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ASSESSMENT OF FLOOD HAZARD AND AGRICULTURE DAMAGE UNDER CLIMATE CHANGE IN THE BAGMATI RIVER BASIN OF NEPAL

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Abstract

Assessment of flood hazard and damage is a prerequisite for flood risk management in the river basins. The mitigation plans for flood risk management are mostly evaluated in quantified terms as it is important in decision making process. Therefore, analysis of flood hazards and quantitative assessment of potential flood damage is very essential for mitigating and managing flood risk. This study focused on assessment of flood hazard and quantitative agricultural damage in the Bagmati River basin including Lal Bakaiya River basin of Nepal under climate change conditions. Flood hazards were simulated using Rainfall Runoff Inundation (RRI) model. MRI-AGCM3.2S precipitation outputs of present and future climate scenarios were used to simulate flood hazards, flood inundation depth, and duration. Flood damage was assessed in the agricultural sector, focusing on flood damage to rice crops. The flood damage assessment was conducted by defining flood damage to rice crops as a function of flood depth, duration, and growth stage of rice plants and using depth-duration-damage function curves for each growth stage of rice plants. The hazard simulation and damage assessment were conducted for 50- and 100-year return period cases. The results show that flood inundation area and agricultural damage area may increase in the future by 41.09 % and 39.05 % in the case of 50-year flood, while 44.98 % and 40.76 % in the case of 100-year flood. The sensitivity to changes in flood extent area and damage with the intensity of return period was also analyzed.

Keywords: flood hazard, agricultural damage, climate change, hydrological scenario, future impact

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Introduction

Recently risk of flood disaster has been increased by rapid urbanization and developmental activities in many countries, which is expected to increase more in the future by climate change impact. Flood disasters cause serious damage such as loss of lives, loss of properties and loss of livelihoods. Recent researches have also reported changes in precipitation pattern and intensity as well as changes in river runoff due to climate change (Babel *et al*., 2014; Shrestha and Lohpaisankrit, 2017; Iwami *et al*., 2017). In order to reduce flood damage in the future by implementing flood mitigation measures and adaptation planning, it is necessary to understand future changes in precipitation and flood hazard conditions considering climate change scenarios, and also, it is necessary to assess flood hazard and expected damage in the future. Furthermore, quantitative analysis of flood hazard and risk under climate change is also essential for reducing flood damage and for the evaluation of risk mitigation measures (Meyer *et al.*, 2007). Some researchers have recently attempted to assess flood hazard and risk under climate change focusing in socio-economic impacts (Bouwer *et al*., 2010; Ranger *et al*., 2011; Rojas *et al*., 2013; Hattermann *et al*., 2014; Alfieri *et al*., 2015; Detrembleur *et al*., 2015), and pointed out importance of flood hazard and damage assessment considering climate change and social changes.

This study focuses on assessment of flood hazard and agriculture damage under climate change in the Bagmati River basin of Nepal, including Lal Bakaiya River basin. The Bagmati River basin is one of the major basins of Nepal, which is also an important basin in Nepal in terms of socio-economic and industrial activities as the capital city (Kathmandu valley) located in the basin. This basin also plays a significant role in water supply for drinking and irrigation purposes in the basin (Shrestha and Sthapit, 2015). Therefore, it is necessary to investigate changes in river flows, flood hazards and damage conditions due to climate change in the basin for adaptation measures. To analyze climate change impact, Atmospheric General Circulation Model (AGCM) precipitation outputs produced by the Meteorological Research Institute (MRI) of Japan (MRI-AGCM3.2S) were used for the present study. MRI-AGCM3.2S outputs based on the representative concentration pathways RCP8.5 greenhouse gas emission scenario experiments were used for future climate (2075-2099) while the MRI-AGCM3.2S precipitation under the Atmospheric Model Intercomparison Project experiment (AMIP-type) was used for the present climate (1979-2003). Flood discharge and flood inundation were simulated using Rainfall-Runoff-Inundation (RRI) model to assess flood hazards under present and future climatic conditions. To assess flood hazard and damage for specific return period (50- and 100-year floods), frequency analysis was also conducted for both present climate and future climate cases using 1-day basin average annual maximum precipitation. The hazard simulation and damage assessment were conducted for different year return periods, and sensitivity to changes in flood extent area and damage was also analyzed.

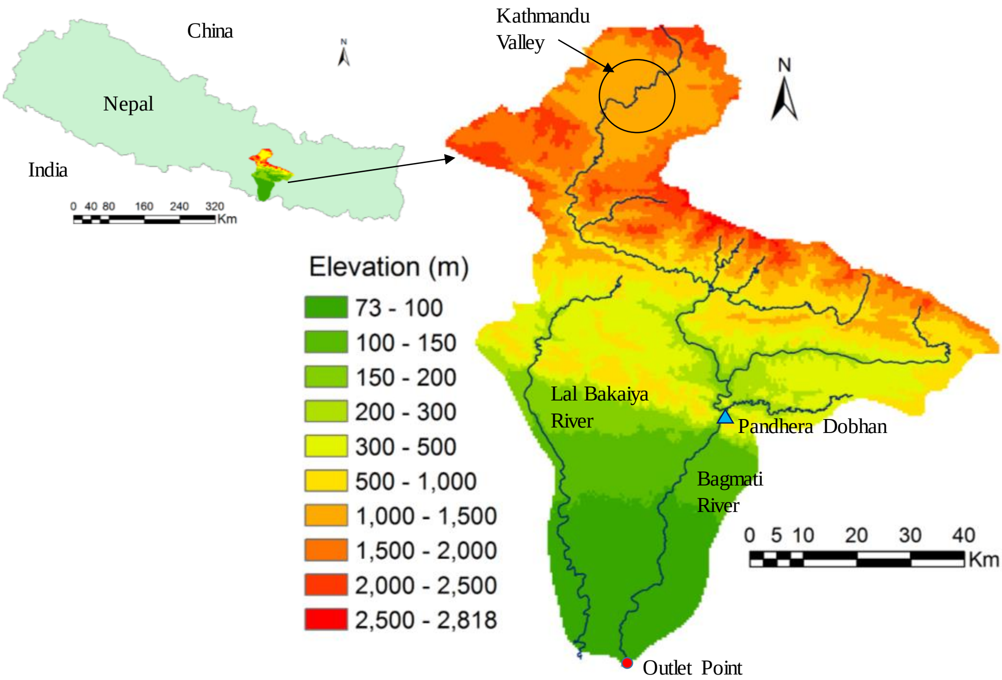

Figure 1. Map showing location and elevation ranges of study area.

Study Area

Bagmati River basin, which is located in the central part of Nepal, is one of the most flood-prone river basins in Nepal. **Figure 1** shows the location and basin boundary of study area and it covers an area of 4958 km^2 (including area of Lal Bakaiya River basin). The Bagmati River originates in the north of the Kathmandu valley and runs through the middle of the valley. Average annual precipitation in the basin is about 1800 mm with 80 percent of the total rain in the monsoon season (Babel *et al.*, 2014; Shrestha and Sthapit, 2015). During every monsoon season, high floods in the basin cause serious damage such as damage to agriculture, houses, infrastructure and loss of lives. Rural and urban areas as well as agricultural lands were affected almost every year in the study area, and flood risk in the low laying areas of the basin is increasing due to intense monsoon rainfall, improper land use practices and changes in rainfall pattern.

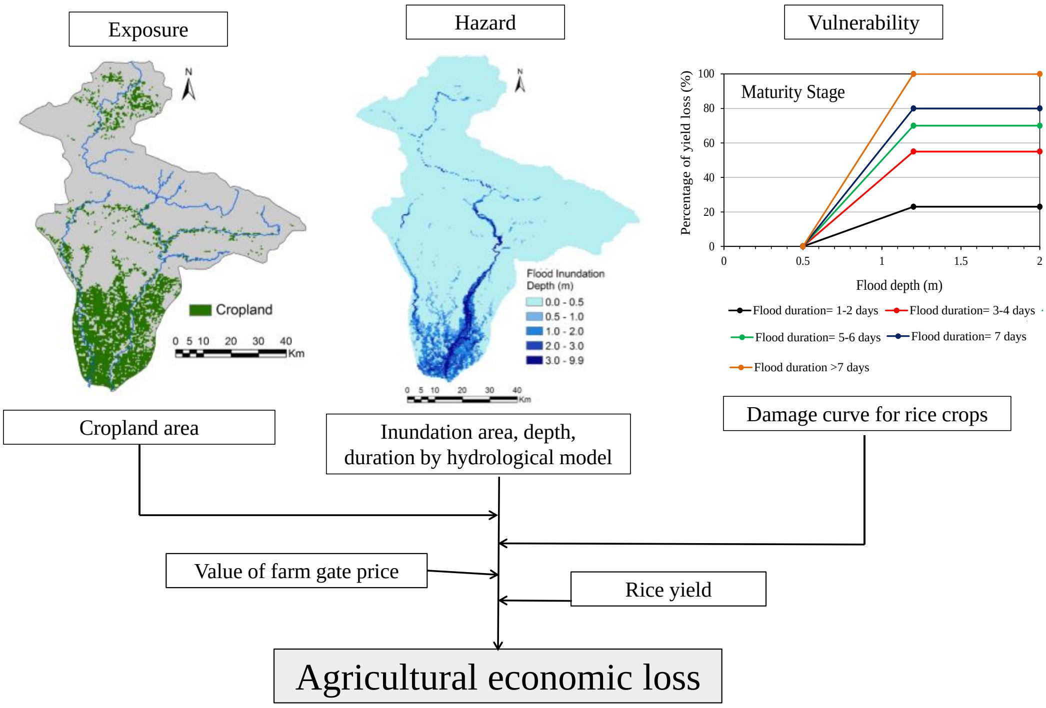

Figure 2. Schematic diagram of flood damage assessment methodology.

Methodology

Figure 2 shows the overall process of flood hazard and agricultural damage assessment. Flood hazard assessment is conducted by applying a hydrological/hydraulic simulation model using hydro-meteorological data, topographic data, land-use data, and the operation rules of river management structures. Information on past flood hazards, such as rainfall, river water level, discharge volume, and inundation area and depth, is required to develop and calibrate a simulation model (Shrestha *et al.*, 2019b).

Flood Hazard Assessment

The RRI model, which was developed by Sayama *et al.* (2012), was employed to simulate rainfall runoff process and flood inundation. The RRI model is a two-dimensional model and it can simulate rainfall-runoff processes and flood inundation simultaneously. The RRI model calculates flood runoff in the slopes and river channels separately. The flow on the slope surfaces is calculated with a two-dimensional diffusive wave model, while the channel flow is calculated with a one-dimensional diffusive wave model. The details of the RRI model can be found in Sayama *et al.* (2012). The digital elevation model of HydroSHEDS (Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales) data at 15 arc-s (approximately 450 m spatial resolution), which was developed by the World Wildlife Fund and the U. S. Geological Survey, was used in the study. The river width and depth at each river grid cell were approximated by using empirical equations (Sayama *et al.*, 2012). The Green-Ampt infiltration model was employed to calculate vertical infiltration through surface and subsurface soil layers. Silty-clay soil type was assumed in the study area by referring digital soil map of FAO (Food and Agriculture Organization). The values of Green-Ampt infiltration parameters were initially defined according to soil texture class and which were fine-tuned during the process of calibration. The ground gauge rainfall data were used for past flood events and the rainfall distributions in the basin were computed using Thiessen polygon method. The model parameters were calibrated with 2002 flood event and validated with 2004 flood, by comparing calculated flood discharge with observed data at Pandhera Dobhan gauging station. In addition, calculated flood inundation area was also compared with flood extent area observed by Moderate Resolution Imaging Spectroradiometer (MODIS) satellite images, which was delineated based on Normalized Difference Vegetation Index (NDVI).

To analyze climate change impact on flood hazard, MRI-AGCM3.2S precipitation outputs based on the representative concentration pathways RCP8.5 greenhouse gas emission scenario experiments (a highest greenhouse gas emission scenarios in RCPs and emissions continue to rise throughout the 21st century) were used for future climate (2075-2099), while the MRI-AGCM3.2S precipitation under the AMIP-type was used for the present climate (1979-2003). In this study, the bias-corrected precipitations of MRI-AGCM3.2S for the aforementioned experiments by Hasegawa *et al*. (2016) were used, in which bias correction was performed with grid-based daily APHRODITE precipitation data (Asian Precipitation-Highly-Resolved Observational Data Integration towards Evaluation of Water Resources-APHRODITE) using method proposed by Inomata *et al.* (2011). For flood hazard assessment under climate change, a series of flood simulations were conducted using RRI model to assess flood hazards under present and future climatic conditions produced by MRI-AGCM3.2S for different year return periods. To assess flood hazard and damage for specific return period (50- and 100-year floods), frequency analysis was also conducted for both present climate and future climate using MRI-AGCM3.2S precipitation data based on 1-day basin average annual maximum precipitation. For flood hazard assessment with different rainfall intensity, two rainfall patterns from each climate were selected according to highest rainfall volume from the 25 years period precipitation data of each climate. The hazard simulation and damage assessment were conducted for 50- and 100-year return period cases. To analyze sensitivity of intensity of return period, flood hazard simulation and damage assessment were also conducted for 10- and 25-year flood events.

Flood Damage Assessment

This study focused on assessment of flood damage to agriculture, particularly focusing on flood damage to rice crops. Flood damage to agriculture was defined as a function of flood depth, flood duration, and rice growth stage, and it can be estimated by the following equations (Shrestha *et al*., 2019a, b):

$$LossVolume = Rice\ Yield \times Damaged\ Area \times Yield\ Loss \quad (1)$$

$$DamageValue = LossVolume \times Farm\,Gate\ price \quad (2)$$

Calculation was performed using the values of farm gate price equal to 21 Rs/kg, and the rice yield equal to 3880 kg/ha (Pant *et al*., 2013). Flood damage curves derived by Shrestha *et al.* (2016) were applied to assess flood damage to rice crops in the study area. The paddy fields were extracted using a global land cover map prepared by the Global Land Cover by National Mapping Organizations for the study areas. Total cropland areas in the study area was about 1020.802 km^2 (approximately 20.5 % of the whole study area). Since flood event usually occurs during reproductive stage of the rice crops, flood damage curves for reproductive stage of rice crops were applied to assess flood damage for different return period flood events.

Results and Discussion

The RRI model was calibrated with 2002 flood event and validated with 2004 flood event. **Figure 3** shows comparison of calculated flood discharge with observed discharge at Pandhera Dobhan station for flood events of July 2002 and July 2004. The figures show that calculated discharges were agreeable to the observed data. The model performance was also evaluated using R^2 (squared of correlation coefficient) and Nash Sutcliff Coefficient of Efficiency (NSCE) metrics. The values of R^2 and NSCE of discharge at the Pandhera Dobhan were about 0.814 and 0.79 in the case of July 2002 flood event, while 0.821 and 0.796 for July 2004 flood. The calculated discharge matches well with the observations indicating high R^2 and NSCE values. **Figure 4** shows the maximum flood inundation depth and flood extent area calculated by the model and observed flood inundation extent based on 8-days MODIS satellite remote sensing which were acquired on 28 July 2002. The calculated flood inundation extents were very similar to the observed extents by MODIS satellite remote sensing.

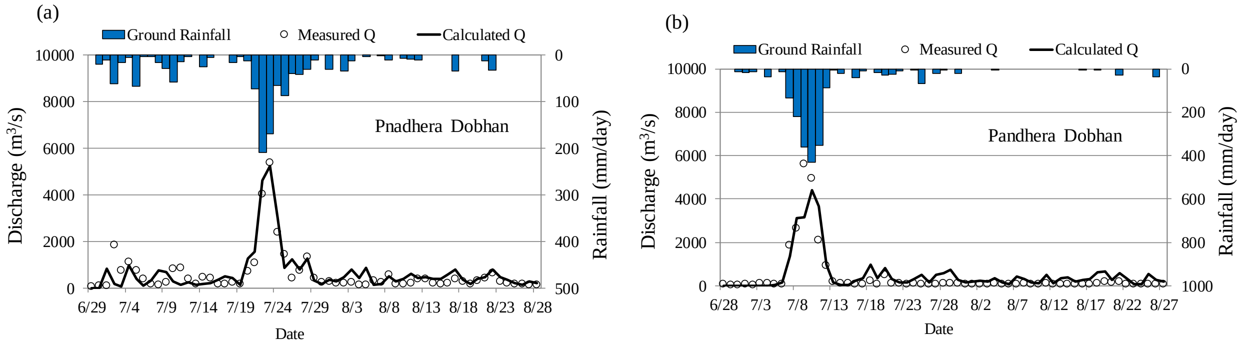

Figure 3. Calculated and observed flood discharge at Pandhera Dobhan station (a) 2002 flood, and (b) 2004 flood.

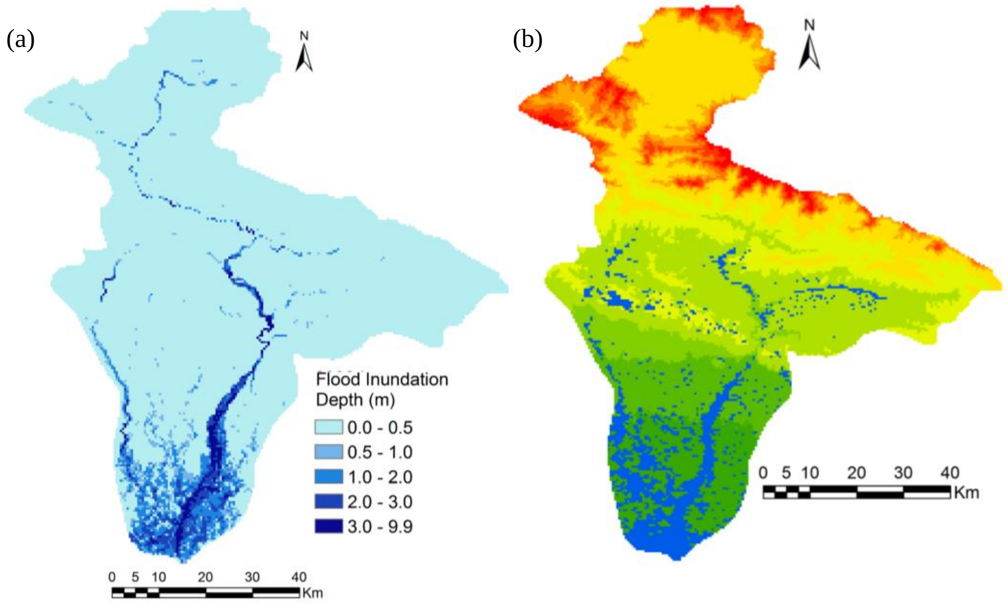

Figure 4. (a) Calculated maximum flood inundation depth during July 2002 flood and (b) observed flood extent area based on 8-days MODIS remote sensing images acquired on 28 July 2002.

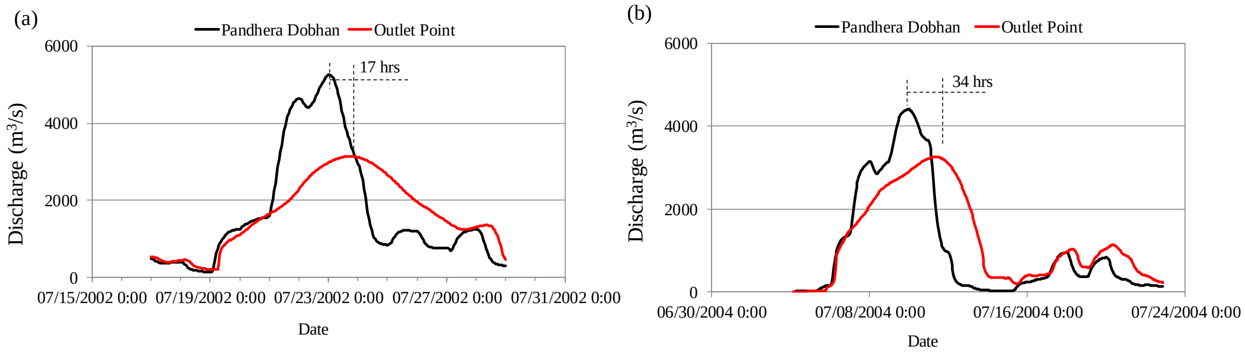

Figure 5. Comparison of simulated flood discharges at Pandhera Dobhan and outlet point and flood travel time (a) 2002 flood, and (b) 2004 flood.

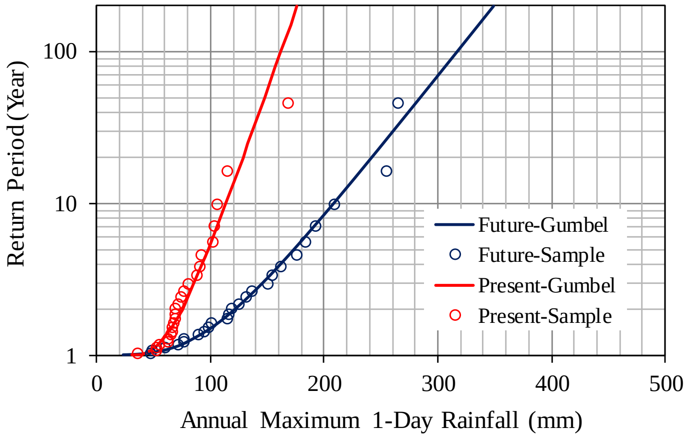

Figure 6. Plot of return period analysis for both present climate and future climate cases.

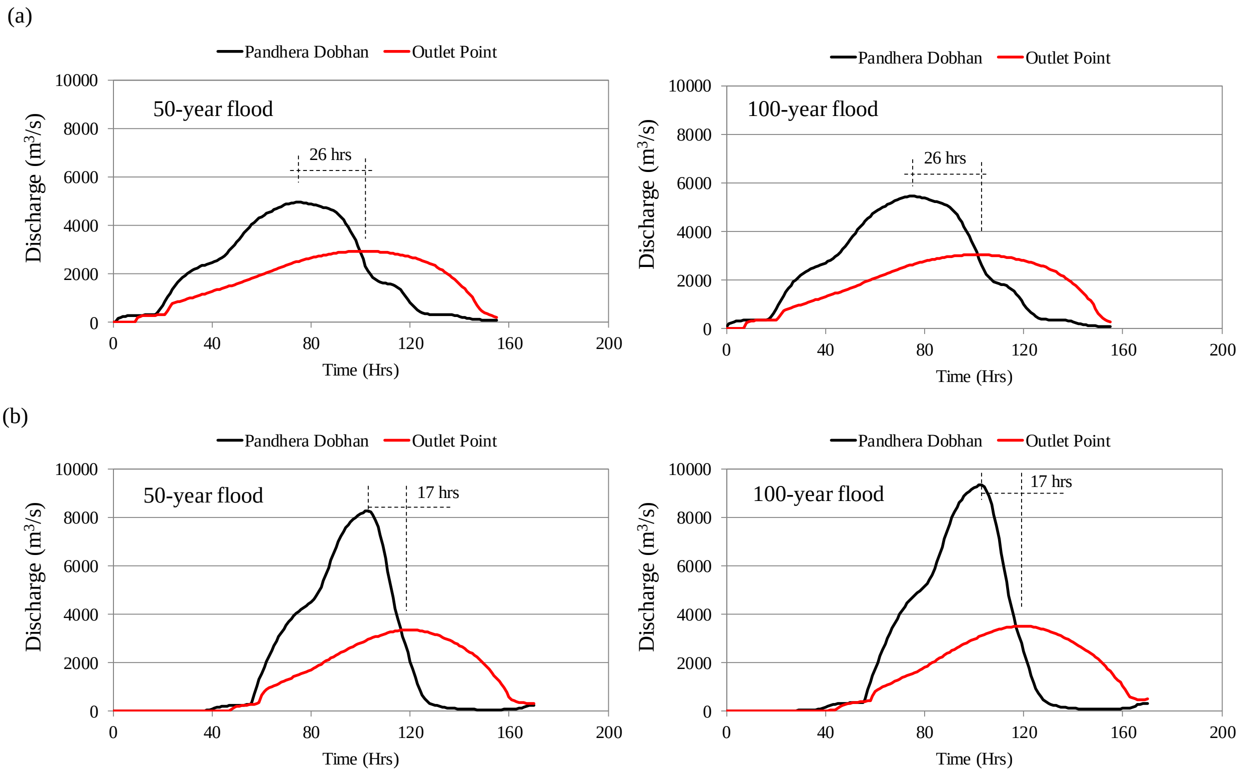

Figure 7. Comparison of simulated flood discharges at Pandhera Dobhan and outlet point for 50- and 100-year flood events (a) present climate, and (b) future climate conditions.

Figure 5 shows the comparison of simulated flood discharge of 2002 and 2004 flood events at the Pandhera Dobhan and outlet point. The figure shows that the flood peak was significantly reduced at the outlet point compared to Pandhera Dobhan, which was due to various reasons such as overflow of river water in the upstream areas, changes in river slopes, flood storage in the river reach and others. The travel time of flood peaks between Pandhera Dobhan and outlet point was about 17 hrs in the case of 2002 flood event, while it was about 34 hrs in the case of 2004 flood event. The flood discharges with higher peak have a shorter flood travel time, and the information on flood travel time is very useful for flood forecasting and warning systems as well as for preparedness activities.

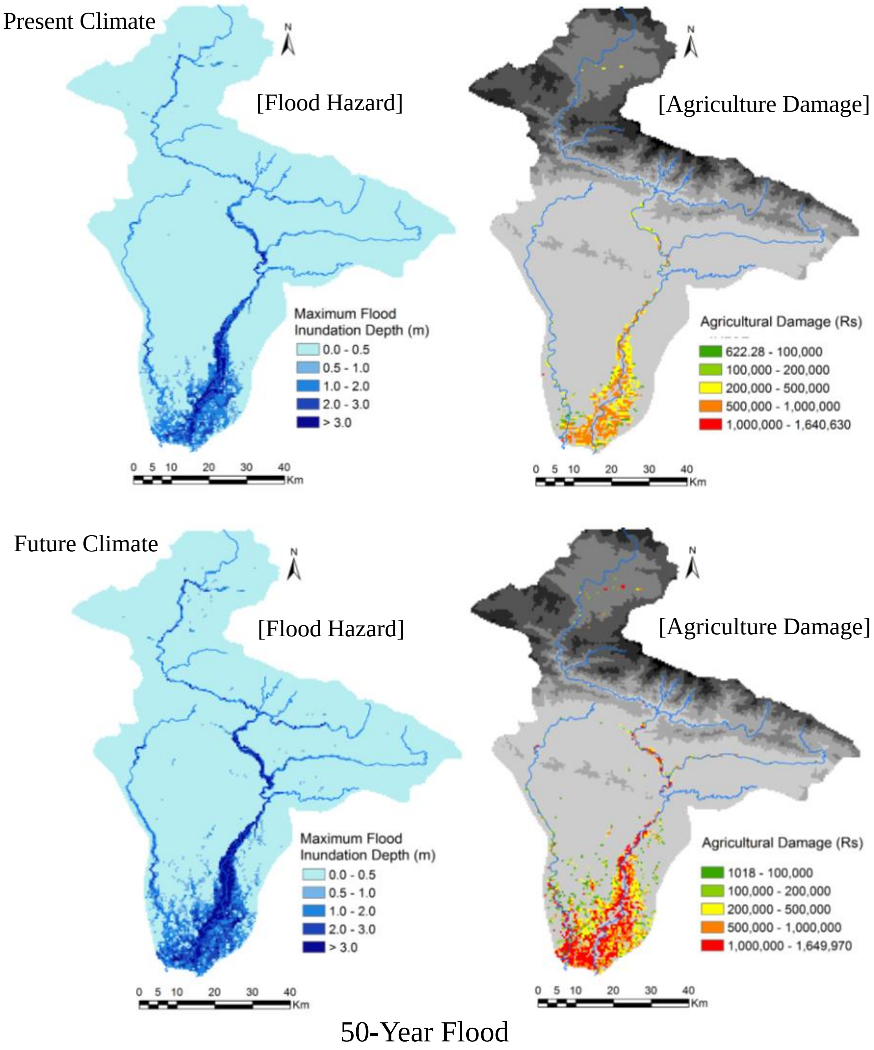

Figure 8. Comparison of flood hazard and agriculture damage under present climate (upper) and future climate (lower) for 50-year flood.

Figure 6 shows the frequency curves for both present climate and future climate cases. The figure shows that extreme precipitation may increase significantly in the future due to climate change. The amount of 1-Day precipitation for 50- and 100-year floods were 148 mm/day and 162 mm/day in the case of present climate conditions, while they were 284 mm/day and 316 mm/day in the case of future climate condition. The frequency analysis results show that precipitation may increase in the future by more than 90%. Previous researches also reported that precipitation in the Bagmati River basin is increasing in trend (Shrestha and Sthapit, 2015; Mishra and Herath, 2015). Shrestha and Sthapit (2015) reported that the increase rate of the precipitation in the Bagmati River basin is about 2.17 mm/year on the average. If rainfall continuously increases with this rate in the basin, large scale flood disasters may occur in the future.

Figure 7 shows the simulated flood discharges at Pandhera Dobhan and outlet point for 50- and 100-year flood events under present and future climate conditions. The figure also shows the travel time of the flood peak between the Pandhera Dobhan and the outlet point. The flood peak is higher in the case of future climate conditions compared to the present climate conditions. The results suggest that the flood peak discharge at Pandhera Dobhan may increase in the future by 67 % in the case of 50-year flood and by 71 % in a 100-year flood; at the outlet point, by 14 % and by 15 %. Mishra and Herath (2015) also found that increase of peak flood discharge in the future due to climate change was about ranges from 24 to 40 % in the Bagmati River basin. The flood peak travel time between the Pandhera Dobhan and the outlet point was about 26 hrs in the case of present climate condition, while it was about 17 hrs in the case of future climate condition. **Figure 8** and **Figure 9** show the calculated flood hazard and agricultural damage for 50- and 100-year flood events under both present climate and future climate scenarios. The comparison results in the figure are the worst damage value cases in each climate condition. **Table 1** and **Table 2** summarize calculated results of flood hazard and damage under present and future climate cases. The results suggest that the flood inundation area in the study area may increase in the future by 41.09 % in the case of 50-year flood, and by 44.98 % in the case of 100-year flood. The flood damage area in agriculture sector may also increase in the future by 39.05 % in the case of 50-year flood, and by 40.76 % in the case of 100-year flood. The agricultural economic loss in the future may also increase by 68.7 % in the case of 50-year flood, and by 73.7 % in the case of 100-year flood. The agricultural economic loss was estimated based on current condition and value, which may differ in the future conditions. The results show that flood hazard and damage are more serious in low land areas, most downstream of the basin and along the main river.

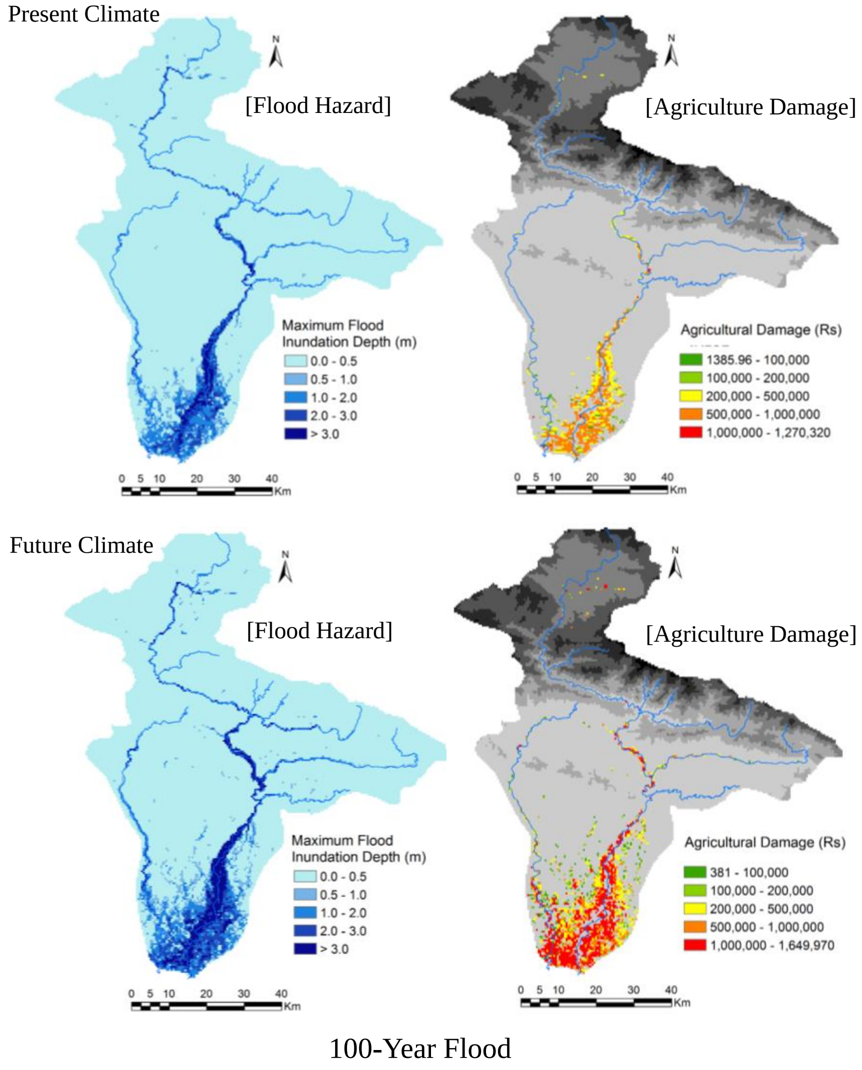

Figure 9. Comparison of flood hazard and agriculture damage under present climate (upper) and future climate (lower) for 100-year flood.

Table 1 Summary of flood inundation areas under present and future climate conditions.

Flood Scale	Inundation area (km^2) (Present Climate)	Inundation area (km^2) (Future Climate)	% Change in future (+ or -)
50-year flood	437.60	617.42	+41.09
100-year flood	474.45	687.89	+44.98

Table 2 Summary of agricultural damage under present and future climate conditions.

Flood Scale	Damage area [value] (Present Climate)	Damage area [value] (Future Climate)	% Change in future area [value] (+ or -)
50-year flood	276.4 km^2 [864.06 mil. Rs]	384.34 km^2 [1458.3 mil. Rs]	+39.05 [+68.7]
100-year flood	301.1 km^2 [982.4 mil. Rs]	423.83 km^2 [1706.9 mil. Rs]	+40.76 [+73.7]

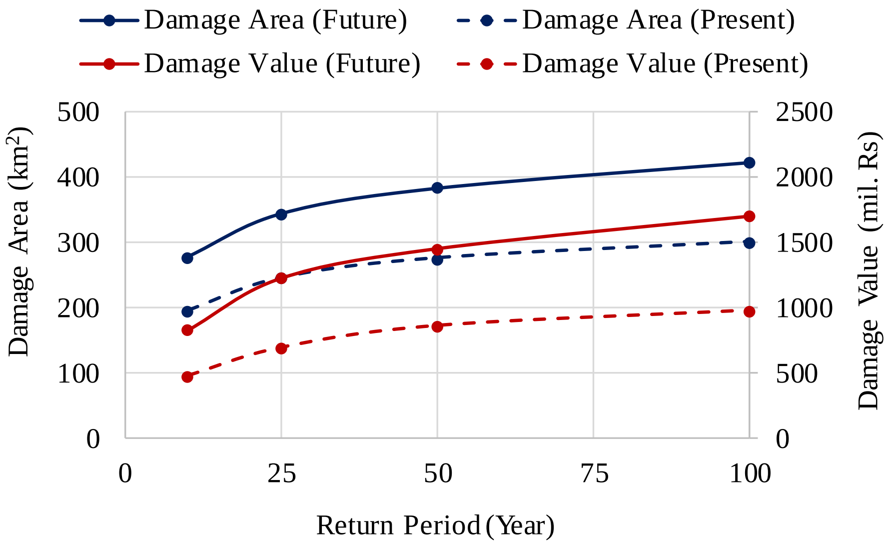

Figure 10. Change in agricultural damage area and damage value with different return period floods.

The sensitivity to changes in flood extents areas and damage with intensity of return periods was analysed using the simulated results. The increase in flood inundation area between 50- and 100-year floods in the present climate case is about 8.4 %, while it is about 11.4 % in the case of future climate case. The increase rate of flood inundation area with intensity of the return periods is higher in the future climate case compared to present climate case. **Figure 10** shows the changes in agricultural damage area and value with different return periods under both present and future climate conditions. The increases in agricultural damage area and damage value between 50- and 100-year floods in the present climate case are about 8.9 % and 13.6 %, while they are about 10.2 % and 17.04 % in the case of future climate case. The increases in agricultural damage area and damage value with changes in flood intensity from 50- to 100-year flood are comparatively higher in the case of future climate case compared to the present climate case. The results of this study suggest that flood hazard areas and agriculture damage in the Bagmati River basin may increase in the future due to climate change. The increase of flood hazard areas and damage due to climate change in the future has also been reported by previous studies for other river basins. Shrestha *et al.* (2019a) found that flood inundation areas and rice-crops damage in the future will likely to increase in the river basins of Southeast Asia. Iwami *et al.* (2016) also reported that flood inundation in the river basins of Asia may increase in the future due to climate change. Alfieri *et al.* (2015) also reported that projected socio-economic impact of flooding in Europe was about 220% on average by the end of the century. Bouwer *et al.* (2010) also reported that expected flood damages in a Dutch polder area of the Netherland may increase by between 46 to 201 % due to climate change by the year 2040, compared to the condition in the year 2000. The flood risk due to impact of climate change may increase in the future, not only at river basin scale, but also at global scale (Nigel *et al.*, 2016).

The results of this study provide useful information to implement flood mitigation actions for climate change adaptation such as land use planning and new flood defenses. By understanding flood hazard and damage conditions in the future, flood mitigation plan and climate change adaptation measures should be properly planned and implemented in the study area to reduce flood disaster in the future.

Conclusion

Flood hazard and agricultural damage were assessed in the Bagmati and Lal Bakaiya River basins under climate change scenarios. The precipitation amount for specific flood events such as 50- and 100-year floods may increase in the future by more than 90 %. Analysis results also suggest that flood inundation area, agricultural damage area and agricultural economical loss may increase in the future. The flood inundation area in the study area may increase in the future by 41.09 % in the case of 50-year flood, and by 44.98 % in the case of 100-year flood. The agricultural flood damage area may increase in the future by 39.05 % in the case of 50-year flood, and by 40.76 % in the case of 100-year flood. The agricultural economic loss in the future may also increase by 68.7 % in the case of 50-year flood, and by 73.7 % in the case of 100-year flood. The increases in flood extent area and damage with the intensity of return period are higher in the future climate case compared to present climate case.

The results of flood damage assessment in this study can be useful to implement flood mitigation actions for climate change adaptation. The effects of land-cover and social changes in the future were not considered in this study; however, it is recommended to consider such effects in further study. The impact of climate change on flood damage in the agricultural sector using MRI-AGCM3.2s precipitation outputs were analyzed; however, it is also recommended to use more ensemble data and other GCM experiment outputs to evaluate uncertainty in further study for better understanding impacts of climate change with various scenarios.

In this study, flood hazard and agricultural damage were assessed using globally available topographical data and global land cover data. Flood hazard and damage can be further improved by adjusting globally available topographical data with ground observed elevation data, and also, by using locally available land use/land cover data to consider actual local characteristics. The damage curves for rice crop applied in this study were developed for other Asian country because such curves or past flood damage data are not available for the study area. Though there are many similarities of rice crop in Asian countries, it is recommended that each country should develop damage curves to reflect the actual characteristics of their rice-crop cultivation.

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