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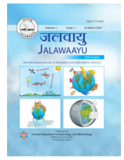

Research Article

Conceptualising Flooding Systems Globally and Preferred Adaptation Strategies Locally under Climate Change

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Abstract: Climate induced natural disasters and extreme events are escalating with the increased variability of climatic parameters due to climate change. This study assesses the flood adaptation strategies that are applicable at the community level in two Terai districts of Nepal. This research aimed to analyse existing and preferred future flood adaptation strategies in a flood prone West Rapti River (WRR) Basin of Nepal, and a social survey of 240 households (HHs) and focus group discussions (FGDs). The specific objectives were to identify flood adaptation strategies based on people's perception. Flood inundation maps are generated for four scenarios based on return periods: Scenario I; Scenario II; Scenario III; and Scenario IV. Peoples' choice of flood mitigation strategies mainly depends on the current needs of the people and their knowledge of harm. Current needs govern current choices while the basis of future choice is generally made on the degree of the impact or perceived risk of the hazard. This can be clearly seen from the ranking made by the people for Scenarios I and IV. "Household level preparation /management"

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was ranked first for Scenario I while in Scenario IV "Watershed management" was ranked highest. "Watershed management" was felt to be an important strategy, as it was second ranked even in Scenarios II and III. People may have realised that the mounting flood risk is increasing with time and that such risk can be reduced only through catchment management. When the risk is considered as of low level, people try first to adapt to it at the personal and household level. However, when the risk level increases, people look for alternatives or higher levels of adaptation. The perceptions of people in the study were found to be in agreement with these findings: as the flood risk increases from Scenario I to Scenario IV, the movement in choice of strategies changed accordingly. It can be concluded that when people are well-informed, they will do long term planning and formulate appropriate strategies. This research provides an overall framework for deriving potential mitigation and adaptation strategies to flood for Nepal in particular and other developing countries in general.

1. Introduction

Long-term changes in the climate are generally accompanied by changes in the frequency of extremes (Devkota et al. 2020; Andrea 2017). Where floods are generated from heavy rainfall, the frequency and magnitude of flooding is likely to increase with an increase in precipitation and temperature (Knox 1993; Motta et al. 2021). Although climate change is a global phenomenon, both its trends and impacts may vary at a local scale. The local hydrology of every river in the world is likely to be affected by climate change in some way. Changes in river hydrology resulting in increased flooding represent risks, not only to water resources and associated infrastructure but to physical and social assets as well (Devkota et al. 2014).

Rivers and river systems are very important to community. Rivers and their adjacent flood plain corridors fulfill a variety of functions both as part of the natural ecosystem and for a variety of human uses however, they often also cause great damage and death due to flooding. Flood hazard is the probability of occurrence of a potentially damaging flood event of a certain magnitude within a given time period and area (Devkota et al. 2015). Surface water flooding is caused by the volume of water falling or flowing into the surface overwhelming existing drainage systems (Xu 2007; Kazmierczak & Cavan 2011); this includes pluvial flooding that results from high rainfall generated overland flow (Falconer 2009). Flooding is also a function of the surface of the land and characteristics of the river basin. Surface water flooding is predominantly caused by short duration, intense rainfall occurring locally and/or in upstream areas (Devkota et al. 2014). As a result, surface floods are often difficult to forecast. Additionally, high relief, steep slopes, complex geological structures with active tectonic processes and continued seismic activities and a climate characterized by great seasonality in rainfall all combine to make Nepal an area prone to natural disasters and, particularly, water induced disasters such as floods, landslides and glacier lake outburst flooding (Liu et al. 2020).

The interactions between increased greenhouse gases in the atmosphere and hydrological systems are very complex (Figure 1). Increases in temperature could result in changes in evapotranspiration, soil moisture, (possibly) chance of soil salinity, and ground water (Devkota & Gyawali 2015). Increased atmospheric CO_2 may increase global mean precipitation as indicated by all GCMs (IPCC 2014) even though some sub-tropical areas will be generally drier. Increased evapotranspiration enhances the water vapor in the atmosphere and, thereby, the greenhouse effect potentially driving global mean temperatures rise even higher. Possible changes in rainfall, temperature and evapo-transpiration may result in changes in soil moisture and groundwater recharge (Devkota & Gyawali 2015); and runoff and could alter the flooding patterns (IPCC 2014).

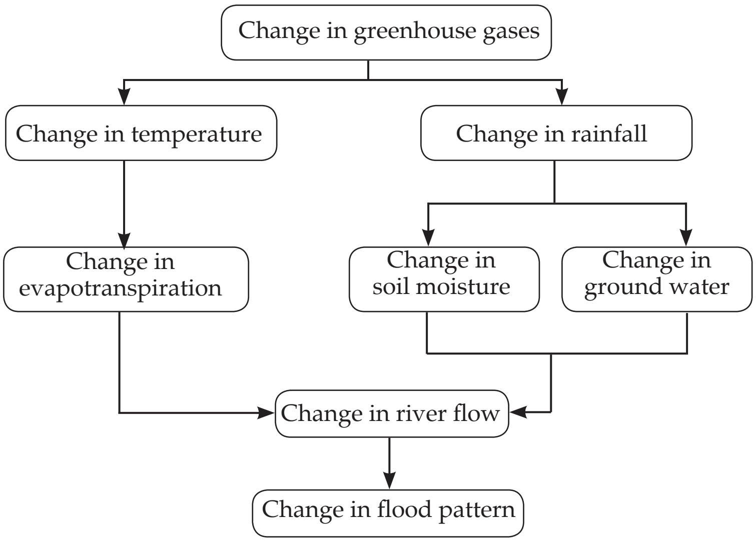

Figure 1. Flow diagram on the relationship between climate change and flood

2. Global System of Flood Adaptation Strategies

Mitigation and adaptation are approaches that respectively deal with the cause and effect of climate change. Mitigation focuses on the reduction of greenhouse gas emissions, while adaptation reduces the impacts of global warming. According to the European Environmental Agency (EEA) adaptation involves "policies, practices, and projects with the effect of moderating damages and realising opportunities associated with climate change", including climate variability and extremes, and sea level rise. Adaptation to climate change is defined by the IPCC as adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (Parry et al. 2009). Thus, adaptation refers to changes in processes, practices or structures to moderate or offset potential damages or to take advantage of opportunities associated with changes in climate" (IPCC 2014).

Adaptation involves reducing potential damages of climate change and taking advantage of new opportunities. Through the implementation of adaptation measures, the adaptive capacity of the system increases and the sensitivity reduces, thereby reducing the vulnerability of a society to the impacts of flood due to climate change (Moss et al. 2010). Therefore, it can be concluded that adaptation is a policy, practice, or project that has the effect of moderating damages or realising opportunities associated with climate change including climate variability and extremes. Adaptation to unavoidable climate changes, therefore, becomes an important coping strategy, alongside more traditional mitigation strategies (Sgobbi & Carraro 2008).

According to IPCC (2014) adaptation assessment refers to the practice of identifying options to adapt to climate change effects and evaluating them in terms of criteria such as availability, benefits, costs, effectiveness, efficiency and feasibility. Flexibility and cost effectiveness of adaptation measures were found to be the key criteria in decisions around approaches to address both potential changes in climate as well as potentially significant impacts of climate change to ecosystems and natural resources. Table 1 provides some examples of key traditional strategies for flood management in Nepal.

Table 1. Traditional flood adaptation strategies

	Adaptation strategies	References
Farming	– Traditional erosion control – Changing crop cycles – Use of flood resistant rice in Terai region – Planting more cash crops in winter season – Indigenous seed saving	(Burton et al. 2002) (Charmakar 2010) (Tiwari et al. 2010) (Manandhar et al. 2013)
Land use	– Controlling forest fires – Using marginal land for fodder farming – Controlling erosion maintaining natural flow – Capturing upland forest land	(Charmakar 2010)
House	– Building double storey house – Storing valuable goods on elevated level – Building orientation to avoid storm damage	(Maharjan 2011) Charmakar 2010)
Flood	– Storing seeds on elevated level to avoid flood damage – Rearing cattle on higher grounds – Capturing upland forest land – Temporary migration upland	(Maharjan 2011)
Watershed management	– Preserving trees around water source – Water harvesting from rain and river – Developing irrigation system,	(Tiwari et al. 2010)

Therefore, adaptation is a process through which societies are better able to cope with an uncertain future. The IPCC (2014) stated that adaptation can reduce vulnerability where adaptive capacity is intimately connected to social and economic development but is unevenly distributed across and within societies. Berrang-Ford et al. (2019) stated that the major risk reduction approach to global climate change is adaptation. Fussel (2007) argues that the emphasis should be given to adaptation as the mitigation process takes several decades while adaptation can be undertaken at local or national level and have more immediate benefits. Climate change especially affects those populations which are already vulnerable and struggle with current climate variability and extreme weather events (Devkota et al. 2013). In developing countries, uninsured economic losses fall on vulnerable households who are particularly dependent on climate sensitive systems such as agriculture and other natural resource-based livelihoods (Devkota and Maraseni, 2018). Despite this, research on adaptation to climate change has mostly focused on responses and their costs (Sheila & Olmstead, 2014, Devkota & Bhattarai, 2015). Therefore, the development of adaptation options requires the assessment of flood impacts and the design and selection of adaptation options in close consultation with stakeholders and experts. Policymakers also play an important role in taking well-considered policy decisions which are aimed at reducing vulnerability to climate change induced flood (IPCC 2014; Füssel & Klein 2007). Figure 2 presents the involvement of various stakeholders in explaining the vulnerability of a system.

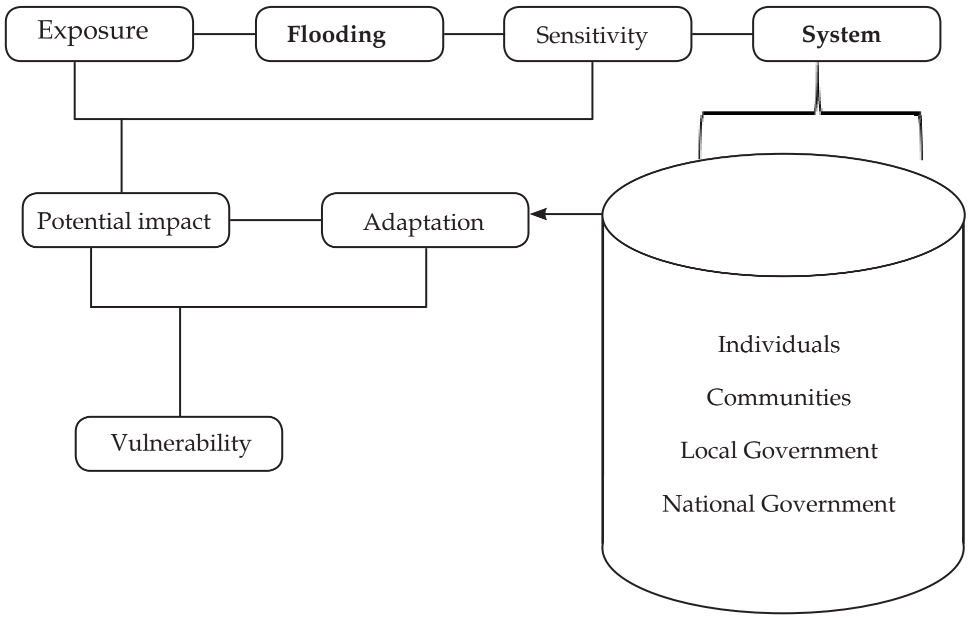

Figure 2. Concept of flooding, vulnerability and adaptation from individual to global system (Source: Adapted and modified from Marshall et al. 2010)

2. Study Area

The West Rapti River Basin (WRRB), in which this study was conducted, lies in the Mid-Western Development Region of Nepal, draining a small part of the Lesser Himalaya, some parts of Siwaliks and major parts of the Terai. The total catchment area within the Nepalese territory is about 6,500 km^2 and the elevation varies from about 131 m (at the Indian border) to 3,620 m amsl. About 45% of the basin lies in the mountain area and the rest lies in the plain area.

Geographically, Banke and Dang districts represent Terai and Inner Terai regions, respectively, while Arghakhanchi, Gulmi, Salyan Pyuthan and Rolpa districts represent middle mountain region. The main tributaries of the West Rapti River are the Madi and Jhimruk Rivers. The basin is bordered in the west by the Babai Basin, in the north by the Bheri Basin (one of the sub-basins of the Karnali Basin), in the east by the Narayani Basin and in the south by the Terai region. The source of flow of the West Rapti River is rainfall and groundwater.

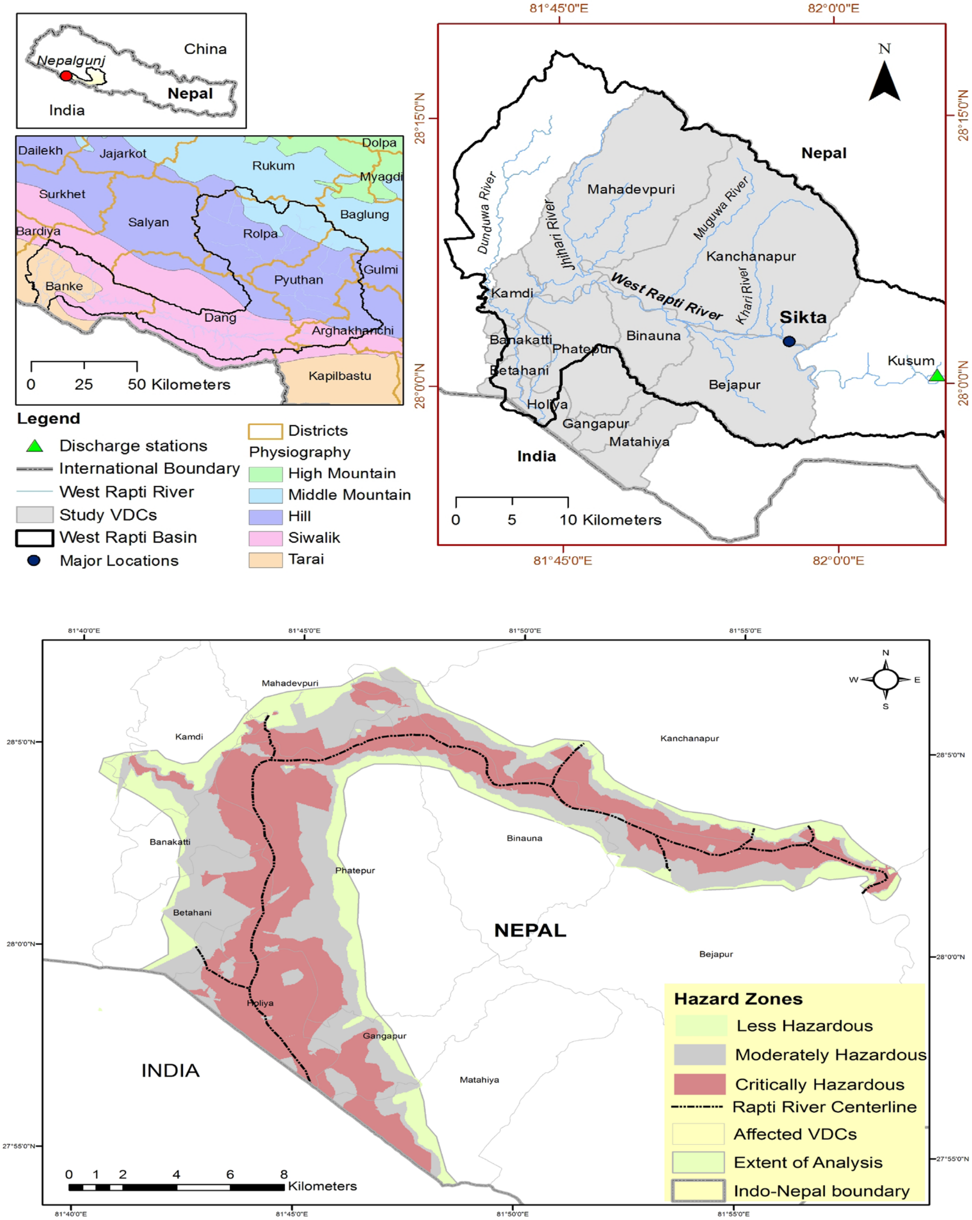

Figure 3. Location map of study area with flood severity zones, adapted Devkota et al. 2018. (West Rapti River Basin of Nepal)

3. Methodology

The return period of these floods is directly correlated to the probability of occurrence and thus their severity. A 2-year return period flood is a regularly occurring flood: this has been considered Scenario I. Similarly, a 20-year flood has a higher magnitude, is expected once in a while and is likely to be more devastating than Scenario I: this has been called Scenario II. Further, a 50-year period flood is a large flood with chances of significant damage - Scenario III. And finally, a 100-year period flood is a very large flood with high likelihood of extensive damage to life and property: it has been modelled as Scenario IV (details of the Scenarios and flood zones are available at Devkota, 2014, Devkota et al. 2020).

During the focus group discussions (FGDs), local people were asked to prepare a list of flood adaptation strategies. They were further requested to identify five applicable techniques that are most relevant for household (HH) survey. A simple random sampling method with proportion of HH numbers was adopted and a total of 240 HHs (over 25% of the total flooded HHs) were randomly interviewed for semi-structured questionnaire survey. There were 720 HHs in the three flood risk zones - 144 in high; 274 in moderate; and 302 in low. Stratified random sampling with proportion of HH numbers was considered as a basis of allocating the sampling effort in each zone (Devkota et al. 2020). Before administering HH survey and FGDs, the questionnaire was pre-tested. During the HH survey, key person of each HH was requested to rank the selected flood adaptation strategies on a 1–5 scale, 1 being the least preferred and 5 the most preferred option (Maraseni and Xinquan, 2011). For each strategy, frequency (F), relative frequency (RF) and cumulative relative frequency (CRF) of scores were calculated; strategies were then ranked on the basis of CRF for the most preferred (MoP), very preferred (VeP) and moderately preferred (MdP) levels based on the methodology developed by Devkota, (2014) and Devkota et al. (2017). The adaptation strategies for each flood scenario were then ranked, based on total scores, from the overall preferred strategies. Five FGDs were conducted in the flood prone areas within the study domain for the reliability and validity of the information/perception assessed.

4. Results and Discussion

The most plausible adaptable strategies explored in the study were:

Changing farming practices. This includes changing the types of crops grown (e.g. cultivating flood resistant crops, planting more cash crops in the winter season and growing crops with short crop cycles) and enhancing landholders' farming capacity through the training.

Land use management: Land use management covers local level erosion control by land levelling; making land for building construction higher than the surrounding land wherever possible; using marginal land for fodder farming; making temporary arrangements to limit the extent to which river water invades agricultural fields or housing.

Household level preparation and management: This includes building double storey houses; making arrangement so that valuable goods can be stored at elevated levels; and positioning buildings to avoid storm damage as much as possible.

Controlling flood levels and food storage: This strategy includes constructing drainage around house so that flood waters cannot easily enter the house; storing seeds and food stuffs at elevated levels to avoid flood damage; rearing cattle on higher grounds; and migrating temporarily to upland areas.

Watershed management: This includes preservation of forested areas of the catchment and trees around water sources; taking landslide and erosion control measures in the hilly area of the river basin; rain and flood water harvesting; and developing irrigation systems.

4.1 Adaptation strategies for current flood scenario (Scenario I)

Perceived preferences for the strategies for the current scenario (i.e. Scenario I, are presented in Table 2. "Household level preparation/management" was the most preferred adaptation strategy for this scenario with the highest ranking (CRF = 85.7%). It is followed by "controlling flood level and food storage" (CRF = 81.9%), "change farming practices" (CRF = 81.0%), "land use management" (CRF = 80.9%) and "watershed management" (CRF = 80.0%). Again, since CRF of all strategies are 80% or more and the differences between them are small, we can conclude that all are considered important.

Table 2. Adaptation strategies for current flood scenario I

Responses	Household level preparation / management			Controlling flood level & food storage			Change farming practices			Land use management			Watershed management		
	F	RF	CRF	F	RF	CRF	F	RF	CRF	F	RF	CRF	F	RF	CRF
MoP	35	16.7	16.7	52	24.8	24.8	25	11.9	11.9	67	31.9	31.9	24	11.4	11.4
VeP	91	43.3	60.0	64	30.5	55.2	72	34.3	46.2	34	15.2	47.1	77	36.7	48.1
MdP	54	25.7	85.7	56	26.7	81.9	73	34.8	81.0	71	33.8	80.9	67	31.9	80.0
LsP	24	11.4	97.1	24	11.4	93.3	35	16.7	97.6	32	16.2	97.1	38	18.1	98.1
LeP	6	2.9	100	14	6.7	100	5	2.4	100	6	2.9	100	4	1.9	100
Rank	I			II			III			IV			V		

Note: MoP = Most preferred; VeP=Very preferred; MdP = Moderately preferred; LsP= Less preferred LeP= Least preferred & 'F' is frequency, 'RF' is relative frequency (%) and 'CRF' is cumulative relative frequency (%)

4.2 Adaptation strategies for near-future flood Scenario II

Participants were presented with the probable flood scenario for 2030 and asked their views on adaptation strategies in that flood situation (Table 3). "Household level preparation/management" again scored highest (CRF = 88.5%). This was followed by "watershed management" (CRF = 83.8%), "controlling flood level & food storage" (CRF = 83.3%) and "change farming practices" (CRF = 83.0%), while "land use management" ranked fifth (CRF = 82.4%). The higher ranking of "watershed management" from fifth in Scenario I to second rank implies that it is likely to be considered of increasing importance for flood Scenario II. As in Scenario I, CRFs of all strategies were more than 80%.

Table 3. Flood Adaptation strategies for flood exposure scenario II

Responses	Household level preparation / management			Watershed management			Controlling flood level & food storage			Change farming practices			Land use management		
	F	RF	CRF	F	RF	CRF	F	RF	CRF	F	RF	CRF	F	RF	CRF
MoP	33	15.7	15.7	39	18.6	18.6	39	18.6	18.6	11	5.2	5.2	16	7.6	7.6
VeP	88	41.5	57.5	51	24.3	42.9	64	30.5	49.0	72	34.0	39.2	87	41.4	49.0
MdP	65	31.0	88.5	86	41.0	83.8	72	34.3	83.3	92	43.8	83.0	70	33.3	82.4
LsP	18	8.6	97.1	29	13.8	97.6	33	15.7	99.0	28	13.7	96.7	36	17.1	99.5
LeP	6	2.9	100	5	2.4	100	2	1.0	100	7	3.3	100	1	0.5	100
Rank	I			II			III			IV			V		

Note: MoP = Most preferred; VeP=Very preferred; MdP= Moderately preferred; LsP= Less preferred LeP= Least preferred & 'F' is frequency, 'RF' is relative frequency (%) and 'CRF' is cumulative relative frequency (%)

4.3 Adaptation strategies for mid future flood scenario III

"Household level preparation/management" remained the highest priority and the most preferred adaptation strategy for Scenario III (CRF = 90.0%) (Table 4), followed next by "watershed management" (CRF = 89.0%), "land use management" (CRF = 88.6%), "controlling flood level & food storage" (CRF = 86.2%) and "change farming practices" (CRF = 81.0%).

Table 4. Flood Adaptation strategies for flood exposure scenario III

Responses	Household level preparation / management			Watershed management			Land use management			Change farming practices			Controlling flood level & food storage		
	F	RF	CRF	F	RF	CRF	F	RF	CRF	F	RF	CRF	F	RF	CRF
MoP	15	7.1	7.1	35	16.7	16.7	11	5.2	5.2	54	25.7	25.7	48	22.9	22.9
VeP	92	43.8	51.0	79	37.6	54.3	89	42.4	47.6	51	24.3	50.0	81	38.6	61.4
MdP	82	39.0	90.0	73	34.8	89.0	86	41.0	88.6	65	31.0	81.0	52	24.8	86.2
LsP	16	7.6	97.6	21	10.0	99.0	21	10.0	98.6	32	15.2	96.2	27	12.9	99.0
LeP	5	2.4	100	2	1.0	100	3	1.4	100	8	3.8	100	2	1.0	100
Rank	I			II			III			IV			V		

Note: MoP = Most preferred; VeP=Very preferred; MdP= Moderately preferred; LsP= Less preferred LeP= Least preferred & 'F' is frequency, 'RF' is relative frequency (%) and 'CRF' is cumulative relative frequency (%)

4.4 Adaptation strategies flood far future scenario IV

The probable flood information for Scenario IV was provided to the household survey participants to investigate any change in people's perceptions of flood adaptation strategies. Based on their insight on the potential flood damage, it was found that the respondents had changed their adaptation strategies for this case, ranking the strategies differently than previous cases. Based on the CRF for 'most appropriate' to 'moderately appropriate' level strategies (Table 5), "watershed management" now had the highest value (CRF = 89.5%) and was the most preferred adaptation strategy, followed by "land use management" (CRF = 88.1%), "household level preparation/management" (CRF = 87.6%), "change farming practices" (CRF = 86.8%) and "controlling flood level and food Storage" (CRF = 83.3%).

Table 5. Flood Adaptation strategies for flood exposure scenario IV

Responses	Watershed management			Land use management			Household level preparation / management			Change farming practices			Controlling flood level & food storage		
	F	RF	CRF	F	RF	CRF	F	RF	CRF	F	RF	CRF	F	RF	CRF
MoP	44	21.0	21.0	77	37.3	37.3	18	8.6	8.6	65	31.0	31.0	19	9.0	9.0
VeP	88	41.9	62.9	47	23.7	61.0	85	40.5	49.0	66	31.4	62.4	78	37.1	46.2
MdP	56	26.7	89.5	57	27.1	88.1	81	38.6	87.6	51	24.4	86.8	78	37.1	83.3
LsP	17	8.1	97.6	10	4.1	92.2	23	11.0	98.6	22	10.5	97.3	32	15.2	98.6
LeP	5	2.4	100	18	7.8	100	3	1.4	100	6	2.7	100	3	1.4	100
Rank	I			II			III			IV			V		

Note: MoP = Most preferred; VeP =Very preferred; MdP = Moderately preferred; LsP = Less preferred LeP = Least preferred & 'F' is frequency, 'RF' is relative frequency (%) and 'CRF' is cumulative relative frequency (%)

Flood adaptation strategies for the four climate induced flood scenarios were identified and ranked through the focus group discussions and household survey, respectively. Five adaptation strategies identified were: (1) Changing farming practices; (2) Land use management, (3) Household preparation/management; (4) Controlling flood level & food storage; and (5) Watershed management. During the household survey, flood information for different scenarios was provided and then these strategies were ranked for different flooding scenarios. A summary of changes in the preference of adaptation strategies with the exposure to different of flood scenarios are presented in Table 6.

Table 6. Changes in the preference of adaptation strategies with the exposure to different flood scenarios

Flood scenarios	Watershed management	Change farming practices	Land use management	Household level preparation / management	Controlling flood level & food storage
Current Scenario	V (80.0)	III (81.0)	IV (80.9)	I (85.7)	II (81.9)
Near Future Scenario	II (83.8)	IV (83.0)	V (82.4)	I (88.5)	III (83.3)
Mid future Scenario	II(89)	V (81.0)	III (90.0)	I (88.6)	IV (86.2)
Far-future Scenario	I (89.5)	IV (86.8)	II (88.1)	III (87.6)	V (83.3)

It is worthwhile to mention here that "household level preparation/management", the lowest level of flood adaptation strategy, is within a realm of a household member in terms of control and dimension. Controlling flood level and food storage around one's property is slightly higher in level, as it involves storing of food for the future (temporal domain) and controlling the flood level around the house and their own agricultural land (spatial domain) which are broader than the household level preparation. In terms of the horizon (temporal and spatial) and magnitude of strategies, change in farming practices and land use management are of even higher levels. The top among these strategies is watershed management which demands multi-sectoral management and multi-stakeholder involvement. When the whole catchment is managed with proper planning and appropriate techniques, the level of risk is decreased. It is the reason why it is considered as one of the best options among various strategies and appropriate in rural contexts (Devkota et al. 2014).

Peoples' choice of flood mitigation strategies mainly depends on the current needs of the people and their knowledge of harm. Current needs govern current choices while the basis of future choice is generally made on the degree of the impact or perceived risk of the hazard. This can be clearly seen from the ranking made by the people for Scenarios I and IV. "Household level preparation /management" was ranked first for Scenario I while in Scenario IV "Watershed management" was ranked highest. "Watershed management" was felt to be an important strategy, as it was second ranked even in Scenarios II and III. People may have realised that the mounting flood risk is increasing with time and that such risk can be reduced only through catchment management. When the risk is considered as of low level, people try first to adapt to it at the personal and household level. However, when the risk level increases, people look for alternatives or higher levels of adaptation. The perceptions of people in the study were found to be in agreement with these findings: as the flood risk increases from Scenario I to Scenario IV, the movement in choice of strategies changed accordingly.

Another interesting change in preferences was noticed for "controlling flood level and food storage" strategy. This was the second preferred strategy for the flood Scenario I and gradually moved to lower part on the list of preferred strategies with progression through to Scenario IV. Decreasing preference for this strategy could be due to the loss of hope in this strategy's effectiveness as enough food cannot be safely kept in high flood conditions and controlling such a flood with small scale efforts is useless. Hence, government of Nepal should initiate food storage facilities in high flooding areas. The preference level for land use management also jumped in the latter flood scenarios (Scenarios III and IV). The basis of the choice is similar to that presented earlier.

5. Conclusions

Peoples' preferred of flood adaptation strategies mainly depends on the current needs of the people and their knowledge of harm. Current needs govern current choices while the basis of future choice is generally made on the degree of the impact or perceived risk of the hazard. This can be clearly seen from the ranking made by the people for Scenarios I and IV. It could be argued that when people have more information, they will do long term planning and formulate long term strategies. This indicates the value of providing information on the potential risks associated with climate change induced flood using various scenarios to help people choose appropriate adaptation strategies. The effective flood adaptation measures are applicable for local and central level policy makers. This helps government and other stakeholders to choose appropriate short-term, medium-term and long-term flood adaptation strategies among the many alternatives. This research provides an overall framework for deriving potential mitigation and adaptation strategies to climate change for Nepal in particular and other developing countries in general.

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