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Analyzing the Future Flooding and Risk Assessment under CMIP6 Climate Projection Using HEC-HMS And HEC-RAS 2D Modelling of Babai River Basin

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Abstract
Floods are the mostly occurring natural hazards around the globe. Many lives and property are in a serious threat every year due to this hazard. Nepal has also always been a part of it due to fast flowing larger rivers. Terai mainly becomes the main victim yearly and bring about loss of lives and property. Due to these Hazards, flood prediction has always been useful in eradicating the Risks it brings about. In order to simulate the rainfall-runoff process in river basins, various well-known and widely-applicable hydrologic models have been developed, including HEC HMS (version 4.9) by the US army corps of Hydrologic Engineering center. and HEC-RAS version 6.0.2 which is able to perform two dimensional unsteady simulations. In this study Babai River is modeled and run using HEC HMS rainfall runoff model for hydrologic analysis and HEC-RAS 2D unsteady simulation for hydraulic analysis of results and for preparation of hazard and risk maps for different flood flows and future climatic flood flows. HEC-HMS is used for the hydrologic analysis, and HEC-RAS is used for the hydraulic modeling. By creating flood inundation maps, forcing the model with predicted precipitation can benefit the flood warning system. CMIP6 climate projection is used for generating future precipitation data of extreme climatic condition. This study also compared the future and existing flooding scenarios with to understand the increased severity of flooding in future years. This study compares the historical flooding extent to the estimated flooding in the future as a result of changing global climate. The predicted flood risk was assessed, and vulnerability and hazards assessments were used to help determine the level of risk in the research area. Finally, the projected design discharges were used to map the risk zones. The area of the future floodplain that will be flooded was thus predicted by this study. In order to assess the extent to which urban and agricultural regions might be affected by rising flood levels, it also evaluated the potential for future flooding.

Keywords
Climate Change, Coupled Model Inter Comparison Project Phase 6 (CMIP6), HEC-HMS, HEC-RAS

1. Introduction

Flooding is Nepal's most catastrophic hazard, caused by an excessive deforestation, unplanned habitation, deforestation near the watershed, unstable geology, heavy monsoon rains, and rough mountain terrain. If we look globally then there are various deadly cases of flood which has cost loss of valuable lives [1]. Various Flood modelling programs have given benefits to scientific communities to reduce the negative impacts of flooding. Both structural and non-structural are the key factors for the reduction of the hazards associated with flood. Hard measures to minimize the loss associated with flood may be costly and time consuming but soft measures are of equal importance [2]. A study conducted for the flood hazard assessment for the return period of 20, 50,100 and 200 years in Khando River (Tributary of Koshi River). Study quantifies the hazards and vulnerabilities all over the catchment. Study coupled flood hazard analysis with vulnerability 5 analysis of the prevailing construction structures such as daub house and wattle. On the basis of the inundation depth, vulnerable and delicate function were created for 2017 flood event [3].

Climate change is an alarming topic that is posing many extreme hydrological events such as floods, heatwaves, and drought, all over the world. The International Panel on Climate Change (IPCC) projected an increase of 1.5-2 degrees centigrade of temperature beween 2030 to 2052 [4]. Rising temperature could lead to the changes in hydrological cycles along with changing precipitation which could eventually impact the variability of streamflow. [5] conducted research utilizes the hydrologic engineering center - hydrologic modelling system (HEC-HMS) and Hydrologic Engineering Center – River Analysis System (HEC-RAS) as the modelling tool to develop runoff and floodplain inundation evaluation model for known precipitation. The model also incorporates Aeronautical Reconnaissance Coverage Geographic Information System (ARCGIS) extensions- HEC-Geo RAS and HEC-Geo HMS for the spatial analysis of the watershed. The hydrologic analysis is performed using HEC-HMS while the hydraulic modeling is done using HEC-RAS. [6] used the HEC-RAS One Dimensional model to study a section of the Balkhu River inside the Balkhu Catchment and discovered that higher flood depth rises and low flood depth reduces with rise in flood intensity. Forcing the model with forecasted precipitation can also help with flood warning system by generating pre-flood inundation maps.

[7] studied to evaluate the behavior of river flooding and the spread of Karaj in Alborz province, combining hydrological model HEC-HMS and HEC-RAS hydraulic model was used for this purpose, meteorological and hydrometric stations using rainfall data and runoff area HEC-HMS model was calibrated and HEC-RAS hydraulic model using river channel and terrain data, flood zones showed with return periods of 10, 20 and 50 years in GIS was prepared. [2] studied hazard mapping and flood risk assessments in the downstream region of the Karnali River basin for different return-period floods, using HEC-RAS hydraulic model. In this paper HEC-HMS is used to generate hydrograph using known precipitation data of met station of study area. CMIP6 climate projection is used for generating future precipitation data of extreme climatic condition. HECRAS 2D is used to simulate the flood event in the Babai river. The simulated results are validated using the flood extent database created from satellite images. Flood hazard map, vulnerability and exposure analysis is done which leads to generate flood risk map.

2. Material and Methods

2.1 Study area

The Babai River, which is the subject of the current study, is a medium-sized perennial river that flows through the lowlands of the Dang and Bardiya districts and begins at the eastern end of the Dang valley in Lumbini Province. The research area is in the Bardiya district, which begins in the Bardiya National Park area and runs down the Babai River until it flows at the Nepal-India border.

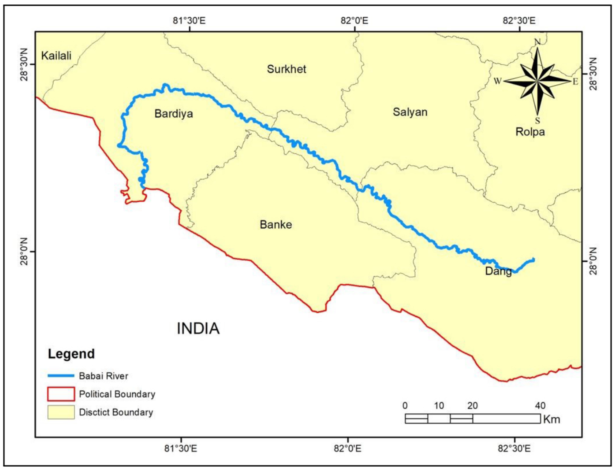

Figure 1: Location map of study area

This watershed's catchment area is approximately 3250 km2. It is located between 27°56' and 28°32' N latitude and 81°14' and 82°38' E longitude. Flowing into the Karnali River from the Babai stream (the third biggest river of Nepal). The Babai river basin is located partly in the Middle Mountainous Zone. The basin's height ranges from 147 to 2880 meters above mean sea level. It is situated in a subtropical area. Based on data from 1975 to 2005 collected at seven climatological stations, the basin experiences 1468 mm of rainfall annually on average. The months of June through September account for about 83% of all rainfall. The single hydrological station on the Babai River is at Chepang, with a catchment area of 2570 km2.

2.2 Modeling and Analysing Process

This study generally deals with the flood risk mapping by using land use map and affected population and inundation depth and velocity which is obtained with the help of simulated model.

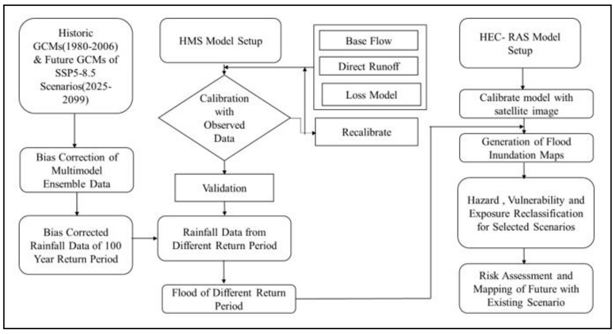

Figure 2: Stepwise methodology involved in the analysis

Digital Elevation Model is downloaded from respective sites and processed by using Arc GIS. Various hydrological information of the catchment such as flow direction, flow accumulation, watershed boundaries, and stream networks are extracted from a DEM through GIS applications and HEC-HMS. This hydrological information is useful in flood estimation of the river and acts as input parameters in hydraulic modelling. Hydrological analysis was done using hydrograph obtained from HEC-HMS. The Hydrologic Modeling System (HEC-HMS) is designed to simulate the precipitation-runoff processes of dendritic drainage basins. Hydrographs produced by the program are used directly or in conjunction with other software for studies of continuous model, event-based model etc. Model was calibrated for the year 2008 and validated for the year 2009. Shared Socioeconomic Pathways (SSP) are part of a new scenario framework developed by the climate change research community to make it easier to analyze future climate impacts, vulnerabilities, adaptation, and mitigation. Sustainable development, regional competition, inequality, fossil-fueled development, and middle-of-the-road development are all described in the SSPs. Among the SSPs, SSP5 demonstrates the Fossil-fueled development - Taking the highway (high challenges to mitigation, low challenges to adaptation). It takes into account about the drive for economic and social progress goes hand in hand with the worldwide embrace of resource- and energy-intensive lifestyles and the exploitation of enormous fossil fuel resources. By the year 2100, the various policy scenarios result in a range of radiative forcing values, from 1.9 to 8.5 W/m2, with higher values indicating stronger climate warming effects. Radiative forcing is a measurement of how much GHGs in the atmosphere warm or cool the climate, expressed in watts per meter squared (W/m2). Here, SSP 5 having the radiative forcing 8.5 W/m2 (SSP5-8.5), estimates the higher climate warning effects and the different models incorpated with SSP5-8.5 are used in this study. Hydraulic modelling of the rivers under study is done in HECRAS 2D. Terrain model is created by RAS-Mapper by utilizing available DEM data which is then used for extracting the geometry and hydraulic properties of 2D flow area. Computational cells of resolution 50m X 50m are created along the 2D flow area of the river reach. Hydraulic properties of each cell are then created by running geometric pre-processor in RAS Mapper. Manning's coefficient of the underlying terrain was assigned based on land cover data. Upstream (U/S) and Downstream (D/S) boundary condition lines are created to provide the boundary condition values for unsteady flow simulation. In the U/S boundary condition, stream hydrograph is assigned, whereas for D/S boundary condition normal depth channel slope was assigned. Computational time step was adjusted by the model based on Courant condition criteria. It is based on numerical stability of the solution, mesh size and velocity profile of the computational regime. Validation of the model is done by comparing the model flooding extent result against flooding extent obtained by using satellite image. Post validation, flood hazard (based on inundation depth and velocity), flood vulnerability (based on affected land use type) and flood exposure (based on flood affected population density) maps are prepared which leads to flood risk map. Hence, flood risk is the function of hazard, vulnerability and exposure.

3. Results and Discussions

3.1 HEC – HMS

The HEC – HMS Model was calibrated for the year September 2008 and validated subsequently for the year. These years were chosen based on the maximum flood measured in the gauging station. After the successful calibration and validation of the model, the parameters were used to estimate the other floods of different return period.

Comparing the hydrograph from the newly developed HEC-HMS model and the hydrograph obtained from the gauging station allowed to determine the robustness of the model using statistical parameters like NSE and R2.The values of NSE, and R2, and were 0.821 and 0.844 for calibration period and 0.61 and 0.7264 for validation period respectively based upon the observed and simulated data. The NSE value closer to 1 suggested that the observed and simulated hydrograph were closely fitted. The obtained R2 value signifies that the observed and simulated hydrograph are closely matched with minimal dispersion. Due to the calibration of only flooding event for short time the NSE and R2 values are not very closer to 1. The robustness of the calibrated HEC HMS model was demonstrated by the estimated statistical parameters, which were all within an accepted level. The projected flows can then be used to generate a floodplain inundation map.

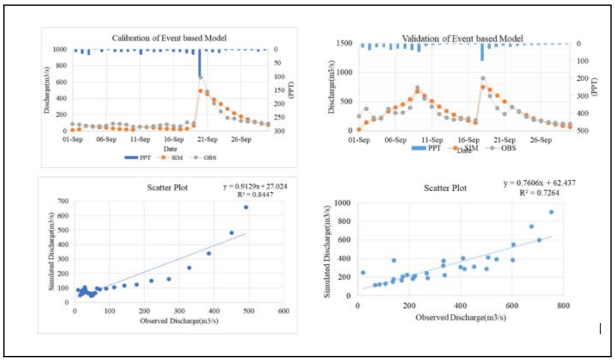

Figure 3: Calibration and Validation of HEC-HMS Event Based Model

3.2 Return Period Flood

Return period analysis was done for each historical and future climate. Each data was done return period analysis using Gumbel, Log Pearson-III and Log-Normal distribution. Return period was calculated based on the comparison between observed value and estimated rainfall value. Distribution which gives minimum of the compared values is selected. For future climate data, the maximum rainfall of different model of SSP585 scenario are used. 100-year return periods is conducted for each scenario. SSP 585 scenario is further divided into near future, mid future and far future. One day annual maximum basin average rainfall is used for return period analysis .Assessment of flood hazard of specific return period is done by estimating a rainfall hyetograph. Rainfall hyetograph for particular flood period is estimated by multiplying selected rainfall pattern of that flood period by a conversion factor.

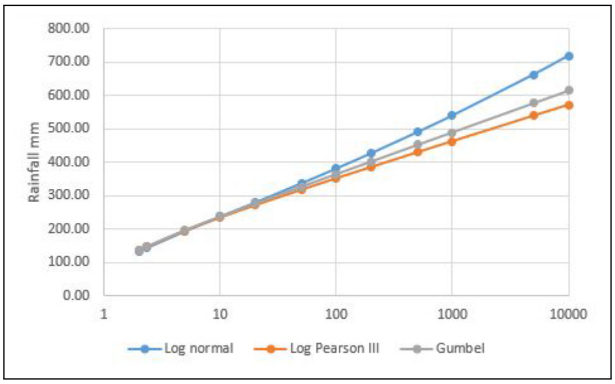

Figure 4: Graph showing rainfall values obtained from different distribution for return period calculation

3.3 Projection of Future Flows

The calibrated and validated HEC-HMS model is used for the estimation of discharge. The different return period rainfall are the inputs for the model and the model performs hydrologic operation and estimate the flood of different return period. For estimation of future 100 year return period floods, the bias-corrected precipitation data from GCM for 100 year return period are the inputs. The outputs based on the Shared Socio-economic pathways SSP585 emission scenario of greenhouse gases were used for Near future (2025-2049) , Mid Future (2050-2074) and Far Future (2075-2099) under CMIP6 (Coupled Model Intercomparison Project) was used. Across all five models ie ACCESS CM2, EC EARTH 3, INM CM 5, MPI ESM 1 and MRI ESM 1 of SSP5-8.5, EC EARTH 3 from EC Earth Consortium generated the maximum flows. For the different scenarios representing the different emission pathways, SSP5-8.5 was utilized to evaluate the design peak flows of different recurrence intervals for different future scenarios. Considering the 100-year return period flood, the future scenarios using SSP5- 8.5 Figure 2 3 Illustrates the flood hydrographs of 100 year return near, mid and far future floods

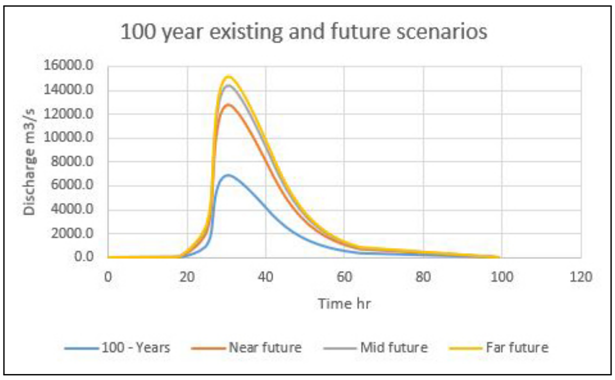

Figure 5: 100 Yr existing and future hydrograph

	100 year	Near future	Mid Future	Far Future
Peak Discharge (m^3/s)	6865.3	12770.9	14355.6	15116.3

Figure 6: Peak flow of differenct scenarios

The peak discharge of Far future, Mid Future and Near future flood was found to increase by 2.2, 2.1 and 1.9 times 100 years flood respectively. This shows the indication of increase of flood inundation extent in future.

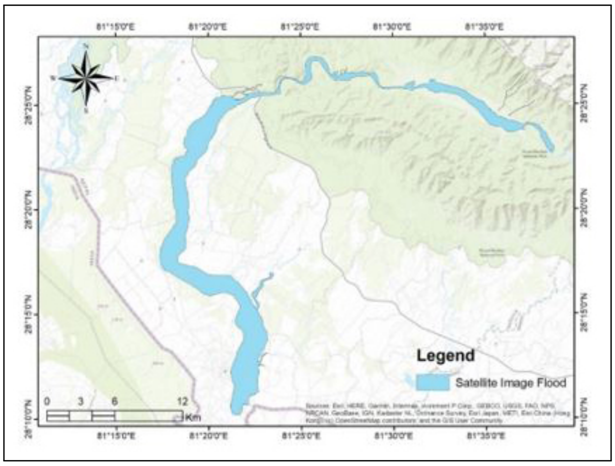

Figure 8: Validation of Flood Extent

3.4 Validation of Simulated FLow

The results obtained from HEC-RAS are validated by capturing the flood marks from satellite images obtained. It is assumed that, those flood mark are of recurrent flooding event and considered as 2 years return period of flood. Summary of Validation of Simulation result with satellite image is presented in Table 2 2 : Validation of Inundation Extent. The area of flooding extent was obtained from satellite image and 2D model of HEC-RAS. This area was used as main basis for validation of our Results.

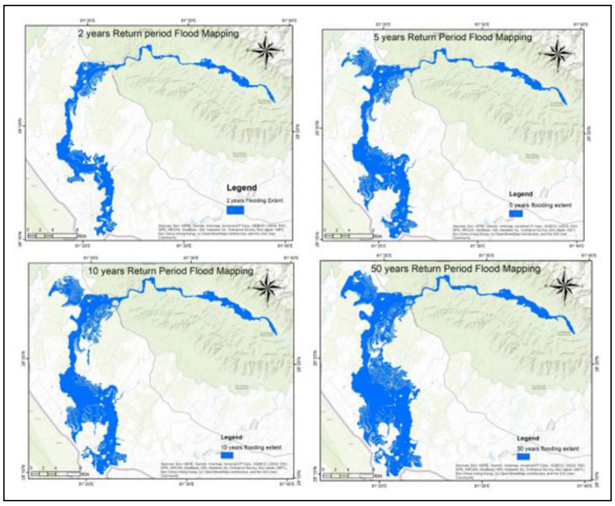

Figure 9: Inundation Map for 2, 5, 10 and 50 years Return Period Flood

River ID	River Name	2 years simulated Flow (Km sq.) 2D	Flooding as per satellite image (Km sq.)	Model validity (%) 2D
1	Babai	76.2	73.1236	95.9

Figure 7: Validation of Inundation Extent

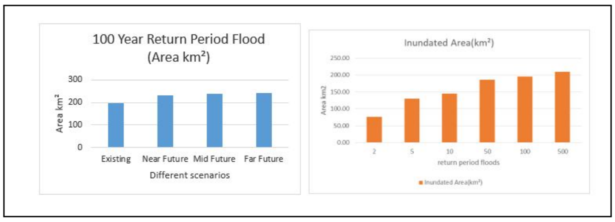

Figure 10: Inundation extent for different year return period flood and 100 year future scenarios flood

As per Figure below, it is seen that 2D result was validated to the satellite images flooding extent. Here it is seen that HEC-RAS 2D model can meet the criteria with greater accuracy. HEC-RAS 2D model showed a very good validation percentage of 95.90 % suggesting 2D model to be highly accurate for Babai River in our study. Figures 4.15 represent the inundation extent for Babai River respectively for 2 years return flood as obtained from satellite data.

3.5 Flood Hazard

Water depth and velocity was evaluated as a quantitative variable to examine the possible threat induced by existing and future flooding scenarios for 100-year design floods in order to assess the flood hazard. Both present and potential flood scenarios were classified for each of the four hazard groups and flood inundation areas under different scenarios was extracted and analysis was done. Also hazard map were prepared for different scenarios. Hazard summary of the study region is shown in Figure below..

	Area (km²) Under 100- Year return period of flood			
Hazard Type	Present	Near Future	Mid Future	Far Future
Low	83.68	55.29	50.67	51.69
Medium	21.69	19.55	19.00	16.42
High	28.72	21.19	25.98	28.94
Severe	61.59	134.58	142.78	145.83
Total	195.67	230.61	238.43	242.88

Figure 11: Flood Hazard for Different Scenarios

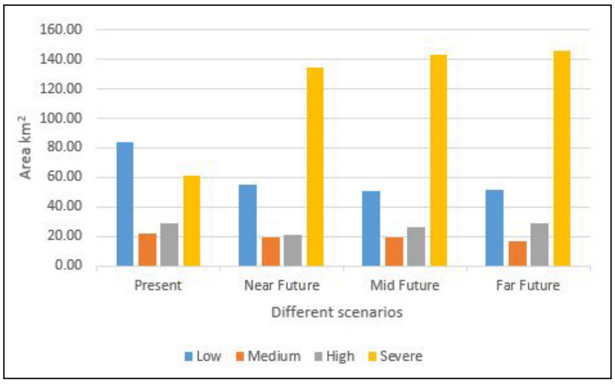

Figure 12: Hazard extent for 100-year return period flood of existing and future scenarios

Additionally, flood hazard mapping was completed for both existing and future events so that the expansion of the hazard may be closely investigated in future studies. For each scenario involving existing and future 100-year flood events, the figure shows the extent of the areas covered by each hazard classification. In comparison to the current flooding, the future scenarios has a higher flood hazard for the 100-year design flood. Furthermore, the scenario for this flooding occurrence in the far future includes a smaller low hazard floodplain and a greater severe hazard floodplain. For both existing and far future 100 year return period flood event has a severe hazard categories with 315%(61.59 km2) and 60.0%(145.83 km2) respectively. And, for both existing and far future 100 year return period flood event has a low hazard categories with 42.8%(83.68 km2) and 21.3%(51.69 km2) respectively. Since SSP5-8.5 had the highest peak flow, there may be a rise in the area of the floodplain that is flooded, with the potential for low or severe hazards. For both existing and far future 100 year return period flood event has a moderate and high hazard categories with 11.1%(21.69 km2) and 147%(28.72 km2) and 6.8%(16.42 km2) and 11.9%(28.94 km2) respectively. This shows the results extent of severe hazard area under Far future flooding extent were found to increase by 2.4 times 100 years existing flood. Similarly the results shows extent of low hazard area under Far future flooding extent were found to decrease by 0.6 times 100 years existing flood. The severity of 100-year flooding escalates in the scenarios for the present and the future, indicating probable damage in the future. In order to determine the level of risk posed within the study region, these hazard areas are linked with a vulnerability and exposure parameter.

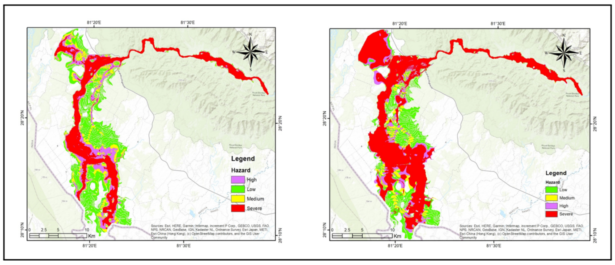

Figure 13: Hazard mapping of 100 year return period existing flood and Far Future flood

3.6 Flood Vulnerability

Vulnerability analysis of the flooded area is essential in flood risk zoning. Vulnerability of the flooded area indicates what sort of land use gets affected by the flood event. The vulnerable zones were determined by crossing the land use map of the research area polygon with each of the modeled flood events. The higher vulnerability includes cultivation land and settlement/built-up area, medium vulnerability includes forests, barren land and bushes/grass and low vulnerability includes the river bed and water bodies. Vulnerability summary of the study region is shown in the Figure below.

100 Year Return Period Flood (Area km²)				
Landuse	Far Future	Mid Future	Near Future	Present
Forest	67.29	65.29	61.23	47.19
Crops	115.09	113.09	110.16	93.73
Builtup Areas	14.57	14.33	14.03	11.19

Figure 14: Flood Vulnerability for Different Scenarios

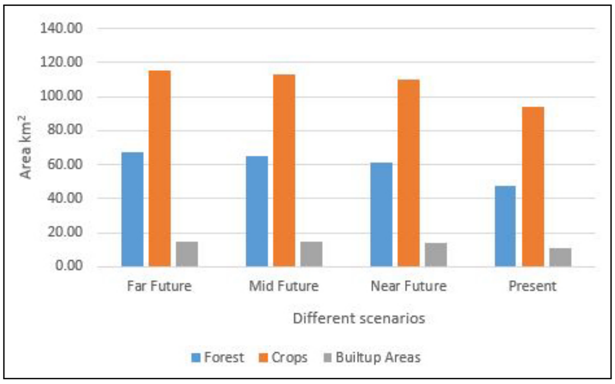

Figure 15: Flood Vulnerability for Different Scenarios

Since the results shows that area of all land use categorize are increasing in future scenarios in comparison to existing 100 year return period flood events. Results shows for far future scenario built up areas, crops (agricultural) areas and forest area were found to increase by 1.3, 1.23 and 1.43 times the existing flooding events of 100 year return period flood respectively. This shows the land use type used in this study are more vulnerable to future scenarios in contrast to existing scenario. In our study, it shows agricultural areas are more vulnerable than others categories.

3.7 Flood exposure

Flood exposure analysis is done based on the population density directly affected by the flood event. The criteria of which has been discussed in methodology. Summary of the flood exposure in the entire study region is shown in the Figure below.

Population (Nos) Affected By 100 Year Return Period Flood				
Local Authorities	Present	Near Future	Mid Future	Far Future
Badhaiyatal	20	20	20	26
Barbardiya	25598	30041	31203	31634
Gulariya	64563	75040	76998	77954
Madhuwan	5678	6050	6199	6452
Thakurbaba	15492	20461	21452	22311

Figure 16: Flood Exposure for 100 years return period flood

Here the above presented results shows in flooding events in future scenarios are more exposed than in existing flooding events. 1,38,377 numbers of people are exposed in 100 year return period flooding event in far future. Similarly, 1,35,873 nos, 1,31,613 nos and 1,11,351 nos of people are affected in 100 year return period flooding event in mid future, near future and existing scenario respectively. For far future scenario population exposed were found to be increased by 1.12 times in the existing flooding events of 100 year return period flood. It shows Gulariya municipality is highly exposed with flooding in Babai River.

3.8 Risk Zone assessment and mapping

After the Calculation of Hazard, Vulnerability and Exposure, overlay analysis was conducted with equal importance to all the above-mentioned parameters to calculate the risk map of the study area of Babai River basin.

Risk Type	100 Year Return Period Flood (Area km²)			
	Present	Near Future	Mid Future	Far Future
Low	37.12	20.7	20.1	20.0
Medium	94.65	91.6	92.3	92.8
High	59.65	103.0	108.8	112.0
Severe	4.28	15.4	17.2	18.0
Total	195.7	230.6	238.4	242.8

Figure 17: Flood risk extent on zonal classification

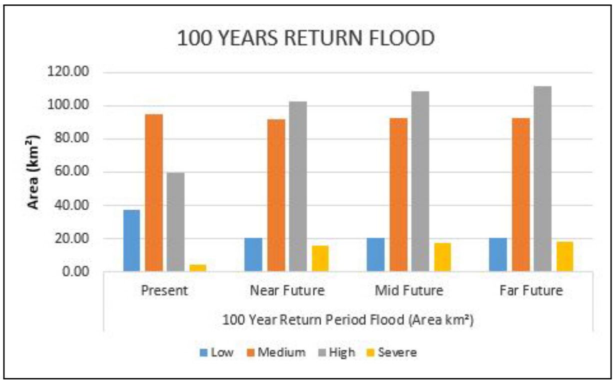

Figure 18: Flood risk extent based on risk zone on bar plot

Risk zone maps for 100-year flooding occurrences were extracted from the intersection of hazard, vulnerability, and exposure map of the present and future climatic scenario SSP5-8.5.The area that each danger zone covers is summarized in Table 2 6. A region that could incur damage is shown on the Risk Zone map (Alfieri et al. 2015). According to the existing 100-year risk maps, a larger portion of the floodplain is covered by a moderate risk zone, which covers an area of 94.65 km2. With an area of 59.65 km2, the high risk zone has the area coverage of the four risk zones for the 100-year existent flood. Also with an area of 37.12 km2 and 4.3 km2, the low risk zone and severe risk zone has area coverage for the

100-year existent flood respectively. Similarly, for 100 year flood for far future scenario, the area coverage for low, moderate, high and severe risk zones are 20.0 km2, 92.8 km2, 112.0 km2 and 18.0 km2 respectively. Moreover, Table 2 6 shows the 100-year flood potential risk area for existing near future, mid future and far future to be, 195.7 km2, 230.6 km2, 238.4 km2 and 242.8 km2 respectively. Additionally, when 100-year flood occurrences were evaluated, the flood risk extent of future scenarios was greater than that of existing scenarios, demonstrating an increase in flood risk in the future.

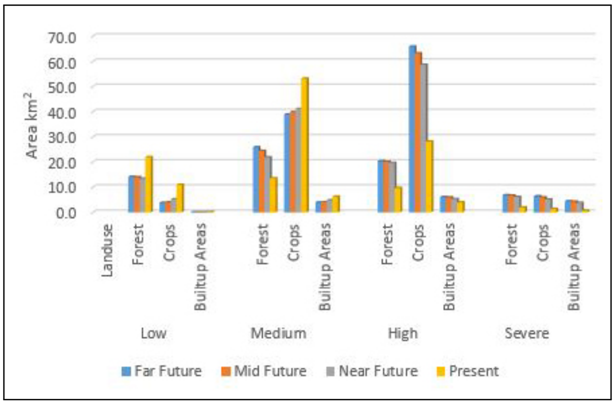

Figure 19: Risk associated with Landuse in barplot

The size of the risk zone in the study area is shown in Figure 2 12 . Risk zone mapping is an important element in this study for identifying the potential risk to each land use. Plot demonstrates that the existing 100-year poses little threat to builtup areas. The entire presence of forests in the severe to high risk zone will lessen the hazard to human life but it can cause severe risk to wild lives. Additionally, agricultural lands are seen to be in the moderate to high risk area, which could lead to a potential reduction in crop yield during flooding occurrences. The risk for built up areas seems increasing with the future scenario, demonstrating an increase in flood risk in human life in the future. The results shows mostly crops production lands falls under high risk zone, forest area falls under moderate risk zone and built up areas mostly lies on moderate to severe risk zones. Thus, the expansion of risk zone extent was greater for future scenarios, suggesting a potential increase in the hazard to human settlement and agricultural lands in the future. As a result, there may be an increase in streamflow in the future, which could result in the expansion of flood risk zones. Since 100-year floods occur more frequently than average historically and are projected to do so in the future as well, it is important to assess the risk for both existing and potential 100-year flood events. Additionally, assessing future risk would show how the study region's socioeconomic impact has changed in relation to the changes in the flood hazard area.

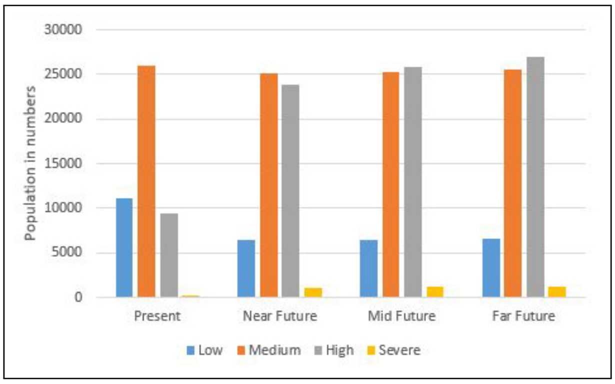

Figure 20: Risk associated with population (Bar Plot)

Figure below shows the most number of people are in moderate risk in 100 year flooding event in existing scenarios but it changes with future flooding events. Most number of population falls under high risk zone in far future 100 year flooding events. In present scenario 11171 nos, 26000 nos, 9462 nos and 166 nos of people lies in low risk, moderate risk high risk and severe risk respectively. Similarly in Far future scenario of 100 year flooding event, 6556 nos, 25613 nos, 26976 nos and 1277 nos of people lies in low risk, moderate risk high risk and severe risk respectively. As a result, there is an increase in streamflow in the future, which could result in the expansion of flood risk zones which directly affect in increase in population under risk due.

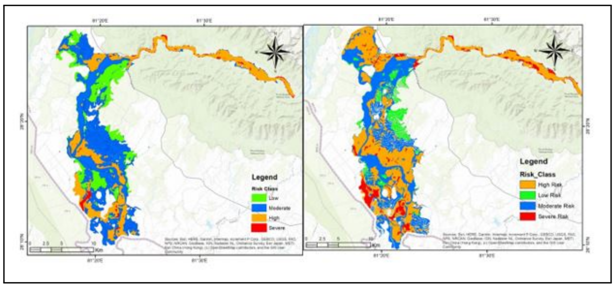

Figure 21: Risk zone mapping of 100 years return existing and Far future flood

4. Conclusion and Recommendation

• Using two flood events data from Chepang gauge station, HEC HMS model was calibrated and validated with Nash Efficiency and R2 82.1%and

0.844 and 61% and 0.7264 respectively. The future flood was forecasted using validated HEC HMS model for forecasting future extreme events. • Flood modelling of Babai river was done using HEC-RAS 2d unsteady model and the flood results was validated with reference to published satellite images of Rastrapati Chure Conservation Programme. • The future extreme climatic data obtained from SSP5-8.5 scenario of CMIP6 climatic model were used for flood analysis 100 years return flood for Near, Mid and Far future. The results of Far future flooding extent were found to increase by 1.24 times 100 years flood. • Using the SSP5-8.5 scenario for risk assessment, hazard, vulnerability, exposure and risk were reclassified and mapped. Future risks and their severity will likely increase, as seen by the size of the various flood risk zones for future flows for flood events occurring in 100 years. From the present study following recommendations has been made for flood control and mitigation at policy level: • The settlement and cultivated land areas falling under high risk and very high-risk zones need counter measures to reduce the damages and losses due to inundation. • Construction of levees and flood wall, improvement of river channels, river bank stabilization are some of the flood control measures that can be adopted. • All the infrastructure development planning should be carried out by considering the potential flood risk in the area. Following recommendations has been made for further study: • Comprehensive data base of flood risk zoning of Nepal can be prepared by incorporating rivers in Terai Plain. • Some more criteria can be incorporated for flood risk zoning study. Some criteria can be duration of inundation, financial loss due to flood, etc. • Flood study can be done by considering permanent structures like bridge, headworks, etc. across the river.

Acknowledgments

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