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Cascading adaptation of rural livelihood to changing environment: Conceptual framework and experiment from the Koshi River basin

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Abstract

Rural communities in the Koshi River basin, a trans-boundary river basin in the Hindu Kush-Himalayas, have been experiencing unprecedented difficulties for adapting with the livelihood challenges arising from floods, droughts and other climatic, environmental and socio-economic stresses. The single purpose adaptation approach often fails to address the multiple challenges arises from cascading effects of climate change at different scales and stages. To fill this gap, we developed a multi-dimensional flexible adaptation framework looking at the four dimensions of adaptation, structure, issue, time, and space (SITS). The SITS framework provides a comprehensive approach for cascading adaptation at trans-boundary river basin level and it could effectively enhance the adaptive capacity and transform livelihood outcome if properly implemented. Following the SITS framework, we examined four cascading adaptation pathways for: i) reducing disaster stressors on livelihoods, ii) enhancing access to crucial livelihood capitals, iii) improving equal rights to livelihood, and iv) strengthening synergies and exploiting complementarities at trans-boundary river basin level. The findings revealed that in the context of changing climate, it is necessary to employ different livelihood adaptation strategies and multiple responses simultaneously or sequentially to successfully adapt to the cascading effects of changing climate. The cascading adaptation may provide a sound basis on which to cope with the climate uncertainty through realistic scenarios of structure, issue, time and space. Its implementation, however, has several obstacles, for example, differences in national system, investment capacity, complexity of trans-boundary basin, remained particularly in trans-boundary river basin where managing transnational trade-offs and harness spatial synergies are critically important.

Keywords: Cascading adaptation; Rural livelihood; Trans-boundary river basin; SITS framework

1. Introduction

Rural residents living in river basins are highly vulnerable and particularly sensitive to climate change. The Koshi River basin, a trans-boundary river (originates from the Tibetan Plateau of China passes through Nepal Himalaya, Terai and flood plain areas of Bihar, India), is one of the hotspots of climate change (Nepal, 2016). About 40 million people living in the basin have been experiencing unprecedented challenge of adapting to multiple effects arising from the floods, droughts, landslides, and other environmental and socio-economic stress. There is a growing urgency for exploring objective adaptation pathways to deal with multiple stresses at scale of the basin.

Cascading effects of climate change are a comprehensive reflection of producing a chain of unexpected second- and

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third-order events (Hempel et al., 2018; Helbing et al., 2005; Pescaroli et al., 2018; Zuccaro et al., 2018). Estimating potential cascading impacts of climate change and natural disasters on human-environment system requires understanding numerous linkages and interdependence among people experiencing vulnerability (for example food-insecure people), governance practitioners (for instance village development committee in Nepal), academics (researchers and scientists), policymakers (such as Nepal Ministry of Energy, Water Resources and Irrigation), the public, and climate systems (humid tropical climate in the Terai, arid steppe cold climate, temperate climate with dry winter warm summer, and arctic climate on the High Himal). The heavy interdependence between human and environment system increases the incentive for further ecological-economic-social integration by a spatial–temporal mesh. Especially in adaptation domain experiencing climate change, the scope and scale of adaptation approaches are increasingly moving away from single dimension towards multi-component, multi-site and multi-sector endeavors (Holman et al., 2019). As is increasingly evident, the impacts of climate change will cascade across all sectors of nature and society and call for more coherent adaptation regime (Steele et al., 2018; Xu et al., 2009). To adequately capture the complexity of interconnected systems is an important issue through an integrated, cross-sectoral, cross-regional and meshed approach (Olazabal et al., 2018), which depends on multiple drivers, multiple paths and multiple impacts on humans and the environment (Leonard et al., 2014).

Adaptation needs and addresses multi-disciplinary investigations, for this reason, meanings of the term differ by field and in practice (Moser and Ekstrom, 2010). However, to cascade the potential adaptation knowledge scattered in diverse fields is a difficult task. Many of the lessons learned through practices demonstrate the importance of systems approaches for meeting the challenges of climate change adaptation over the last decade (Antle et al., 2018; Bai et al., 2016a, b; Kelly, 1998; Nguyen et al., 2015; Ross et al., 2015; da Silva et al., 2012; Fiksel, 2006). They emphasized the importance of coupled whole-of-system approaches to understanding climate change and adaptation needs towards integrated and comprehensive solutions. A systems approach for adaptation provides a new platform for discovering cross-sectoral interactions, and identifying the trade-off ways of adaptation. However, the 'system approach' is difficult to delineate cascading effects of climate change at river basin level. It is also difficult to describe accurately the meshed attributes of adaptation, the spatial attributes of adaptation as well as the dynamic attributes of adaptation. Actually, mesh adaptation refers to the adaptation procedure at grid or nodes level in order to provide more precise solutions based on the distinguished geographical differences caused by rapid elevation drop in river basins. Spatial heterogeneity in geographical conditions, ecosystems, natural resources, or extreme events often interact with intertemporal change in contexts such as disasters risk management, water allocation, land use change, poverty alleviation, and labor migration. There is to date no complete model for describing the interactions and interdependencies of these critical variables or structural elements. In addition, cascading effects of climate change coupled with socio-economic changes is widely realized that it cannot be understood by traditional approach of gradual adaptation and sectoral approach (Xu et al., 2009). That is why the existing frameworks need to be improved by structural adaptation (key elements orientation), issue-oriented adaptation (key obstacles orientation), spatial adaptation (hot spots orientation), and dynamic adaptation (key stages orientation) at different scales and time. The study aims to establish a general framework of cascading adaptation that may have contributed to the development of a novel theory to analyze adaptation to climate change in a systematic and flexible way. The theory's potential can be demonstrated by a systematic logical deduction of adaptation from cascading impacts to cascading adaptations. The theory framework puts emphasis on the accuracy and efficiency of adaptations, and on the implications of the fact that exposure units, crucial issues, spatial heterogeneities, dynamic processes of adaptation are frequently not identical. The study is also crucial to focus on the practice and application of livelihood resilience for rural residents at transboundary river basin level.

2. Methodology and approach

2.1. The logical transformation from cascading impact to cascading adaptation

The human-environment relationship, as the core theory of geography, has been the scientific foundation of the issues of human impact on, adjustment to or adaptation to the environment since antiquity (Turner, 2015). Importantly, the surge of sustainable development is changing the knowledge scope of human-environment relationship in the context of responding to changing environment (Zimmerer, 2017). Due to the complexity of human-environment interaction, an understanding of the non-linear dynamics and feedback loops is the foundation stone of current human-environment relationship research (Liu et al., 2007a, 2007b). There is an increasing trend of human-environment relationship to situate the changing environment through interacting scales of space and time (Moran, 2010; Liu et al., 2007a, 2007b). Therefore, theories and concepts of human-environment hybridization have become central to recognizing the multifaceted, and multiple spatial–temporal intermingling of the nature and society (Zimmerer, 2017).

Recently, transformative on human-environment relationship is increasingly being addressed owning to the discourse of climate change. These focuses tend to cluster around human-environment interactions in hazards risk, vulnerability, and resilience, along with human-environment relationships in food security, health and livelihoods (Zimmerer, 2017; Kőszegi et al., 2015). Consequently, increasingly widespread concepts like disasters risk, vulnerability and adaptation are transformed into an applied framework by incorporating human-environment interactions. Climate change impacts are observed in both human and the environment systems. The importance of adaptation to these impacts is increasingly being emphasized in human adjustments to climate change at multi-spatial and temporal scales (Moran, 2010; Costanza et al., 2007). According to Johnson (1979), adaptation is defined as adjustment of living matter to the environment. However, adaptation to the environment is not a simple negative feedback issue (Moran, 2010). Instead, with the changing environment, they need to constantly adjust structure and functional components of system over time (Rappaport, 1977; Costanza et al., 2007). A central challenge of understanding adjustment or adaptation is the effectiveness and efficiency that are very critical in judging success based on the sustainable solutions facing an uncertain future (Holman et al., 2019). Current adaptation analysis seems to be inefficient in highlighting cascading impacts on coupled human-environment system (Pescaroli et al., 2018). A fundamental aspect in enhancing adaptation efficiency is the need for an appreciation of both spatial and temporal features associated with climate change and natural disasters (Epanchin-Niell et al., 2017). It is also essential for a response with experience or preparation when a crisis occurs (Berkes and Folke, 2002). Ideally, one successful course of action is to adjust human activities both short- and long-term, in term of probability and temporal variability (i.e. not static, but rather dynamic) (Dearing et al., 2006). Based on cascading effects of climate-driven impacts, the effectiveness and efficiency of adaptation is not possible to ignore the targeted, planned and preparatory adjustment mobilized in human-environment interactions. In response, as processes involving the multilayered networks of human and the environment system, promoting transformation from cascading impact to cascading adaptation can play a central role in adaptive efficiency (Olazabal et al., 2018; Holman et al., 2019).

A multi-scale and multi-dimensional scheme for adaptation can enable more targeted strategies at multi-scales for overcoming blindness and unplanned response to climate change (Rasul and Sharma, 2016). The available evidences suggest that the interface between upstream and downstream of river basin is characterized by high interdependence, beyond hydrological links. Accordingly, high interdependence inspires the incentive of improving adaptation efficiency for river basin (Garrick et al., 2018). To enhance interdependency awareness and the effectiveness of adaptation, studying the cascading adaptation based on the cascading effects of climate change on rural livelihoods can thus serve to abate vulnerability and promote adaptive capacity which is a necessary means to respond to changing climate. Cascading adaptation, reflecting the degree of response to uncertainty or probability, is a comprehensive, diverse and effective network of adaptation strategies in the context of climate change. Meanwhile, it is also an optimized approach to simulating the potential for adaptation to reduce adverse impacts and vulnerabilities associated with climate change. However, the application of the concept has a number of implications. Although cascading adaptation is unlikely to be a panacea coping with cascading impacts of climate change, furthermore, it is also almost impossible to understand the cascading effects of climate change at all levels. For specific targets such as residents' livelihoods, however, it can reduce significantly the decision blindness as a result of uncertainty or possibility of climate change. We use the concept here, referring to an integrated and comprehensive process of multidisciplinary adaptation knowledge (adaptation measures in different fields are based on different disciplinary knowledge), a space configuration process of nesting different blocks (different regions and stages of development require different adaptation strategies), and a collaborative process between scientists and all stakeholders including institutions (an effective adaptation is the synergy of disciplines, government departments, NGOs, individuals and social systems). It is a nested complex adaptive system with three distinguishing features and four key properties. Cascading adaptation can be positive, anticipated, and active, helping the livelihood system of rural residents become more reasonable, more effective, more resilient and less vulnerable in response to the changing climate and environment. Therefore, cascading adaptation shares three characteristics of rationality, effectiveness and flexibility. It highlights four key properties of dynamic, active, and seamless adaptation portfolio where group with multiple levels (hierarchical), mesh with multiple nodes (meshed), deal with geographical heterogeneity (regional), and state change with time (dynamic) (Fang, 2018).

2.2. The SITS framework of cascading adaptation

In order to further describe the features and properties of cascading adaptation, cascading adaptation includes, inevitably, cross-sectorial issues, cross-regional issues, cross-time issues, and cross-institutional issues at trans-boundary river basin level. Trans-boundary river basins experience complex cascading effects and coordination challenges to deal with cascading effects of climate change. Due to significant cascading effects of ongoing climate change to human and environment systems, when the upstream adaptation decisions have cascading effect on the downstream area in different periods, the multi-spatial–temporal nature of the cascading adaptation may generate the possibility of spillovers. The challenge is to combine this complexity with a relatively simple conceptual framework so that we can provide a coherent narrative about what is structural adaptation and what is a spatial adaptation, taking into account any changes in context along the way. In our approach we conceive a development framework, called the structure, issue, time, and space (SITS) framework that considers all these aspects with their mutual relationships as shown in Fig. 1. Briefly, we apply four dimensions of structure (key elements of adaptation), issues (major challenges of adaptation), time (dynamic process of adaptation), and space (hot areas of adaptation) to characterize cascading adaptation to guide future formal qualitative and quantitative evaluations of adaptation strategies.

Structure dimension (S) is defined here as critical elements that are used as criteria for identifying the goal of adaptation,

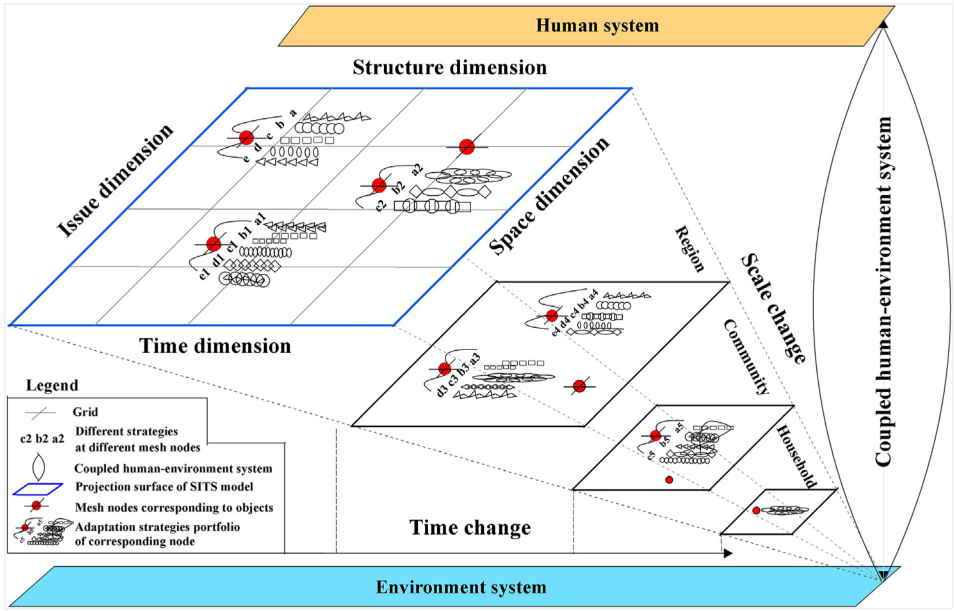

Fig. 1. SITS framework for cascading adaptation.

object of adaptation, and type of adaptation. Assessing and understanding climate change adaptation is conceptually more ambiguous, focusing on the adjustments of human systems at different scales and by different actors, and the pathway of success may be considered different. The structural elements emphasized by different research objects vary. For example, the structural elements of livelihood adaptation to climate change can be stressed as livelihood quality, livelihood promotion, livelihood provision, and livelihood pressure (Fang et al., 2018). And it also can be emphasized by livelihood capital, livelihood stresses, and livelihood resilience (Quandt, 2018). Another example, the structural elements of livestock sector adaptation can be expressed as grassland quality (grass), grazing management (livestock), and demographical and industrial policy (population and institution) (Fang et al., 2011). Structural dimensions research has an important role in the process for climate change adaptation (Garrick et al., 2016; Adam et al., 2018). The clarification of critical elements is the first step in designing for cascading adaptation. And penetration of structural approaches into the framework of cascading adaptation provides a conceptually appropriate and practical opportunity for rigor in testing and evaluating adaptation precise and performance.

Issue dimension (I) refers to the key obstacles or major problems that restrict goals, constrain actions and influence outcome around specific objects like livelihood. These barriers can be solved with targeted strategies, related shifts in institutions and concerted effort, etc. This is not as straightforward as it seems. When faced with a decision, stakeholders often spend the bulk of their time reviewing possible choices. The reason is that they fail to do the up-front work of problem identification. Therefore, in the context of climate change, the concern or issue needs to be identified initially, yet consistently revisited as key links of the framework are considered. The issue-oriented identification would form a core of the framework.

Time dimension (T) is a dynamic process of adaptation to climate change. Since the changing climate is continuous and uncertain whereas adaptation choices are discrete, in reality, we are unable to make a perfect and precise one-to-one or step-by-step matching from adaptation schemes to changing environment. The consideration of time dimension aims at emphasizing the balance between continuous environmental change and discrete adaptation in a certain period. This process, indeed, emphasizes the mapping of different adaptation scenarios to the different stages of a changing environment according to actual requirements.

Space dimension (S) of adaptation to climate change, the overlap between climate and space is giving rise to important new questions and challenges relating both to risks and opportunities (Donohue and Biggs, 2015). The traditional time-only conception of adaptation neglects important spatial attributes of how people make adaptation decisions. The need for spatial adaptation is particularly acute in many aspects of climate change adaptation due to the complex spatial heterogeneity of climate change impacts. Indeed, one reason we focus on adaptation is because the differentiation of adaptation demand at different regional levels. Thus the analysis of integrated spatial adaptation offers advances in our understandings of both adaptation performance and coupling complex nature-society phenomena.

Four key dimensions underlie the SITS framework for cascading adaptation. We call it the seating chart of adaptation to changing climate. Indeed, the SITS model is a projection surface of a four-dimensional state space embedded in a coupled human-environment system. The projection surface can delineate clearly the scale process, temporal process, as well as the coupled processes that may be responsible for the cascading impacts of the observed climate change. In a changing human-environment system, as shown in Fig. 1, through the intersection of structure, issue, time and space dimensions, we can target the cluster and portfolio of cascading adaptation at different cross-nodes, at different time periods, and at different scales.

2.3. Description of the study area

The Koshi River basin, which passes through China, Nepal, and India, originates from the Tibetan Plateau in China, and ends at the Ganga River in India. It is one of the important trans-boundary river basins in the HKH region (Fig. 2). The basin covers six geological and climatic belts including the Tibetan Plateau, the Himalayas, the Himalayan mid-hill belt, the Mahabharata Range, the Siwalik Hills and the Terai from south to north respectively, the altitude ranges from 21 m to above 8800 m (Doody et al., 2016). Steep hillslopes are typical geomorphological features of the region (Uddin et al., 2016). The basin is drained by seven major river systems: the Indrawati, Sun Koshi, Tama Koshi, Likhu, Dudh Koshi, Arun, and Tamor, and it is one of the largest tributaries of the Ganga River (Fig. 2). These rivers drain a catchment area of over 87,970 km^2, approximately 22% in India, 33% in China, and 45% in Nepal (Rajbhandari et al., 2016). The temperature shows a progressively decreasing trend from south to north which reflects the increasing elevation. The precipitation is affected not only by topography but also by monsoon, the precipitation trend increases with elevation but decreases at higher elevation in the Himalayas (Agarwal et al., 2014, 2015). Precipitation concentration increased dramatically during the monsoon, the maximum precipitation, observed in high mountainous areas, is 3078 mm annually, and minimum rainfall of 207 mm in the Himalayas (Moench, 2010; Uddin et al., 2016).

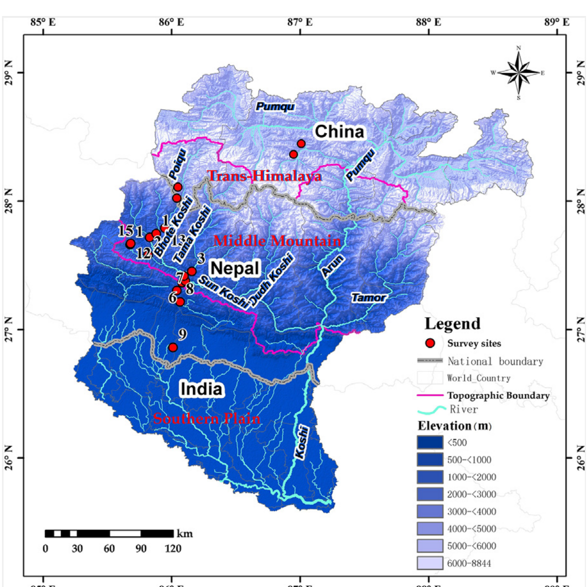

Fig. 2. Map of Koshi River basin.

It is quite obvious that socio-economic disparity covers a wide variety of topics as a result of inherent differences in demographic, cultural, historical, institutional, and environmental milieu among China, Nepal and India. In spite of the level of socio-economic development has improved markedly in recent decades, underdevelopment is still the main feature across this basin. Farming and animal husbandry is the pillar sector of economy supporting livelihood of more than 32 million people. Grain yield of China side was significantly higher than that of Nepal side, for instance, the average grain yield per unit area is more than 5000 kg hm^{-2} in Tingri and Nyalamu counties. By contrast, grain yield ranges from 1500 to 2000 kg hm^{-2} in most districts of Nepal side such as Sindhupalchok, Dolakha, Ramechap, and Sinduli (Fang, 2014). Additionally, the Koshi basin is experiencing rapid development in tourism due to rich tourism resources and colorful cultures in recent years. However, the poverty, water availability, food insecurity, and poor infrastructure are threatening the socio-economic sustainability.

2.4. Survey methods

Mixed method is the mixing of qualitative and quantitative approaches. Its purpose is to broaden the analysis perspective and offset the weaknesses of using only one method. At the same time, there is a sizable gap of existing data to understand the cascading impacts of climate change and adaptation at household, community, and trans-boundary river basin levels. That is why mixed method is adopted in this study. In particular, questionnaires and in-depth interviews are used together in investigating rural livelihood. Household questionnaires help to understand of respondents' opinions, attitudes, thoughts, and actions about issues of particular concern to the livelihood. It can also quantitatively describe the causal relationship between main variables and livelihoods. Selecting survey sites at regional scale, we considered five important principles, namely, covering the upper, middle, and lower reaches of the basin; the topographies of the plateau, high mountains, hills, and plains; the climate ranges from the cold Himalayas to the tropical Terai; the main tributaries of the Koshi River; and country differences in administrative regions (China, Nepal, India). At the household scale, we emphasized family income levels, livelihood constraints, and the diversity of respondents. In April 2018 and October 2017, 130 households structured questionnaire and 15 qualitative in-depth interviews were conducted in the three areas of Koshi River basin (Nepal side). In the upstream of the Koshi River basin (China side), we also facilitated several informal discussions and interviews with local government authorities like Nyalamu Land Bureau, Water Conservancy Bureau, and Bureau of Agriculture and Animal Husbandry in June 2014 and July 2013, respectively. In the Koshi River basin of Bihar (India side), we used literature review and document analysis to supplement data from questionnaires and interviews (Table 1).

In addition, workshops are also important research tools used. For example, workshops were held in Beijing in

Table 1
Details of the field survey and major documents review.

Koshi River basin	District	(Rural) Municipality	Quantitative	Qualitative		
			Sample number of questionnaires	Sample size of in-depth interviews	Interview with local governments	Major documents review (literature and official reports)
Sun Koshi	Kavrepalanchok	Panchkhal-12	22	1		√
		Panauti-5		1		
		Dhulikhel-4		1	√	
	Sindhupalchowk	Sunkoshi-3	6	1		√
		Sunkoshi-7		1		
		Sunkoshi-8	15			
		Chautaragadi-11		1		
	Saptari	Kankali-1	15			√
		Kanchanrup-12	28			
	Dhanusa	Janakpur-8(sub-metropolitan city)		1	√	
	Nyalamu county	Khasa Township			√	
		Chongdui Township			√	
Tama Koshi	Sindhuli	Kamalamai-6		1		√
		Kamalamai-8	8	1		
		Kamalamai-9	22			
		Golanjor-5		1		
		Golanjor-7		1		
	Mahottari	Bardibas-3	14			
	Dolakha	Melung-1		1		√
	Ramechhap	Manthali-4		2	√	
		Manthali-6		1	√	
Arun River	Tingri county	Zhaxi Zong Township			√	
		Jiacuo Township			√	
Koshi	Bihar	The Koshi basin of Bihar				√
		Saharsa				√
		Khagaria				√

February 2015 and Kathmandu in March 2016, with more than 100 participants including media reporters, NGOs, government officials, scholars and students etc.

3. The livelihood challenges of Koshi River basin

3.1. Challenge of climate change and vulnerability

From 1960 to 2009, the maximum and minimum temperatures were reported to be increasing at the rate of 0.058 °C per year and 0.014 °C per year in the Koshi River basin respectively (Nepal, 2016). The spatial variation of precipitation varies greatly. Importantly, many researchers have argued that precipitation is projected to increase in the upper trans-mountain sub-watersheds and to decrease in the lower sub-basins during the period of 2040−2050 (Nepal, 2016). The significant impacts of climate change are likely to be reflected at the level of seasonal variability and sub-basins (Agarwal et al., 2014, 2015; Bharati et al., 2014). The hydrothermal conditions do not match the demand of economic activities like agricultural production (Nepal, 2016). These realities will not only directly affect crop yields and species ranges, but also cause a decline in the quality and quantity of livelihood capitals such as fresh water, arable land and alpine grassland. This will dramatically increase the livelihood risk and vulnerability of many poor people, particularly through declining livelihood resources and capacity of agricultural production. Furthermore, the poor infrastructures cannot support water supply for agricultural production and resident life. This particularly true of weak irrigation facility occurs in the vast mountain and hilly areas of basin. The effective irrigation area is less than 10% in most of hilly regions of Nepal like Kavreplanchok and Ramechhap (Fang, 2014). It means that farming and animal husbandry practices highly rely on rainfall for water. Consequently, rural residents, especially living in mountainous and hilly areas, are highly vulnerable to extreme weather events such as droughts, and floods. Thus, backward infrastructure is an extremely important pitfall in coping with the potential risks created by climate variability.

3.2. Challenge of natural hazards

The basin particularly is prone to natural hazards as a result of complicated and diversified ecosystem, diverse topography, young geology, and strong monsoon influence. And, according to Rajbhandari et al. (2017) and Khadka et al. (2015a), the frequency and intensity of climate extremes events such as very dry days, very wet days, and peak flows of river will increase greatly due to changes in rainfall and runoff pattern. Frequent and increasing natural disasters such as droughts, floods, debris flow and landslide will affect many areas, but Trans-Himalaya (snowstorm and Glacial Lake Outburst Flood

(GLOF)), Middle Mountain (droughts, debris flow, and landslide), and Southern Plain (floods, sedimentation and droughts) are particularly vulnerable. Additionally, Owing to high erosion, the high levels of sedimentation can destroy farmland and even cause downstream fluvial hazards (Uddin et al., 2016). Changing climate patterns will have an impact on new livelihood activities such as tourism, beekeeping and poultry breeding, which directly reduces opportunities for livelihood diversity and widens the livelihood vulnerability of local rural residents.

3.3. Challenge of food insecurity and poverty

Agriculture and grassland-based animal husbandry are highly complex ecosystem, which depend on the interaction of water, soil, atmosphere, biology and agricultural and animal husbandry practices (Fang et al., 2015). This fully highlights the sensitivity and vulnerability of agriculture and grassland-based animal husbandry to climate change. In most parts of the basin, it was demonstrated that the warming trends of the growing season mean a negative impact on rice, maize and wheat yields during 1967–2008 (Bhatt et al., 2014). In the Koshi River basin in Nepal, 83% of people depend on agriculture, which is the main source of income for rural families (Wahid et al., 2017). Therefore, climate change, especially increased temperature results in greater evapotranspiration and thus surface drying, increasing the intensity, frequency and duration of drought events, increasing the instability of livestock products, crop yield and the vulnerability of food supply (Hussain et al., 2016; Fang et al., 2015). Chen et al. (2013) shows that 40% of the population at Nepal part of Koshi River basin are under poverty line which is higher than the national average of 25%. Poverty headcount and multi-dimensional poverty index is higher particularly in the Province Two (No. 2) of the Koshi River basin in comparison to national figure in Nepal (GF, 2018). In Bihar, the overall average poverty rate in the Koshi River basin districts is 43%, while Muzaffar is as high as 65% (compared to 30% for national average of India) (Chaudhuri and Gupta, 2009).

3.4. Challenge of water scarcity

The water resource of the basin is at increasing risk as a result of rapid population growth, season imbalance and spatial mismatch in precipitation, frequent water disasters, and insufficient water infrastructure (Neupane et al., 2015a; Chen et al., 2013). Water is becoming so scarce in certain areas that some mountain settlements and communities are actually battling in court over it. The truth is that fresh water is very rapidly becoming one of the most valuable commodities in the Koshi River basin. Out of total 0.9 million ha of arable land in Nepal part of Koshi River basin, only 0.3 million ha land is irrigated which is 33% of total arable land and the national figure is more than 55% (MoAD, 2012, 2016). The proportion of year round irrigation is even lower. A big variation in irrigated land within the basin districts is found which ranges in different ecological zones ranging from the lowest 5% percent of irrigated area in some mountains districts to almost 100% irrigated area in case of Morang and Saptari districts (DoI, 2018). In Bihar part of Koshi River basin, overall irrigated areas at basin districts are lower (49%) than the Bihar state (56%) but is better than the national irrigation coverage which is only 39% for whole India (Neupane et al., 2015b). More than 65% irrigation comes from groundwater in Bihar. The overall irrigation efficiency for the whole Bihar state is 42.5% (GI, 2012) which shows a higher inefficiency of irrigation system in Bihar and enough room for improvement. In Nepal part of Koshi River basin, the Province One and Three (No. 1 and No. 3) of the Koshi River basin is poor in terms of drinking water access in comparison to national figure. Whereas Province Two (No. 2) is lag behind in terms of sanitation (GF, 2018). In Bihar part of Koshi River basin, the access to drinking water is relatively fair (about 75%) but drinking water quality is a bottleneck restricting the quality of livelihood of local rural residents. Also, the households with no access to toilet are the highest in Bihar. Therefore, the use of groundwater is pivotal to alleviate the contradiction of water scarcity, to balance the large swings in precipitation and improve the adaptive capacity of climate change in the Koshi River basin.

3.5. Challenge of growing landlessness

Agriculture is the livelihood pillar of more than 80% of rural residents in the basin. For historical reasons, a quarter of Nepal's population may be landless or near-landless, and almost half of agricultural households own only 15% of agricultural land (Wickeri, 2011). The overall holding size in Nepal has decreased at the rate of 15% from 2001 to 2011 (CBS, 2014). In the ADB (2012) report, the average land holding from 51.5% of households of Nepal are less than 0.5 hm^2 of land. The average size of landholding for Koshi River basin districts of Nepal is 0.76 hm^2 per household which is relatively higher than the national figure (0.70 hm^2 per household). At district level, the landholding is the highest for Saptari district (1.05 hm^2 per household) and minimum for Sindhupalchowk (0.60 hm^2 per household) (CBS, 2001; 2011). Questionnaires statistical results show that the average land area is 0.53 hm^2 per household, and 52% of households have an average land area of less than 0.25 hm^2 in Sun Koshi and Tama Koshi basin. Similarly, in the five villages (Chandrain, Aina, Rohuamon, Tilanthi, and Dhamara) surveyed in the Koshi River basin of Bihar, India, the land area per household is only 0.34, 0.34, 0.48, 0.19, and 0.99 hm^2, respectively (Singh et al., 2009). In all these villages, landlessness is widespread, with only 20%–30% of people owning land and the rest being laborers (Singh et al., 2009). In the upper reaches of the Koshi River basin in China, although alpine grassland and animal husbandry is the main source of livelihood for most herders and it is the amount of alpine grassland that often determines local residents' livelihood security, the population increase and rapid urbanization have led to the reduction of cultivated land over recent years. The cultivated land area of unit household has declined from 1.01 hm^2 in 1990 to 0.84 hm^2 in 2015. Accordingly, this is a major concern with livelihood challenge because of the large share of the agricultural population, the strong dependence on agriculture, and the inequality of access to land.

3.6. Challenge of gender inequalities

The impact of climate change and disasters is different for different groups, and the more vulnerable, especially women, are often more severely affected (Neumayer and Plümper, 2007; Bern, 1993). Evidently, one of the particular concerns for women during floods is the problem of sanitation owing to no proper toilets, which can lead to infection and long-term health consequences. Pregnant women may increase mortality because of the inaccessibility of the villages and lack of health facilities. Collection of drinking water remains the responsibility of women. Often, these women spend hours a day collecting water to meet their family's needs. The labor intensity of women to collect drinking water will increase greatly when there is flooding. The situation is worse in the rural villages in the southern part of the Koshi River basin. Moreover, gender inequalities in social institutions and access to livelihood capitals affect the livelihood capacity of women. Especially in the Indian and Nepal regions of the Koshi River basin, gender, caste and ethnicity-based social exclusion results in significant differences between men and women in cultural, economic and political rights, for example, women spend an average of 4.2 h per day collecting water and fuel wood, almost three times as many as men (Khadka et al., 2015b). Also, one of the most prominent aspects in which gender inequality exists is in income-earning opportunities. According to household survey conducted in the Koshi River basin, the payment of women is only an average 400 NPR (approximately 3.6 USD) per day, while men can reach 700 NPR (approximately 6.3 USD) per day. These evidences illustrate that gender inequality greatly affects women's livelihoods, health and overall well-being, which is the greatest challenge facing rural residents in the Koshi River basin.

3.7. Cascading risks in the Koshi River basin

The bio-physical and socio-economic challenges in Koshi River basin differ along the topographical landscape. The cascading effect of climate and socio-economic changes vary along with the region. The upper part of the basin has the issues of snow melting, soil erosion and grassland degradation while the lower part has the problem of water logging, rapid population growth, urbanization and shrinking of agricultural land. The vulnerability of Koshi River basin based on socio-economic and bio-physical characteristics is relatively high. But the source of vulnerability is different in different ecological zones. And the risks factors in vulnerability cascade the risks on the other ecological zones over time (Table 2). These issues on the upstream amplify the problems in the downstream over time exposing the basin into multiple disasters risks. Koshi River basin is characterized by multiple hazards environments where two of more hazards occurred in the same area, at the same time or at different time. Understanding the possible interaction of the different hazards is important for the development of appropriate adaptation strategies. A first hazard triggers a second hazard, and that triggers a third hazard and so on. The triggers factors have parallel relationship for example one or more triggers factors may induce one or more hazards in parallel resulting into cascading impacts. To develop a sustainable adaptation strategy in the basin, the both temporal and spatial dimensions of the main issues should be considered. For example 2014 Jure landslide in Sunkoshi, an erratic rainfall causes landslides. The debris from the landslides blocked the Sunkoshi River damages road and water infrastructures such as hydropower. More than 150 people were killed, million economic losses due to loss of livestock, damage to crop yield and land, public infrastructures. Causes flashfloods in the downstream but the downstream losses was minimized by realizing inundated water from the dam in time. This is an example how an event in the upstream cascade the other impacts in parallel.

4. The experiments of cascading adaptation

4.1. Reducing disaster stressors on livelihoods

A cascading adaptation view of natural disaster risks is an important instrument in preventing, reducing and mitigating the negative impacts of shocks on livelihoods. As outlined in Fig. 1, SITS framework includes four dimensions of structure, issue, time and space while determining precise adaptation options together. We first give an overview of livelihood capacity and its basic elements, from categories of livelihood capital to livelihood activity and outcome. Guided by livelihood issues, we then present a recommended adaptive cluster that encompasses the different components of livelihood capacity and allows for better identification of local attribute (space) as well as a clearer understanding of the possible dynamic strategies surrounding climate change (time).

In structure dimension, the components of disasters defensive capacities, capacities for access to livelihood capital, capacities for livelihood option and transformation, and livelihood outcome capacities is entrenched in the SITS framework and takes a holistic approach to incorporating disaster risk reduction into livelihood necessities, livelihood processes, and livelihood activities work.

In issue dimension, it explicitly recognizes the adverse effects of disasters on rural livelihoods. The middle mountain, located Nepal side of Koshi River basin, has been faced with frequent drought and geological disaster events. In addition, climate change threatens to bring more variable rainfall and more extreme floods in the Southern Plain. As having a direct relationship with each element of the livelihoods, the issues of drought, flood and geological disasters are highlighted.

Table 2
Illustration of cascading risks in Koshi River basin.

Koshi basin zones	First order risks	Second order risks	Third order risks	Fourth order risks
Trans-Himalaya	- Climate change - Glacier melting - Glacial Lake Outburst Flood (GLOF) - Avalanches - Deforestation	- Debris flow - Landslides - Avalanches	- Decrease pasture and agriculture productivity	- Increase in fallow land - Decrease in pasture land and productivity - Reduction in livestock production - Out-migration - Relocation of settlement
Mountains/Hills	- Erratic rainfall - Droughts - Deforestation - Road construction	- Landslides - Flashfloods - Erosion - Drying of springs	- Damage to water infrastructures such as hydropower, drinking water	- Challenges of electricity access, drinking and irrigation water - Reduction in crop yield and livestock production - Deforestation - Increase vulnerabilities of poor and women - Increase in out-migration
Southern Plains	- Erratic rainfall - Droughts	- Floods - Sedimentations - Reduced water supply in the downstream	- Damage to agriculture land, water infrastructures, and houses	- Challenges of electricity access, drinking and irrigation water - Changes in water quality, increase in water-borne diseases, ground water contamination - Reduction in crop yield, livestock production, fish production - Increase vulnerabilities of poor and women - Increase in out-migration

In time dimension, we focus primarily on the current and recent lack of adaptation strategies that clearly restricts livelihood capacity.

In space dimension, at the trans-boundary river basin scale, in order to facilitate analysis, we divide the river basin into three parts according to landform type: Trans-Himalaya (upper stream), Middle Mountain (middle stream) and Southern Plain (downstream) (Fig. 2). Questionnaires survey and in-depth interviews were mainly conducted in the Middle Mountain, with a small amount distributed in the Southern Plain. At the community scale, three key in-depth interviews are done to understand critical disaster stressors on rural livelihoods in Kamalamai Municipality-8 of Sindhuli district, Nepal (flood) (Fig. 2, site8), Kamalamai Municipality-6 of Sindhuli district, Nepal (geological disaster) (Fig. 2, site7), and Manthali Municipility-6 of Ramechhap district, Nepal (drought) (Fig. 2, site11). Please see Appendix Table A1 and A2 for detail information on in-depth interviews (sites).

In the light of the three key issues, that is, stressors of drought, flood, and geological disaster on rural livelihoods mentioned above, the following three cascading adaptations are formed in order to mitigate the pressure of natural disasters on rural livelihoods, namely, (a)+(d)+(e), (b)+(d)+(f), and (c)+(d)+(g) (Fig. 3). In other words, in terms of drought, the cascading adaptation is a portfolio of adaptive strategies (d) and (e). Similarly, for floods and geological disasters, the corresponding cascading adaptation is the portfolio of adaptive strategies (d) and (f), as well as the combination of (d) and (g), respectively. These cascading adaptations, in turn, may have a determined impact on residents' livelihood resilience. To our knowledge, there are no studies of cascading adaptation that have examined livelihood resilience in which trans-boundary river basins or multiple disaster-stressed rural areas. The enhancement of the cascading adaptation according to changing climate and cascading effects is viewed as a requisite to resilient livelihood. It is important that the idea of sustainable livelihood be extended beyond the notion of minimizing environmental change adverse impact; it should address issues such as managing vulnerability, reducing stresses, promoting resilience and enhancing the capacity to adapt and respond to natural disasters by cascading of disaster defensive capacity, capacity for access to livelihood capitals, capacity for livelihood option and transformation, and livelihood outcome capacity. In addition, adaptation related to natural hazard events and climate issues is a complex process involving multi-level, multi-sectoral, multi-tasking governance from the bottom up and from the top down (Biesbroek et al., 2014). Therefore, strengthening coordination and knowledge share like disaster risk reduction across public sector agencies and levels may help to overcome multi-faceted obstacles caused by different scales. Indeed, the Koshi DRR Knowledge Hub initiated by ICIMOD is such a platform that aims to foster regional cooperation by encouraging the sharing of knowledge and information on disasters at multiple levels.

4.2. Enhancing access to crucial livelihood capitals

Drinking water and food constitute a critical basic need and looms large in any conceptualization of household livelihood. The Koshi River basin, especially in the middle and lower reaches of the river basin, faces worsening water and food crisis due to climate change and a shortage of water conservancy facilities. Based on two in-depth interviews carried out in Melung Rural Municipality-1 of Dolakha district (food extreme shortage) (Fig. 2, site 3), and Manthali Municipality of Ramechhap district (water scarcity) (Fig. 2, site 11), we find

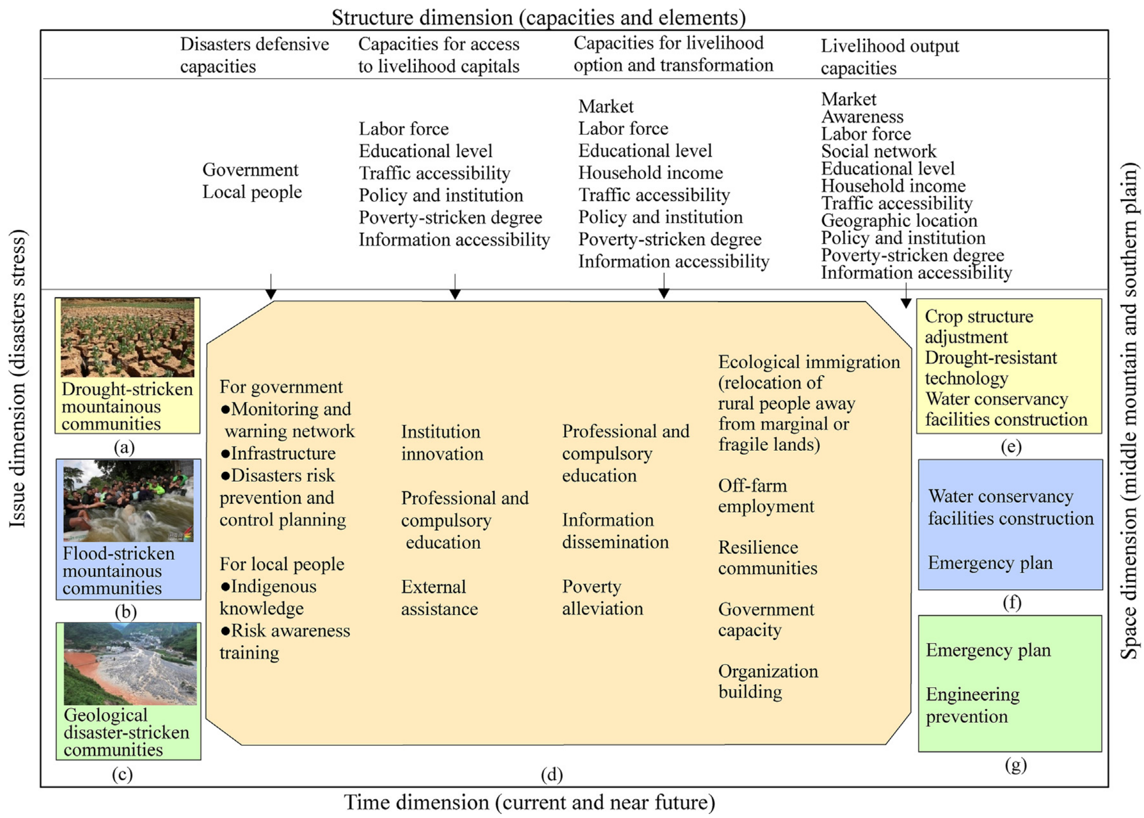

Fig. 3. Cascading adaptation of rural livelihood based on mitigating disaster stressor.

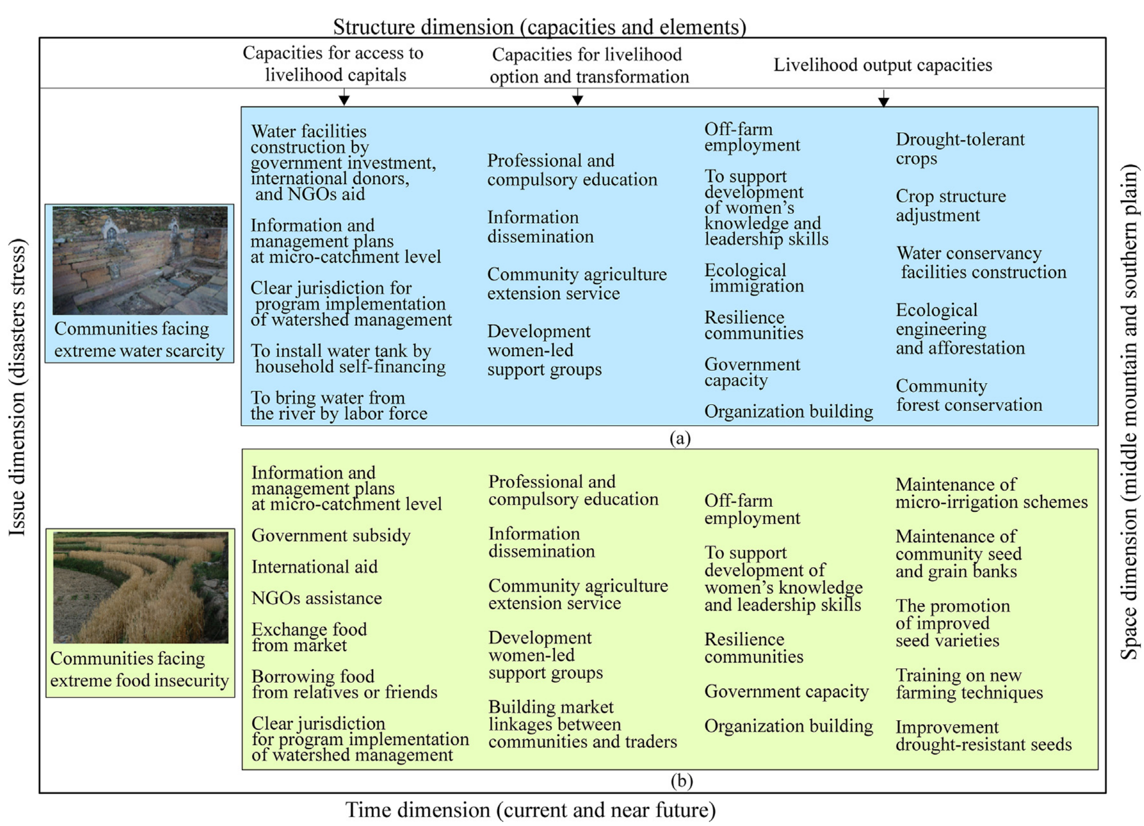

Fig. 4. Cascading adaptation of livelihood through increasing crucial capitals level.

that the average self-sufficiency level of food is less than 50% (less than 6 months). Moreover, despite recent achievements in bringing water to a growing percentage of the population, Manthali Municipality of Ramechhap district continues to suffer from a water crisis, with many people still unable to access to clean water sources. For communities in the remote mountains and hills in middle reaches of the Koshi River, fetching water means hours of walking for just one pot. In this sense, one way to reconcile crisis-reduction is to envision livelihood strengthening on a livelihood pathway towards increased income, improved infrastructure, and reduced vulnerability. As Fig. 4 shows, two key cascading adaptations exist on the livelihood pathway (e.g. from capacities for access to livelihood capitals, capacities for livelihood option and transformation to livelihood outcome capacities) indicating decreasing levels of water vulnerability and increasing levels of food security. That is, (a) cascading adaptation for alleviating water scarcity, and (b) cascading adaptation for mitigating food shortage.

Households located here on the essential livelihood pathway need adaptations to guarantee the most basic livelihood necessities and build the stock of critical assets (for example water and food) they have to draw on in the event of shocks or debilitating stresses. According to our investigation in Pokhanbesi, Chautaragadi, Municipacity-11, Dhulikhel, and Manthali (wards#4), a common method to build basic livelihood assets is to link household members (often women) together in social and economic networking groups, such as USAID, ADB, International Women's Health Coalition (WHC), Nepal Social Service Association (NSSA), Nepal Remote Villages Trust (NepalRVT), women-led support groups, community forest conservation groups, professional and compulsory education groups, community agriculture extension service etc.

In addition, Nepal's formal watershed management began in 1974 and has accumulated extensive experiences (Pandit et al., 2007). Watershed management can improve the endowment of major livelihood capitals for rural households, and provide new opportunities for households to achieve their livelihood objectives by the adoption of a participatory watershed planning and management. The high reliance on rain fed agriculture and the livelihood vulnerability of mountain households means that sound watershed management should be a priority in shaping access to crucial livelihood capitals and enhancing adaptive capacity. Therefore, watershed management as one more holistic and effective undertaking of cascading adaptation, the resource planning and management at watershed level should apparently contribute to enhancing the key livelihood capitals like water and food. However, watershed management is faced with new challenges such as climate change, inequitable land distribution, land degradation and low productivity, lack of information and management plans at micro-catchment level, as well as overlapping responsibilities, unclear jurisdiction for implementation between departments.

It should be noted that water and food shortage caused by inadequate water facilities is an important aspect. There needs to be increased investment in water and sanitation facilities on a local level. Considering the differences of local financial capacity and national systems, it may be a feasible way for local governments, international aid, NGOs and community residents to jointly invest in the construction of water facilities in the middle and lower reaches of the Koshi River. Importantly, UNICEF is committed to improving basic water services for remote areas and the poor through WASH component (water, sanitation and hygiene) (2016–2030) and Nepal country program (2018–2020). The Global Sanitation Fund established by the Water Supply and Sanitation Collaborative Council (WSSCC) is also an important financial source to improve water, sanitation and hygiene facilities.

4.3. Improving gender and social inclusion in livelihood

The Koshi River basin is characterized by complex social caste and class stratification. In the context of multiple social structures and existing institutions, gender- and caste-based discrimination persists around the basin (Khadka et al., 2014, 2015b). As Khadka et al. (2015b) point out, the lower the castes, the poorer the households, the Dalit (lower caste) are significantly more deprived than all the other groups like Brahmin/Chhetri (upper caste) and Hill/Mountain Janajati (middle caste). There is 48% of Hill Dalits and 46% of Talai Dalits below the poverty line, which are 17% and 15% higher than the national average, respectively. Nearly 50% of the Dalits do not own land. On the basis of the household survey, only 14% of women owned some land, while the proportion of men was as high as 81.5% (Khadka et al., 2015b). Women spend more than 90% of their time cooking, collecting water and firewood, and their contribution to remittances is very low. These situations place women, the poor and disadvantaged groups at greater risk of losing their rights to livelihood capitals or not receiving an equitable share of the social and economic benefits (Khadka et al., 2014, 2015b). Despite significant progress of inclusive practices made in the Koshi River basin (ICIMOD, 2017), innovation of appropriate institution remains the first step forward for gender equality and social inclusion (GESI) mainstreaming. Inclusive decision making through an equitable participatory process (for example inclusive participation, inclusive distribution of resources, inclusive target and approach) has a crucial role to increase access to livelihood capitals and strengthen capacity of livelihood options for women, the poor and disadvantaged groups. Considering the widespread penetration of land- and gender-inequality, hence, we focus on land- and gender-inclusive issues in cascading adaptation. Fig. 5b is few highlights of the steps taken towards achieving GESI. To build the workforce of knowledge and skills for women workforces need to provide equal education opportunity over time rather than to find and retain a specific job. For this reason, vocational education and development women-led support groups are a common type of workforce development adaptation. Land ownership is a key indicator of identity, power, wealth, and political access. Land, as a necessary livelihood capital for food production, access to water, and housing, most obviously impacts a range of socio-economic rights. Consequently, the

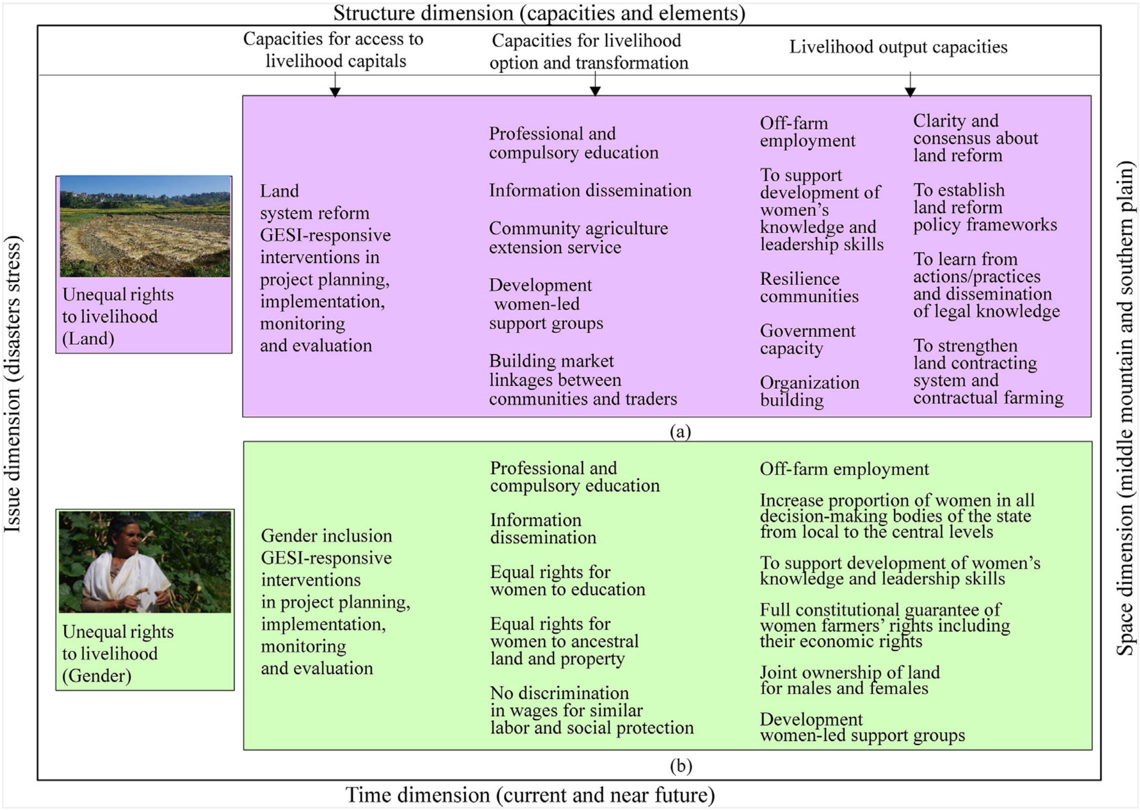

Fig. 5. Cascading adaptation of livelihood through stressing social equality.

government has sought to engage the issue of land reform in a variety of ways. According to the SITS framework, Fig. 5a identifies some of the adaptations appropriate for households located at each capacity on the livelihood pathway. Note that certain adaptations may be appropriate at different livelihood outcomes on the pathway. Land-poor or landlessness households may be different and thus the type of livelihood support that is appropriate for each may also differ. Gaining an understanding of these differences is critical in designing appropriate cascading adaptations for improving livelihood of land-poor or landlessness households. However, to significantly decrease livelihood vulnerability due to landlessness or land-poor households and improve their capacity of livelihood for these households, the reform practice of the land tenure and lease system is essential to ensure maximum benefit to the poor and rural women (CSRC, 2013; Wickeri, 2011). NGOs throughout Nepal have targeted land-poor and landless households by offering support services in agriculture, agro-processing etc. for number years. Also, how to expand land-ownership of forest and wildlife reserves for local communities has become an important objective of land reform in the middle and lower reaches of the Koshi River basin.

4.4. Livelihood for trans-boundary river basin nexus

The nexus approach selected for this study put the emphasis on the interconnections between disaster, water, land, food, gender and livelihood-related institutions. Water, land, food, female labor as the crucial assets and elements of rural livelihood, the nexus of disaster-water-land-food-gender and livelihood-related mechanism in trans-boundary basins aims at identifying these linkages and understanding how best to integrate them in future livelihood planning, to improve the efficiency of livelihood adaptation while coping with changing climate at trans-boundary basin level. One significant aspect of the nexus is its focus on land ownership, GESI, specifically the role of women in the decision making processes. The nexus of disaster-water-land-food-gender and livelihood-related mechanism in trans-boundary basins is an effective adaptation approach towards collaboration among the rural residents, scientists, policymakers, developmental practitioners and countries. The main reason is the following four aspects. First, there is high dependency between upstream and downstream communities in the Koshi River basin for dry season water for domestic use, irrigation and hydropower. Linkages between these communities are critical from the perspective of food, water security. Second, due to the water scarcity in most areas of the basin, we need to understand suitable water management options for livelihoods improvement of the community. Third, with increasing outmigration of men, women have a larger role in irrigation and agricultural development, especially in the middle and lower reaches of the Koshi River basin. Fourth, there is a need for policy-relevant action research at the local level focusing on land system reform, poverty alleviation, and gender equitable development that links evidence to policy with the aim of supporting livelihood strategies of local communities in the basin (ICIMOD, 2017). Following our proposed SITS framework and livelihood-

Table 3
Proposed cascading adaptation based on SITS of the Koshi River basin.

Adaptation based on river basin nexus	Adaptation based on livelihood outcome	Adaptation to reduce gender discrimination	Adaptation based on insufficiency of food	Adaptation based on unequal land rights	Adaptation based on shortage of water	Energy-based adaptations	Adaptation based on natural disaster stressor on livelihood	
Disaster - Collaboration research in projection of climate change and extreme events - Formation of a knowledge hub of disasters risk reduction - Integrating disaster risk reduction into rural livelihood programming at multi-levels	- Increase stocks of forages during winter - Improve pastoralists' perception of livestock production system - Increase off-farm employment opportunity for family members	- Professional training and education - Increase number of women, the poor and disadvantaged groups in all decision-making bodies	- Precise approach taken on poverty relief - Subsidies of livestock production material - Increase productive fixed assets and labor productivity	- Revising agriculture land use policies - Stressing that the state protects the stability and consistency of rural land contracts	- Safe drinking water programs - Maintenance of ecosystem diversity and service functions	- Avoid construction of energy infrastructures in disaster prone areas - Develop disaster friendly infrastructures - Development and utilization of solar energy	- Frozen disasters early warning system - Construction of livestock warm shed and sown grassland - Establishment of livestock insurance system - Maintenance of ecosystem functions	Upper reaches /Trans-Himalaya
Water - Developing both Integrated River Basin Management and Integrated Water Resources Management strategy planning - Information and management plans at micro-catchment level Livelihood - Collaboration in study of livelihood resilience - Dissemination and sharing network of livelihood adaptation knowledge	- Improve irrigation systems and their efficiency - Improve use/store of rain water - Improve information exchange system on new technologies - Build market linkages between communities and traders - Community forest conservation and management - Access to credit - High value crops - Off-farm employment - Agritourism	- Gender equality and social inclusion responsive interventions in project panning, implementation, monitoring and evaluation - Support development of women's knowledge and leadership skills - Protect women and the poor's political rights, economic and social rights, such as health, work, and marriage - Increase number of women, the poor and disadvantaged groups in all decision-making bodies	- Community agriculture extension service - External assistance - Increase productivity - Improve community agriculture extension service - Increase employment opportunity for family members	- Land right movement - Establish land reform policy frameworks - Strengthen land contracting system and contractual farming - Learn from practices and dissemination of knowledge - Professional training	- Invest on water conservation facilities - Promotion of drought-tolerant crops and traditional drought tolerance cultivars - Sustainable utilization of ground water - Conservation of diversity of mountain ecosystem - Maintenance of water conservation function of ecosystem	- Improve energy access to rural people - Use of energy to lift water from river to rain-fed area in mountains and hills - Ground water pumping in the plain area - Electricity based livelihoods diversification such as food processing, storage etc. - Encourage community participation in rural electrification	- Drought early warning system - Construction of irrigation system - Establishment of crop weather based insurance system - Maintenance of ecosystem functions	Middle reaches /Middle mountain
					- Wastewater treatment - Hygienic guarantee for drinking water		- Floods early warning system - Construction of water conservancy facilities	Lower reaches /Southern Plain

(continued on next page)

Table 3 (*continued*)

Adaptation based on river basin nexus	Adaptation based on livelihood outcome	Adaptation to reduce gender discrimination	Adaptation based on insufficiency of food	Adaptation based on unequal land rights	Adaptation based on shortage of water	Energy-based adaptations	Adaptation based on natural disaster stressor on livelihood
Organization and institution - Establishment of a social inclusive watershed management committee - Formation of a trilateral dialogue mechanism for trans-boundary basin - Clear jurisdiction for program implementation of watershed management		- Develop women-led support groups			- Development and utilization of groundwater - Conservation ecosystem diversity		- Establishment of weather-based crop insurance system - Maintenance of ecosystem functions

related adaptation measures practiced by local community, the livelihood factors that constrain adaptation and the potential adaptation measures, we can propose a set of adaptation measures that could be helpful to mitigate climate risks and to improve resilience of rural livelihood (Table 3). Considering trans-boundary basin as the logical connecting line of disasters, water, land, food, gender as well as climate change at the upper-, middle- and lower-stream three geographical scales, we established the key linkages shown in Table 3.

In the upper reaches of the basin (China side), frozen early warning system, construction of livestock warm shed and sown grassland, establishment of livestock insurance system (disaster issue) could help local herdsman to deal with snowstorm risks. Safe drinking water programs supported by China' central government could help local people to get safety, sanitation, hygiene drinking water (water issue). Revising rural land contract law could be crucial for improving enthusiasm of herdsman and farmers' production and land productivity (land issue). Precise poverty alleviation, subsidies of livestock production material, and increasing investment in productive fixed assets and labor productivity could help to ensure the safety of food (food issue). Professional training and education, gradually increasing number of women in all decision-making bodies are the important aspects of livelihood adaptation against gender discrimination (gender issue) (Table 3).

In the middle- and lower-reaches of the basin (Nepal and India side), the cascading adaptations focus on the improvement of water facilities, land contracting system (CSRC, 2013), food security, social inclusion of the poor and women (Table 3).

At trans-boundary basin level, all four components of disaster, water, livelihood and institution present different but nevertheless plausible cascading adaptations for the Koshi River basin. Importantly, they have differing implications across the disaster-water-livelihood-institution nexus at trans-boundary basin scale. While the paths related to institution construction, IRBM (Integrated River Basin Management) and IWRM (Integrated Water Resources Management) strategy planning will impact disaster risk reduction, water security at basin scale, they also have direct implications for local water and food security (Chinnasamy et al., 2015). At the same time, livelihood adaptation and resilience as a response to external rapid environmental changes depends very much on how the collaboration in study of livelihood resilience, the situation in dissemination and sharing network of livelihood adaptation knowledge. Consequently, the nexus of disaster-water-livelihood-institution at tans-boundary basin level forms a critically important, effective, flexible cascading adaptation for the whole of Koshi River basin, yet is under natural disaster threat from the climate changes will reduce the adverse impact of natural disaster on rural livelihood. Therefore, the SITS framework is expected to radically reduce the vulnerability of rural livelihood, leading also to remarkable improvements in livelihood resilience.

In terms of climate-related scenarios and dynamics, the reality of rural livelihood's vulnerability to climate change is increasingly apparent. Uncertainty in climate change will inevitably increase the difficulty of estimating cascading effects on rural livelihoods. It is clear that an effective response to the uncertainty and potential risks posed by climate change should be placed on the understanding of multi-spatio-temporal range of cascading adaptation. Thus, it emphasized the interconnectedness of complex activities that address research in disasters risk mapping, management at both micro/macro-watershed levels, livelihood resilience. And formation of a trilateral dialogue mechanism for trans-boundary basin, and clear jurisdiction for program implementation of watershed management, is also a major building block of cascading adaptation for the Koshi River basin.

5. Conclusions

Due to complicated and diversified ecosystem, diverse topography, young geology, frequency natural disasters, and agricultural-dominant production model in the Koshi River basin, climate change multi-faceted influences on the livelihoods of rural residents. The cascading effects of climate change, extreme events and socio-economic changes must be considered in the context of multiple stressors and factors with spatial and temporal dimensions. Without considering adaptation of multi-spatial–temporal dimensions, this may result in inefficient adaptation response to extreme events and multiple stressors. The logical transformation from cascading influence to cascading adaptation can be considered as an important pathway to foster the sustainable livelihood at basin level.

To cope with the cascading impact of climate change on rural livelihoods, climate change adaptation requires an integrated, cross-sectorial, cross-regional and meshed approach to adequately capture the complexity of interconnected systems. Cascading adaptation of rural livelihood is a comprehensive, diverse and effective network of adaptation strategies in the context of climate change. The Koshi River basin experiences complex cascading effects and coordination challenges. The SITS framework provides a comprehensive experiment approach for cascading adaptation at trans-boundary river basin level, while such integrated approaches are being explored conceptually, there is much less emerging to implement or operationalize such integrated approaches. Even though this study focuses on selected four aspects only (for example disaster stressor on livelihood, crucial capital of livelihood, equal right to livelihood, and trans-boundary river basin), the cascading adaptation also emphasizes the importance to look at the interconnections and related trade-offs between those sectors. The Koshi River basin context requires consideration of a greater diversity of perspectives, as multiple institutional and political scales usually mean less social cohesion and more heterogeneity on views towards the cascading adaptation when compared to a community, a river basin within a single country. While the cascading adaptation can help to refocus the stakeholders' activities and extend their understanding and even leverage policy, we suggest that the cascading adaptation as a multi-sectorial, multi-regional, and multi-level process should preferably not have a single owner. As can be seen, some of these processes also have important connections beyond the river basin itself. Accordingly, it would be important to implement the cascading adaptation through a multi-stakeholder process, where key actors from disaster to water, from land reform to food sector, from water availability to food sector, from gender to social inclusion take initiative.

As uncertainty is a prominent feature of climate change, cascading adaptation may provide a sound basis on which to cope with the uncertainty through realistic scenarios of structure (element), issue (challenge), time (stage) and space (location). This process was supported by results from detailed adaptation strategies cluster that was undertaken in SITS model to react possible multi-faced impacts of climate change on livelihood capitals, livelihood options, and livelihood outputs. The disaster risk, water availability, food security, and GESI become the key determinants of strengthening capacity of livelihood adaptation in the Koshi River basin. To deal with the uncertainty of climate change, the cascading adaptation based on SITS model drives an innovation to achieving the accuracy and efficiency of livelihood adaptation in space, time, and issue through a structured approach and stratification.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.accre.2020.05.005.

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