
	13	Panchet	23° 41′ 24.12″ N	86° 45′ 36.18″ E
	14	Salanchi	23° 36′ 17.74″ N	86° 42′ 00.62″ E
	15	Modharjhor Alias Nunirdi	23° 36′ 39.15″ N	86° 42′ 09.61″ E
	16	Amtor	23° 37′ 06.60″ N	86° 42′ 32.23″ E
	17	Chandra	23° 36′ 38.45″ N	86° 41′ 33.38″ E
	18	Khalsa	23° 36′ 19.42″ N	86° 41′ 17.48″ E
	19	Lachhyara	23° 37′ 03.67″ N	86° 41′ 06.69″ E
	20	Bagraybari	23° 37′ 34.60″ N	86° 41′ 31.17″ E
	21	Dhanara	23° 37′ 53.49″ N	86° 41′ 33.42″ E
	22	Gunyara	23° 38′ 31.43″ N	86° 41′ 56.10″ E
	23	Ajodhya	23° 38′ 44.98″ N	86° 42′ 16.36″ E
	24	Dudhiapani	23° 38′ 48.92″ N	86° 43′ 13.14″ E
	25	Hari Raydi Alias Birbaldi	23° 39′ 44.83″ N	86° 43′ 35.08″ E
South-Western	26	Bhurkunrabari	23° 40′ 23.14″ N	86° 43′ 11.24″ E
	27	Kalipathar	23° 40′ 39.34″ N	86° 41′ 37.88″ E
	28	Simuliya	23° 39′ 55.30″ N	86° 40′ 43.54″ E
	29	Bhiring	23° 40′ 38.39″ N	86° 40′ 43.63″ E
	30	Bakbari	23° 40′ 15.89″ N	86° 40′ 07.16″ E
	31	Lakhyabad	23° 39′ 48.11″ N	86° 39′ 17.36″ E
	32	Ranipur	23° 39′ 05.44″ N	86° 39′ 17.58″ E
	33	Jorberya	23° 39′ 09.80″ N	86° 38′ 36.61″ E
	34	Bhaura Mahul	23° 39′ 14.32″ N	86° 37′ 46.78″ E
	35	Lalpur	23° 38′ 51.86″ N	86° 37′ 01.29″ E
	36	Jaypur	23° 38′ 51.33″ N	86° 36′ 43.27″ E
	37	Balabani	23° 39′ 15.41″ N	86° 36′ 36.36″ E
	38	Gurudi	23° 38′ 45.10″ N	86° 35′ 53.26″ E
	39	Jemuadi	23° 38′ 38.65″ N	86° 35′ 12.19″ E
	40	Tulsibari	23° 38′ 00.14″ N	86° 34′ 22.35″ E
	41	Shwetpalas	23° 37′ 59.10″ N	86° 33′ 27.96″ E
	42	Kargali	23° 37′ 36.10″ N	86° 32′ 15.37″ E
	43	Murabag	23° 37′ 34.28″ N	86° 31′ 02.40″ E

Table 11 continued

Part of the dam	Point	Name of the villages	Latitude	Longitude
North-Western	44	Domgarh	23° 38′ 41.83″ N	86° 29′ 27.17″ E
	45	Sarisakundi	23° 38′ 18.81″ N	86° 32′ 15.28″ E
	46	Kalipur	23° 38′ 56.46″ N	86° 32′ 28.97″ E
	47	Gharbar	23° 39′ 24.56″ N	86° 33′ 27.97″ E
	48	Sheopur	23° 40′ 30.31″ N	86° 34′ 40.49″ E
	49	Barisal Alias Salbisal	23° 40′ 29.21″ N	86° 33′ 45.96″ E
	50	Neamatpur	23° 41′ 13.35″ N	86° 34′ 40.51″ E
	51	Susunliya	23° 41′ 08.83″ N	86° 35′ 30.54″ E
	52	Khanrapathar	23° 40′ 48.40″ N	86° 36′ 15.97″ E
	53	Chhagaliya	23° 40′ 49.29″ N	86° 36′ 52.23″ E
	54	Begunbari	23° 40′ 50.21″ N	86° 37′ 28.34″ E
	55	Kulbana	23° 40′ 28.34″ N	86° 38′ 50.13″ E
	56	Dumurya	23° 42′ 34.06″ N	86° 39′ 21.96″ E
	57	Bandrabad	23° 42′ 03.59″ N	86° 40′ 25.36″ E
	58	Sheopur	23° 42′ 39.43″ N	86° 40′ 31.93″ E
Northern	59	Daldali	23° 42′ 25.64″ N	86° 41′ 01.59″ E
	60	Urma	23° 43′ 09.47″ N	86° 41′ 56.05″ E
	61	Sanolapur	23° 42′ 28.29″ N	86° 43′ 08.40″ E
	62	Talberia	23° 42′ 40.05″ N	86° 43′ 50.36″ E

threat as water level fluctuation inundates their land periodically. The reservoir reaches to its highest storage capacity in rainy season after receiving continuous rain in the upper catchment area. In such circumstance, a number of villages in the upper catchment area of the dam get inundated, thus A3 alternative demands more weightage in the AHP. It also possesses the first rank in AHP that emphasizes more risk prone factor than the others. Diversion of water channels at the peak flow season may be an effective solution to overcome the problem.

Figure 13 shows the risk analysis chart based on AHP result for the WLF of the Panchet dam. Impact of the risk alternatives and risk probability has been plotted along the 'X' axis and 'Y' axis respectively. Impact and risk probability of A3 alternative has belonged to high zone indicating by red colour. Impact of A6 risk alternative has situated in medium zone though its risk probability has occupied the high zone. These two alternatives are the most risk prone for the area. A8 and A9 alternatives are medium impacted alternatives but they are probable to medium and highly risk respectively. A1, A4, A7, A5 and A2 all are identified as low impacted risk alternatives. On the other hand, A1, A4 and A7 alternatives are belonging to the medium risk probability zone whereas, A5 and A2 belonging to the low risk probability zone. The analysis clearly explains that A3 is the highly vulnerable for both the cases of impact and risk probability while, A5 has the lowest impact and A2 is the lowest risk probable alternative.

Using two Multi-Criteria Decision making (MCDM) methods such as TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) and WASPAS (Weighted Aggregated Sum Product Assessment), the human risk of the Panchet dam has been explained previous (Bid and Siddique 2019a, b). Risk priority result obtained from TOPSIS method 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.

Result of WASPAS methods depends on 3 conditions of WASPAS parameter λ such as minimum

Table 12 Villages located between high and low water level

Point	Name of the villages	Latitude	Longitude
63	Gopal Chak	23° 37′ 07.67″ N	86° 43′ 26.68″ E
64	Jhaburdi	23° 37′ 10.70″ N	86° 43′ 46.95″ E
65	Kharikabad	23° 37′ 21.86″ N	86° 41′ 51.46″ E
66	Paharudi	23° 37′ 43.74″ N	86° 42′ 18.55″ E
67	Belyak Hajra	23° 37′ 55.55″ N	86° 43′ 12.96″ E
68	Mahuda	23° 38′ 16.34″ N	86° 42′ 45.95″ E
69	Krishtapur	23° 38′ 49.88″ N	86° 43′ 49.24″ E
70	Bathanbari	23° 39′ 16.33″ N	86° 43′ 44.79″ E
71	Shalchura	23° 40′ 26.56″ N	86° 44′ 16.34″ E
72	Belyadanga	23° 40′ 13.68″ N	86° 38′ 18.52″ E
73	Gopal Chak	23° 39′ 35.37″ N	86° 37′ 37.54″ E
74	Chak Mangla	23° 39′ 02.32″ N	86° 34′ 56.47″ E
75	Saltora	23° 38′ 37.92″ N	86° 34′ 36.06″ E
76	Baghadabar	23° 38′ 26.64″ N	86° 34′ 08.81″ E
77	Simpathar	23° 39′ 25.69″ N	86° 34′ 22.42″ E
78	Kalhajpur	23° 40′ 31.47″ N	86° 35′ 35.12″ E
79	Jeratanr	23° 40′ 56.47″ N	86° 38′ 18.38″ E
80	Ankbaria	23° 41′ 19.14″ N	86° 39′ 12.88″ E
81	Hatikundar	23° 41′ 43.17″ N	86° 41′ 19.85″ E
82	Katral	23° 42′ 04.69″ N	86° 42′ 13.45″ E
83	Kalmegha	23° 42′ 13.98″ N	86° 43′ 49.94″ E
84	Rangametya	23° 42′ 14.37″ N	86° 44′ 52.57″ E

Table 13 Villages placed within low water level

Point	Name of the villages	Latitude	Longitude
85	Kharbana	23° 39′ 54.64″ N	86° 44′ 25.40″ E
86	Tantloi	23° 41′ 14.79″ N	86° 44′ 11.87″ E
87	Banshjor	23° 41′ 54.95″ N	86° 44′ 14.18″ E
88	Ghatkul	23° 41′ 24.08″ N	86° 43′ 08.36″ E
89	Malancha	23° 41′ 22.78″ N	86° 42′ 14.30″ E
90	Naynakuri	23° 40′ 35.83″ N	86° 38′ 54.72″ E
91	Bharatpur	23° 40′ 12.90″ N	86° 37′ 42.16″ E
92	Telkupi	23° 39′ 49.97″ N	86° 36′ 29.57″ E

(λ = 0), medium (λ = 0.5) and maximum (λ = 1). The results are as follows:

$$\lambda = 0: \ A3 > A6 > A9 > A1 > A4 > A7 > A8 > A5 > A2$$

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.

$$\lambda = 0.5: \ A3 > A9 > A6 > A4 > A8 > A2 > A1 > A7 > A5$$

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.

$$\lambda = 1: \ A3 > A2 > A9 > A4 > A6 > A8 > A1 > A7 > A5$$

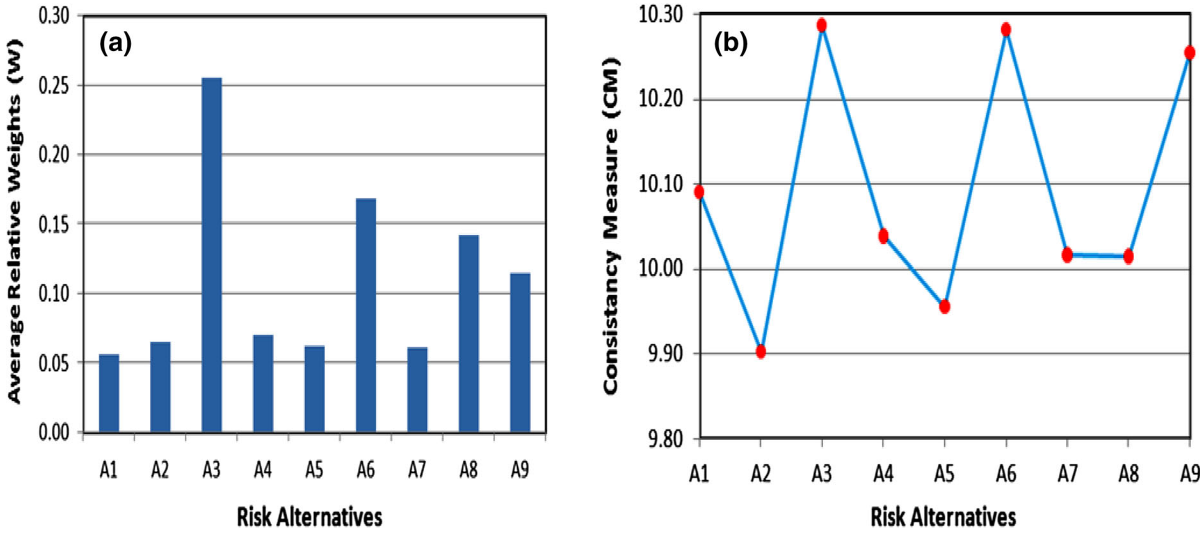


Fig. 12 Diagrammatic representation of **a** Average relative weight, **b** Consistency measure resulted from AHP result

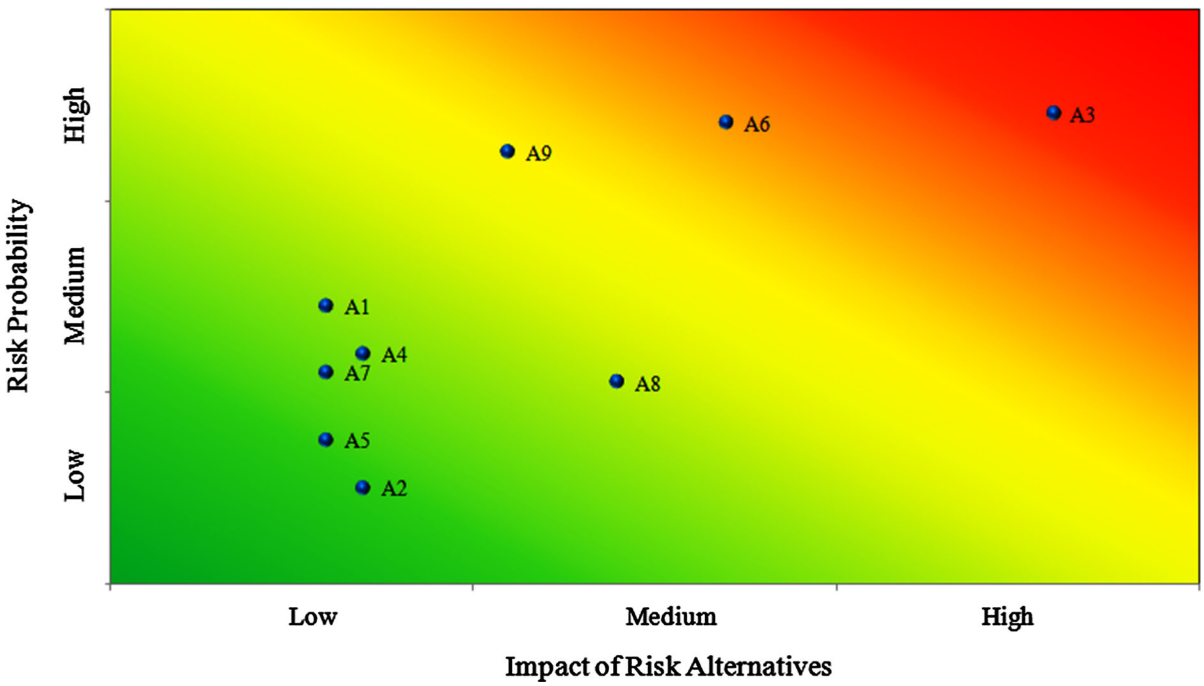


Fig. 13 Risk analysis chart based on AHP result

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.

In the present study, 'Population displacement' (A3) is identified as the top most risk priority alternative. The result is similar in the case of TOPSIS and WASPAS (in all cases when $\lambda = 0$, $\lambda = 0.5$ and $\lambda = 1$) methods of the previous work. The least risk priority alternative resulted from the current study is 'Inundation of settlement' (A2) and it is same with the result of TOPSIS and WASPAS (only in the case of when $\lambda = 0$) methods that prove the robust validation of the current research work though there are some dissimilarity between risk priority result obtained from the present and previous works.

Conclusion

Major findings of the study are: (1) 30% performance capacity of the dam have been reduced since its installation and a 250 years life span has been estimated if the surrounding conditions remain unchanged. (2) Temporal fluctuation of the reservoir water is greater than the seasonal water level fluctuation. The WLF is significant temporally ($p < 0.05$) with the range of 12 mts while, it is significant seasonally ($p < 0.01$) with 8 mts fluctuation range. (3) A3 ('Population displacement') and A2 ('Inundation of settlement') are the highest and lowest risk alternatives respectively. The impact and risk probability of A3 alternative has occupied the high zone whereas, A2 alternative has possessed the low zone. A3 and A6 are the high-risk probable; A9, A1, A4, A7 and A8 are probable to medium risk; A5 and A2 are probable to low risk alternatives. Real-time monitoring and strategic protection of dam is essential as it provides a number of economic, social and environmental benefits. Hence, the present work has immense potentialities for further study on the impact of WLF on dam surrounding environment. The AHP method is appropriately used in this work for decision making process. It provides a hierarchical segmentation of a decision and helps to understand the overall process of decision making despite some of its drawbacks in ranking of reversal conditions. After identification, quantification and prioritization of dam risks, a comprehensive risk response plan will be required to offer the proper strategies for dealing with the identified risks and providing appropriate decision alternatives before the occurrence of any hazardous event.

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Compliance with ethical standards

Conflict of interest The author declares that there is no conflict of interest.

Ethical approval This research does not involve individual participants in the study, and thus ethical approval is not required.

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