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Analysis of Climate Change-Induced Flood hazard and Cropland Inundation in the Tinau River Basin

Shiva Kumar Das [a], Pawan Kumar Bhattarai [b]

[a, b] *Department of Civil Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
[a] 078msdrm012.shiva@gmail.com, [b] nepalpawan@gmail.com

Abstract
This research study primarily focused on examining the potential inundation of cropland in the context of future flood scenarios influenced by climate change. Specifically, the study concentrated on the Tinau and Danau rivers as its focal points. To assess flood hazards under both current and anticipated climatic conditions,rainfall–runoff–inundation (RRI) model was used flood depth, flood duration and flood hazard. The model's performance was assessed using indicators like Nash-Sutcliffe Efficiency (NSE), Percent Bias (P-BIAS), and the coefficient of determination (R^2). The calibration yielded NSE, P-BIAS, and R^2 values of 0.804, 6.727, and 0.859, respectively, while the validation phase resulted in values of 0.832, 8.636, and 0.946, suggesting robust model performance. The assessment was conducted for Near Future(NF),Mid Future(MF) and Far Future(FF), using precipitation datasets generated by the Coupled Model Intercomparison Project Phase 6 (CMIP6) model for two scenarios: Shared Socioeconomic Pathways SSP245 and SSP585. The findings of this study indicate that under the higher emission pathway represented by SSP585, the potential damage to cropland due to 100 years return period flooding is more substantial compared to the SSP245 scenario. In the Far Future under SSP585, Cropland Inundation is forecasted to surge by a staggering 104.03% in comparison to present conditions. These trends signal a concerning outlook, particularly under SSP585, where the future may bring about severe flooding in Nepal's agricultural regions, with the potential to lead to food shortages.

Keywords
Flood Hazard, Climate change, RRI, CMIP6, Cropland Inundation

1. Introduction

In South Asia, Nepal is the second-highest risk country for flooding [1]. Due to changes in the natural slope, river morphology, drainage system, and land use/land cover, the Nepal's monsoon climate, which is characterised by significant rainfall between June and September, raises the risk that landslides and flood hazards would occur more frequently [2].

Floods in Tinau river and its impact has a long history. Every few years, Tinau floods, cutting across agricultural land and squatter communities, particularly in the Marchawar area southwest of Bhairahawa bazaar. During inundations, Tinau significantly damages agricultural products [3]. Plains of Lumbini Province is one of the largest Cereal crops production ground of Nepal, with production of 14 metric tons in 2079 B.S [4]. With a yield of 4.24 Mt/Ha [5], Rupandehi district is one among the main paddy growing areas in Nepal. Rupandehi district's agricultural loss has been primarily caused by floods in Tinau and Danau khola. Every year, the Rupandehi district's productivity is decreased during the monsoon season because the crop areas next to riverbanks are drowned. The destruction of paddy is a significant economic barrier in Nepal.

For developing nations like Nepal, the effects of climate change have been especially challenging. The influence of global warming has changed the pattern of precipitation, accelerated glacial melting, reduced water availability in rivers, and caused droughts and floods [6]. Evolving weather pattern due to climate change provide a challenge to conventional agricultural methods and knowledge, endangering food security [7]. Since Rupendehi district being one of the highest yielding cereal crop production district in nepal [5], it is necessary to investigate the flood hazard and cropland inundation due to climate change.

This study intends to identify and evaluate the flood risks brought on by climate change and analyze the effects of those risks on cropland in terms of flood depth, duration, and inundated cropland area. For hydrological simulation, Rainfall-Runoff-Inundation (RRI) has been used [8]. SSP585 and SSP245 were the two scenarios taken into consideration for the analysis of climate change. In contrast to SSP 2-4.5, which depicts a future in which greenhouse gas emissions are moderated and have a radiative forcing trajectory of about 4.5 watts per square meter (W/m2) by the year 2100, SSP 5-8.5 describes a future scenario characterized by high levels of fossil fuel use and rapid economic growth [9]. To assess the impact of flood due to climate change in both future scenarios, GCM projected precipitation outputs produced by the CMIP6 model was used. For this study , Present event from 1985 to 2019 and three future events viz. Near Future (NF) from 2024 to 2045, Middle Future (MF) from 2035 to 2065, and Far Future (FF) from 2070 to 2100 were considered. 100 year return period frequency analysis was conducted for both present and future events , to assess the flood hazards and cropland inundation, using one day annual maximum frequency [10].

2. Study Area

The Tinau River Basin is a perineal river basin in western Nepal.

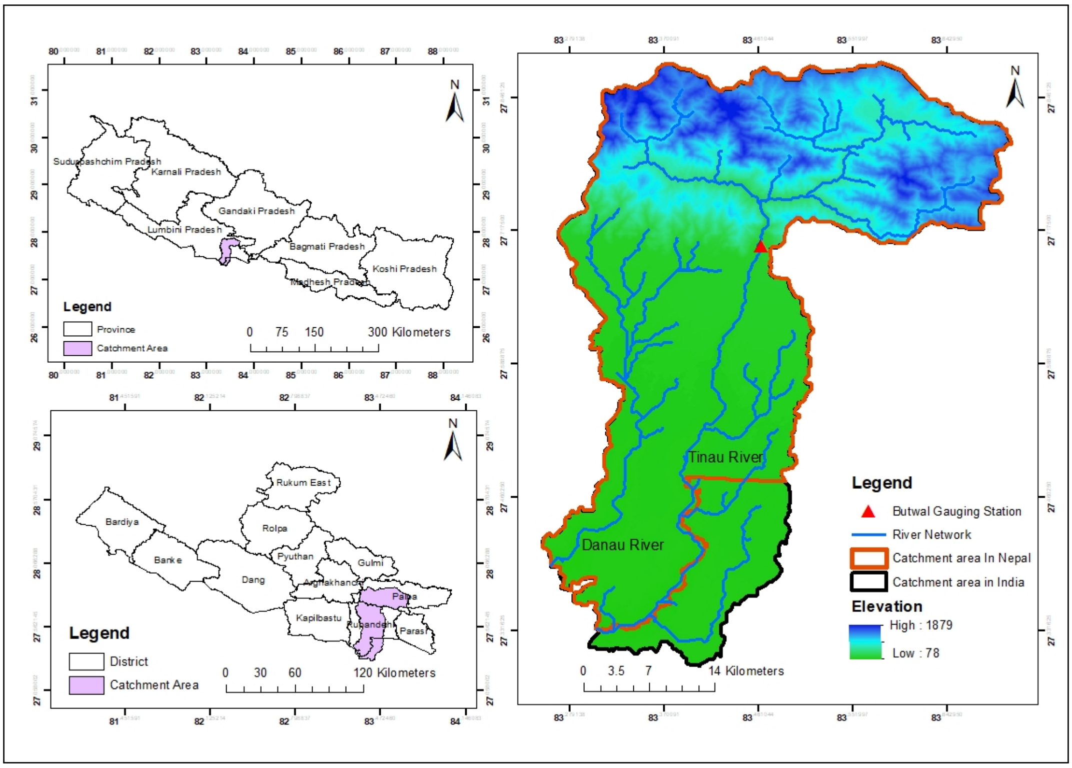

Figure 1: Location of Study Area

The Tinau river originates in the Mahabharat Range, flows through siwalik of Palpa and debouches in Terai at Butwal in Rupendehi districts before entering India, where it joins the West Rapti River near Gorakhpur, India [11]. The catchment area of Tinau river basin up to Nepal's border is 1081 sq km . Tinau river contributes to two project: small hydroelectric project upstream of Butwal bazaar, which was constructed during 1970s and Tinau Irrigation Project constructed during 1962-1967 [3].

This study also takes Danau River (Dano River) into consideration which is small river originates at the slope of siwaliks, west of Tinau River. The total catchment area, including Danau River, is 1443 sq km where around 168 sq km area lies in India. The topography of the study area varies in altitude i.e., elevation ranging from 70 m to 1879 m. (Fig 1)

3. Methodology

3.1 Data Collection and processing

Hydrosheds data of resolution of 3 arcsec was preprocessed in Qgis and converted in ASCII format for RRI model input. RRI model uses inbuilt Land Use and Soil Map developed by Food and Agricultural Organization. The Butwal Guaging station's daily discharge data and the daily historical precipitation data from 5 rainfall stations (Table 1) were used in this study. Global Cropland data (30m *30m) developed by Global Land Analysis and Discovery in 2019 was used in this study . The Cropland of the catchment area was masked out from Global Cropland data and downscaled to 90m*90m using QGIS, to achieve the same resolution as that of Hydroshed data.

Table 1: List of Meterological Station

Station Index	Name	District
0702	Tansen	Palpa
0703	Butwal	Rupandehi
0705	Bhairahawa Airport	Rupandehi
0701	Ridi	Gulmi
0729	Lumbini	Rupandehi

3.2 RRI Model Setup

Based on the landcover and soil , model categorized study area in 4 landuse. The parameters for each landuse was iterated several times till model has reached desired value of indicators (NSE, P-BIAS and R2) for strong performance of model during calibration. Rainfall data from 10th July ,2016 to 1st August, 2016 given as input for calibration period. The model's credibility was tested through a validation phase using distinct rainfall data spanning from 19th July 2017 to 9th August 2017. The parameters derived from the calibration phase were retained, and the model was assessed against the validation period. Remarkably, the model maintained favorable indicators (NSE, P-BIAS, and R2) values, indicating its ability to generalize beyond the calibration period.Upon successful calibration and validation, the obtained model parameters were adopted for projecting future inundation scenarios.

3.3 Future Climate Projection

In this research, climate projections for the twenty-first century are derived from the CMIP6 model. Global climate model (GCM) simulations, a part of the sixth Coupled Model Intercomparison Project (CMIP6) of World Climate Research Program, are employed. These simulations use a standardized historical forcing dataset spanning from 1850 to 2014 and make forecasts based on emissions scenarios from Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSPs) for the period from 2015 to 2100 [12].For our case , GCM's were chosen on the basis of accessibility of both historical and future daily rainfall data for both SSP245 and SSP585 and mostly used in south Asian region [13]. However, we chose 5 GCM viz. "access", "earth", "miroc", "mpi", "mri", statistically downscaled to 0.25°The robust empirical quantiles (RQUANT) approach was utilized for bias correction of obtained future precipitation data [14]. To proceed with the subsequent analysis, the optimal GCM needed to be determined. To achieve this, we employed the Thiessen polygon technique to calculate the area of influence for each station and established corresponding station weights. These station weights were then utilized to scale the indicators of each station for each GCM The pre-Bias indicators of each stations for each GCM were multiplied by weightage of respective stations and single value of each indicators (NSE, P-BIAS,R2) were obtained for each GCM.

Table 2: GCM Performance Indicators

GCM	NSE	P-BIAS	R2
ACCESS	0.86	23.62	0.97
EARTH	0.92	10.87	0.96
MIROC	0.95	15.25	0.98
MPI	0.96	6.35	0.97
MRI	0.94	13.29	0.975

Table 2, the MPI GCM demonstrates the most favorable indicators, boasting an NSE value of 0.962 and a P-BIAS value of 6.352. Therefore, for further analysis, we used future projected precipitations generated by the MPI GCM.

3.4 Frequency Analysis

Basin average of each day of present and future projected bias corrected precipitation was obtained by multiplying the rainfall of each station with the weightage respectively, obtained from Thiessen polygon. 100 years return period basin average precipitation was calculated from respective time span of NF, MF and FF for both SSP scenarios, using GUMBEL, Log-Gumbel, Log-Pearson, Log-Normal and Extrapolation(trendline method) methods. Exptrapolation method was chosen for frequency analysis. Certain duration of precipitation data was needed for model input to calculate the flood inundation for a specific return period. To obtain this, one day annual maximum rainfall was multiplied by conversion factor, since the correlation between observed precipitation and observed flood discharge, show the maximum correlation between 1 day precipitation and flood discharge [3]. For each present, NF, MF and FF, one month data (comprising 15 days prior to the peak rainfall and 15 days subsequent to the peak rainfall) was formulated for further RRI simulation, by multiplying only the respective maximum precipitation data by respective conversion factor of 100 years return period .

Table 3: Correlation between Accumulation of Rainfall (days) and Peak Discharge

Rainfall Accumulation	Correlation
1 day	0.642
2 day	0.566
3 day	0.504
4 day	0.477

$$\text{Conversion factor} = \frac{\text{one day max annual precipitation}}{\text{Precipitation of specific return period}} \quad [8]$$

4. Results and Discussion

4.1 RRI Model Calibration and Validation

The daily-observed rainfall was used to calibrate the simulated discharge at Butwal Gauging station in the Tinau River Basin from 10th July ,2016 to 1st August, 2016. The Nash-Sutcliffe efficiency (NSE), P-BIAS and R2 obtained is 0.804, 6.727 and 0.859 respectively. After calibration, Model was validated at Butwal Gauging station in the Tinau River Basin from 19th July ,2017 to 9th August, 2017. The Nash-Sutcliffe efficiency (NSE), P-BIAS and R2 obtained is 0.832, 8.626 and 0.946 respectively. The model's performance aligns with the criteria established by [15], demonstrating excellence with NSE values ranging from 0.75 to 1 and P-BIAS values ranging from 0 to 10 in both calibration and validation phases. This concludes that the model is performing effectively.

The inbuilt FAO landuse and soil data type showed clay loam and clay as soil type in the basin.Clay almost covered 80% of the basin. For landuse 3, lateral flow(ka) was considered as it lies in hill and for rest of parameter, green ampt filtration(ksv)

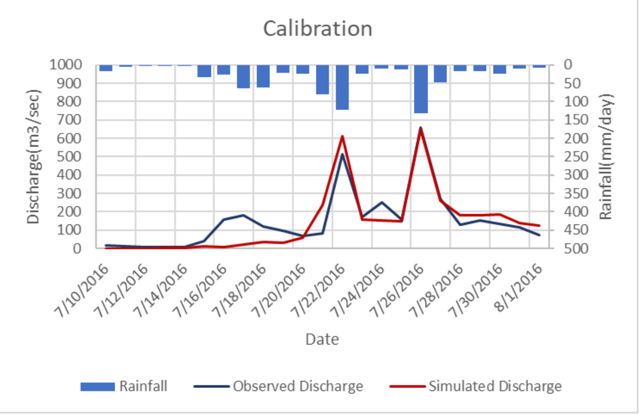

Figure 2: Calibration Plot of Butwal Gauging station

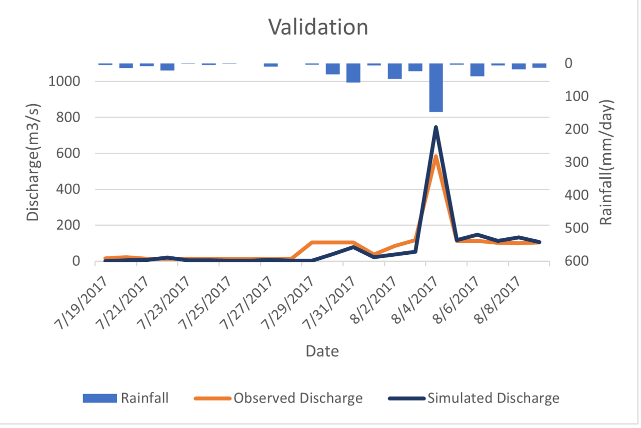

Figure 3: Validation Plot of Butwal Gauging station

was considered. The respective value of the coefficient for each parameter was considered with reference of RRI model manual and later fine-tuned while calibration. Table 4 shows all the detailed parameters of model.

Table 4: Parameters of RRI model

Parameters	Landuse			
	1	2	3	4
ns_slope	3.000d-1	3.000d-1	1.000d0	1.000d0
ns_river	9.000d-2	9.000d-2	9.000d-2	9.000d-2
soildepth	1.000d0	1.000d0	1.300d0	1.500d0
gammaa	3.090d-1	3.090d-1	3.850d-1	3.850d-1
ksv	5.560d-7	5.560d-7	0.000d0	3.500d-7
faif	2.088d-1	2.088d-1	3.163d-1	4.000d-1
ka	0.000d0	0.000d0	1.200d-3	0.000d0
gammam	7.500d-2	7.500d-2	9.500d-2	9.000d-2
beta	4.000d0	4.000d0	8.000d0	4.000d0

4.2 Correction Factor

Table 5: Correction Factor

Scenarios -MIP	Events	Correction Factor
Historical	Present	1.16
SSP245	NF	1.49
	MF	1.31
	FF	1.38
SSP585	NF	1.17
	MF	1.16
	FF	1.16

4.3 Flood Hazard Assessment

The inundation map generated through the simulation using the RRI model provides maximum inundation depth,discharge and Flood duration. The comparison between the Present(fig 4), SSP245 (fig 5) and SSP585 (fig 6) scenarios reveals that the flood inundation and subsequent durations exhibit notable differences. Within the context of the NF, MF, and FF categories, the flood extent and duration for SSP585 consistently surpass those of SSP245. This implies that under the given circumstances, the SSP585 scenario experiences more extensive flooding and longer flood durations compared to the SSP245 scenario. The flood depth and duration between 2024 and 2045 are similar for the SSP245 and SSP585 scenarios. Looking ahead in future, there are distinct differences, with SSP585 having more severe and persistent floods than SSP245, which is visible. It's important to understand that prolonged flood events worsen the damage to agriculture. The projected flood conditions for the years 2070 to 2100 are extremely alarming. The estimated flood depth and duration for SSP245 are 8.29 metres and 5 days, respectively. SSP585, on the other hand, is subject to much worse flood conditions, lasting seven days and reaching a depth of 9.48 metres. The significant difference in flood severity between the two scenarios is concerning. It emphasises how urgent it is to address climate change challenges. Flood hazards that are more extreme and persistent under SSP585 could become a terrible reality if we don't take measures to combat climate change. This demonstrates how urgently it is necessary to take action to lower greenhouse gas emissions, adapt to climate change, and protect vulnerable communities and ecosystems from its effects.

Table 6: Maximum Flood Inundation Depth and Flood Duration for 100 years return period

Scenarios -MIP	Events	Max Flood depth(m)	Flood Duration (Days)
Historical	Present	5.5	2
SSP245	NF	6.58	3
	MF	8.19	4
	FF	8.29	5
SSP585	NF	7.83	4
	MF	8.25	6
	FF	9.48	7

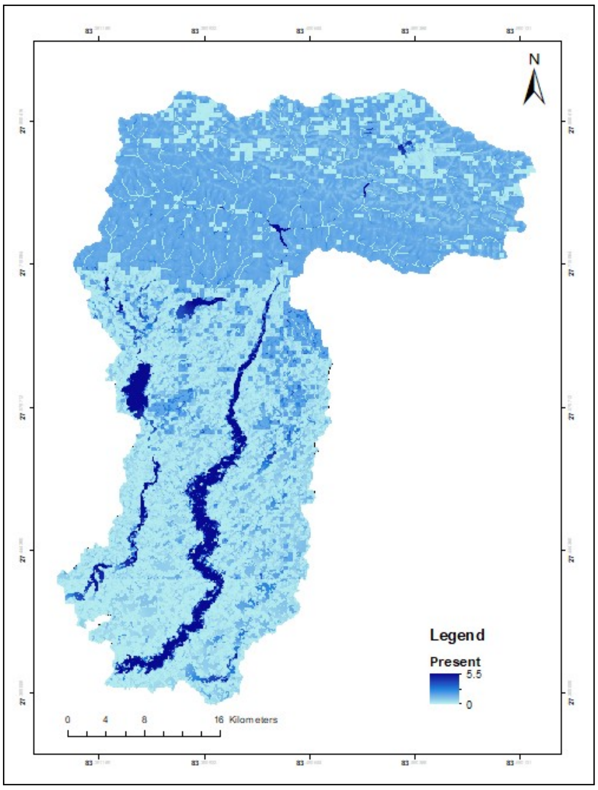

Figure 4: Present 100 years Return Period Flood Hazard

4.4 Cropland Inundation Assessment

In the assessment of cropland damage, the portion of the basin located within the geographical boundaries of Nepal was only taken into account. The derived inundation maps were selectively extracted, encompassing solely those regions of the basin that are characterized as cropland. To conduct an in-depth analysis of inundation within these cropland areas, a criterion was established: only inundation instances with a depth exceeding 0.5 meters were taken into consideration. This was achieved by tallying the number of pixels present in the obtained inundation map. The aggregated pixel count served as a representation of the inundated cropland area. To convert this representation into tangible unit, the pixel count was multiplied by the resolution of the digital elevation model (DEM), which stands at 90 meters by 90 meters. The final transformation involved converting this area from square meters to hectares, thereby expressing the extent of inundated cropland in standardized hectare units.

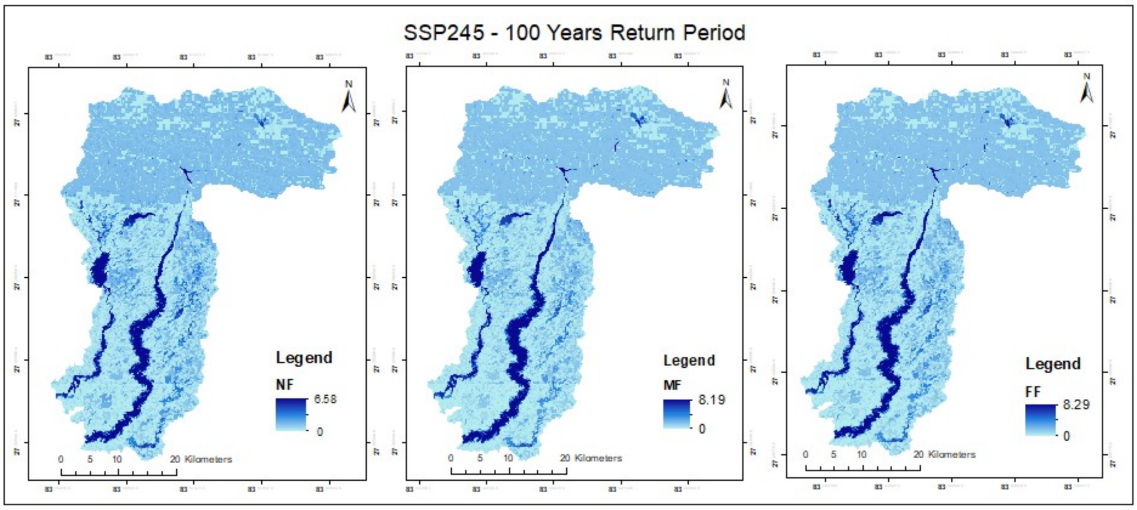

Figure 5: SSP245 100 years Return Period Flood Hazard

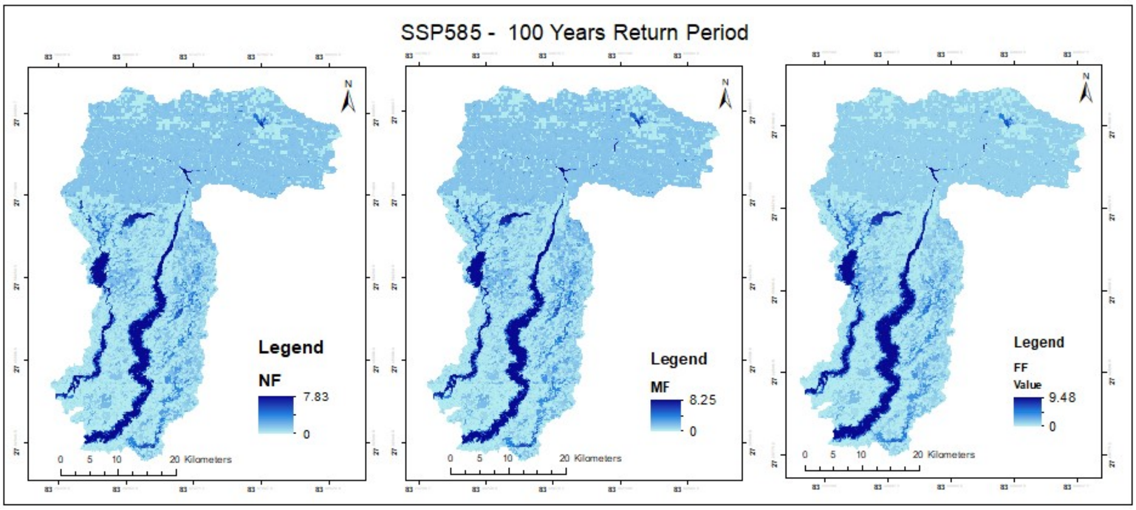

Figure 6: SSP585 100 years Return Period Flood Hazard

In the SSP245 scenarios, Cropland Inundation is projected to increase by 48.57% in the Near Future, 52.73% in the Moderate Future, and 63.94% in the Far Future. In contrast, under SSP585, Cropland Inundation is expected to rise by 67.61% in the Near Future, which surpasses the Far Future projection of SSP245. Notably, in the Far Future of SSP585, Cropland Inundation is forecasted to surge by 104.03% compared to the present conditions. These trends suggest that under SSP585, the future could bring severe flooding to agricultural areas in Nepal, potentially leading to food shortages.

Table 7: Increment of future Cropland Inundation Area with respect to Present cropland inundation (%)

Scenarios -MIP	Events	Increment of cropland Inundation w.r.t Present(%)
SSP245	NF	48.57
	MF	52.73
	FF	63.94
SSP585	NF	67.61
	MF	68.72
	FF	104.03

The current Cropland Inundation, resulting from a 100-year return period flood, encompasses a substantial 11,280 hectares, signifying a significant threat to agricultural productivity. This concern is poised to intensify due to the impending impacts of climate change. Projections for the period spanning 2070 to 2100 indicate that Cropland Inundation will expand considerably, reaching approximately 18,490 hectares for the SSP245 scenario and a staggering 23,012 hectares for the SSP585 scenario. These projections are deeply concerning for our nation's future, particularly in view of fact that paddy cultivation, which accounts for about 7

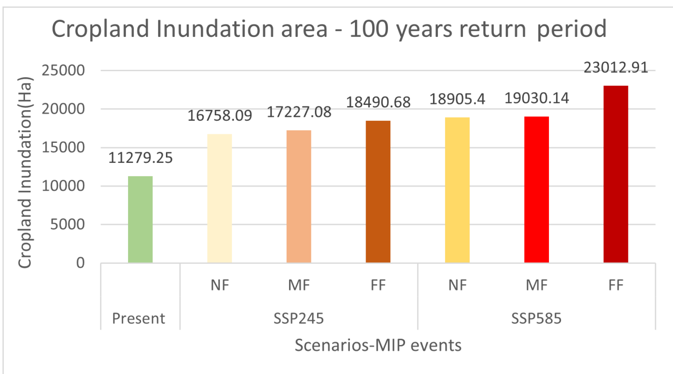

Figure 7: SSP585 100 years Return Period Flood Hazard

percent of the national gross domestic product and serves as the primary income source for over half of the population, faces a substantial threat [5]. The potential destruction of paddy crops represents a major impediment to Nepal's economic stability. It's not just the inundation of the flooded cropland area is a problem but also floods duration in terai is for about. In fact, we might see a drop of about 60% in crop yields [16]. This is a serious threat to our country's food supply and the future of farming.

5. Conclusion

The study offers a comprehensive perspective on the potential impacts of different climate change scenarios on cropland areas, particularly in the context of cropland inundation. Comparing the SSP245 and SSP585 scenarios, a clear trend emerges for NF, MF and FF, the SSP585 scenario consistently shows higher levels of damaged cropland areas. This pattern indicates that the more severe emission pathway projected by SSP585 amplifies the vulnerability of croplands to flooding, highlighting the pressing need for robust adaptation strategies. The 100-year return period accentuates the escalating threat of extreme flood events, reiterating the need for adaptive measures that can withstand increasingly severe scenarios. The choice of emission pathway and floodplain management strategy significantly influences the vulnerability of cropland areas to flooding. The scenario projecting higher emissions (SSP585) consistently results in more extensive cropland damage, emphasizing the urgency of addressing climate change and emissions reduction. Proactive and well-implemented floodplain regulations can considerably reduce the impacts of flooding on cropland areas. Rupendehi being the highest grain yielding district of Nepal, the flood impact on rupendehi district ,agricultural damage may effect the economic and grain supply of Nepal.

In conclusion, this analysis underscores the imperative for comprehensive strategies that integrate emissions reduction, floodplain management, and disaster preparedness. Such strategies are vital for safeguarding cropland areas from the escalating risks posed by flooding under various climate scenarios.

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References

[1] Buddhi Raj Shrestha, Raj Kumar Rai, and Saroj Marasini. Review of Flood Hazards Studies in Nepal. *Geogr. Base*, 7:24–32, 2020.

[2] Noor Dangol. Flood Modeling Assessment: A Case of Bishnumati River. *J. Geoinformatics, Nepal*, 20(1):31–37, 2020.

[3] Hari Dhungana, Adam Pain, and Sindhu P Dhungana. Disaster Risk Management and Meso-Level Institutions in Nepal: A Case Study of Floods in Tinau River in Western Terai. page 56, 2016.

[4] 2079 Krishi Diary. Agriculture Diary. *Minist. Agric. Livest. Dev.*, page 356, 2020.

[5] 2021 MoALD. Statistical Information On Nepalese Agriculture (2077/78). *Publ. Nepal Data Portal*, 73:274, 2021.

[6] Britta Horstmann. Glacial Lake Outburst Floods in Nepal and Switzerland New Threats Due Glacial Lake Outburst Floods in Nepal and Switzerland. New Threats Due to Climate Change. *Germanwatch*, pages 1–12, 2004.

[7] CIAT, World Bank, CCAFS, and LI-BIRD. Climate-Smart Agriculture in Nepal. CSA Country Profiles for Asia Series. International Center for Tropical Agriculture (CIAT); The World Bank; CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS); Local Initiatives for Biodiver. *CSA Ctry. Profiles Asia Ser.*, page 26, 2017.

[8] B. B. Shrestha, T. Okazumi, M. Miyamoto, and H. Sawano. Flood damage assessment in the Pampanga river basin of the Philippines. *J. Flood Risk Manag.*, 9(4):355–369, 2016.

[9] Brian C. O'Neill, Claudia Tebaldi, Detlef P. Van Vuuren, Veronika Eyring, Pierre Friedlingstein, George Hurtt, Reto Knutti, Elmar Kriegler, Jean Francois Lamarque, Jason Lowe, Gerald A. Meehl, Richard Moss, Keywan Riahi, and Benjamin M. Sanderson. The Scenario Model Intercomparison Project (ScenarioMIP) for CMIP6. *Geosci. Model Dev.*, 9(9):3461–3482, sep 2016.

[10] Badri Bhakta Shrestha, Akiyuki Kawasaki, and Win Win Zin. Development of flood damage functions for agricultural crops and their applicability in regions of Asia. *J. Hydrol. Reg. Stud.*, 36, 2021.

[11] Som Nath Poudel. Tinau River Conservation and Integrated Water Resource Management. *Hydro Nepal J. Water, Energy Environ.*, 10(10):24–31, 2012.

[12] Nicola Scafetta. CMIP6 GCM Validation Based on ECS and TCR Ranking for 21st Century Temperature Projections and Risk Assessment. *Atmosphere (Basel).*, 14(2):345, feb 2023.

[13] Vimal Mishra, Udit Bhatia, and Amar Deep Tiwari. Bias-corrected climate projections for South Asia from Coupled Model Intercomparison Project-6. *Sci. Data 2020 71*, 7(1):1–13, oct 2020.

[14] Yao Tong, Xuejie Gao, Zhenyu Han, Yaqi Xu, Ying Xu, and Filippo Giorgi. Bias correction of temperature and precipitation over China for RCM simulations using the QM and QDM methods. *Clim. Dyn.*, 57(5-6):1425–1443, sep 2021.

[15] Hugo Henrique Cardoso de Salis, Adriana Monteiro da Costa, João Herbert Moreira Vianna, Marysol Azeneth Schuler, Annika Künne, Luís Filipe Sanches Fernandes, and Fernando António Leal Pacheco. Hydrologic modeling for sustainable water resources management in urbanized karst areas. *Int. J. Environ. Res. Public Health*, 16(14), 2019.

[16] Badri Bhakta Shrestha. Assessment of Flood Hazard and Agriculture Damage Under Climate Change in the Bagmati River Basin of Nepal. *Int. J. Environ.*, 8(2):55–69, sep 2019.