HISTORICAL TREND AND FUTURE PROJECTION OF EXTREME CLIMATE IN NEPAL

A Thesis Submitted to the

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In Partial Fulfilment of the Requirement for the Award of Degree of Master of Science in Hydrology and Meteorology

By

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DECLARATION

I hereby declare that the work presented in this dissertation is a genuine work done originally by me and has not been submitted anywhere for the award of any degree. All the sources of the information have been specifically acknowledged by reference to the author(s) or institution(s).

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Khem Raj Upreti

December, 2023

RECOMMENDATION

This is to certify that Mr. Khem Raj Upreti has completed this dissertation work entitled "**HISTORICAL TREND AND FUTURE PROJECTION OF EXTREME CLIMATE IN NEPAL**" as a partial fulfillment of the requirement of M.sc in Hydrology and Meteorology under my supervision and guidance. To my knowledge, this research has not been submitted for any other degree, anywhere else.

We therefore, recommend the dissertation for acceptance and approval.

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LETTER OF APPROVAL

On the recommendation of supervisor Dr. Binod Pokharel this dissertation submitted by Mr. Khem Raj Upreti entitled "**HISTORICAL TREND AND FUTURE PROJECTION OF EXTREME CLIMATE IN NEPAL**" has been approved for the examination and submitted to the Tribhuvan University in partial fulfillment of the requirement of M. Sc. In Hydrology and Meteorology.

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CERTIFICATE OF ACCEPTANCE

This dissertation entitled "**HISTORICAL TREND AND FUTURE PROJECTION OF EXTREME CLIMATE IN NEPAL**" submitted by Mr. Khem Raj Upreti has been examined and accepted as partial fulfillment of the requirements of M. Sc. In Hydrology and Meteorology.

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Khem Raj Upreti

ABSTRACT

Climate is critical for a country like Nepal where water resources and agriculture largely depend on the existing climate. However, climate is changing at a much faster rate with changes in temperature and precipitation that have far-reaching implications for a country's economic and sustainable development. This study investigates the historical trends in daily extreme temperature and precipitation indices in Nepal using the in situ measurements from 1980 to 2020 and provides future projections of extreme climate indices using five Coupled Model Inter-comparison Project Phase 6 (CMIP6) model datasets under the Shared Socioeconomic Pathways (SSP245 and SSP585) scenarios for the time period of 2021 to 2100. Historical observed climate data from 85 meteorological stations were considered for extreme precipitation, and 23 stations for extreme temperature. In this research, thirteen temperature indices and eleven precipitation indices were developed considering the Expert Team on Climate Change Detection and Indices (ETCCDI).

The findings reveal a significant warming trend across Nepal, with increased occurrences of warm days and warm nights in most stations, while cool days and cool nights are decreasing. The precipitation data show changes in precipitation patterns with increasing consecutive dry days (CDD) in most locations, while trends in consecutive wet days (CWD) are diverse, with some regions experiencing longer consecutive rainy periods, and others facing shorter intervals without precipitation. Future projections based on climate models suggest a probable increase in the duration of consecutive dry days (CDD) across all models, which could have implications for agriculture and water resources. Trends in consecutive wet days (CWD) show variability among models, with both increasing and decreasing patterns observed. Overall, annual total precipitation is expected to increase, along with the number of heavy precipitation events represented by R10mm and R20mm indices.

Keywords: Extreme precipitation, Extreme temperature, CMIP6, Climate change, Sustainable development, Nepal.

LIST OF ABBREVIATIONS AND ACRONYMS

DHM	Department of Hydrology and Meteorology
MOALD	Ministry of Agriculture & Livestock Development
WCRP	World Climate Research Programme
CMIP	Coupled Model Intercomparison Project
SSP	Shared Socioeconomic Pathways
ETCCDI	Expert Team on Climate Change Detection and Indices
ET-SCI	Sector-specific Climate Indices
ICIMOD	International Centre for Integrated Mountain Development
GCMs	General Circulation Models
IPCC	Intergovernmental Panel on Climate Change
WFP	World Food Program
NAP	National Adaptation Plan
ADS	Agriculture Development Strategy (ADS)
NASA	National Aeronautics and Space Administration
NEX-GDDP_CMIP6	NASA Earth Exchange Global Daily Downscaled Projections
WMO	World Meteorological Organizations
PCIC	The Pacific Climate Impacts Consortium
PR	Precipitation
TN	Minimum Temperature
TX	Maximum Temperature
NOAA	National Oceanic and Atmospheric Administration
Tmax	Maximum Temperature
Tmin	Minimum Temperature

TX10p	Percentage of days when maximum temperature less than 10^{th} percentile
TX90p	Percentage of days when maximum temperature greater than 90^{th} percentile
WSDI	Warm Spell Duration Indicator
SU	Summer Days
USA	United States of America
QC	Quality Controls
NetCDF	Network Common Data Form
CDO	Climate Data Operator
SDII	Simple Daily Intensity Index
CDD	Consecutive Dry Days
CWD	Consecutive Wet Days
PRCPTOT	Annual Total Precipitation

LIST OF SYMBOLS

°C	degree Celsius
%	Percentage
mm	millimeter
mm/day	millimeter per day
°F	degrees Fahrenheit
kg/ha	kilogram per hectare
$kg/m^2/s$	kilogram per square meter per second
m	meter
days/decades	days per decades
mm/year	millimeter per year
mm/day/year	millimeter per day per year

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CHAPTER 1: INTRODUCTION

1.1 Background

Climate change is one of the biggest challenges facing the world today, with extreme weather events becoming increasingly frequent and intense (Easterling et al., 2000). In countries like Nepal, where vulnerability to extreme weather events is particularly high, understanding the changes in extreme temperature and precipitation indices is essential for assessing climate change and formulating feasible adaptation solutions (Shrestha et al., 2019). The consequences of extreme climate events, including extreme temperature, heavy rainfall, floods, and droughts, have emerged as key research areas, given their increasing frequency and substantial impact on society, biodiversity, ecosystems, and human lives (Meehl & Tebaldi, 2004). Temperature and precipitation are vital inputs for simulating the rainfall-runoff process, monitoring freshwater availability, evaluating flood and drought conditions, assessing landslide activity, estimating crop yields, and understanding water-related illnesses. Reliable precipitation records and estimates play a crucial role in hydro-meteorological forecasting, irrigation management, hydropower generation, and agricultural studies. Notably, the occurrence of high-intensity-short-duration rainfall events leading to hydrological extremes and associated disasters has been noticeably increasing in recent years (Talchabhadel et al., 2018), severely affecting the lives and livelihoods of local communities (ICIMOD, 2017). Furthermore, climate change has resulted in increased dryness during both wet and dry seasons (Seneviratne et al., 2012).

In the context of Nepal, studies have shown an increase in heavy precipitation and heat extremes (Karki et al., 2017, 2020a; Khadka et al., 2020; Pokharel et al., 2020; Poudel et al., 2020b). These changes in extreme climate events are likely attributable to climate change, and their impacts on agriculture, infrastructure, and human lives have been highly detrimental. Agricultural productivity losses resulting from climate change-related factors have led to severe food insecurity and adversely affected the overall economy of the country (Chalise et al., 2017). The rising temperature has already had negative consequences for major cereal crop production, including wheat, rice, and maize, across Nepal (Bocchiola et al., 2019). Climate change not only alters water availability and soil moisture but also increases water demand and disrupts crop yield and productivity.

This research aims to conduct a comprehensive analysis of extreme temperature and precipitation indices, examining their historical trends and projected changes over the period from 1980 to 2020. Additionally, the research seeks to deepen our understanding of the relationship between climate and crop yield in three districts in Nepal, namely Rupandehi, Dang, and Kailali.

By assessing the effects of these climatic factors on agriculture, the study will contribute valuable insights to the existing knowledge on climate change impacts in Nepal, particularly within the agricultural sector.

Furthermore, this research will identify and address literature gaps related to the underutilization of advanced General Circulation Models (GCMs) from the CMIP6 dataset in previous studies. By utilizing these advanced models, the study aims to provide more accurate simulations of future climate scenarios and insights into extreme climate.

The findings of this research will contribute significantly to the ongoing efforts to understand the trends and characteristics of extreme climate in Nepal. This information will be crucial for policymakers, researchers, and stakeholders to develop informed strategies for enhancing agricultural resilience and mitigating the adverse effects of extreme climate on food security and the economy.

In the subsequent sections of this thesis, we will present the employed methodology, conduct a thorough analysis of extreme climate indices, and discuss the trend of extreme climate in Nepal.

1.2 Rationale of the Study

Significance of this research are:

- Insights into Warming Trend and Precipitation Patterns: The study provides valuable insights into the warming trend and changing precipitation patterns in Nepal, aligning with global climate change trends.
- Guidance for Climate Adaptation Strategies: The findings offer crucial guidance for formulating climate adaptation strategies tailored to Nepal's specific challenges. This aids in preparing for the implications of rising temperatures and altered rainfall patterns across various sectors in the country.

- Informing Region-Specific Planning: The research contributes to inform region-specific planning by enhancing our understanding of the potential impacts of climate change. This allows decision-makers to develop targeted and effective measures to mitigate adverse effects.
- Addressing Socio-Economic Implications: Understanding the changing climate dynamics aids in addressing the socio-economic implications of climate change. It empowers policymakers and stakeholders to develop interventions that protect livelihoods, infrastructure, and economic stability.

1.3 Problem Statements

The Western Terai region of Nepal has been relatively overlooked in previous studies on climate and its impact on crop yield, limiting our understanding of the specific climatic conditions in the area and their effects on agricultural productivity. Additionally, the use of advanced General Circulation Models (GCMs) from the CMIP6 dataset has been underutilized in research, despite their potential to provide more accurate simulations of future climate scenarios and insights into extreme climate events.

Furthermore, the limitation of shorter historical data periods in prior studies hinders the comprehensive assessment of long-term variability and trends in extreme climate events in the region. This thesis aims to address these research gaps by analyzing a more extensive and diverse set of historical data spanning from 1980 to 2020, thereby enabling a more thorough understanding of historical trends and variability of extreme climate in Nepal.

To bridge these gaps, this research will utilize five GCMs from the CMIP6 dataset to conduct a comprehensive assessment of future climate scenarios. Incorporating these advanced models into the analysis will yield more accurate projections of future extreme climate, facilitating informed decision-making and adaptation strategies.

The research will particularly focus on exploring the relationship between precipitation, temperature, and crop yield in three West Terai districts: Rupandehi, Banke, and Kailali. By addressing these research gaps and providing localized insights, this thesis aims to contribute significantly to the existing body of knowledge, benefiting policymakers, planners, and agricultural practitioners in formulating effective strategies for climate change adaptation and sustainable agricultural development in the region.

1.4 Research Questions

The following are the research questions developed for this study:

- How have the frequency, intensity, and spatial distribution of extreme climate changed in Nepal over the past?
- How does future climate change impact the frequency, intensity, and spatial distribution of extreme climate in Nepal?

1.5 Research Objectives

The objective of this research is to analyze the historical observational and bias corrected downscaled climate model data to examine the climate extremes in Nepal

- To understand the spatial and temporal patterns of extreme climate in Nepal
- To evaluate the impacts of extreme climate on crop yield, and to understand the factors that influence crop production

1.6 Limitations

The assumptions inherent in climate models may introduce uncertainties in predicting future climate patterns, and these models may not fully represent all aspects of Nepal's unique climate system

The lack of localized data restricts the precision of the findings, as climate impacts can vary widely at local scales due to topography, land use changes, and microclimates

One limitation of this research is the potential limited generalization of findings, as they rely on specific climate models (CMIP6 models) and may not fully represent all complexities of Nepal's diverse climate.

CHAPTER 2: LITERATURE REVIEW

The Intergovernmental Panel on Climate Change (IPCC) reports that the frequency and intensity of extreme temperature have increased in most land regions, and heavy precipitation events have increased in many regions since the 1950s (IPCC, 2021). Similarly, extreme temperature, heavy rainfall have become more frequent and intense in some regions, such as the Mediterranean, southern Africa, and the Amazon (IPCC, 2021). According to the NOAA's 2021 Annual Climate Report, the combined land and ocean temperature has shown an average increase of 0.14 degrees Fahrenheit (0.08 degrees Celsius) per decade since 1880. However, since 1981, the rate of increase has more than doubled, reaching 0.32 °F (0.18 °C) per decade (NOAA, 2021) . This accelerated rate of warming cannot be solely attributed to natural variability. The emissions of greenhouse gases resulting from human activities are believed to be the primary factor driving this rapid increase in global warming(IPCC, 2023). In addition, Katz and Brown have emphasized that even minor shifts in mean rainfall patterns caused by global warming can have significant implications for extreme precipitation events (Katz & Brown, 1992). Hence, it is crucial to conduct thorough investigations into the impacts of climate change on such extreme temperature and rainfall occurrences. Manton et al. (2001) analyzed the trends in extreme daily temperatures from 1961 to 1998 in Southeast Asia and documented a significant escalation in the number of warm days and nights annually, while there was a notable reduction in cool days and nights. Similarly Klein Tank et al. (2006) discovered a noteworthy rise in the proportion of warm nights (TN90p) and days (TX90p), accompanied by a decline in the proportion of cold nights (TN10p) and days (TX10p) across 70% of stations in central and south Asia. It was observed that the increase in maximum temperature extremes during the daytime was comparatively smaller than the increase in minimum temperature extremes during the nighttime. In a study conducted on the Northern Tibetan Plateau, Cuo et al. (2013) investigated the trends of extreme Tmax and Tmin temperatures over a specific period. Their analysis revealed notable increases in both extreme maximum (Tmax) and minimum (Tmin) temperatures. Specifically, Tmax exhibited a statistically significant upward trend with a rate of 0.028°C per year, while Tmin demonstrated an even more pronounced increase at a rate of 0.068°C per year.

In recent decades, Nepal has experienced an increase in extreme weather events, including extreme rainfall, extreme temperature, floods and droughts, which have had significant impacts on agriculture. The frequency and intensity of these events have been influenced by global climate change, characterized by rising temperatures and changing precipitation patterns. In each climate location, extreme weather events are common, but their frequent occurrence would be devastating to the environment and the socioeconomic state of the area. For example, recently destructive floods caused by post-monsoon heavy rainfall in the western region of Nepal (more than 100 mm of rain fell in 24 hours on October 20, 2021) destroyed paddy crops that were ready for harvest throughout the nation (FloodList, 2021). Flash floods caused by extremely heavy rainfall events have severely damaged property and disrupted normal life in Nepal in recent decades. In recent years, a growing body of research conducted at both regional and local levels has consistently documented a concerning escalation in maximum (Tmax) and minimum (Tmin) temperatures, accompanied by an increased frequency of heat waves (Alexander et al., 2006; Baidya et al., 2008; Frich et al., 2002; Goswami et al., 2006; Luterbacher et al., 2004). Additionally, these studies have highlighted notable changes in extreme precipitation patterns, revealing a complex picture of climate variability and its potential impacts on various aspects of the environment and society. Numerous investigations have independently confirmed the upward trend in both Tmax and Tmin temperatures. Such trends are indicative of a broader global warming pattern driven by anthropogenic influences, including greenhouse gas emissions and land-use changes. The observed temperature rise at regional and local scales has significant implications for ecosystems, agriculture, water resources, and human health, necessitating informed and targeted climate adaptation strategies.

In parallel with the trends in temperature extremes, numerous studies have documented changes in extreme precipitation events (Donat et al., 2016; Sun et al., 2021; Zhang et al., 2013). Extreme precipitation, characterized by intense and heavy rainfall, has become more frequent in various regions, contributing to an increased risk of flooding, landslides, and other hydrological hazards These changes in precipitation patterns can have far-reaching consequences for communities, economies, and ecosystems, impacting water availability, agricultural productivity, and water quality.

Over the past century, Nepal has seen a significant rise in the occurrence of heavy precipitation events, characterized by intense and heavy rainfall. In the western mountainous regions, extreme precipitation events have also shown an increasing trend in recent decades (Talchabhadel et al., 2018). Considering the anticipated rise in temperatures in the future, it is expected that Nepal will experience an increase in the magnitude and frequency of extreme precipitation events. These extreme precipitation events have the potential to lead to devastating floods (Karki et al., 2017). Nepal, being reliant on agriculture as a significant component of its economy, is particularly vulnerable to the impacts of floods. Hence, it is crucial to thoroughly investigate the variations of extreme precipitation events under future climate conditions in Nepal. Understanding these patterns is essential for effective flood management and risk assessment in the country.

These findings align with global trends reported by the Intergovernmental Panel on Climate Change (IPCC), which indicate an overall increase in the frequency and intensity of heatwaves, extreme temperature and heavy precipitation events since the 1950s (IPCC, 2023). The impacts of climate change on agriculture in Nepal have been severe, with floods, landslides, and droughts causing damage to crops, infrastructure, and food insecurity (ICIMOD, 2017; WFP, 2018).

Climate models and projections for Nepal suggest that these extreme weather events will continue to increase in frequency and intensity in the future. Studies have projected a rise in the occurrence of extreme temperature, heavy precipitation events, and droughts. These projections indicate that the impacts of climate change on agriculture in Nepal are likely to worsen, posing significant challenges to the country's food security and economic stability.

To address the impacts of climate change on agriculture, Nepal has developed policies and strategies aimed at building resilience and promoting climate-resilient agriculture. The National Adaptation Plan (NAP) focuses on enhancing the agriculture sector's capacity to adapt to climate change (GON, 2021). The Agriculture Development Strategy (ADS) aims to increase the productivity and income of small-scale farmers through climate-resilient practices (GON, 2015). However, the implementation of these policies and strategies has been limited, indicating a need for more concerted efforts to effectively mitigate the impacts of climate change on agriculture in Nepal.

In conclusion, extreme weather events are becoming more frequent and intense in Nepal, with significant impacts on agriculture, which is the backbone of the country's economy. The literature reviewed suggests that climate change will continue to exacerbate these impacts in the future, with projections indicating more frequent and intense heatwaves, heavy precipitation events, and droughts. While Nepal has developed policies and strategies to address the impacts of climate change on agriculture, there is a need for greater implementation and more concerted efforts. Future research should focus on identifying specific adaptation and mitigation strategies that are effective in Nepal's unique context and can be implemented at scale. Additionally, there is a need for continued monitoring and data collection on extreme weather events in Nepal to better understand their impacts and inform policy decisions.

CHAPTER 3: DATA AND METHODOLOGY

3.1 Observed historical data

Daily precipitation, maximum and minimum temperature data collected by the Department of Hydrology and Meteorology (DHM) Government of Nepal (www.dhm.gov.np), for a period of 41 years (1980 – 2020) was used in this study. Initially, a total of 126 meteorological stations with long-term time series data were chosen to represent all of Nepal's geographical areas. However, some stations contain missing values, discontinuous series of data, continuous month and day of year missing those stations were discarded. After quality control, 23 stations are eligible for calculating the annual trend of extreme temperature indices, and 85 stations are eligible for calculating the annual trend of extreme precipitation indices. The district level annual crop yield data for wheat were obtained from the Ministry of Agriculture & Livestock Development, Government of Nepal. The annual crop yield data were used for three districts of west Terai, namely, Rupandehi, Banke, and Kailali for the period of 1980 to 2020. The temperature and rainfall data during the month of growing and harvesting season wheat were used. The Pearson correlation coefficient was used to determine the correlation between the precipitations, and annual crop yield of wheat for Rupandehi, Banke and Kailali districts.

Table 3.1 Description of data used

S.N	Data	Description	Units	Resolution	Source
1.	Rainfall	Daily observed rainfall	mm	85 stations (1980-2020; daily)	DHM, Nepal
2.	Maximum and minimum temperature	Daily observed maximum and minimum temperatures	°C	23 stations (1980-2020; daily)	DHM, Nepal
3.	Crop yield	Wheat of annual crop yield	kg/ha	3 districts crop yield (1980-2020;annual)	MOALD, Nepal

3.2 Climate model data

The climate model data utilized in this study are from the NASA Earth Exchange Global Daily Downscaled Projections archive (NEX-GDDP-CMIP-6) (Thrasher et al., 2022). This archive provides an extensive collection of high-resolution climate projections derived from the latest generation of climate models known as the Coupled Model Inter-comparison Project Phase 6 (CMIP6). The dataset encompasses historical records as well as future projections for the period from (1950-2100). The CMIP6 data used in this study are daily precipitation for the study period.

The NEX-GDDP-CMIP-6 archive offers a carefully curated set of bias-corrected climate projections, ensuring more accurate representations of climate conditions. It comprises data from thirty-five global climate models, encompassing a range of experiments that include the historical period and four distinct Shared Socioeconomic Pathways (SSPs) identified as SSP126, SSP245, SSP370, and SSP585 (Thrasher et al., 2022). These SSPs delineate different scenarios of future socioeconomic development along with corresponding greenhouse gas emissions.

For the purposes of this analysis, the annual trends of several extreme precipitation indices were computed. These indices include consecutive dry days (CDD), consecutive wet days (CWD), total precipitation (PRCPTOT), number of days with precipitation exceeding 10mm (R10mm), number of days with precipitation exceeding 20mm (R20mm), maximum 1-day precipitation amount (RX1day), and simple daily intensity index (SDII). The trends were calculated using data from five CMIP6 climate models: ACCESS-ESM1-5 (Australia), BCC-CSM2-MR (China), CNRM-ESM2-1 (France), GFDL-ESM4 (USA), and INM-CM5-0 (Russia). The analysis encompassed both SSP245 and SSP585 scenarios, providing a comprehensive understanding of the projected changes in extreme precipitation indices under different future climate conditions.

Table 3.2 Description of CMIP6 climate model data used

S.N.	Model Name	Country	Spatial Resolution	Projections
1.	ACCESS-ESM1-5	Australia	0.25°×0.25°	2021-2100
2.	BCC-CSM2-MR	China	0.25°×0.25°	2021-2100
3.	CNRM-ESM2-1	France	0.25°×0.25°	2021-2100

4.	GFDL-ESM4	USA	0.25°×0.25°	2021-2100
5.	INM-CM5-0	Russia	0.25°×0.25°	2021-2100

3.3 Quality control

The quality control of meteorological station data using Climpact software involves several steps to ensure the reliability and accuracy of the data. The process begins by checking the data quality before calculating climate indices. The Climpact QC tools are employed for this purpose. The Climpact QC tools are designed to identify potential outliers and errors in the data. Various checks are performed to flag data points that may be erroneous or fall outside the expected range. Some of the specific quality control checks conducted by Climpact QC tools include:

i. Negative Precipitation Values: Climpact QC tools identifies any negative values recorded for precipitation, which is illogical as precipitation cannot have negative values.

ii. Inconsistent Temperature Values: Climpact QC tools checks for cases where the maximum temperature (Tmax) is less than the minimum temperature (Tmin), which is not physically possible and indicates a data error.

iii. Typing Errors: The software detects any obvious typing errors or anomalies in the data that could impact the accuracy of the results.

iv. Out-of-Range Values: Climpact flags values that fall outside the expected range, such as extremely high or low temperature values (e.g., values exceeding 50°C), which may indicate data entry errors or other issues.

In addition to these checks, Climpact also considers data gaps when assessing the quality of the meteorological station data. Station with significant data gaps are excluded from the analysis during the specified time period. The criteria for exclusion typically include gaps of more than three days per month, more than two weeks per year, or a total of five years. By performing these quality control checks using Climpact, researchers can ensure that the data used for calculating climate indices is of high quality and free from major errors or inconsistencies. This helps to maintain the reliability and integrity of the subsequent analysis and interpretations based on the data.

3.4 Extreme Temperature and Precipitation Indices Calculation

After conducting quality control measures, the ETCCDI (Expert Team on Climate Change Detection and Indices) sector-specific climate indices were computed using the

Climpact software for the baseline period spanning 1981 to 2010. This study focused on analyzing the trends of 11 extreme precipitation and 13 extreme temperature indices, utilizing observed meteorological station data collected between 1980 and 2020. Also in this study analyzed the annual crop yield data from three districts in west Terai: Rupandehi, Banke, and Kailali. The data covered the period from 1980 to 2020. Additionally, temperature and rainfall data during the growing and harvesting seasons were used in the analysis. The Pearson correlation coefficient was employed to examine the relationship between precipitation, temperature, and annual crop yield.

To gain insights into future climate trends, the study also performed an analysis on seven extreme precipitation indices using Climate Data Operator (CDO) tools. The analysis extended from 2021 to 2100 and incorporated five model-biased corrected datasets sourced from CMIP6 (Coupled Model Intercomparison Project Phase 6) under two different scenarios, namely SSP245 (Shared Socioeconomic Pathway 2-4.5) and SSP585 (Shared Socioeconomic Pathway 5-8.5). These scenarios encompass a range of greenhouse gas emissions levels and provide valuable information regarding potential climate futures.

The ETCCDI indices utilized in this study are presented in a Table, where "PR" represents daily precipitation, "TN" denotes minimum temperature, and "TX" signifies maximum temperature. By conducting this comprehensive analysis, the study aims to enhance our understanding of how extreme climate indices influence crop yield for wheat and maize in the specified districts of West Terai. Furthermore, the future trends derived from the analysis will contribute to predicting potential impacts of climate change on extreme precipitation indices, which is crucial for agricultural planning and decision-making in the region.

Table 3.3 Temperature and precipitation indices used in this study, along with their names, definitions, and associated units

Element	Short name	Descriptive name	Definition	Units	Sectors
Temperature	SU	Summer days	Number of days when TX > 25 °C	days	Health, disaster risk reduction
	WSDI	Warm spell duration indicator	Annual number of days contributing to events where 6 or more consecutive days experience TX > 90th percentile	days	Health, agriculture, water resources and food security, cryosphere, forestry
	TXx	Max TX	Warmest daily TX	°C	Agriculture and food security, energy, forestry, cryosphere
	TXn	Min TX	Coldest daily TX	°C	Cryosphere
	TNx	Max TN	Warmest daily TN	°C	Cryosphere
	TNn	Min TN	Coldest daily TN	°C	Agriculture and food security, energy, forestry, cryosphere
	TMm	Mean TM	Mean daily mean temperature	°C	Water resources and food security, cryosphere
	TXm	Mean TX	Mean daily maximum temperature	°C	Water resources and food security, cryosphere
	TNm	Mean TN	Mean daily minimum temperature	°C	Cryosphere
	TX10p	Amount of cool days	Percentage of days when TX < 10th percentile	%	Energy
	TX90p	Amount of hot days	Percentage of days when TX > 90th percentile	%	Energy

	TN10p	Amount of cold nights	Percentage of days when TN < 10th percentile	%	Energy
	TN90p	Amount of warm nights	Percentage of days when TN > 90th percentile	%	Energy
Precipitation	PRCPTOT	Annual total wet-day PR	Sum of daily PR >= 1.0 mm	mm	Agriculture and food security, water resources, forestry
	SDII	Daily PR intensity	Annual total PR divided by the number of wet days (when total PR >= 1.0 mm)	mm/day	Water resources and food security, forestry
	CDD	Consecutive Dry Days	Maximum number of consecutive dry days (when PR < 1.0 mm)	days	Health, agriculture and food security, water resources, disaster risk reduction, forestry
	CWD	Consecutive Wet Days	Maximum annual number of consecutive wet days (when PR >= 1.0 mm)	days	Coasts
	R10mm	Number of heavy rain days	Number of days when PR >= 10 mm	days	Coasts
	R20mm	Number of very heavy rain days	Number of days when PR >= 20 mm	days	Agriculture and food security, water resources, forestry
	R50mm	Number of customized rain days	Number of days when PR >= 50mm	days	Coasts
	R99pTOT	Contribution from extremely wet days	100*r99p / PRCPTOT	%	Agriculture and food security, water resources, forestry
	R95p	Total annual PR from heavy rain days	Annual sum of daily PR > 95th percentile	mm	Coasts

	Rx1day	Max 1-day PR	Maximum 1-day PR total	mm	Agriculture and food security, coasts, disaster risk reduction, forestry
	Rx5day	Max 5-day PR	Maximum 5-day PR total	mm	Agriculture and food security, coasts, disaster risk reduction, forestry

3.5 Climpact Software

Climpact is an R-based software package designed to calculate climate indicators for various socio-economic sectors, including health, agriculture, and water resources. These indicators are derived from daily temperature and rainfall data. While it is preferable to use long and complete instrumental observations for data input, Climpact also allows for the calculation of indicators using alternative sources such as remote sensing data from satellites or reanalysis (Alexander & Herold, 2016). One of the key features of Climpact is its versatility in working with different types of weather data. Users can calculate climate indicators using their own daily weather data, whether it is in plain-text point format from a weather station or in a gridded NetCDF file like climate model output. This flexibility enables researchers to analyze and process data specific to their needs the process is as represented in Figure 3.1.

Climpact was originally developed by the Expert Team on Sector-Specific Climate Indices (ET-SCI), which is part of the World Meteorological Organization (WMO). The software aims to provide useful and relevant climate information to sector users, helping them understand the impacts of climate change on various sectors such as agriculture, health, water resources, disaster risk reduction, forestry, energy, and cryosphere. It is worth noting that Climpact is based on the same core software as the Pacific Climate Impacts Consortium's R-climdex (PCIC), ensuring a reliable and robust foundation for calculating climate indices and conducting related analyses.

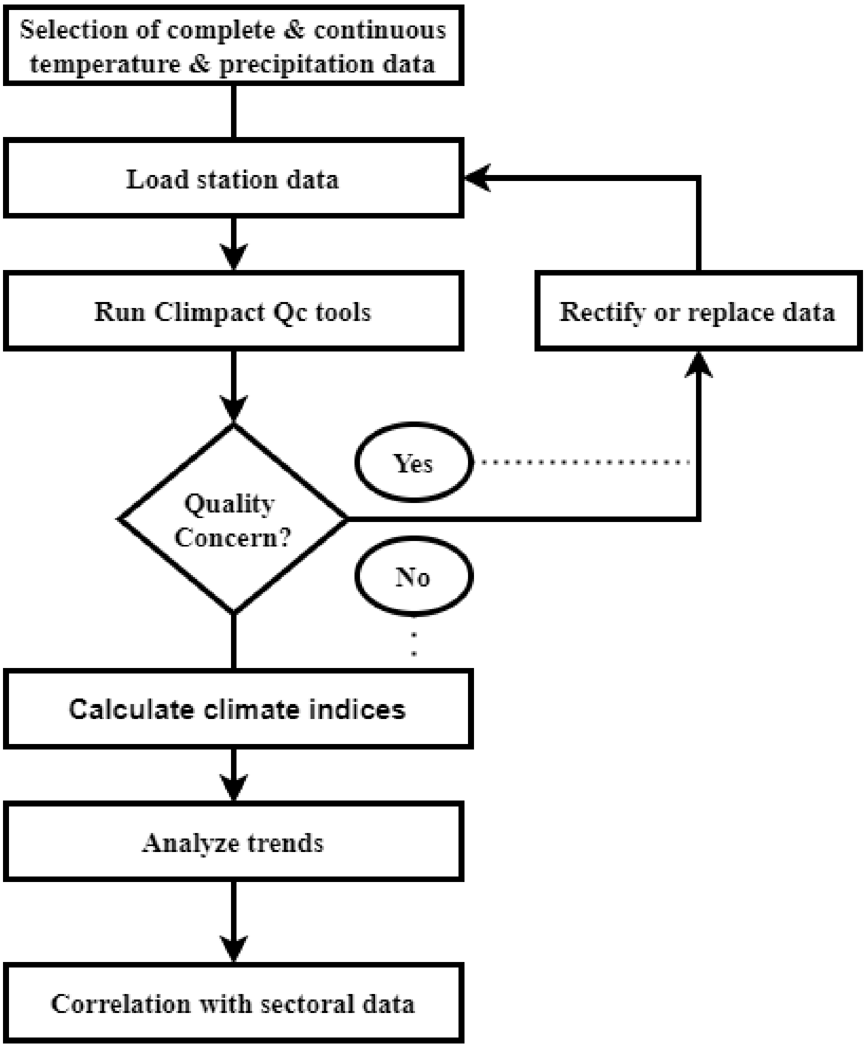


Figure 3.1 Flow chart of Climpact process

3.6 Study Area

Nepal, located in South Asia between China and India (26°22 to 30°27 N, 80°04 to 88°12 E), exhibits diverse geography with elevations ranging from 60 meters to the highest peak in the world, Mount Everest at 8,848 meters. The country can be divided into five physiographic regions that span from east to west: Terai/plain (60-200 m), Siwalik (150-700 m), Middle Mountain (700-2000 m), High Mountain (2000-3000 m), and High Himalayas (> 3000 m). Nepal stretches approximately 885 kilometers from east to west and 130 to 260 kilometers from north to south.

Nepal experiences four distinct seasons: pre-monsoon (March to May), monsoon (June to September), post-monsoon (October to November), and winter (December to February). During the pre-monsoon season, the weather is hot, dry, and characterized by westerly winds, with localized precipitation in a narrow band. The monsoon season brings moist southeasterly monsoonal winds from the Bay of Bengal, occasionally from the Arabian Sea, resulting in widespread precipitation. The post-monsoon season is dry, featuring sunny days, with November being the driest month. Winter is a cold season, and in high-altitude mountainous regions, precipitation mainly occurs in the form of snow (Karki et al., 2017).

The Terai region, known as the food basket of Nepal, exhibits high levels of agricultural production. However, climate change and associated climate extremes are expected to have negative impacts on various aspects related to the agricultural system and crop production. The Terai and Hilly areas are densely populated, while the high mountain areas are sparsely populated. Agriculture serves as the primary occupation for the people of Nepal. The main cereal crops cultivated in Nepal are paddy, wheat, maize, and millet. Paddy and wheat are the major cereal crops in the Terai region, while maize is predominant in the Hill and Mountain regions. Additionally, millet is grown in marginal lands with low productivity in the Hill and Mountain areas.

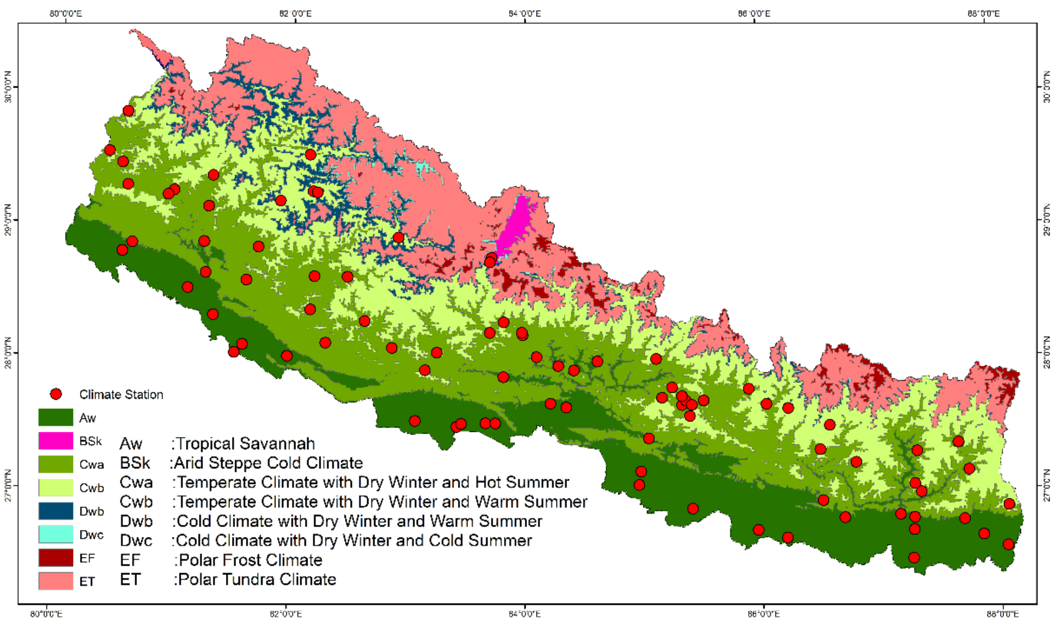


Figure 3.2 The study area map, red dot on a map represents selected quality control climatic stations for extreme climate analysis

3.7 Research Design

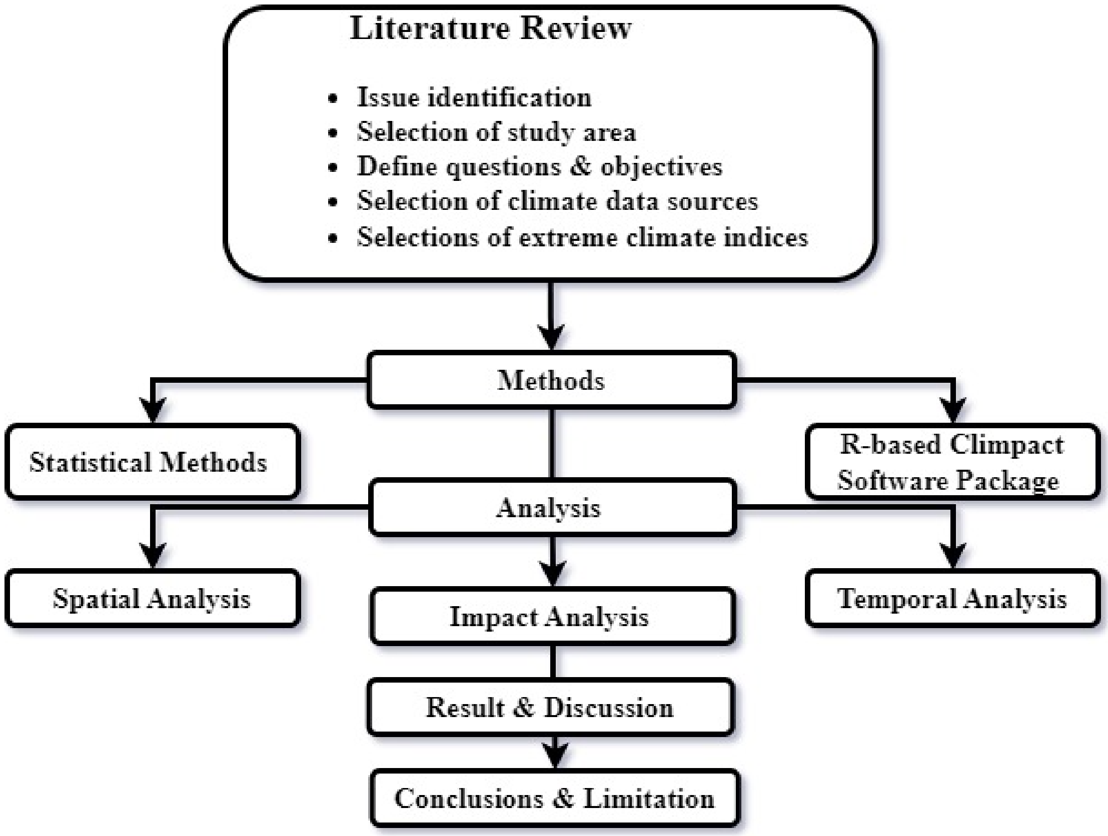


Figure 3.3 Flow chart of research design

CHAPTER 4: RESULT AND DISCUSSION

4.1 Trend in Temperature Extremes

Examining trends in temperature extremes is a crucial part of our climate study, helping us understand the changing thermal conditions in the study region. In this research, we looked at the annual trends in extreme temperatures across Nepal, using data from quality control 23 meteorological stations. We analyzed the years from 1980 to 2020, with a specific focus on the period from 1981 to 2011 as a baseline. This timeframe gives us a strong foundation to capture long-term climate variations and identify patterns beyond short-term changes. Figure 4.1 shows the number of meteorological stations with positive and negative trends in extreme temperature indices. In the next sections, we dive into detailed findings for key extreme temperature indices, exploring trends, statistical significance, and the geographic distribution. This helps us gain a better understanding of how temperature extremes are evolving in Nepal.

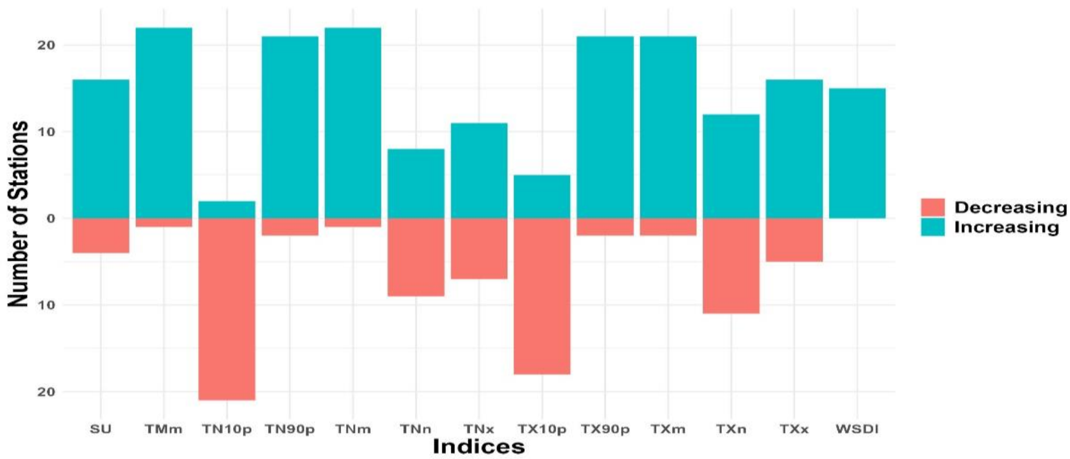


Figure 4.1 Number of stations increasing and decreasing trends of extreme temperature indices

4.1.1 Warm Days (TX90p) and Warm Nights (TN90p)

Among the 23 stations, 21 stations recorded an increasing number of warm days over the analyzed period. Importantly, statistical analysis indicated that in 15 of these stations, the observed increase in warm days was statistically significant at the 5% level, providing a high degree of confidence in the trend. The meteorological station with the maximum rate of increasing trend in warm days (TX90p) is Taplejung, situated at an elevation of 1732 meters. This station experienced the most substantial increase in warm days, with a notable increase of 0.94 percentages per year (as shown in Figure 4.2).

Similarly, the study found that warm night temperatures (TN90p) exhibited a rising trend in the majority of the stations. Among the 23 stations, 21 recorded an increase in warm night temperatures over the analyzed period. Furthermore, statistical significance testing revealed that in 12 of these stations, the observed upward trend in warm nights was statistically significant at the 5% level, providing robust evidence for the trend. The meteorological station with the maximum rate of increasing trend in warm nights (TN90p) is Khumaltar, located at an elevation of 1350 meters. This station observed the most significant increase in warm night temperatures, with a noteworthy increase of 0.42 percentages per year.

These findings collectively suggest that both warm days and warm night temperatures have been on the rise in Nepal. The statistically significant results in a substantial number of stations underscore the reliability of these trends.

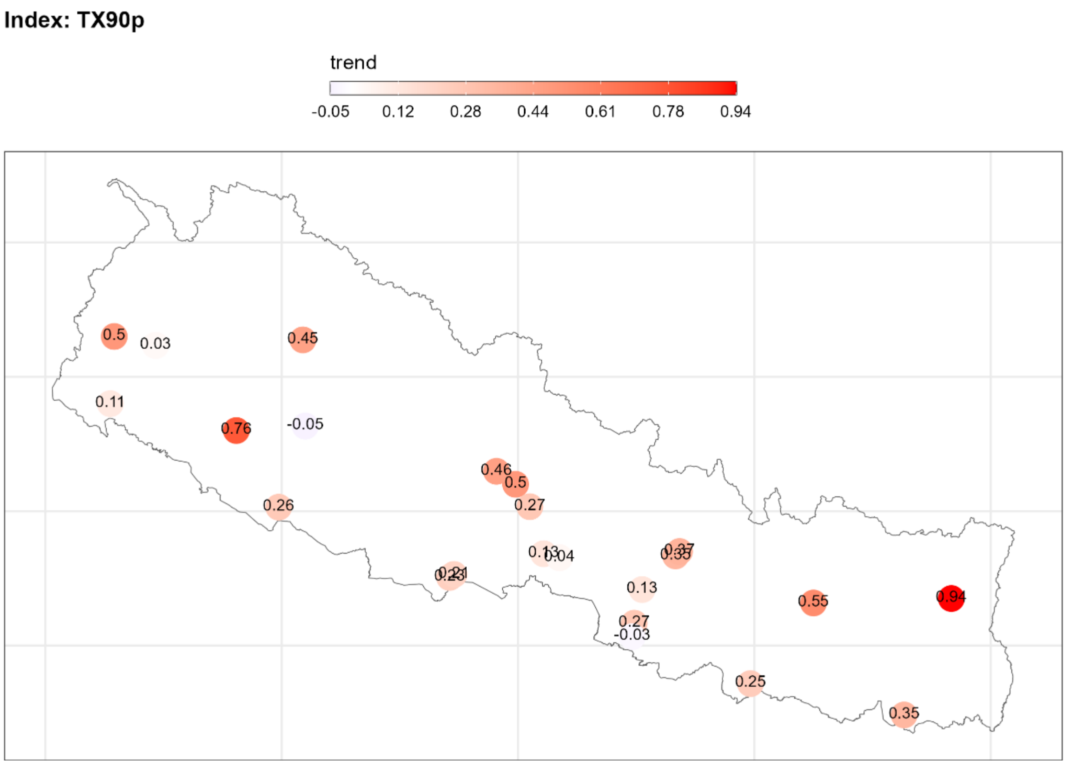


Figure 4.2 Meteorological station wise trend of warm days (TX90p)

4.1.2 Cool Days (TX10p) and Cool Nights (TN10p)

Out of the 23 stations, a significant decreasing trend in the annual occurrence of cool days (TX10p) was observed in 18 stations. This indicates a decline in the number of days with relatively cool maximum temperatures compared to the long-term average, suggesting a possible transition to warmer daytime temperatures. Furthermore, a detailed examination revealed that this decreasing trend was statistically significant at the 5% level in 10 of the 18 stations (as shown in Figure 4.3). This statistical significance strengthens the observation that the reduction in cool days is not merely due to natural variability but likely reflects a consistent long-term change towards a warmer climate in those specific locations. The meteorological station with the maximum rate of decreasing trend in cool days (TX10p) is Okhaldhunga, situated at an elevation of 1720 meters. This station experienced the most substantial decrease in cool days, with a notable decline of -0.45 percentages per year.

Similarly, the analysis indicated a decreasing trend in the annual occurrence of cool nights (TN10p) in 21 out of the 23 stations. This suggests a decline in the number of nights with relatively cool minimum temperatures compared to the historical average, indicating a potential transition to warmer nighttime temperatures. Additionally, the decreasing trend in the annual occurrence of cool nights (TN10p) was found to be statistically significant at the 5% level in 12 of the 21 stations (as shown in Figure 4.3). This statistical significance reinforces the evidence of a consistent and meaningful decline in cool nights, indicating a potential shift towards warmer nighttime temperatures in those specific locations.

The meteorological station with the maximum rate of decreasing trend in cool nights (TN10p) is Kathmandu Airport, located at an elevation of 1337 meters. This station observed the most significant decrease in cool nights, with a noteworthy decline of -0.41 percentages per year.

Taken together, these results underscore a significant trend towards warmer temperatures in Nepal's meteorological stations. The decline in the annual occurrence of cool days and cool nights, especially in stations where the trend is statistically significant, provides substantial evidence of a possible climate shift characterized by a reduction in cooler temperature extremes.

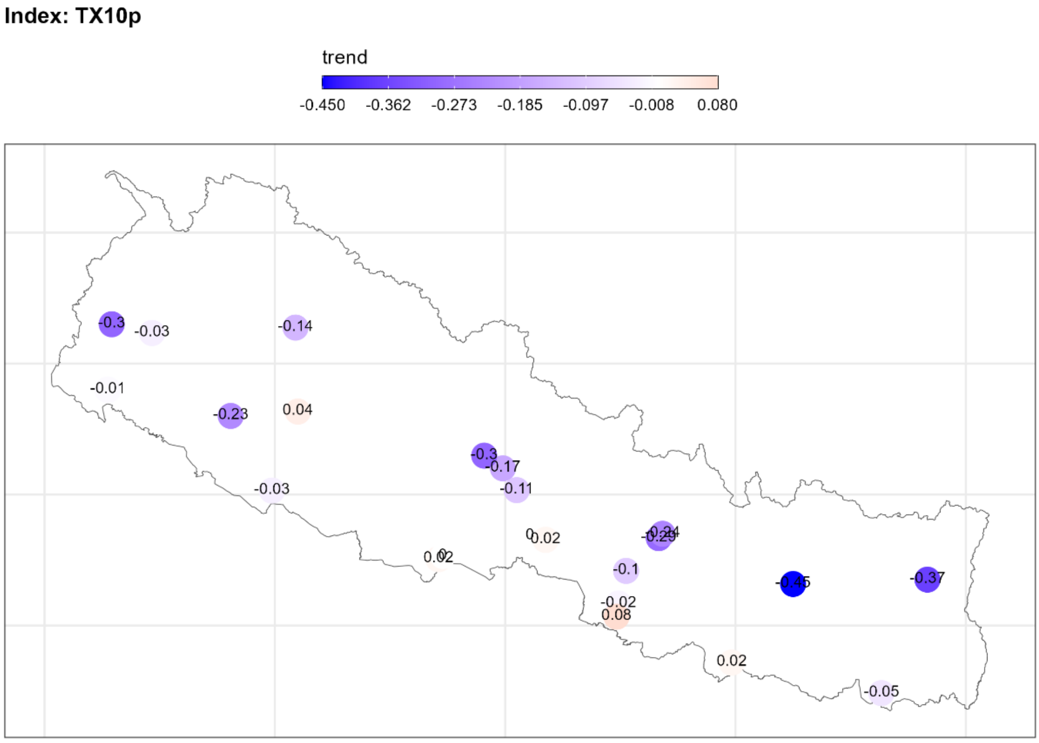


Figure 4.3 Meteorological station wise trend of cool days (TX10p)

4.1.3 Warmest Day (TXx) and Coldest Day (TXn)

Out of the 23 stations, 16 stations displayed an increasing trend in the occurrence of warmest days (TXx), indicating a potential warming trend. This suggests that in these specific locations, the frequency of extremely warm days has been on the rise over time. Conversely, 7 stations exhibited a decreasing trend in warmest days, implying a potential cooling trend in those areas. The meteorological station with the maximum rate of increasing trend in warmest days (TXx) is Taplejung, situated at an elevation of 1732 meters. This station experienced the most substantial increase in the occurrence of warmest days, with a noteworthy trend of 0.07°C per year (as shown in Figure 4.4).

When analyzing the coldest day temperatures (TXn), 12 stations showed an increasing trend, indicating a potential warming trend for those specific locations. This suggests that the frequency of extremely cold days has been decreasing in those areas over time. Conversely, 11 stations displayed a decreasing trend in coldest day temperatures, suggesting a potential cooling trend. In these locations, the frequency of extremely cold days has been increasing over time. The meteorological station with the maximum rate of increasing trend in coldest days (TXn) is Okhaldhunga, located at an elevation of 1720 meters. This station observed the most significant increase in the occurrence of coldest days, with a noteworthy trend of 0.08°C per year.

These results highlight the complexity of temperature changes in Nepal, where some stations show warming trends in terms of both warmest and coldest day temperatures, while others exhibit cooling trends. The variation underscores the influence of regional factors and local climate dynamics on temperature trends in different parts of Nepal.

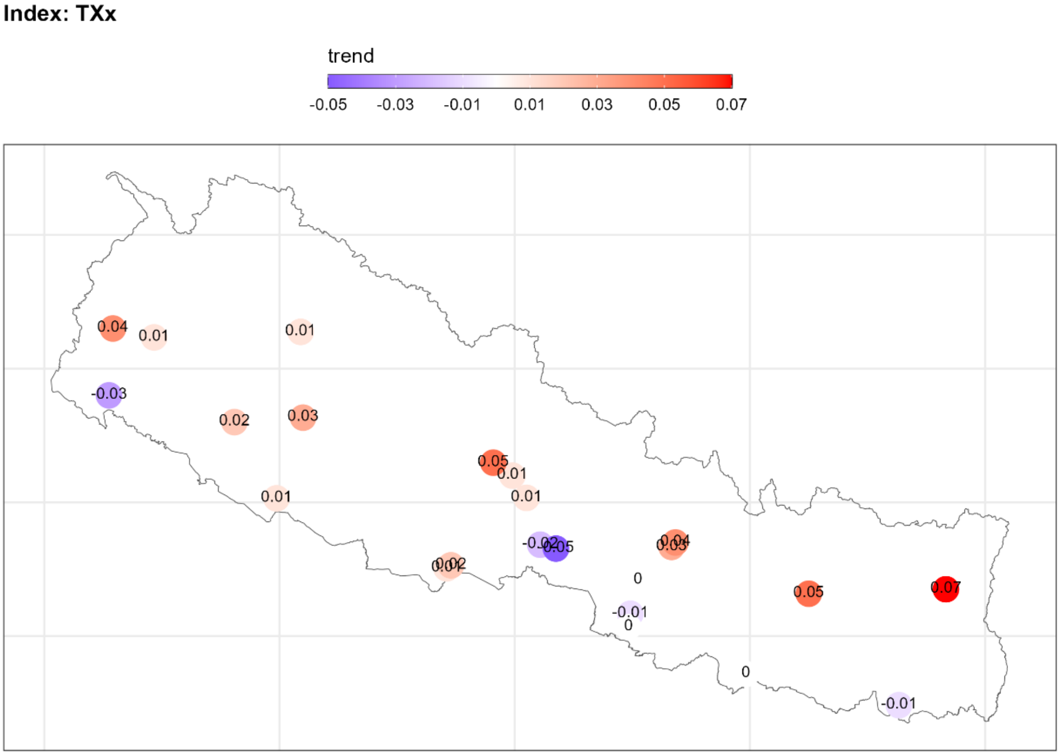


Figure 4.4 Meteorological station wise trend of warmest day (TXx)

4.1.4 Warmest Night (TNx) and Coldest Night (TNn)

Out of the 23 meteorological stations considered in the study, a distinct warming trend in warmest night temperatures (TNx) was observed in 11 stations. In these locations, the highest nighttime temperatures exhibited a consistent increase over time. Notably, 5 of these stations displayed statistically significant trends at the 5% level, providing robust evidence for the warming of nights in these specific areas. Conversely, 7 stations exhibited a cooling trend in warmest night temperatures, indicating a decrease in the highest nighttime temperatures over the study period.

Shifting the focus to coldest night temperatures (TNn), 8 stations demonstrated an increasing trend, indicating a gradual warming of the lowest nighttime temperatures in these areas. On the other hand, 9 stations displayed a decreasing trend in TNn, suggesting a decline in the coldest nighttime temperatures. The complexity of these findings highlights the diverse and intricate patterns of temperature changes across Nepal, influenced by regional factors and local climate dynamics.

Among these trends, the station at Jumla, situated at an elevation of 2366 meters, exhibited a subtle yet positive trend in warmest night temperatures (TNx), with an increase of 0.02°C per year. Conversely, the station at Surkhet (Birendra Nagar), located at 720 meters, demonstrated a cooling trend in TNx, with a decrease of -0.04°C per year (as shown in Figure 4.5). Regarding coldest night temperatures (TNn), the station at Khumaltar, positioned at an elevation of 1350 meters, revealed a significant increase of 0.08°C per year, indicating warming nights. In contrast, the Lumle station, situated at an elevation of 1740 meters, experienced a distinct cooling trend in TNn, with a decrease of -0.12°C per year.

These results emphasize the intricate nature of temperature trends in Nepal, where some stations exhibit warming trends in both warmest and coldest night temperatures, while others demonstrate cooling trends. This variability underscores the significance of regional influences and local climate dynamics in shaping temperature trends in different regions of Nepal.

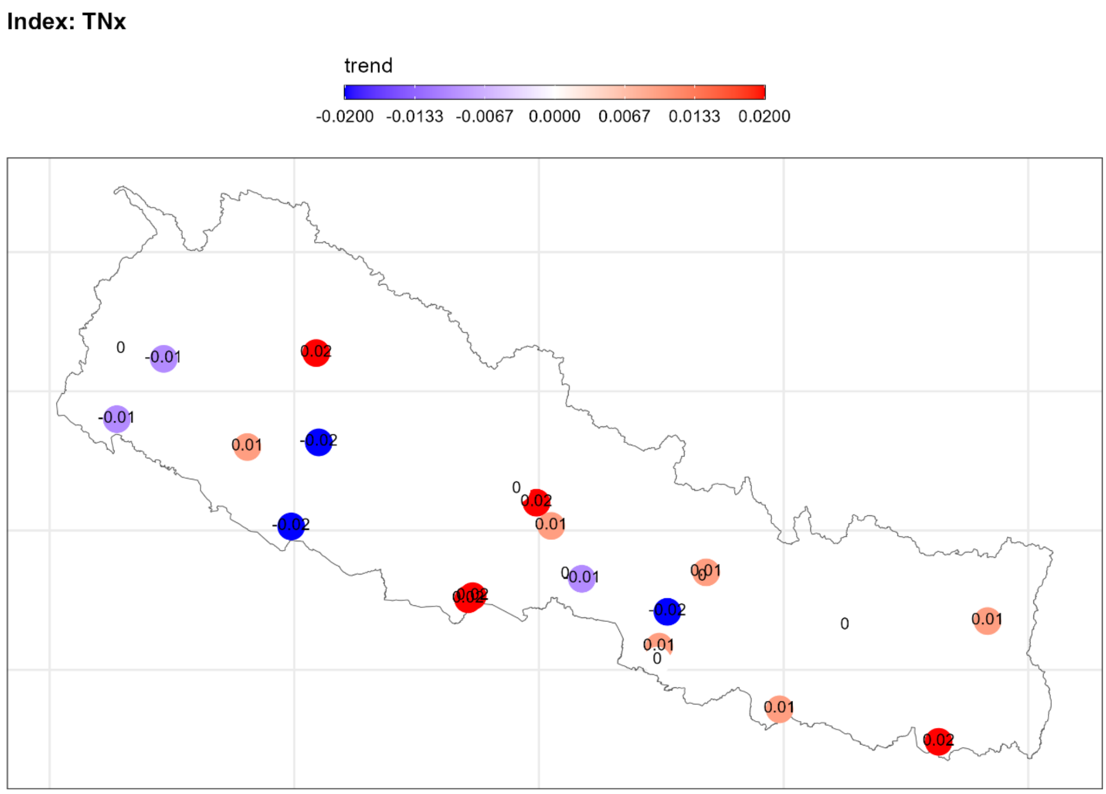


Figure 4.5 Meteorological station wise trend of warmest night (TNx)

4.1.5 Warm Spell Duration Indicator (WSDI) and Summer Days (SU)

The analysis of temperature data from 23 meteorological stations in Nepal has provided significant insights into the Warm Spell Duration Indicator (WSDI) index. Among the 23 stations, statistically significant trends (at $p < 0.05$) in the WSDI index were observed in 14 stations. These findings indicate a substantial increase in the number of days contributing to warm spells over the analyzed period. Warm spells, characterized by prolonged periods of above-average temperatures, have demonstrated a notable upward trend in these specific locations, which suggests a potential linkage to climate change. This phenomenon carries various implications, including heightened heat-related health risks, alterations in agricultural practices, and shifts within ecosystems.

Regarding the WSDI index, the meteorological station displaying the maximum rate of increasing trend is Taplejung, positioned at an elevation of 1732 meters. This station has experienced the most significant increase in the occurrence of warm spells, as evidenced by a noteworthy trend of 1.04 days per year (as shown in Figure 4.6).

Conversely, when considering Summer Days (SU), the analysis reveals diverse trends among the stations, with some stations exhibiting increasing trends in the occurrence of Summer Days while others demonstrate decreasing trends. This variability underscores the complexity of temperature changes in Nepal, influenced by an interplay of regional factors and local climate dynamics.

Specifically, the meteorological station with the maximum rate of increasing trend in Summer Days (SU) is Okhaldhunga, situated at an elevation of 1720 meters. This station has observed the most substantial increase in the occurrence of Summer Days, as indicated by a noteworthy trend of 3 days per year.

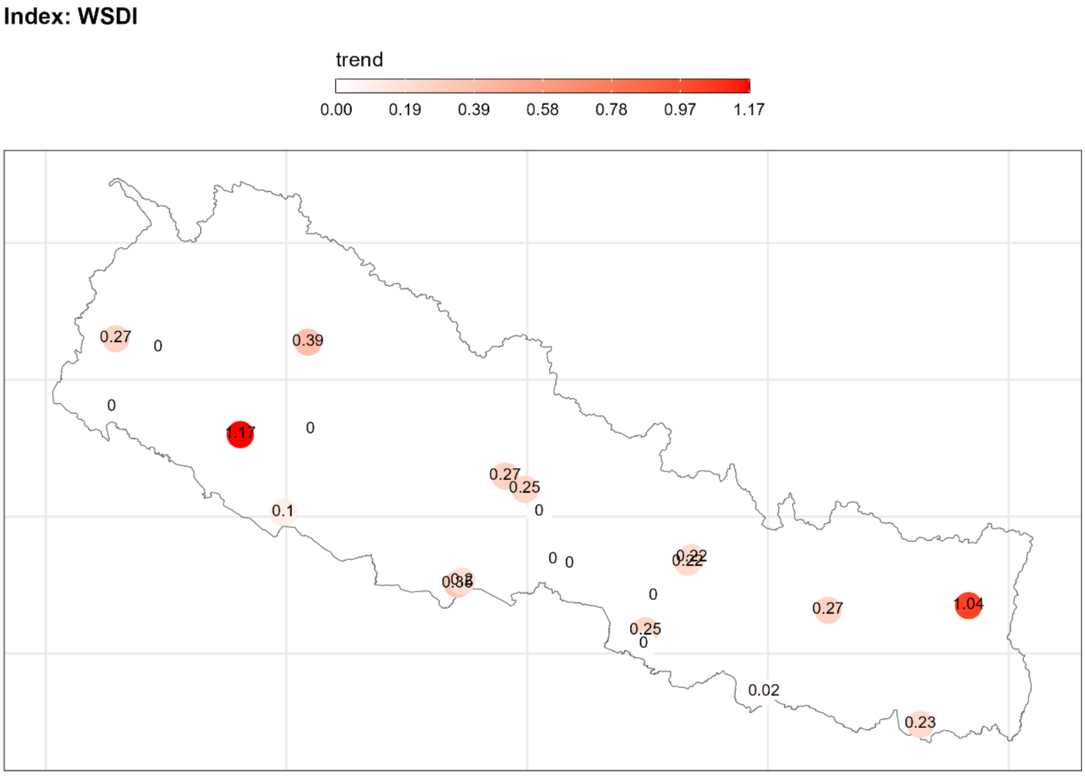


Figure 4.6 Meteorological station wise trend of warm spell duration indicator (WSDI)

4.1.6 Mean Temperature (TMm)

The analysis of annual mean temperature (TMm) data from 23 weather stations in Nepal spanning a 41-year period (1980 to 2020), with a reference base period of 1981-2010, reveals significant temperature trends. Among these stations, Kathmandu Airport stands out with the maximum rate of increasing trend in mean temperature. Situated at an elevation of 1337 meters, Kathmandu Airport has experienced a noteworthy annual temperature increase of 0.05°C per year (as shown in Figure 4.7). This finding underscores the pronounced warming trend observed at this specific location.

Moreover, when considering the average rate of increasing trend in mean temperature (TMm) across all 23 meteorological stations in Nepal, the country-wide average TMm trend is 0.0258°C per year. This result emphasizes the consistent and widespread warming trend in temperatures observed throughout Nepal over the 41-year study period, highlighting the need for further research to explore the underlying drivers and potential regional variations within the country.

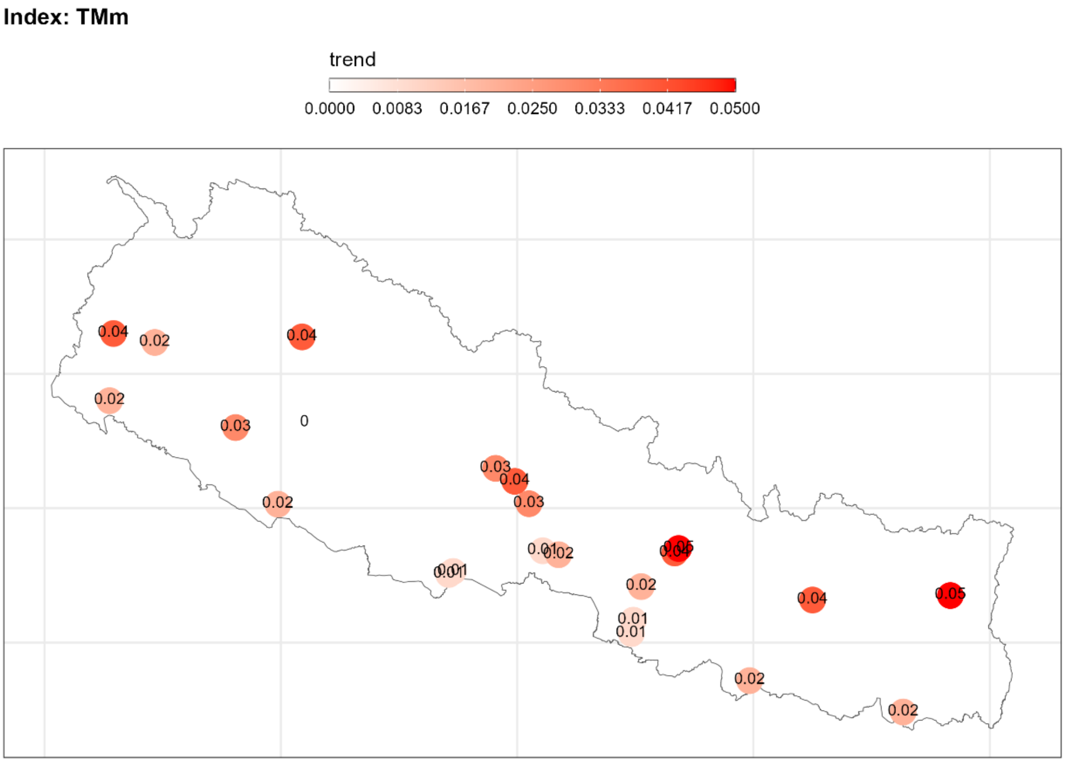


Figure 4.7 Meteorological station wise trend of mean temperature (TMm)

4.1.7 Mean Maximum Temperature (TXm) and Mean Minimum Temperature (TNm)

The comprehensive analysis of mean maximum (TXm) and mean minimum (TNm) temperatures across 23 meteorological stations in Nepal unveils a noteworthy warming trend in both temperature indicators. This pervasive warming trend implies an overall increase in temperatures across these regions, potentially carrying significant implications for the local climate and ecosystems.

Moreover, the observed increasing trends in both mean maximum and minimum temperatures have been statistically verified at a 5% significance level. This statistical significance underscores a high level of confidence that these meteorological stations are indeed undergoing a substantial and meaningful temperature rise.

For instance, the station with the maximum rate of increasing trend in mean maximum temperature (TXm) is Dadeldhura, situated at an elevation of 1848 meters. This station has experienced a remarkable increase in mean maximum temperature, with a substantial trend of 0.09°C per year, as shown in Figure 4.8. Similarly, the station with the maximum rate of increasing trend in mean minimum temperature (TNm) is Kathmandu Airport, located at an elevation of 1337 meters. This station has observed a significant increase in mean minimum temperature, with a noteworthy trend of 0.05°C per year.

These findings emphasize the undeniable impact of temperature rise in Nepal, affecting both daytime and nighttime temperatures. It underscores the urgency for further research and localized adaptation measures to address the consequences of this warming trend on various sectors and ecosystems within the region.

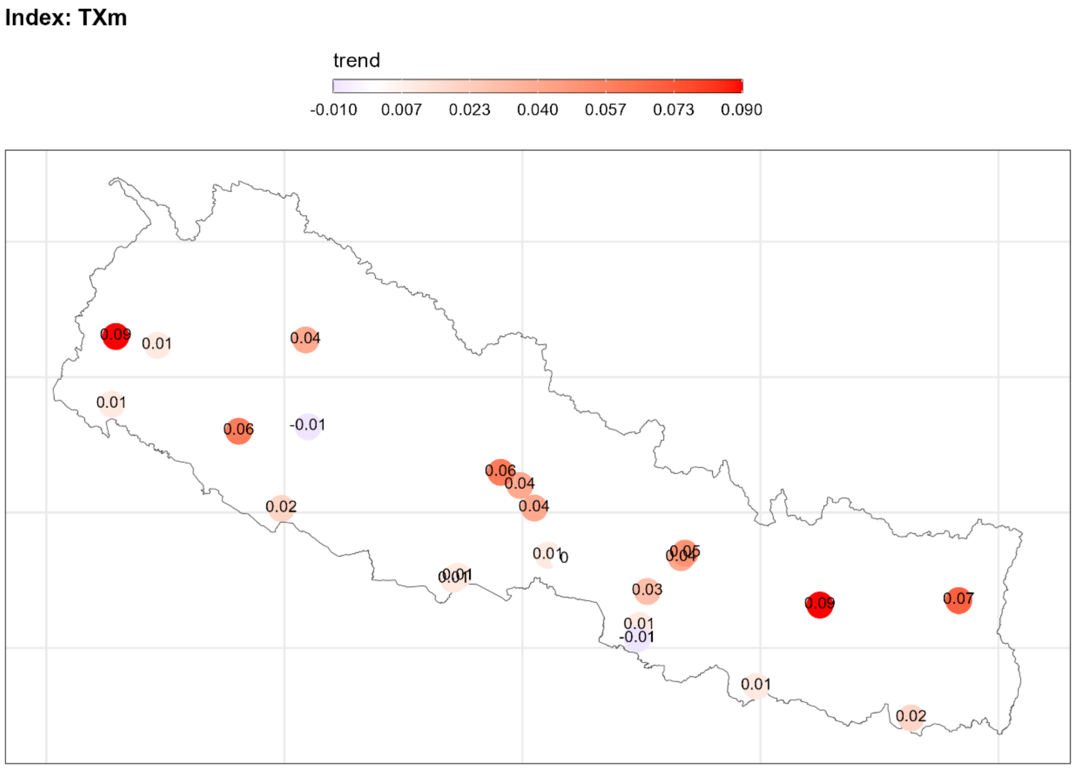


Figure 4.8 Meteorological station wise trend of mean maximum temperature (TXm)

4.2 Trend in precipitation extremes

Investigating trends in extreme precipitation indices is a crucial component of our climatological analysis, providing insights into the changing patterns of precipitation across the study region. In this study, we also examined the annual trends of extreme precipitation indices in Nepal, utilizing data from 85 quality-controlled meteorological stations. Our comprehensive temporal analysis spanned the years from 1980 to 2020, with a specific focus on the baseline period from 1981 to 2011. This extensive timeframe allows us to capture long-term variations in precipitation patterns, extending our understanding beyond short-term fluctuations. Figure 4.9 visually illustrates the number of meteorological stations exhibiting positive and negative trends in extreme precipitation indices. In the subsequent sections, we delve into detailed findings for key precipitation indices, providing thorough examinations of trends, statistical significance, and the geographical distribution of extreme precipitation. This helps us gain a better understanding of how precipitation extremes are evolving in Nepal.

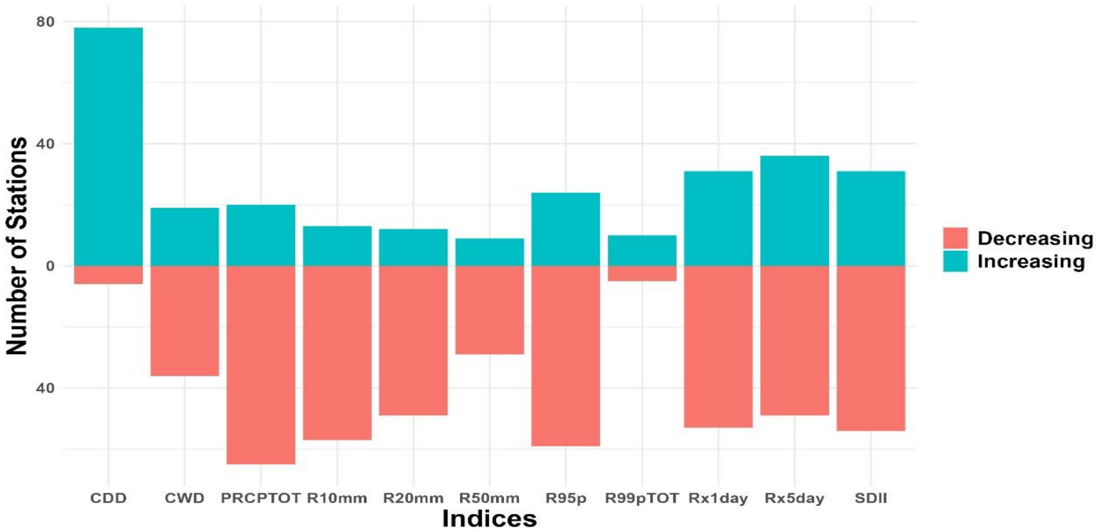


Figure 4.9 Number of stations increasing and decreasing trends of extreme precipitation indices

4.2.1 Consecutive Dry Days (CDD) and Consecutive Wet Days

The analysis of precipitation data from 85 meteorological stations across Nepal for the period of 1980 to 2020 reveals increasing trend in consecutive dry days (CDD). Specifically, 78 out of the 85 stations (92%) exhibited an increasing trend in CDD over the study period. The highest rate of increase in CDD was observed at the Rani Jaruwa Nursery meteorological station, located at an elevation of 155 meters, where the rate was 1.6 days per year (as shown in Figure 4.10). This finding suggests a significant change in the precipitation pattern in Nepal, with longer durations of consecutive days without rainfall. Such an increase in CDD can have potential implications for various sectors, including agriculture, water resources, and ecosystem services, as prolonged dry periods may lead to water scarcity and impact crop yields.

In addition to the CDD trends, the analysis reveals mixed trends in consecutive wet days (CWD). Out of the 85 stations, 36 stations (42%) showed a decreasing trend in CWD, while 19 stations (22%) exhibited an increasing trend (shown in Figure 2). The highest rate of increase in CWD was observed at the Salleri meteorological station, situated at an elevation of 2378 meters, with an average increase of 0.4 days per year. On the contrary, the most substantial decrease in CWD was noted at the Jomsom meteorological station, located at an elevation of 2744 meters, where CWD exhibited a decreasing trend at a rate of -0.3 days per year. These findings suggest a heterogeneous pattern of change in the precipitation regime, with some regions experiencing longer periods without rainfall, and others experiencing longer durations of consecutive rainy days. Such variations in CWD trends can have implications for water availability, flooding risks, and the ecological balance of different regions in Nepal.

These comprehensive findings underscore the complexity of climate change in Nepal, with diverse trends in CDD and CWD across the country. The increasing CDD trend highlights the potential challenges associated with water resources and agriculture due to prolonged dry spells. Simultaneously, the varied CWD trends emphasize the importance of region-specific strategies to manage water resources and mitigate the impacts of changing precipitation patterns.

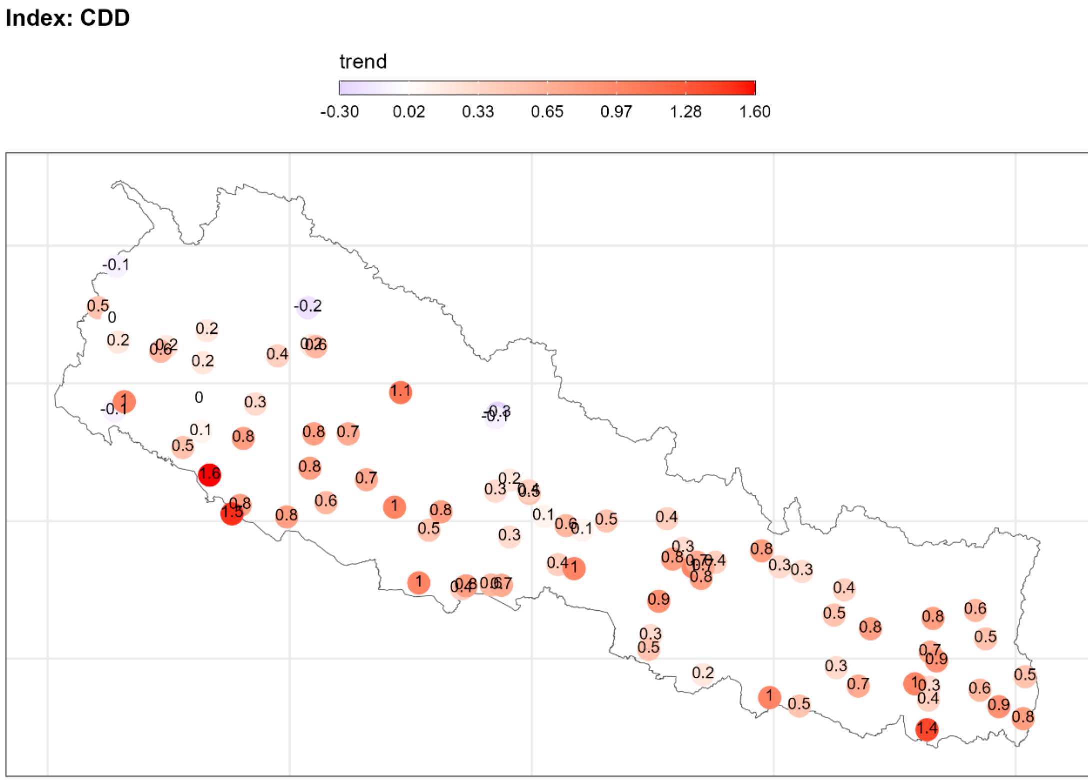


Figure 4.10 Meteorological station wise trend of consecutive dry days (CDD)

4.2.2 Simple Daily Intensity Index (SDII) and Contribution from Extremely Wet Days (R99pTOT)

The Simple Precipitation Intensity Index (SDII), which is calculated as the sum of precipitation in wet days (days with precipitation over 1mm) during the year divided by the number of wet days in the year. The analysis of SDII indicates noteworthy changes in daily precipitation intensity across Nepal. Over this 41-year period, it is observed that 54 stations (64%) exhibited decreasing trend in SDII. This decreasing trend implies a reduction in the intensity of precipitation events in these areas, which could potentially have implications for various sectors such as agriculture, water management, and infrastructure planning.

In contrast, 31 stations (36%) exhibited increasing trend in SDII, as depicted in Figure 4.11. This increase in SDII suggests an intensification of precipitation events in these regions. Such changes in precipitation patterns may lead to increased flood risks and could also impact water resource management strategies.

These findings collectively indicate that the precipitation pattern in Nepal is undergoing significant changes, with some areas experiencing a decrease in precipitation intensity, while others are witnessing an increase. Understanding these variations is crucial for informed decision-making in the face of changing climate conditions.

One notable station, the Rani Jaruwa Nursery meteorological station, located at an elevation of 155 meters, stands out with a substantial increase in SDII at a rate of 1.6 mm per day per year, signifying a significant change in daily precipitation intensity in that particular region.

The analysis of R99pTOT for the 85 meteorological stations in Nepal did not reveal a statistically significant trend at the 5% level for most of the stations. Out of the total stations, 10 stations (12%) showed an increasing trend in R99pTOT; however, this upward trend was not statistically significant. In contrast, 5 stations (6%) exhibited a statistically significant decreasing trend in R99pTOT.

For the majority of the stations (82%), there was no significant trend observed in their R99pTOT values, as shown in Figure. Despite the lack of overall statistical significance, it is crucial to note that changes in extreme precipitation events can have substantial implications for the region, including increased risks of flooding, landslides, and potential impacts on water resource management.

In summary, the analysis of R99pTOT did not reveal a statistically significant trend in contributions from extremely wet days across most stations. However, the variations in this parameter underscore the importance of monitoring and adapting to changes in extreme precipitation events to enhance flood resilience and water resource management strategies in Nepal.

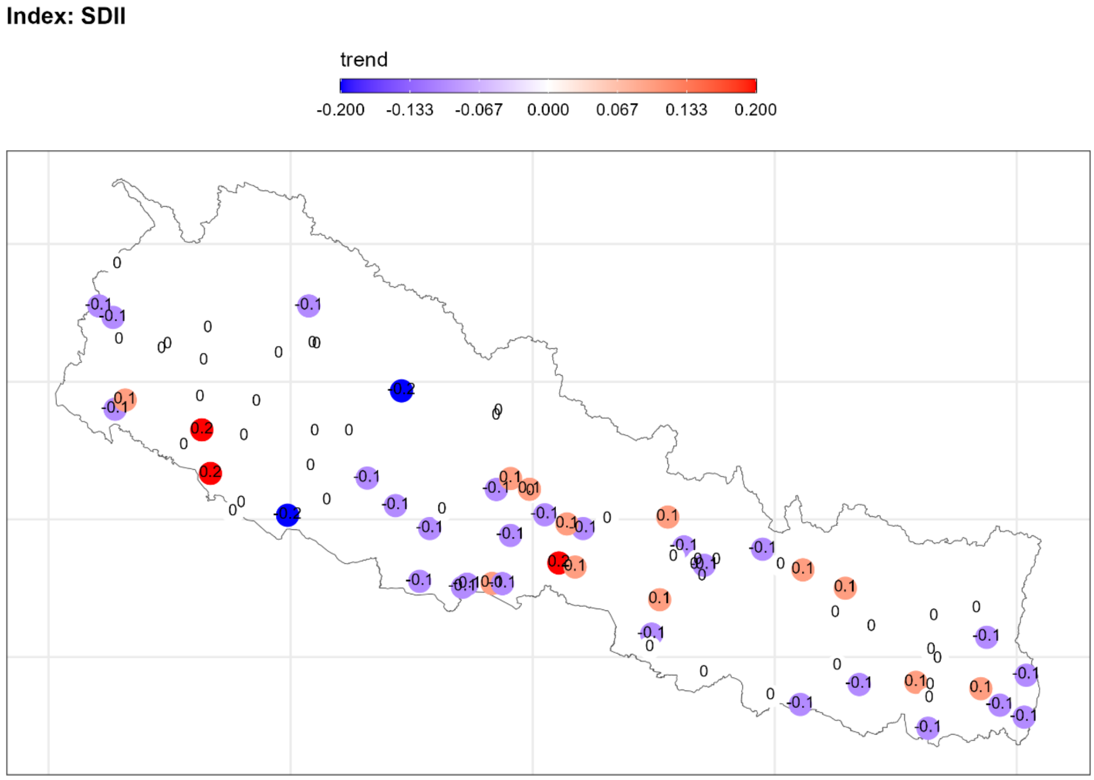


Figure 4.11 Meteorological station wise trend of simple daily intensity index (SDII)

4.2.3 Number of Heavy (R10mm) and Very Heavy (R20mm) Precipitation

The analysis of heavy precipitation events in the country revealed non-uniform changes in both R10mm and R20mm values across the 85 meteorological stations. Specifically, when examining R10mm values, 57 stations (67%) exhibited a decreasing trend, while 13 stations (15%) showed an increasing trend in heavy precipitation events. Among these trends, the R10mm values at the Simari meteorological station, situated at an elevation of 154 meters, displayed the highest rate of increase, with a significant trend of 0.2 days per year. In contrast, the Janakpur Airport meteorological station, located at an elevation of 90 meters, demonstrated the minimum rate of decrease in R10mm values, with a trend of -0.1 days per year.

For very heavy precipitation events (R20mm), 49 stations (58%) exhibited a decreasing trend, while 12 stations (14%) showed an increasing trend over the study period. Notably, the Pansayakhola meteorological station, positioned at an elevation of 1240 meters, experienced the most substantial decrease in R20mm values, with a trend of -0.6 days per year (as shown in Figure 4.12). These findings highlight the non-uniform changes in heavy and very heavy precipitation events across Nepal and underscore the need for region-specific adaptation strategies to address the impacts of shifting precipitation patterns on water resources and disaster management.

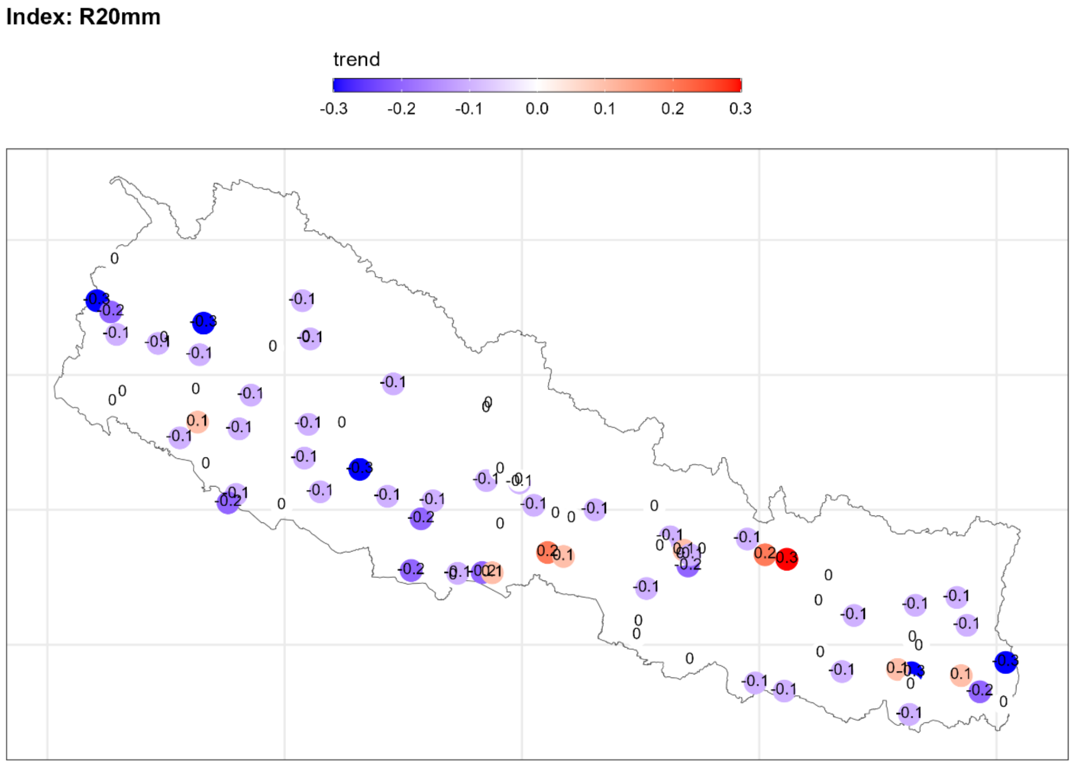


Figure 4.12 Meteorological station wise trend of very heavy precipitation (R20mm)

4.2.4 Maximum 1-Day (RX1day) and 5-Day (RX5day) Precipitation

In terms of Rx1day, it was found that 31 stations (36%) displayed an increasing trend, while 53 stations (62%) exhibited decreasing trend ($p < 0.05$). The most substantial increase in Rx1day was observed at the Patan (West) meteorological station, located at an elevation of 1266 meters, with a notable increase of 1.0 mm per year (as shown in Figure 4.13). Conversely, the most decrease in Rx1day occurred at the Chandra Gadhi meteorological station, situated at an elevation of 90 meters, with a substantial decrease of -1.9 mm per year. These findings underscore the regional disparities in extreme 1-

day precipitation events, with some areas experiencing more intense events, potentially leading to flood risks and landslides.

Similarly, for Rx5day, the analysis indicates that 36 stations (42%) witnessed an increasing trend, while 49 stations (58%) demonstrated a decreasing trend. The highest rate of increase in Rx5day was recorded at the Charikot meteorological station, situated at an elevation of 1940 meters, with a substantial increase of 1.4 mm per year. Conversely, the most significant decrease in Rx5day was observed at the Chandra Gadhi meteorological station, which had the lowest elevation in the dataset at 90 meters, and exhibited a substantial decrease of -5.1 mm per year. These results highlight the significance of regional variations in extreme 5-day precipitation events, with potential implications for flood risks and water resource management.

In summary, the analysis of Rx1day and Rx5day extreme precipitation events in Nepal underscores the regional heterogeneity in these events. While some areas experience increasing trends, indicating heightened risks of heavy precipitation, others exhibit decreasing trends, necessitating region-specific strategies for managing the impacts of changing precipitation patterns on flood risks, landslides, and water resources.

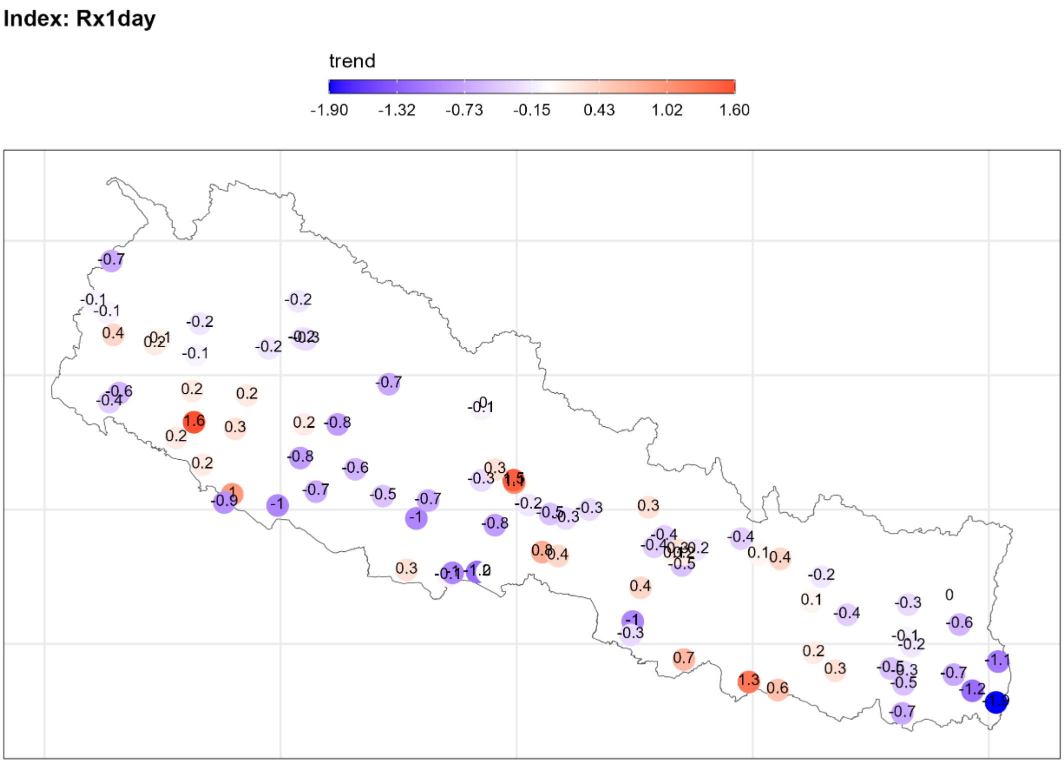


Figure 4.13 Meteorological station wise trend of maximum 1-day precipitation (RX1day)

4.2.5 Annual Total Precipitation (PRCPTOT) and Total Annual Precipitation from heavy rain days (R95p)

In terms of Annual Total Precipitation (PRCPTOT), the analysis across 85 meteorological stations in Nepal reveals significant spatial variability in precipitation trends over the period from 1980 to 2020. Out of the 85 stations, 65 stations (76%) exhibited a decreasing trend in annual total precipitation, indicating a decrease in the amount of precipitation received annually. Conversely, 20 stations (24%) displayed an increasing trend in annual total precipitation.

The most substantial decrease in annual total precipitation occurred at the Kanyam Tea Estate meteorological station, which is situated at an elevation of 1570 meters. This station experienced a notable decrease of -24.2 mm per year. Conversely, the most significant increase in annual total precipitation was observed at the Malepatan (Pokhara) meteorological station, located at an elevation of 856 meters, with a noteworthy increase of 12.3 mm per year (as shown in Figure 4.14).. These findings emphasize the spatial variability in annual total precipitation trends across Nepal

Regarding the analysis of heavy rainfall events exceeding the 95th percentile (R95p), it was observed that 59 meteorological stations (approximately 69% of the total) showed a statistically decreasing trend in these events during the same period. In contrast, 24 stations (approximately 28% of the total) exhibited an increasing trend.

The most substantial decrease in heavy rainfall events occurred at the Chandra Gadhi meteorological station, situated at an elevation of 90 meters, with a significant decrease of -15.2 mm per year. On the other hand, the most significant increase in heavy rainfall events was recorded at the Malepatan (Pokhara) meteorological station, which is located at an elevation of 856 meters. This station experienced a noteworthy increase of 12.7 mm per year in heavy rainfall events.

Overall, these results underscore the considerable spatial variability in both annual total precipitation and heavy rainfall events across Nepal. While a majority of stations displayed decreasing trends, further research is needed to fully understand the underlying causes and potential implications of these trends, taking into account other environmental factors.

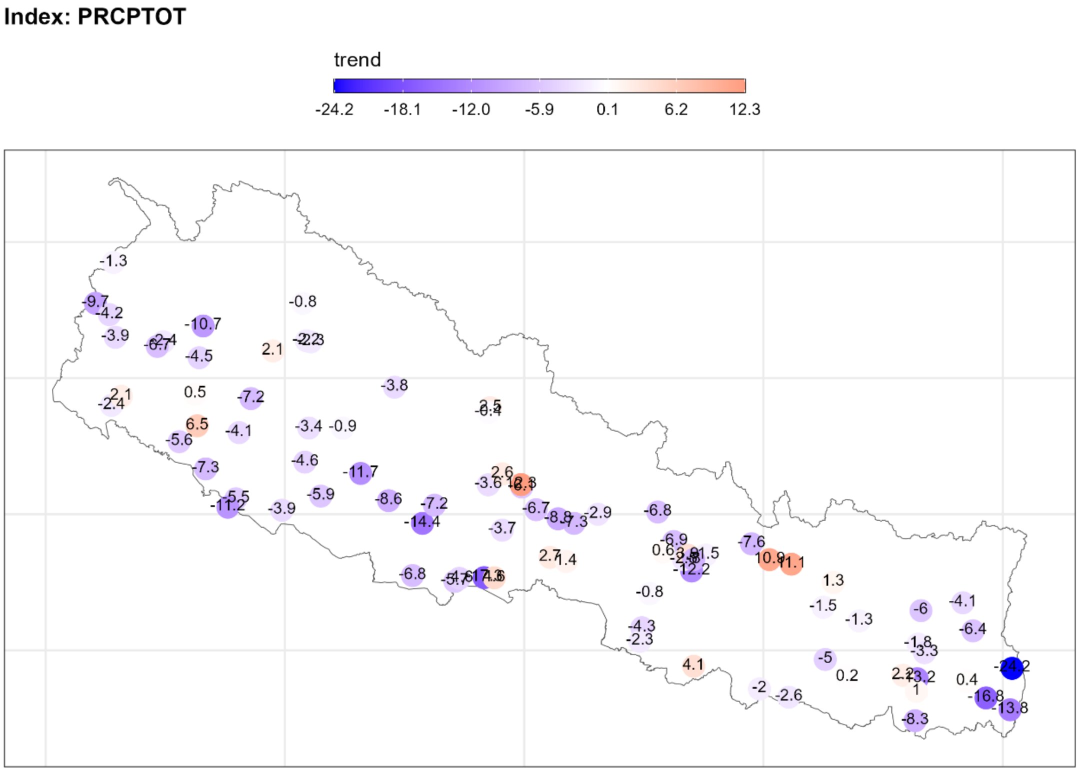


Figure 4.14 Meteorological station wise trend of annual total precipitation (PRCPTOT)

4.2.6 Number of customized rain days (R50mm)

Out of the 85 meteorological stations analyzed, it was observed that 29 stations (approximately 34% of the total) exhibited decreasing trend in the number of customized rain days (R50mm) over the period from 1980 to 2020. This indicates that in these regions, there has been a decline in the frequency of heavy rainfall events exceeding the threshold of 50mm. This decrease in heavy rainfall events can potentially lead to drier conditions in these areas, as there are fewer instances of intense rainfall.

The meteorological station with the maximum decreasing trend in customized rain days (R50mm) is the Chandra Gadhi station, situated at an elevation of 90 meters. This station experienced the most substantial decrease in the number of heavy rainfall events, with a significant decrease of -0.3 days per year.

Conversely, 9 stations (approximately 11% of the total) showed an increasing trend (as shown in Figure 4.15) in the number of customized rain days (R50mm). Among these, the meteorological station with the maximum increasing trend is the Malepatan (Pokhara) station, located at an elevation of 856 meters. This station observed the most significant increase in the number of heavy rainfall events, with a noteworthy increase of 0.2 days per year.

Importantly, it is worth noting that no significant trend was observed in the remaining 47 stations (approximately 55% of the total). This indicates that there is significant spatial variability in the trends of customized rain days (R50mm) across the country, with some regions experiencing changes in heavy rainfall frequency while others remain relatively stable.

Overall, these results highlight the complexity and spatial variability of heavy rainfall events in Nepal. While some areas are experiencing a significant decrease in the frequency of heavy rainfall events, potentially leading to drier conditions, other areas are observing an increase in such events, which can pose a higher risk of flooding. The findings also emphasize the need for localized studies and consideration of local factors when assessing rainfall patterns and associated impacts in different regions of the country.

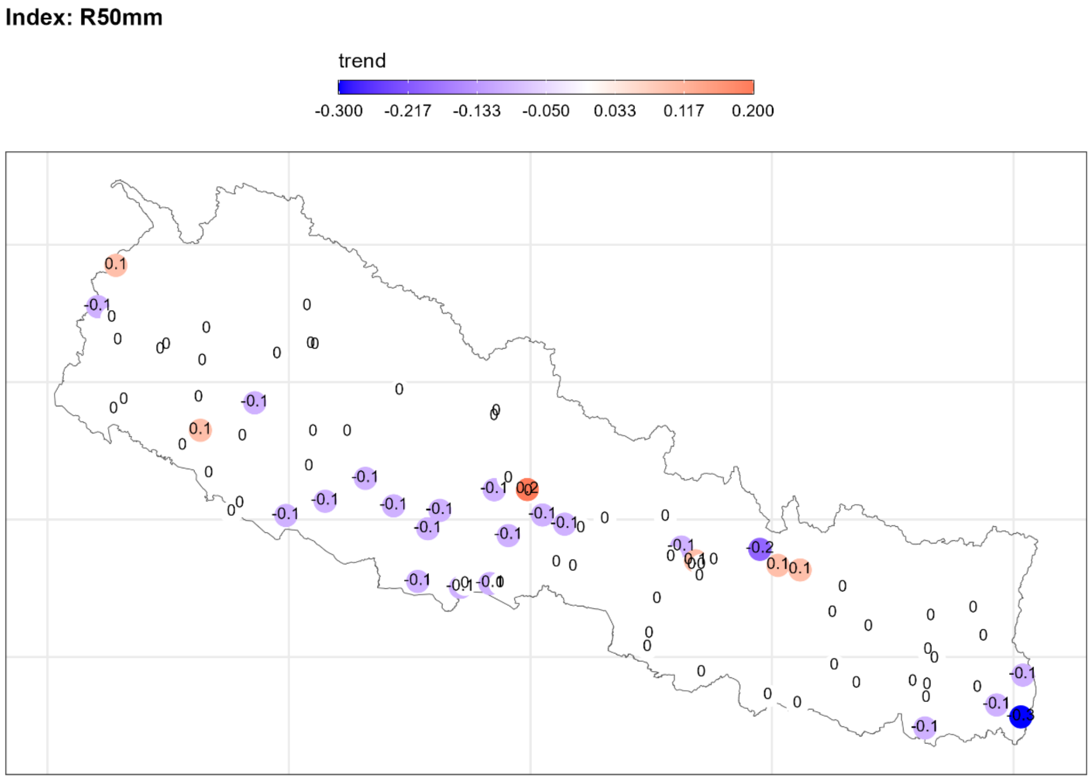


Figure 4.15 Meteorological station wise trend of number of customized rain days (R50mm)

4.3 Annual trend of extreme temperature and precipitation in Rupandehi, Banke, and Kailali Districts of Nepal, association with wheat yield of these three districts

In this study, we also investigated the relationship between wheat production and meteorological factors in three districts of Nepal: Rupandehi, Banke, and Kailali. The analysis focused on the trends observed in wheat crop yield, trend of extreme climate, precipitation anomaly, and total rainfall trends during the wheat crop cycle (October to March). Additionally, the correlation between annual wheat crop yield and precipitation during months of October to March was examined.

4.3.1 Extreme Temperature Trends

In the analysis of extreme temperature indices across three distinct districts reveals nuanced trends indicative of evolving climate dynamics. For mean temperature (TMm) trends, Kailalai, Banke, and Rupandehi all demonstrate increases at rates of 0.02°C, 0.02°C, and 0.01°C per year, respectively. These trends provide insights into the overall warming of the regions. In terms of mean maximum temperature (TXm), Kailalai, Banke, and Rupandehi all show increases at rates of 0.01°C, 0.02°C, and 0.01°C per year, respectively. These findings highlight the warming trends in extreme daytime temperatures. Also, the monthly mean maximum temperature during the wheat crop cycle (October to March) exhibited consistent upward trends, indicating changes in the thermal environment of the study areas. Notably, the highest rate of increase was observed in January, with a significant rise of 0.07 degrees Celsius. The remaining months of the wheat crop cycle also experienced increasing trends in mean maximum temperature. January recorded the increase, with a rise of 0.02 degrees Celsius as represented in Figure4.16. The increasing trends in monthly mean maximum temperatures, especially during critical months such as January, have important implications for wheat growth and development. Higher temperatures can influence crop phenology, potentially altering flowering, grain development, and overall crop yield. For mean minimum temperature (TNm), Kailali and both demonstrate increases at rates of 0.03°C and 0.02°C per year, respectively, while Sikta experiences no significant change.

For warmest day, maximum daily maximum temperature (TXx) Banke, Rupandehi shows increase at rate of 0.01°C, and 0.02°C per year. While coldest night, minimum daily minimum temperatures (TNn) shows decrease at rate of 0.03°C, and 0.05°C per year in Banke and Rupandehi districts respectively. For the analysis of warmest night that is annual maximum daily minimum temperatures (TNx) shows decrease at the rate of 0.01°C, and 0.02°C per year, Kailali, and Banke respectively. Exploring coldest day that is annual minimum daily maximum temperatures (TXn), Kailali, Banke, and Rupandehi all reveal decreases at rates of 0.06°C, 0.1°C, and 0.07°C per year, respectively.

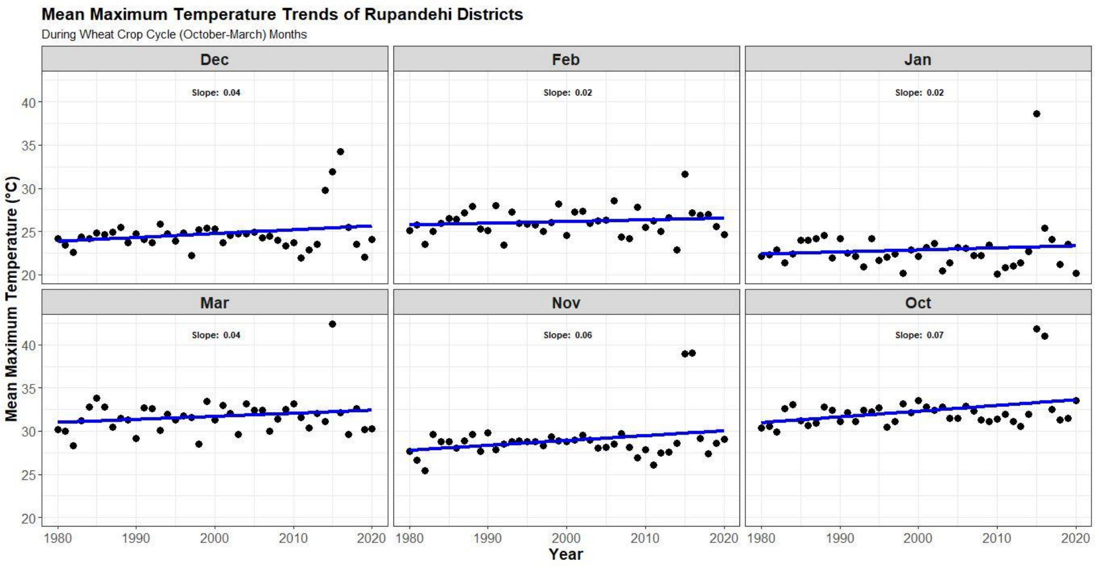


Figure 4.16 Mean maximum temperature trends of Rupandehi Districts during months of Wheat crop cycle

Examining the cool days (TX10p), Kailali and Banke both exhibit decreases at rates of 0.01% and 0.03% per year, respectively, whereas Rupandehi shows no significant change. The percentage of days when maximum temperatures greater than 90 percentile (TX90p) that is warm days increases in all three districts, with Kailali, Banke, and Rupandehi experiencing rises at rates of 0.11%, 0.26%, and 0.21% per year, respectively. These trends highlight the shifts in temperature extremes that may impact agricultural practices and ecological systems. While analyzing the percentage of days when minimum temperatures less than 10 percentile (TN10p) that is cool days, Kailali and Rupandehi both demonstrate decreases at rates of 0.27% and 0.12% per year, respectively, while Banke shows a marginal decrease at the rate of 0.02% per year. These findings highlight the need for further research to understand the specific impacts of temperature changes on wheat crops in the study regions and the potential strategies to mitigate any adverse effects.

4.3.2 Extreme precipitation trends

The analysis of extreme precipitation indices across three distinct districts reveals notable trends indicative of changing precipitation patterns. Kailalai exhibits a decline in consecutive dry days (CDD) at the rate of 0.1 days per year. Conversely, Banke and Rupandehi experiences a notable increase in CDD at the rate of 0.8 days per year, indicating a trend toward more extended dry spells. Examining heavy precipitation, Kailali shows a decrease in the annual count of days with rainfall exceeding 10mm (R10mm) and 20mm (R20mm), both at a rate of 0.1 days per year. This implies a reduction in moderate to heavy rainfall events. Banke and Rupandehi, however, show differing trends, with Banke experiencing no significant change in R10mm and R20mm, while Rupandehi sees a decrease at the rate of 0.1 days per year. The Simple Daily Intensity Index (SDII) in Kailali experiences a decrease at the rate of 0.1 mm per day per year, indicating a reduction in daily precipitation intensity. Banke and Rupandehi also show decreases in SDII at rates of 0.2 mm and 0.1 mm per day per year, respectively.

Analyzing the total annual precipitation (PRCPTOT) in Kailali shows a considerable decrease at the rate of 2.4 mm per year, reflecting a declining trend in overall annual precipitation. Banke and Rupandehi similarly display reductions in PRCPTOT, but at more pronounced rates of 3.9 mm and 4.6 mm per year, respectively, underlining a decrease trend in total annual precipitation. Examining total annual precipitation from heavy rain days (R95p), Kailali reveals a substantial decrease at the rate of 3.4 mm per year, suggesting a decrease in the total annual precipitation from heavy rain days. Banke and Rupandehi both exhibit more pronounced reductions in R95p, with rates of 6.9 mm per year and 4.9 mm per year, respectively, underscoring a decline in the contribution of heavy precipitation to total precipitation. Maximum 1-day precipitation (Rx1day) in Kailali exhibits a decreasing trend at the rate of 0.4 mm per year. Banke and Kailali both display more pronounced declines in Rx1day at rates of 1 mm per year. The annual maximum 5-day precipitation (Rx5day), Kailali experiences an increase at the rate of 0.7 mm per year, suggesting a rise in the intensity of longer-duration heavy rainfall. In contrast, Banke and Rupandehi both exhibit substantial decreases in Rx5day, at rates of 1.2 mm per year.

4.3.3 Precipitation anomaly and correlation between wheat crop yield and precipitation

Analysis of precipitation anomaly during the wheat crop cycle month's revealed inter-annual variability in rainfall patterns. Moreover, the sum of rainfall during the wheat crop cycle exhibited decreasing trends in Rupandehi, Banke, and Kailali districts from 1980 to 2020. Rupandehi experienced a decreasing trend at a rate of -0.07 mm/year (as shown in Figure 4.17), while Banke showed a more pronounced decline of -1.59 mm/year. Similarly, Kailali district exhibited a decreasing trend of -0.08 mm/year. The inter-annual variability in rainfall during the wheat crop cycle indicates fluctuations in the availability of water resources for crop growth and development. The decreasing trends in total rainfall suggest potential challenges in water availability for agriculture, particularly during critical growth stages of wheat. This underscores the need for effective water management strategies, such as efficient irrigation practices and water conservation measures, to ensure sustainable wheat production in the face of changing precipitation patterns.

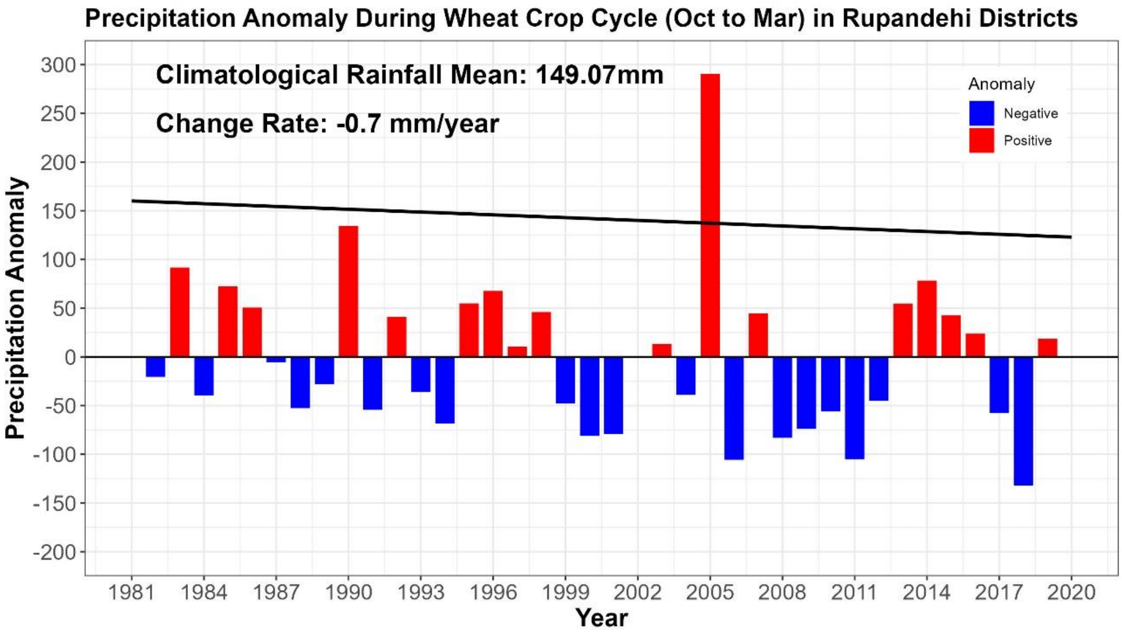


Figure 4.17 Precipitation anomaly during wheat crop cycle (October to March) in Rupandehi District

Investigating the relationship between annual wheat crop yield and precipitation during different months, it was found that November and December exhibited a negative correlation with wheat crop yield as shown in Figure 4.18 This negative correlation suggests that excessive rainfall during these months may adversely affect wheat crop growth and yield. Factors such as waterlogging, increased disease pressure, and nutrient leaching could be potential mechanisms underlying this negative relationship.

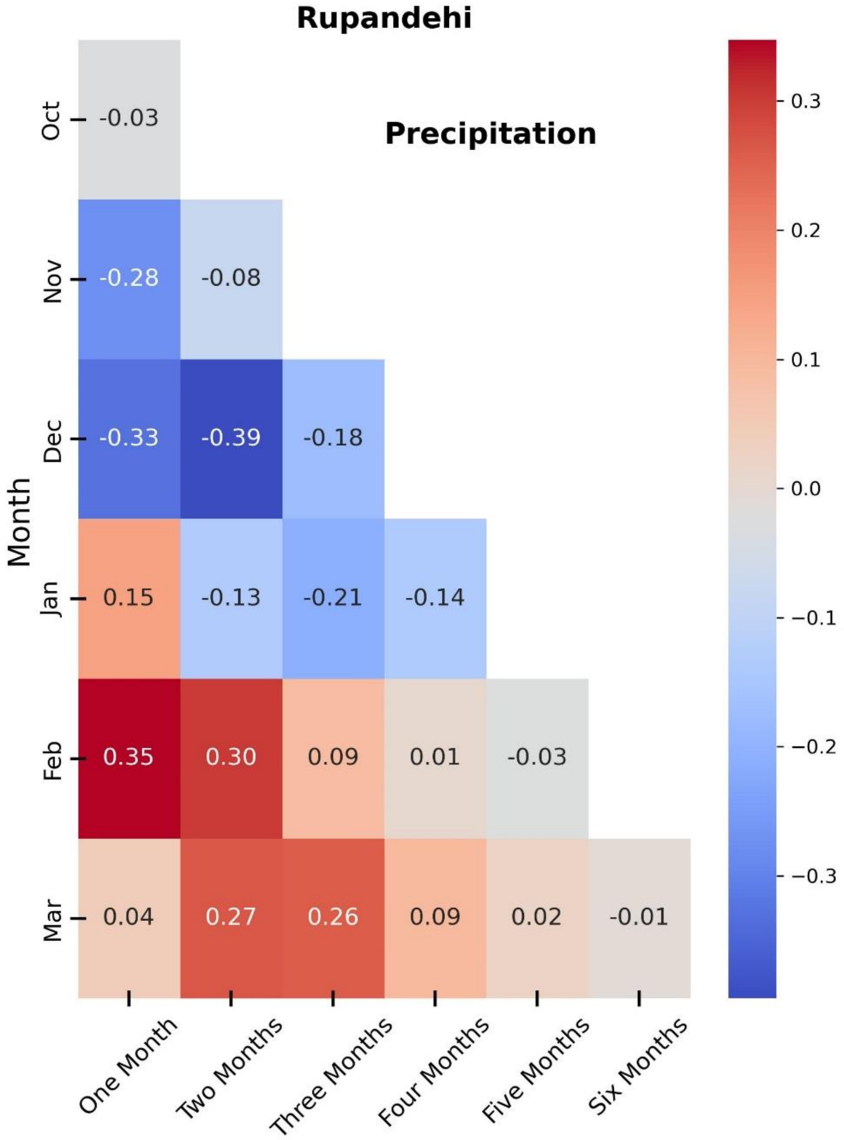


Figure 4.18 the heat map represent correlation between wheat crop yield and monthly rainfall

In contrast, January and February displayed a positive correlation (shown in Figure 4.18), indicating that adequate rainfall during these months can positively influence wheat crop yield. These findings align with the critical growth stages of wheat, particularly flowering and grain development, which are heavily influenced by moisture availability. The positive correlation suggests that rainfall during these months provides the necessary soil moisture and favorable conditions for optimal crop growth and yield.

4.3.4 Wheat crop trend

The analysis of wheat crop yield data from 1980 to 2020 revealed interesting trends in three districts. Rupandehi showed increase, with wheat yield rising by 65.52 kg/ha. Banke also experienced a substantial increase of 61.57 kg/ha. However, Kailali had a comparatively lower increase, with a rate of 47.21 kg/ha (as shown in Figure 4.19). These trends are based on reliable data sourced from the Ministry of Agriculture & Livestock Development, Government of Nepal.

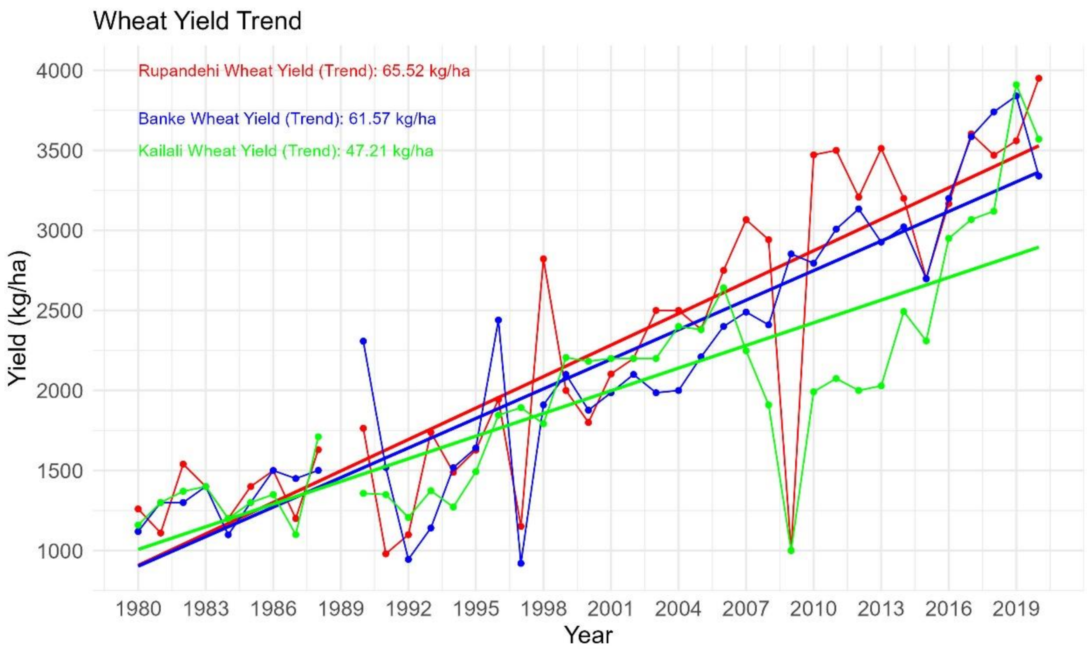


Figure 4.19 Wheat yield trends of Rupandehi, Banke and Kailali districts of Nepal

These increasing trends in wheat crop yield suggest positive developments in agricultural practices, including improved crop management techniques, enhanced irrigation systems, and the adoption of high-yielding wheat varieties. These factors might have contributed to the overall productivity and yield increase in wheat crops in Rupandehi and Banke districts. The relatively lower increase in Kailali district could be attributed to variations in local agronomic practices or other environmental factors specific to the region.

4.4 Projected trend of extreme precipitation indices under SSP245 and SSP585 Scenarios

4.4.1 Consecutive Dry Days (CDD) under SSP245 Scenarios

The ACCESS-ESM1-5 model showed an increasing trend in CDD, with rates ranging from 1 to 5 days per decade. The eastern part of the country experienced a higher rate of increase compared to the central and western parts. This indicates that according to the ACCESS-ESM1-5 model, there is a projected increase in the number of consecutive dry days in Nepal under the SSP245 scenario. The eastern region is expected to experience a more pronounced increase compared to other regions.

Similarly, the BCC-CSM2-MR model also exhibited increasing CDD trends, with rates ranging from 1 to 2 days per decade. The mid-western region and higher elevations in Nepal showed a greater increase in CDD. This suggests that according to the BCC-CSM2-MR model, there is a projected increase in consecutive dry days in the country, particularly in the mid-western region and higher elevation areas.

The CNRM-ESM2-1 model indicated a rise in CDD at a rate of 1 to 3 days per decade, particularly in the central and lower elevation areas. This implies that the CNRM-ESM2-1 model projects an increase in the number of consecutive dry days in Nepal, with a greater impact in the central and lower elevation regions.

Similarly, the GFDL-ESM4 model demonstrated an increasing trend in CDD at a rate of 1 to 3 days per decade. The western part of the country experienced a higher increase compared to the eastern part. This suggests that, according to the GFDL-ESM4 model, the western region of Nepal is projected to experience a more significant increase in consecutive dry days compared to the eastern region.

In the case of the INM-CM5-0 model, CDD trends increased at a rate of 1 to 2 days per decade, primarily in the eastern region. This indicates that the INM-CM5-0 model projects an increase in consecutive dry days, with a stronger impact expected in the eastern part of Nepal.

Overall, under the SSP245 scenarios, all the models suggest an ongoing increase in the number of consecutive dry days (shown in Figure4.16) in Nepal, similar to the present period. The specific rates of increase and regional variations vary between the models. These findings emphasize the potential for more prolonged periods without rainfall, which can have implications for water availability, agriculture, and other sectors dependent on adequate moisture.

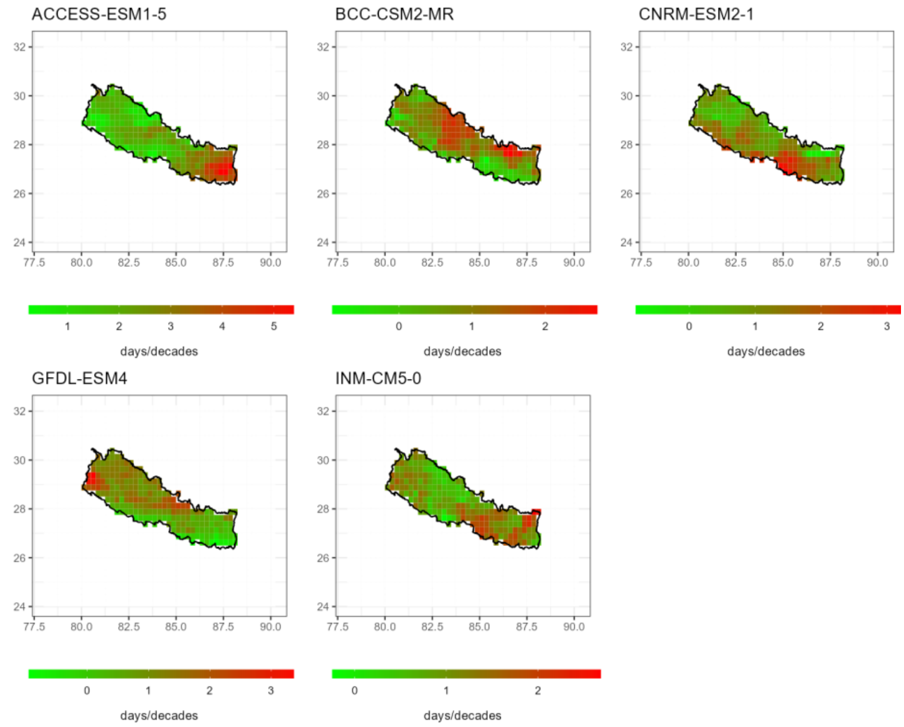


Figure 4.20 CMIP6 Model Projections: Consecutive Dry Days (CDD) under the SSP245 Scenario

4.4.2 Consecutive dry days (CDD) under SSP585 Scenarios

The ACCESS-ESM1-5 model indicated an increasing trend in CDD, with a rate of 1 to 3 days per decade. This trend was more pronounced in the high altitude region and the eastern part of the country. Based on this model, Nepal is projected to experience a greater number of consecutive dry days in the future, particularly in the higher altitude areas and the eastern region.

Contrarily, the BCC-CSM2-MR model showed a decreasing trend in CDD. The western part of the country exhibited a decrease at a rate of 1 to 2 days per decade, while the central region showed an increasing trend of 1 day per decade. This suggests that according to the BCC-CSM2-MR model, the western region of Nepal is expected to experience fewer consecutive dry days, while the central region may see a slight increase in such days.

The CNRM-ESM2-1 model displayed an increasing trend of 1 day per decade in the western region, while the eastern part experienced a decreasing trend of 1 to 2 days per decade. This implies that, according to the CNRM-ESM2-1 model, the western region of Nepal is projected to have more consecutive dry days, while the eastern region may experience a decrease in the number of such days.

In the GFDL-ESM4 model, CDD showed an increasing trend of 2 to 3 days per decade in the lower elevation Terai region and the central part of the country. This suggests that according to the GFDL-ESM4 model, the Terai region and central Nepal may experience a greater number of consecutive dry days in the future.

Finally, the INM-CM5-0 model indicated a decreasing trend of 1 to 2 days per decade across most of the country. According to this model, Nepal is projected to have fewer consecutive dry days in the future, regardless of the region.

Overall, under the SSP585 scenario, the CMIP6 models present varying projections for CDD trends in Nepal. Some models project an increase in consecutive dry days (ACCESS-ESM1-5, CNRM-ESM2-1, GFDL-ESM4) while others suggest a decrease (BCC-CSM2-MR, INM-CM5-0) as shown in Figure4.17. These trends vary across different regions of Nepal, with some regions showing more pronounced changes than others.

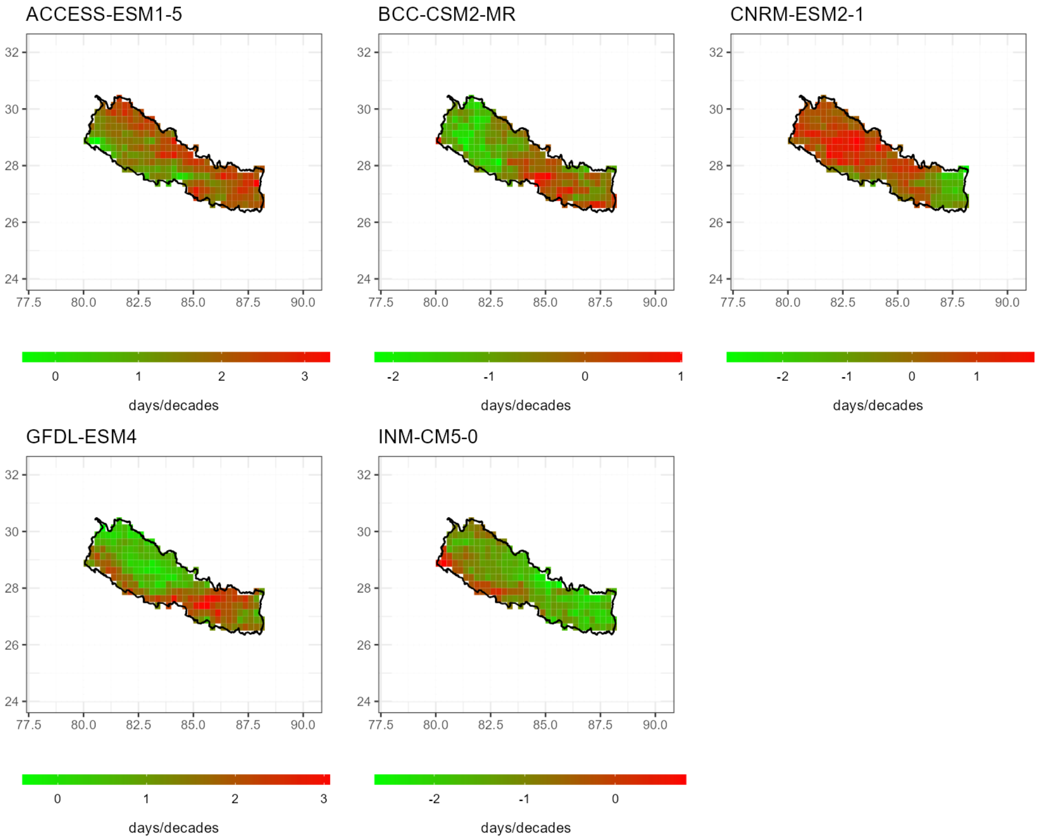


Figure 4.21 CMIP6 Model Projections: Consecutive Dry Days (CDD) under the SSP585 Scenario

4.4.3 Consecutive wet days (CWD) under SSP245 scenarios

The ACCESS-ESM1-5 model shows a mixed pattern of increasing and decreasing CWD trends in Nepal. In the mid-western region, there is a projected decrease of 1 day per decade in consecutive wet days. On the other hand, the far western region of the country is expected to experience an increase of 1 day per decade in consecutive wet days. This suggests that according to the ACCESS-ESM1-5 model, there is spatial variability in CWD trends across Nepal under the SSP245 scenario.

In the BCC-CSM2-MR model, the CWD trends exhibit variation across the country. The rate of change ranges from 0.2 to 0.4 days per decade. Notably, the far western region experiences predominantly increasing CWD trends at a rate of 0.2 days per decade under the SSP245 scenario. This implies that according to the BCC-CSM2-MR model, there is a projected increase in consecutive wet days in the far western region of Nepal, while other regions may see relatively smaller changes.

The CNRM-ESM2-1 model suggests a decreasing trend in CWD of 1 day per decade in most parts of the country. However, the upper part of the Karnali provinces exhibits an increasing trend of 1 to 1.5 days per decade under the SSP245 scenario. This indicates that, according to the CNRM-ESM2-1 model, Nepal as a whole may experience a decrease in consecutive wet days, while the upper part of the Karnali provinces could see an increase.

In the GFDL-ESM4 model, the CWD trend is mixed across most parts of the country, ranging from 0 to 1 day per decade. This suggests that, according to the GFDL-ESM4 model, there may be relatively small changes or no significant trends in consecutive wet days in Nepal under the SSP245 scenario.

Lastly, the INM-CM5-0 model projects increasing CWD trends of 1 to 2.5 days per decade across most parts of the country. This implies that, according to the INM-CM5-0 model, Nepal is expected to experience an increase in consecutive wet days under the SSP245 scenario.

Overall, the CMIP6 models present varying projections for CWD trends in Nepal under the SSP245 scenario. Some models suggest increases in consecutive wet days (ACCESS-ESM1-5, BCC-CSM2-MR, INM-CM5-0), while others indicate decreases (CNRM-ESM2-1) as shown in Figure4.18. The trends vary across different regions of Nepal, highlighting the spatial variability in CWD projections. These results emphasize the importance of considering multiple models and their respective projections when studying future climate scenarios.

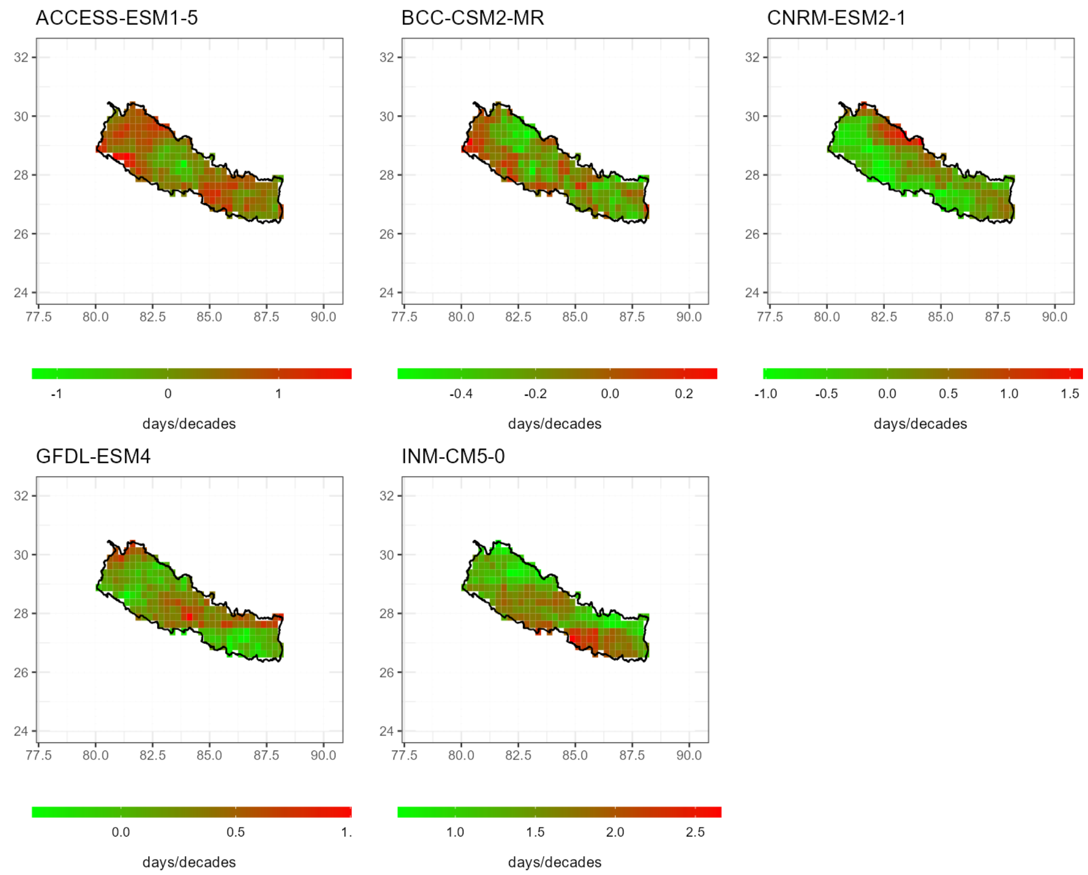


Figure 4.22 CMIP6 Model Projections: Consecutive Wet Days (CWD) under the SSP245 Scenario

4.4.4 Consecutive wet days (CWD) under SSP585 scenarios

The ACCESS-ESM1-5 model projects an increasing trend in CWD in Nepal under the SSP585 scenario. The rate of increase ranges from 2 to 4 days per decade. The western region of Nepal is expected to experience a higher rate of increase compared to the eastern region. This suggests that, according to the ACCESS-ESM1-5 model, Nepal as a whole is projected to experience more consecutive wet days in the future, with the western region experiencing a more pronounced increase.

In the BCC-CSM2-MR model, the CWD trends show a mixed pattern across the country under the SSP585 scenario. The rates of change range from 0.25 to 0.7 days per decade. This indicates that the model projects both increasing and decreasing trends in CWD in different regions of Nepal. This implies that, according to the BCC-CSM2-MR model, Nepal's CWD patterns will vary across different regions in the future.

The CNRM-ESM2-1 model indicates an increasing trend in CWD in the central and eastern parts of Nepal under the SSP585 scenario. The rate of increase is projected to be 1 to 2 days per decade in these regions. In contrast, the western region shows a decreasing trend in CWD at a rate of 1 day per decade under the SSP245 scenario. This suggests that, according to the CNRM-ESM2-1 model, Nepal's CWD patterns will undergo changes that differ across regions, with the central and eastern parts experiencing more consecutive wet days and the western region experiencing fewer such days.

The GFDL-ESM4 model displays a mixed pattern of increasing and decreasing trends in CWD across most parts of Nepal under the SSP585 scenario. The rates of change range from 0.5 to 1 day per decade. This indicates that the model projects varying CWD patterns in different parts of the country. The higher elevation regions may experience a higher rate of increase in CWD. This implies that, according to the GFDL-ESM4 model, there will be spatial variability in CWD trends in Nepal in the future.

Lastly, the INM-CM5-0 model suggests an increasing trend in CWD in Nepal under the SSP585 scenario. The rate of increase ranges from 1 to 5 days per decade. The eastern region of Nepal is projected to experience a higher rate of increase compared to the central and western regions. This indicates that, according to the INM-CM5-0 model, Nepal as a whole is expected to have more consecutive wet days in the future, with the eastern region experiencing a more pronounced increase.

Overall, the CMIP6 models present varying projections for CWD trends in Nepal under the SSP585 scenario. Some models suggest an increase in consecutive wet days (ACCESS-ESM1-5, CNRM-ESM2-1, INM-CM5-0), while others indicate a mixed pattern of increasing and decreasing trends (BCC-CSM2-MR, GFDL-ESM4) as shown in Figure 4.19. These trends also vary across different regions of Nepal, highlighting the spatial variability in CWD projections.

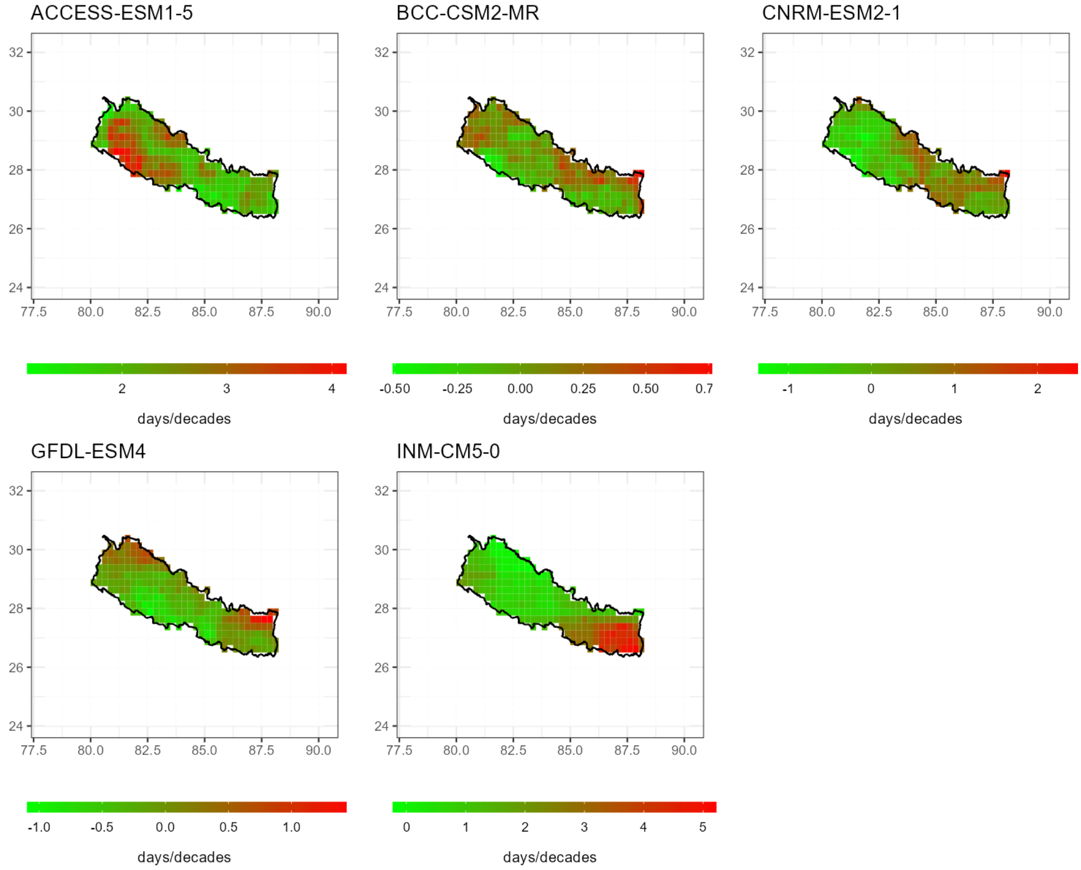


Figure 4.23 CMIP6 Model Projections: Consecutive Wet Days (CDD) under the SSP585 Scenario

4.4.5 Annual total precipitation (PRCPTOT) under SSP245 scenario

The ACCESS-ESM1-5 model projects an increasing trend in PRCPTOT across Nepal. The rates of increase range from 3 to 7 mm per year. The central and eastern regions of the country are expected to experience higher rates of increase compared to the western region. This suggests that, according to the ACCESS-ESM1-5 model, Nepal as a whole is projected to have an overall increase in annual total precipitation, with the central and eastern regions experiencing a more pronounced increase.

In the BCC-CSM2-MR model, PRCPTOT also shows an increasing trend under the SSP245 scenario. The rates of increase range from 1 to 2 mm per year. Eastern Nepal is projected to experience a higher rate of increase compared to the western region. This implies that, according to the BCC-CSM2-MR model, there will be an overall increase in annual total precipitation in Nepal, with the eastern region seeing a more significant change.

The CNRM-ESM2-1 model indicates higher rates of increase in PRCPTOT in the eastern part of Nepal and at high altitudes. The rates of increase range from 1 to 3 mm per year in these regions. In contrast, the lower altitude regions, particularly the Terai belt, show a decreasing trend of 1 to 2 mm per year under the same SSP245 scenario. This suggests that, according to the CNRM-ESM2-1 model, there will be spatial variability in PRCPTOT trends across Nepal, with the eastern and high altitude regions experiencing an increase while the Terai belt shows a decrease in annual total precipitation.

The GFDL-ESM4 model displays a mixed pattern of PRCPTOT trends across Nepal under the SSP245 scenario. The central and eastern regions are projected to experience an increase in PRCPTOT at rates ranging from 1 to 3 mm per year. In contrast, the western region shows a decrease of 1 mm per year. This indicates that, according to the GFDL-ESM4 model, there will be spatial variability in PRCPTOT trends across the country, with the central and eastern regions seeing an increase while the western region experiences a decrease in annual total precipitation.

Lastly, the INM-CM5-0 model exhibits increasing trends in PRCPTOT across Nepal under the SSP245 scenario. The rates of increase range from 2 to 10 mm per year. The central and eastern regions of the country are projected to experience higher rates of increase compared to the western region. This suggests that, according to the INM-CM5-0 model, Nepal as a whole is expected to have an overall increase in annual total precipitation, with the central and eastern regions experiencing a more pronounced increase.

Overall, the CMIP6 models present varying projections for PRCPTOT trends in Nepal under the SSP245 scenario. Some models suggest an overall increase in annual total precipitation (ACCESS-ESM1-5, BCC-CSM2-MR, CNRM-ESM2-1, INM-CM5-0), while others indicate a mixed pattern of increasing and decreasing trends (GFDL-ESM4) as shown in Figure 4.20. These trends also exhibit spatial variability across different regions of Nepal.

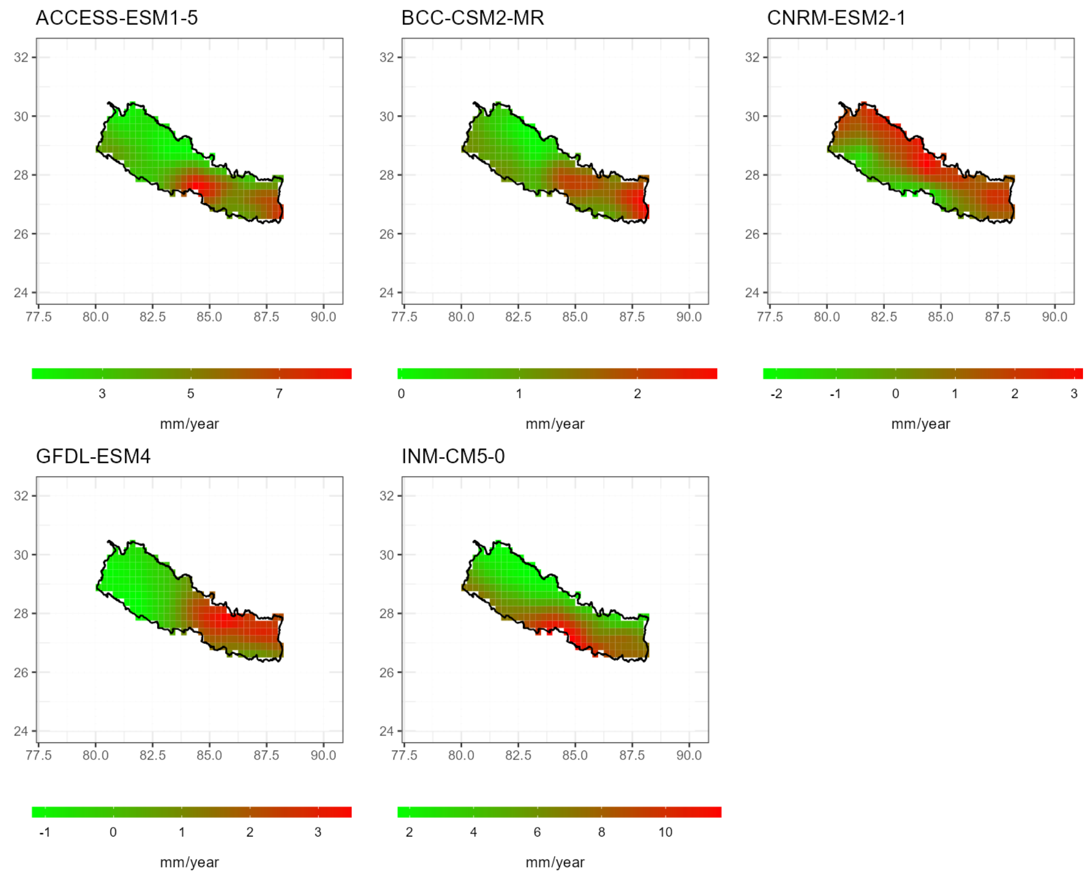


Figure 4.24 CMIP6 Model Projections: Annual total precipitation (PRCPTOT) under the SSP245 Scenario

4.4.6 Annual total precipitation (PRCPTOT) under SSP585 scenario

The ACCESS-ESM1-5 model projects an increasing trend in PRCPTOT across Nepal under the SSP585 scenario. The rates of increase range from 5 to 20 mm per year. The central and eastern regions of the country are expected to experience higher rates of increase compared to the western region. This suggests that, according to the ACCESS-ESM1-5 model, Nepal as a whole is projected to have an overall increase in annual total precipitation, with the central and eastern regions experiencing a more pronounced increase.

In the BCC-CSM2-MR model, PRCPTOT also shows an increasing trend under the SSP585 scenario. The rates of increase range from 2 to 5 mm per year. The central and eastern regions of Nepal are projected to experience higher rates of increase compared to the western region. This implies that, according to the BCC-CSM2-MR model, there will be an overall increase in annual total precipitation in Nepal, with the central and eastern regions seeing a more significant change.

The CNRM-ESM2-1 model indicates higher rates of increase in PRCPTOT in the central and eastern parts of Nepal. The rates of increase range from 2.5 to 7.5 mm per year in these regions. In contrast, the western region shows a slightly lower rate of increase. This suggests that, according to the CNRM-ESM2-1 model, there will be spatial variability in PRCPTOT trends across Nepal, with the central and eastern regions experiencing a more significant increase compared to the western region under the SSP585 scenario.

The GFDL-ESM4 model displays a mixed pattern of PRCPTOT trends across Nepal under the SSP585 scenario. It projects an increasing trend of 1-4 mm per year in some parts of the country, indicating an overall increase in annual total precipitation. However, there is a decreasing trend of 1 mm per year observed in other regions. This suggests that, according to the GFDL-ESM4 model, there will be spatial variability in PRCPTOT trends across Nepal, with some regions experiencing an increase while others show a decrease in annual total precipitation.

Lastly, the INM-CM5-0 model exhibits higher rates of increase in PRCPTOT across Nepal under the SSP585 scenario. The rates of increase range from 5 to 15 mm per year. Similar to the other models, the central and eastern regions of the country are expected to experience higher rates of increase compared to the western region. This indicates that, according to the INM-CM5-0 model, Nepal as a whole is projected to have an overall increase in annual total precipitation, with the central and eastern regions experiencing a more pronounced increase.

Overall, the CMIP6 models present varying projections for PRCPTOT trends in Nepal under the SSP585 scenario. Most models suggest an overall increase in annual total precipitation (ACCESS-ESM1-5, BCC-CSM2-MR, CNRM-ESM2-1, INM-CM5-0), while one model shows a mixed pattern of increasing and decreasing trends (GFDL-ESM4) as shown in Figure 4.21. These trends also exhibit spatial variability across different regions of Nepal, with the central and eastern regions generally projected to experience higher rates of increase compared to the western region. It is important to consider multiple models and their respective projections to gain a comprehensive understanding of future precipitation patterns in Nepal.

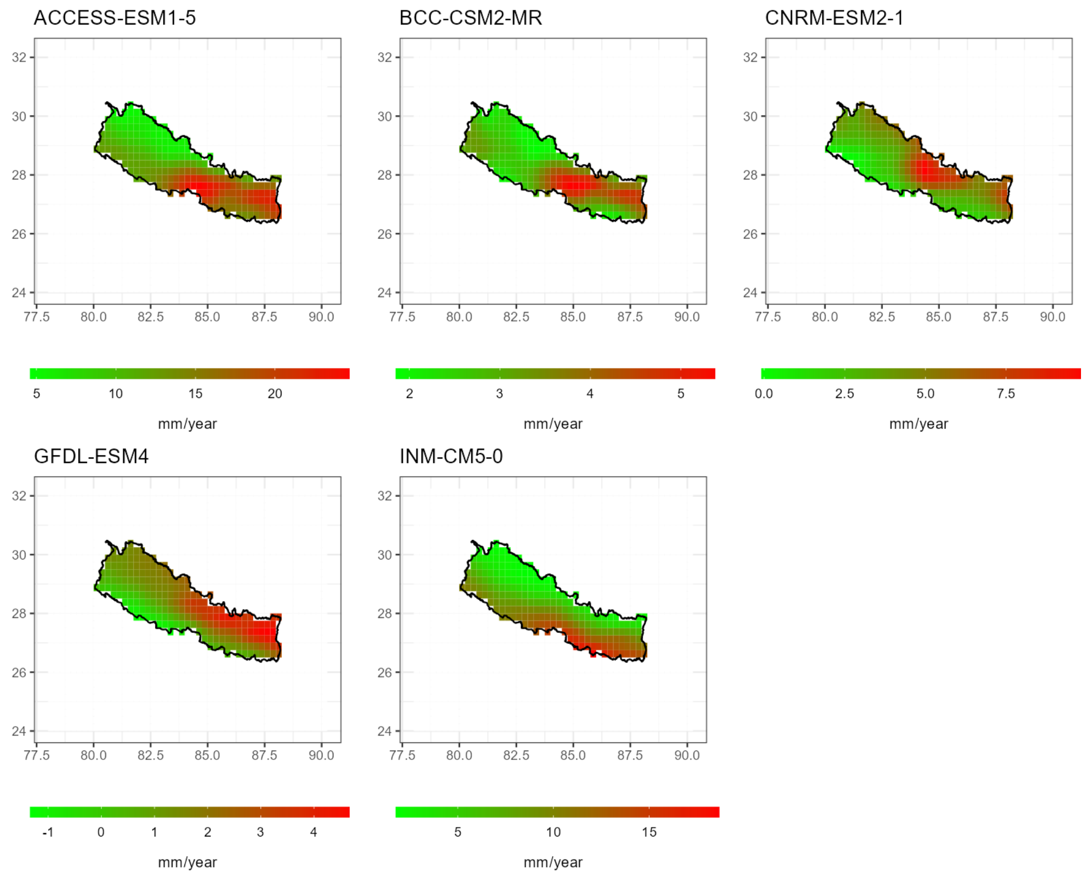


Figure 4.25 CMIP6 Model Projections: Annual total precipitation (PRCPTOT) under the SSP585 Scenario

4.4.7 Maximum 1-Day (RX1day) Precipitation under SSP 245 scenarios

The ACCESS-ESM1-5 model projects a gradual increase in maximum 1-day precipitation (RX1day) across Nepal under the SSP245 scenario. The rates of increase range from 0.1 to 0.3 mm per year. This suggests that, according to the ACCESS-ESM1-5 model, Nepal is expected to experience a slight increase in the intensity of extreme precipitation events over time.

In the BCC-CSM2-MR model, an increasing trend in RX1day was observed in the eastern region of Nepal, with rates of increase ranging from 0.1 to 0.3 mm per year. However, the western region showed a slight decrease of 0.1 mm per year in RX1day. This indicates that, according to the BCC-CSM2-MR model, there may be regional variations in the intensity of extreme precipitation events in Nepal, with the eastern region experiencing a more significant increase compared to the western region under the SSP245 scenario.

The CNRM-ESM2-1 model displayed a mixed pattern in RX1day trends across Nepal under the SSP245 scenario. It showed an increasing trend of 0.1 to 0.2 mm per year in the central and eastern regions, indicating a potential intensification of extreme precipitation events in these areas. However, the mid-western region exhibited a decreasing trend. This suggests that, according to the CNRM-ESM2-1 model, there may be spatial variability in the trends of extreme precipitation events in Nepal, with some regions experiencing an increase while others show a decrease under the SSP245 scenario.

The GFDL-ESM4 model indicated an increasing trend in RX1day precipitation in the eastern part of Nepal, with rates ranging from 0.1 to 0.3 mm per year. In contrast, the western region showed a decreasing trend of 0.1 mm per year. This implies that, according to the GFDL-ESM4 model, there may be regional variations in the intensity of extreme precipitation events in Nepal, with the eastern region experiencing a more significant increase compared to the western region under the SSP245 scenario.

Finally, the INM-CM5-0 model exhibited an increasing trend in RX1day precipitation across Nepal, with rates of increase ranging from 0.1 to 0.2 mm per year. The central region of Nepal experienced a higher rate of increase compared to other parts of the country. This suggests that, according to the INM-CM5-0 model, there may be spatial variability in the intensity of extreme precipitation events in Nepal, with the central region experiencing a more pronounced increase under the SSP245 scenario.

Overall, the CMIP6 models present varying projections for the trends in maximum 1-day precipitation (RX1day) in Nepal under the SSP245 scenario. Most models suggest a gradual increase in the intensity of extreme precipitation events (ACCESS-ESM1-5, BCC-CSM2-MR, CNRM-ESM2-1, INM-CM5-0), while one model shows a mixed pattern of increasing and decreasing trends (GFDL-ESM4) as shown in Figure 4.22. These trends also exhibit spatial variability across different regions of Nepal, with the eastern and central regions generally projected to experience a higher rate of increase compared to the western region. It is important to consider multiple models and their respective projections to gain a comprehensive understanding of future trends in extreme precipitation events in Nepal.

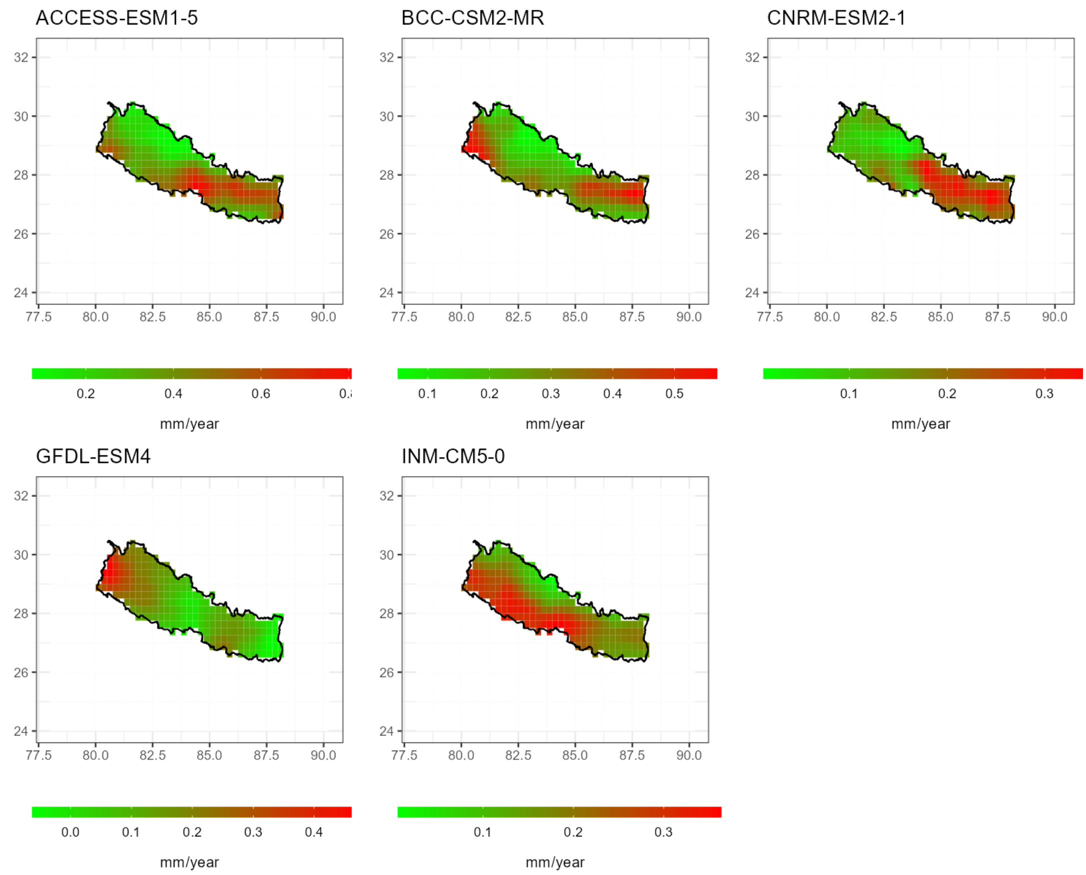


Figure 4.26 CMIP6 Model Projections: Maximum 1-day precipitation (RX1day) under the SSP245 Scenario

4.4.8 Maximum 1-Day (RX1day) Precipitation under SSP 585 scenarios

The ACCESS-ESM1-5 model projects an increasing trend in RX1day precipitation across Nepal under the SSP585 scenario. The rates of increase range from 0.2 to 0.8 mm per year. This suggests that, according to the ACCESS-ESM1-5 model, Nepal is likely to experience a gradual intensification of extreme precipitation events over time. Furthermore, the model indicates that the eastern region of Nepal may experience a higher rate of increase compared to the western region.

In the BCC-CSM2-MR model, an increasing trend in RX1day precipitation was observed, with rates ranging from 0.1 to 0.5 mm per year. This indicates that, according to the BCC-CSM2-MR model, Nepal is expected to experience a gradual increase in the intensity of extreme precipitation events over time. However, the rate of increase in RX1day precipitation is slightly lower compared to the ACCESS-ESM1-5 model. Regional variations are also evident, with the eastern region potentially experiencing a higher rate of increase compared to the western region.

The CNRM-ESM2-1 model also displayed an increasing trend in RX1day precipitation, with rates ranging from 0.1 to 0.3 mm per year. The central and eastern regions of Nepal showed a higher rate of increase compared to the western region. This suggests that, according to the CNRM-ESM2-1 model, there may be spatial variability in the trends of extreme precipitation events in Nepal, with the central and eastern regions experiencing a more pronounced intensification.

Similarly, the GFDL-ESM4 model indicated an increasing trend in RX1day precipitation, ranging from 0.1 to 0.4 mm per year. Notably, the far-western region of Nepal showed a higher rate of increase compared to the central and eastern parts. This suggests that, according to the GFDL-ESM4 model, there may be regional variations in the intensity of extreme precipitation events, with the far-western region experiencing a more significant increase compared to other parts of Nepal.

Finally, the INM-CM5-0 model exhibited an increasing trend in RX1day precipitation at a rate of 0.1 to 0.3 mm per year. This suggests that, according to the INM-CM5-0 model, Nepal is likely to experience a gradual intensification of extreme precipitation events over time. However, it's important to note that the rates of increase in RX1day precipitation are relatively lower compared to the ACCESS-ESM1-5 and CNRM-ESM2-1 models.

Overall, the CMIP6 models present varying projections for the trends in annual maximum 1-day precipitation (RX1day) in Nepal under the SSP585 scenario as shown in Figure 4.23. Most models suggest an increasing trend in RX1day precipitation, indicating a potential intensification of extreme precipitation events. However, there are differences in the magnitude and spatial distribution of these trends among the models. Regional variations are observed, with certain regions of Nepal projected to experience higher rates of increase in RX1day precipitation compared to others. These findings emphasize the importance of considering multiple models to gain a comprehensive understanding of future trends in extreme precipitation events in Nepal.

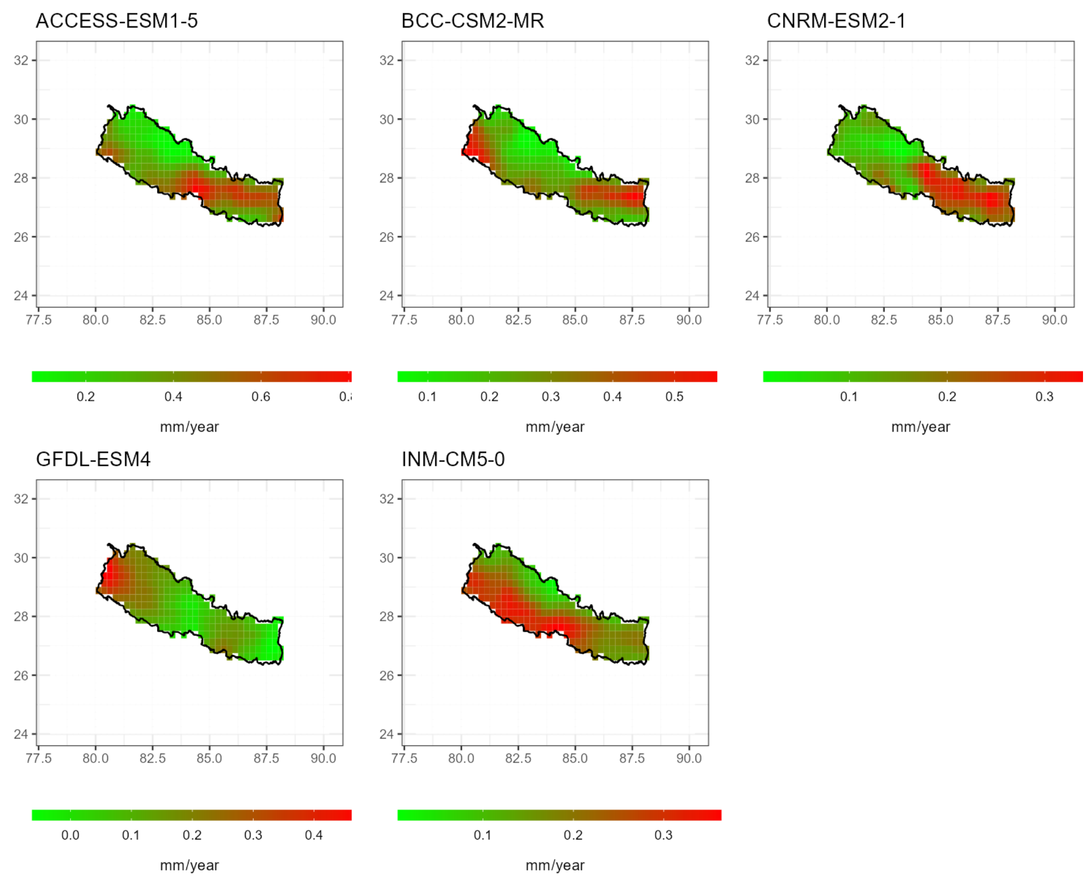


Figure 4.27 CMIP6 Model Projections: Maximum 1-day precipitation (RX1day) under the SSP585 Scenario

4.4.9 Number of Heavy (R10mm) precipitation under SSP245

The ACCESS-ESM1-5 model projects an increasing trend in the annual number of heavy R10mm precipitation in Nepal. The rate of increase is estimated to be approximately 1-2 days per decade. This suggests that, according to the ACCESS-ESM1-5 model, Nepal is likely to experience an upward trend in the occurrence of heavy precipitation events over time. Notably, the central region of Nepal exhibits a higher rate of increase compared to other parts of the country.

In contrast, the BCC-CSM2-MR model indicates a mixed trend in the annual number of heavy R10mm precipitation across Nepal. Both increasing and decreasing patterns are observed in different regions of the country. The rate of change is estimated to be around 0.25-0.50 days per decade. This suggests that, according to the BCC-CSM2-MR model, Nepal may experience spatially variable changes in the occurrence of heavy precipitation events, with some areas showing an increase while others exhibit a decrease over time.

The CNRM-ESM2-1 model demonstrates an increasing trend of 1 day per decade in the higher elevation range of the Western region, while a decreasing trend is observed in other parts of the country. This implies that, according to the CNRM-ESM2-1 model, there may be localized changes in the occurrence of heavy R10mm precipitation, with the higher elevation areas of the Western region experiencing an increase while other regions undergo a decrease in these events.

Similarly, the GFDL-ESM4 model indicates an increasing trend of 0.5-1 days per decade in the central and eastern regions of Nepal. In contrast, the western region shows a decreasing trend of 0.5 days per decade. This suggests that, according to the GFDL-ESM4 model, there may be regional differences in the occurrence of heavy precipitation events within Nepal, with the central and eastern regions experiencing an increase while the western region undergoes a decrease over time.

Lastly, the INM-CM5-0 model shows an increasing trend in R10mm precipitation at a rate of 1-4 mm per decade. This suggests that, according to the INM-CM5-0 model, Nepal is likely to experience a gradual increase in the occurrence of heavy precipitation events over time. However, it's important to note that the magnitude of the increase is relatively higher in this model compared to the other models analyzed.

Overall, the CMIP6 models present varying projections for the trends in the annual number of heavy R10mm precipitation (shown in Figure 4.24) in Nepal under the SSP245 scenario. While some models indicate an overall increasing trend in heavy precipitation events, others demonstrate mixed patterns or localized changes. These findings highlight the spatial variability and uncertainties associated with future projections of heavy precipitation events in Nepal.

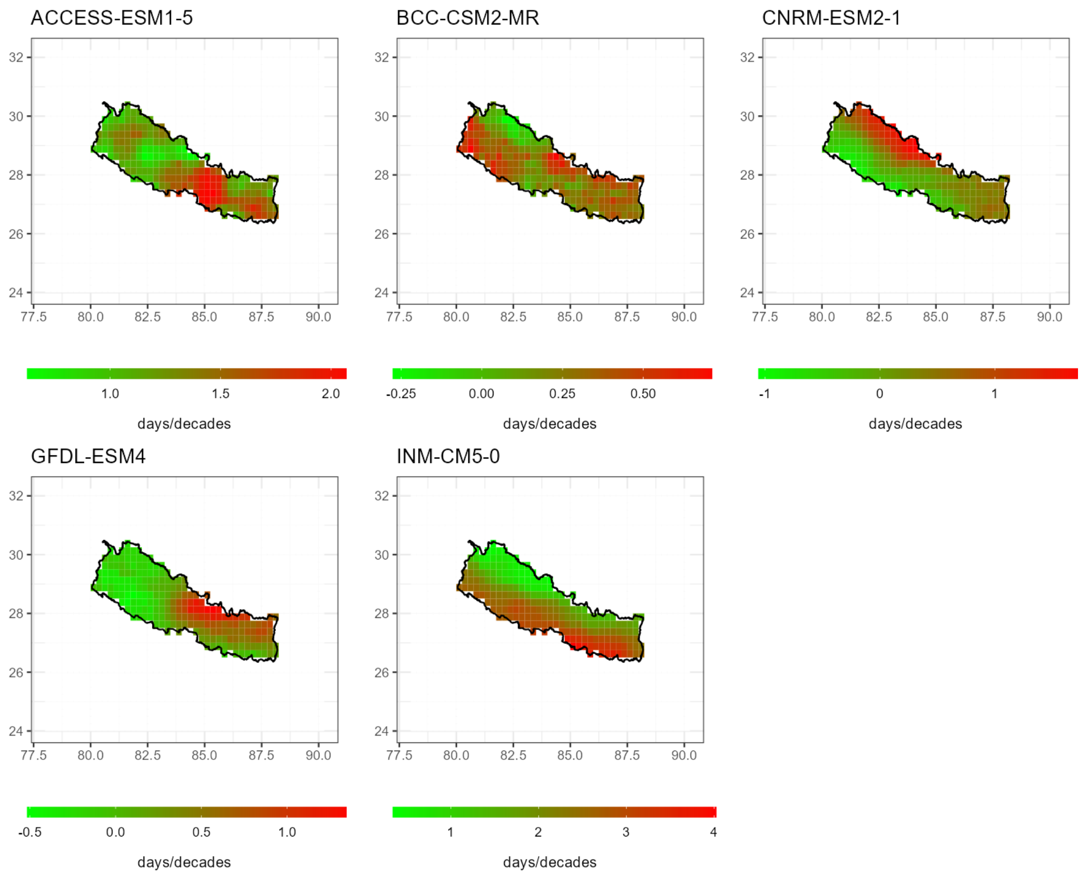


Figure 4.28 CMIP6 Model Projections: Number of heavy (R10mm) under the SSP245 Scenario

4.4.10 Number of heavy (R10mm) precipitation under SSP585

The analysis of the ACCESS-ESM1-5 model reveals an increasing trend in the annual number of heavy R10mm precipitation in Nepal. The rate of increase is estimated to be around 3-4 days per decade. This indicates that, according to the ACCESS-ESM1-5 model, Nepal is likely to experience a substantial rise in the occurrence of heavy precipitation events over time. Notably, the central and eastern regions of Nepal exhibit a higher rate of increase compared to the western region.

In contrast, the BCC-CSM2-MR model displays a heterogeneous increasing trend in the number of heavy R10mm precipitation across Nepal. The rate of change varies from 0.25-1.0 days per decade. This suggests that, according to the BCC-CSM2-MR model, the changes in heavy precipitation events are spatially variable within Nepal, with some areas experiencing a more pronounced increase than others.

Similarly, the CNRM-ESM2-1 model indicates an increasing trend in the annual number of heavy R10mm precipitation, with a rate of 1-3 days per decade. The analysis suggests that the higher elevations in western Nepal exhibit a higher rate of increase compared to other parts of the country. This indicates that, according to the CNRM-ESM2-1 model, there may be localized changes in heavy precipitation events, with the higher elevation areas in western Nepal experiencing a more significant increase compared to other regions.

In the GFDL-ESM4 model, an increasing trend of 0.5-1.5 days per decade is observed in the central and eastern regions of Nepal. However, the western part of the country and lower elevations show a decreasing trend of 0.5 days per decade. This suggests that, according to the GFDL-ESM4 model, there may be regional differences in the trends of heavy R10mm precipitation events within Nepal, with the central and eastern regions experiencing an increase while the western region and lower elevations undergo a decrease over time.

Lastly, the INM-CM5-0 model demonstrates an increasing trend in R10mm precipitation, with a rate of 2-6 mm per decade. This indicates that, according to the INM-CM5-0 model, Nepal is likely to experience a gradual increase in the intensity of heavy precipitation events over time. The magnitude of the increase is relatively higher in this model compared to the other models analyzed.

In summary, the analysis of the five CMIP6 models provides valuable insights into the trends of heavy R10mm precipitation across different regions of Nepal under the SSP585 scenario (as shown in Figure 4.25). The models project varying patterns, with some indicating an overall increase in heavy precipitation events, while others display heterogeneous or localized changes. These findings highlight the spatial variability and uncertainties associated with future projections of heavy precipitation events in Nepal.

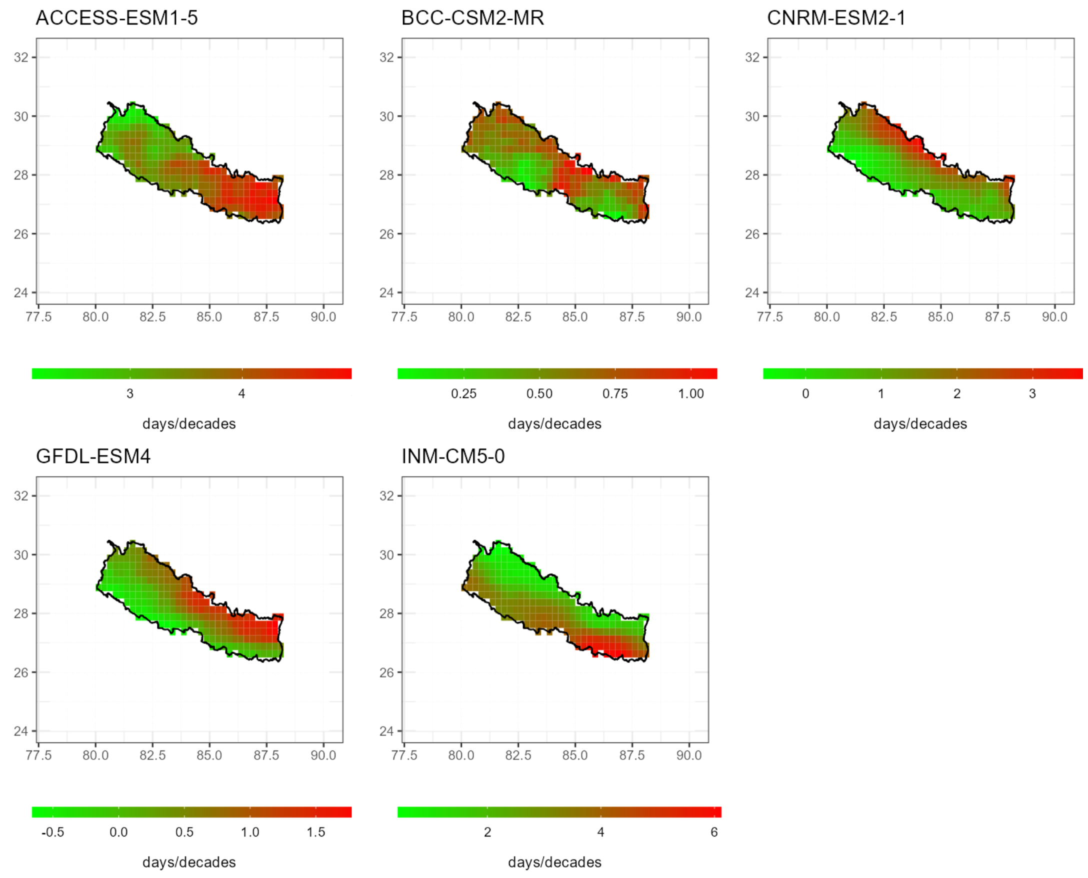


Figure 4.29 CMIP6 Model Projections: Number of heavy (R10mm) under the SSP585 Scenario

4.4.11 Number of very heavy (R20mm) precipitation under SSP245

The analysis of the ACCESS-ESM1-5 model reveals an increasing trend in the annual number of very heavy R20mm precipitation in Nepal. The rate of increase is estimated to be around 0.5-2 days per decade. This suggests that, according to the ACCESS-ESM1-5 model, Nepal is likely to experience an overall rise in the occurrence of very heavy precipitation events over time. Notably, the central and eastern regions of Nepal exhibit a higher rate of increase compared to the western region.

In the BCC-CSM2-MR model, a heterogeneous increasing trend of 0.5-1.5 days per decade is observed across the country. This indicates that, according to the BCC-CSM2-MR model, the changes in very heavy R20mm precipitation events are spatially variable within Nepal, with some areas experiencing a more pronounced increase than others.

Similarly, the CNRM-ESM2-1 model displays a mixed pattern of increasing and decreasing trends in the annual number of very heavy R20mm precipitation, with a rate of 0.5-1 days per decade. This suggests that, according to the CNRM-ESM2-1 model, there may be spatial variations in the changes of very heavy precipitation events within Nepal. Some regions may experience an increase in such events, while others may see a decrease over time.

In the GFDL-ESM4 model, an increasing trend of 0.25-0.5 days per decade is observed in the central and eastern regions of Nepal. However, the western part of the country exhibits a decreasing trend of 0.25-0.5 days per decade in very heavy R20mm precipitation. This indicates that, according to the GFDL-ESM4 model, there may be regional differences in the trends of very heavy precipitation events within Nepal, with the central and eastern regions experiencing an increase while the western region undergoes a decrease over time.

Lastly, the INM-CM5-0 model demonstrates an increasing trend in R20mm precipitation, with a rate of 2-3 mm per decade. This suggests that, according to the INM-CM5-0 model, Nepal is likely to experience a gradual increase in the intensity of very heavy precipitation events over time. The magnitude of the increase is relatively higher in this model compared to the other models analyzed.

In summary, the analysis of the five CMIP6 models provides valuable insights into the trends of very heavy R20mm precipitation in Nepal under the SSP245 scenario. The models project varying patterns, with some indicating an overall increase in very heavy precipitation events, while others display mixed or spatially variable changes as shown in Figure 4.26. These findings highlight the need for further investigation and consideration of the spatial variability and uncertainties associated with future projections of very heavy precipitation events in Nepal.

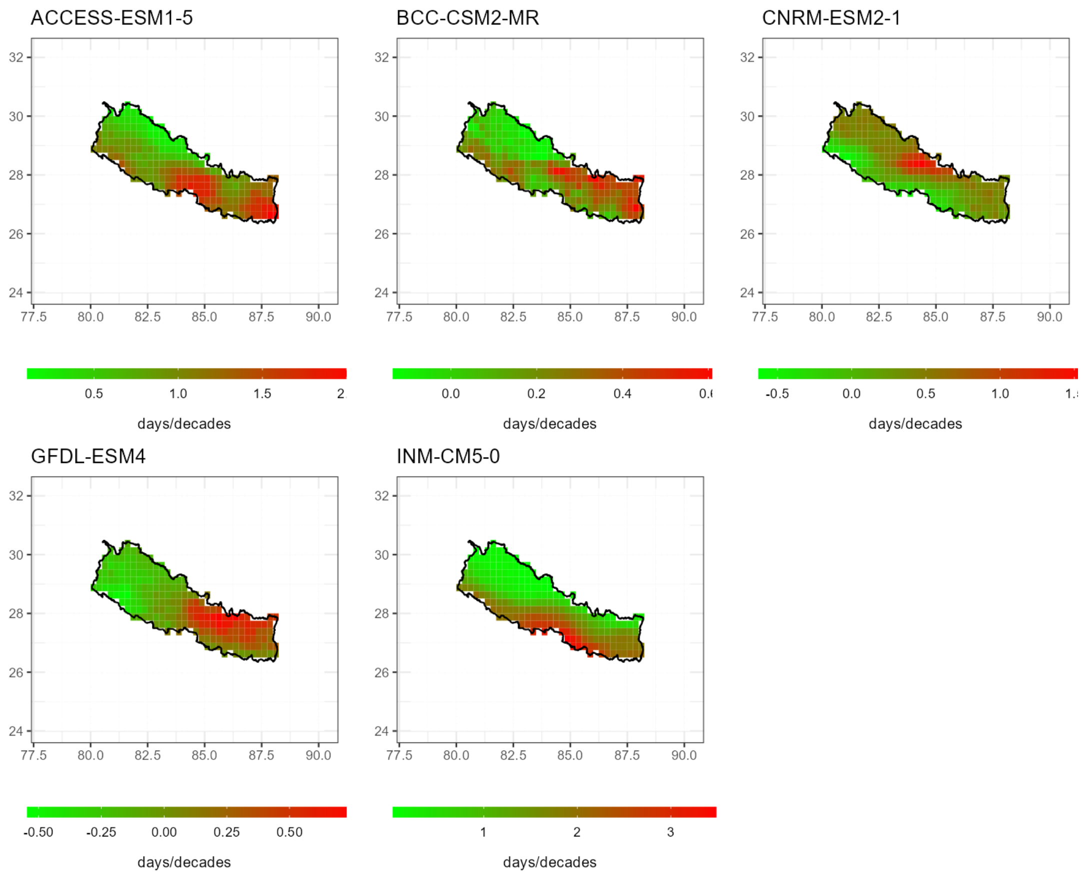


Figure 4.30 CMIP6 Model Projections: Number of very heavy (R10mm) under the SSP245 Scenario

4.4.12 Number of very heavy (R20mm) precipitation under SSP585

The analysis of the ACCESS-ESM1-5 model reveals an increasing trend in the annual number of very heavy R20mm precipitation in Nepal. The rate of increase is estimated to be around 1-4 days per decade. This indicates that, according to the ACCESS-ESM1-5 model, Nepal is likely to experience a greater occurrence of very heavy precipitation events over time. Notably, the central and eastern regions of Nepal exhibit a higher rate of increase compared to the western region, suggesting a spatial variability in the trends of very heavy R20mm precipitation events.

In the BCC-CSM2-MR model, a heterogeneous increasing trend of 0.4-1.5 days per decade is observed across the country. This suggests that, according to the BCC-CSM2-MR model, the changes in very heavy R20mm precipitation events are spatially variable within Nepal. Some regions may experience a more pronounced increase in the occurrence of such events, while others may see a relatively smaller rise over time.

Similarly, the CNRM-ESM2-1 model displays an increasing trend in the annual number of very heavy R20mm precipitation, with a rate of 1-3 days per decade. This suggests that, according to the CNRM-ESM2-1 model, Nepal is likely to experience an overall increase in the occurrence of very heavy precipitation events. The rate of increase varies across different parts of the country, indicating spatial differences in the trends of very heavy R20mm precipitation events within Nepal.

In the GFDL-ESM4 model, an increasing trend of 0.4-0.8 days per decade is observed. The central and eastern regions of Nepal exhibit a higher rate of increase compared to the western part of the country. This suggests that, according to the GFDL-ESM4 model, there may be regional disparities in the trends of very heavy R20mm precipitation events within Nepal. Some regions may experience a more pronounced increase in the occurrence of such events, while others may see a relatively smaller rise over time.

Lastly, the INM-CM5-0 model demonstrates an increasing trend in the number of heavy R20mm precipitation events, with a rate of 2-6 mm per decade. This suggests that, according to the INM-CM5-0 model, Nepal is likely to experience a gradual increase in the intensity of very heavy precipitation events over time. The magnitude of the increase is relatively higher in this model compared to the other models analyzed, indicating a potentially more significant rise in very heavy R20mm precipitation events.

In summary, the analysis of the five CMIP6 models provides valuable insights into the trends of very heavy R20mm precipitation in Nepal under the SSP585 scenario as shown in Figure 4.27. The models project varying patterns, with some indicating an overall increase in very heavy precipitation events, while others display spatially variable changes. These findings emphasize the importance of considering the spatial variability and uncertainties associated with future projections of very heavy precipitation events in Nepal.

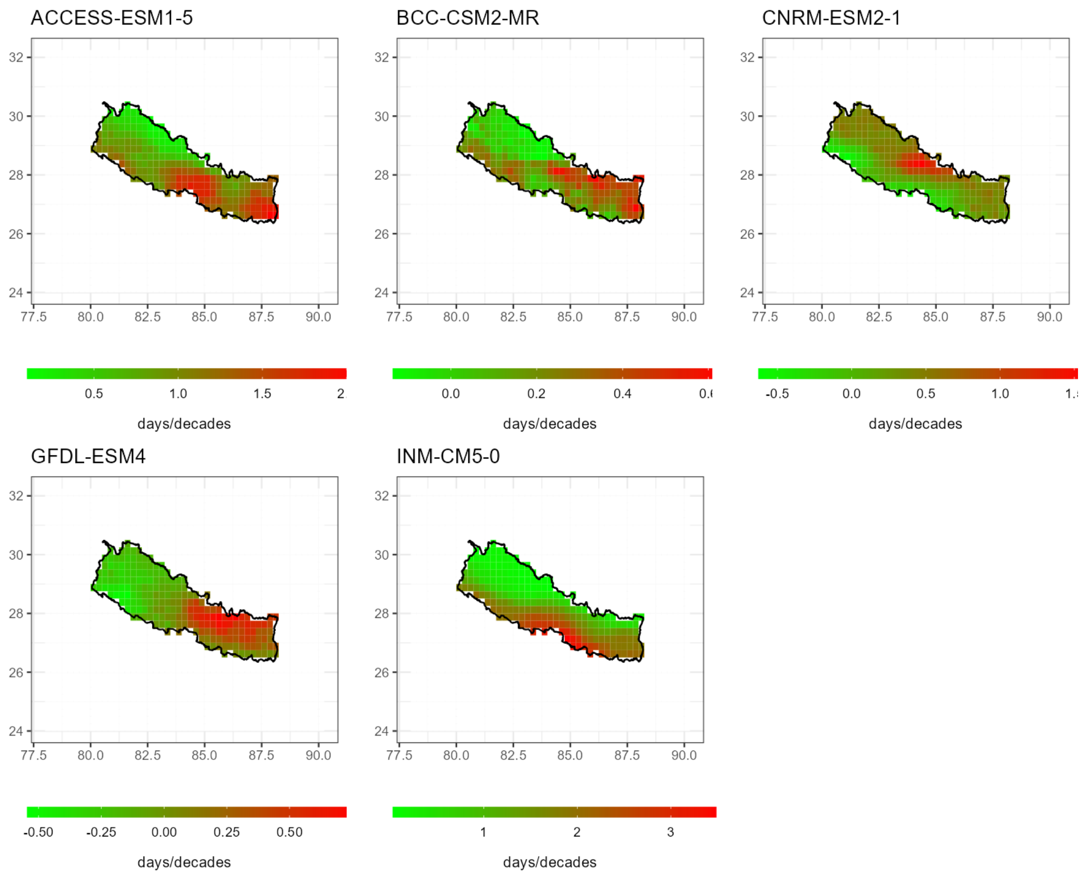


Figure 4.31 CMIP6 Model Projections: Number of very heavy (R10mm) under the SSP585 Scenario

4.4.13 Simple Daily Intensity Index (SDII) under SSP245

The analysis of the ACCESS-ESM1-5 model reveals an increasing trend in the SDII, indicating a rise in daily precipitation intensity over time. The rate of increase is estimated to be around 0.02-0.06 mm per day per year. This suggests that, according to the ACCESS-ESM1-5 model, Nepal is likely to experience an overall intensification of daily precipitation, with rainfall becoming more concentrated and potentially leading to heavier rainfall events.

In the BCC-CSM2-MR model, a heterogeneous pattern is observed across Nepal. The central and eastern parts of the country exhibit an increasing trend in SDII, suggesting a rise in daily precipitation intensity at a rate of 0.005-0.020 mm per day per year. In contrast, the western part of the country shows a decreasing trend, indicating a slight reduction in daily precipitation intensity at a rate of 0.005 mm per day per year. These findings highlight the spatial variability in the trends of daily precipitation intensity within Nepal as projected by the BCC-CSM2-MR model.

Similarly, the CNRM-ESM2-1 model indicates an increasing trend in SDII for Nepal, suggesting an overall intensification of daily precipitation. The rate of increase is estimated to be around 0.01-0.02 mm per day per year. This indicates that, according to the CNRM-ESM2-1 model, Nepal is likely to experience an increase in the intensity of daily precipitation over time.

In the GFDL-ESM4 model, a pattern similar to the BCC-CSM2-MR model is observed. The central and eastern parts of Nepal exhibit an increasing trend in SDII, indicating a rise in daily precipitation intensity at a rate of 0.005-0.010 mm per day per year. On the other hand, the western part of the country displays a decreasing trend at a similar rate, suggesting a slight reduction in daily precipitation intensity. These results highlight the spatial heterogeneity in the trends of daily precipitation intensity within Nepal as projected by the GFDL-ESM4 model.

Lastly, the INM-CM5-0 model shows an increasing trend in SDII for Nepal, indicating a rise in daily precipitation intensity. The rate of increase is estimated to be around 0.01-0.05 mm per day per year. This suggests that, according to the INM-CM5-0 model, Nepal is likely to experience an intensification of daily precipitation, with potentially heavier rainfall events occurring over time.

In summary, the analysis of the five CMIP6 models provides valuable insights into the trends of the Simple Daily Intensity Index (SDII) in Nepal under the SSP245 scenario. The models project varying patterns, with some indicating an overall intensification of daily precipitation, while others display spatially variable changes as shown in Figure 4.28. These findings underscore the importance of considering the spatial distribution and uncertainties associated with future projections of daily precipitation intensity in Nepal.

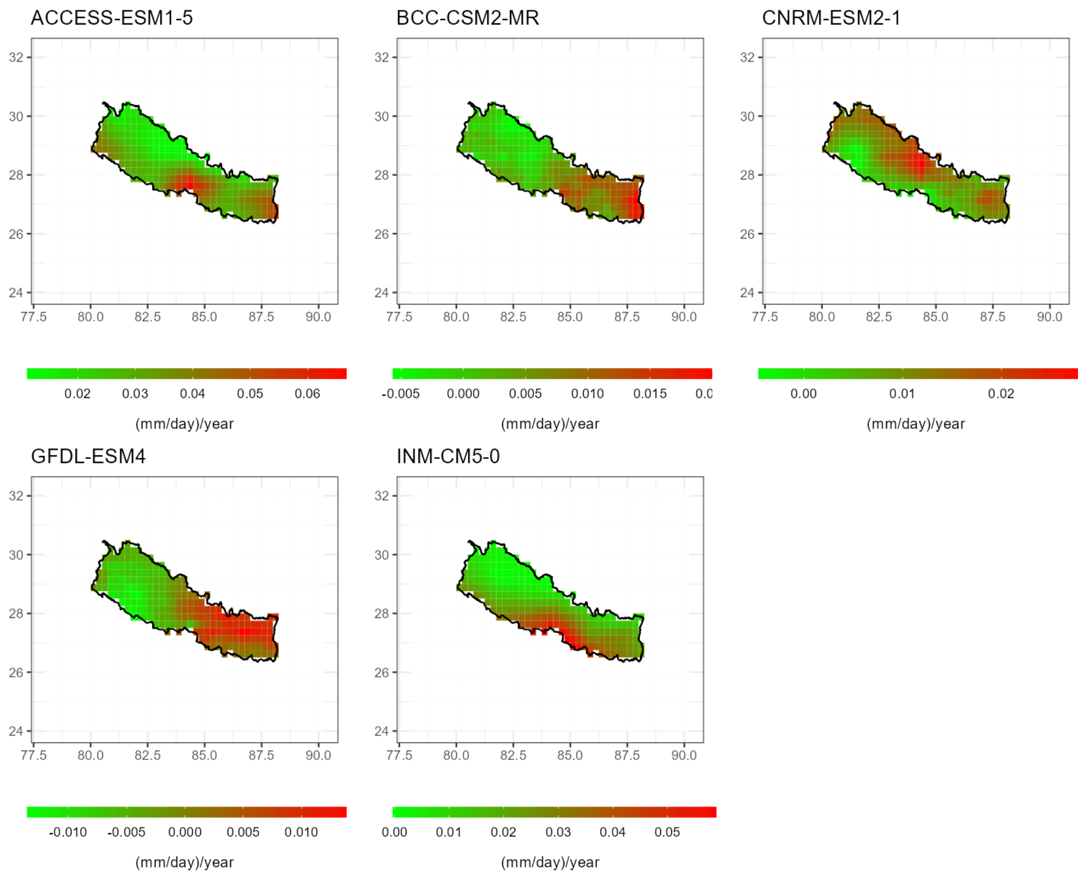


Figure 4.32 CMIP6 Model Projections: Simple daily intensity index (SDII) under the SSP245 Scenario

4.4.14 Simple Daily Intensity Index (SDII) under SSP585

The analysis of the ACCESS-ESM1-5 model reveals an increasing trend in SDII, indicating a rise in daily precipitation intensity over time. The rate of increase is estimated to be around 0.03-0.15 mm per day per year. This suggests that, according to the ACCESS-ESM1-5 model, Nepal is likely to experience a notable intensification of daily precipitation, with rainfall becoming more intense and potentially leading to heavier precipitation events.

In the BCC-CSM2-MR model, an increasing trend in SDII is observed across Nepal. The rate of increase is estimated to be around 0.010-0.030 mm per day per year. This indicates that, according to the BCC-CSM2-MR model, there is a projected increase in the intensity of daily precipitation in Nepal, with rainfall events becoming more intense over time.

Similarly, the CNRM-ESM2-1 model indicates an increasing trend in SDII, suggesting an overall intensification of daily precipitation. The rate of increase is estimated to be around 0.02-0.06 mm per day per year. These findings indicate that, according to the CNRM-ESM2-1 model, Nepal is likely to experience an increase in the intensity of daily precipitation over time.

In the GFDL-ESM4 model, an increasing trend in SDII is observed in most parts of Nepal, indicating a rise in daily precipitation intensity. The rate of increase is estimated to be around 0.01-0.02 mm per day per year. However, it is important to note that some parts of the country experience a decreasing trend of 0.01 mm per day per year. These results suggest that, according to the GFDL-ESM4 model, there is a spatial variability in the trends of daily precipitation intensity in Nepal, with certain areas experiencing an intensification while others may witness a slight reduction in daily precipitation intensity.

Lastly, the INM-CM5-0 model shows an increasing trend in SDII for Nepal, indicating a rise in daily precipitation intensity. The rate of increase is estimated to be around 0.025-0.1 mm per day per year. This suggests that, according to the INM-CM5-0 model, Nepal is likely to experience an intensification of daily precipitation, with potentially heavier rainfall events occurring over time.

In summary, the analysis of the five CMIP6 models provides valuable insights into the trends of the Simple Daily Intensity Index (SDII) in Nepal under the SSP585 scenario. The models project varying patterns of increasing trends (as shown in Figure 4.29), indicating an overall intensification of daily precipitation in most cases. However, it is important to consider the spatial distribution and uncertainties associated with these projections. These findings underscore the need to further understand and adapt to potential changes in daily precipitation intensity in Nepal in the face of future climate scenarios.

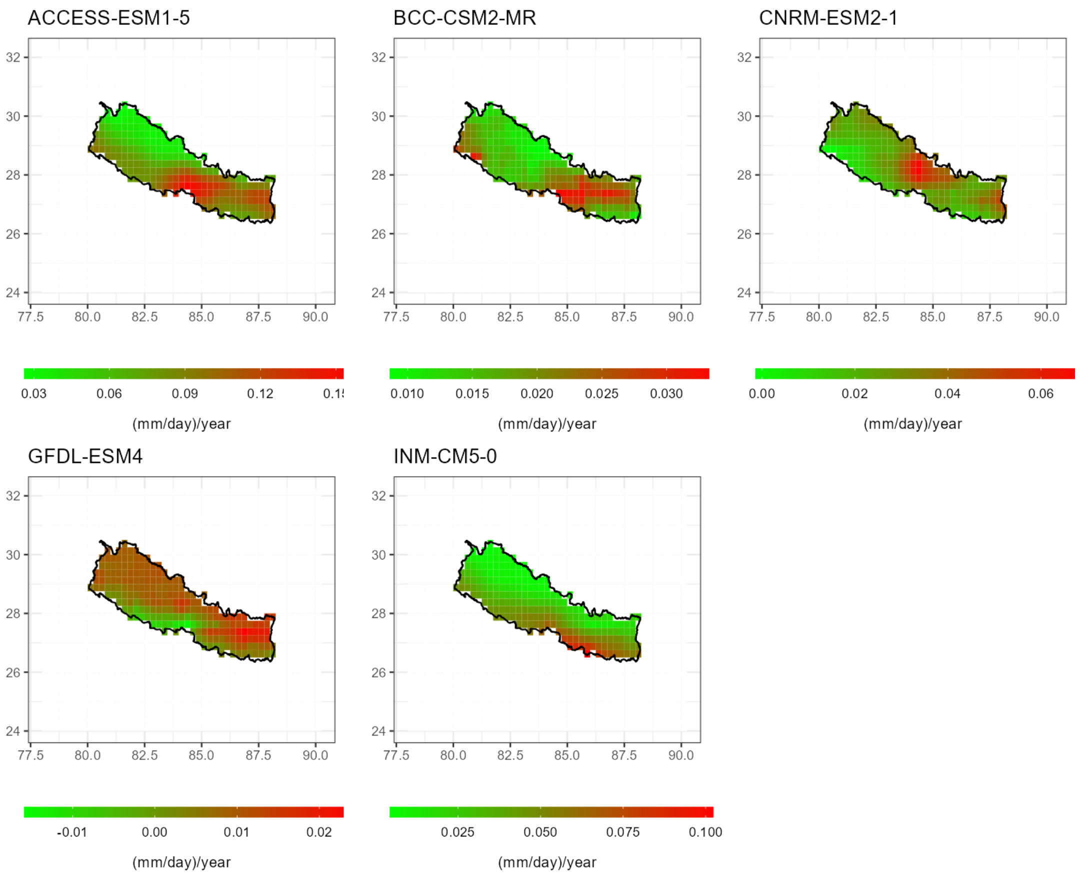


Figure 4.33 CMIP6 Model Projections: Simple daily intensity index (SDII) under the SSP585 Scenario

CHAPTER 5: DISCUSSIONS

Climate change is a pressing global issue with profound implications for regional climates. In Nepal, understanding the trends of extreme climate events is crucial for assessing the impacts on various sectors. Analyzing these trends in the context of global, South Asia, India, and China regions provides valuable insights into the broader climate patterns. Scientific consensus, as outlined in the Intergovernmental Panel on Climate Change (IPCC) assessments, confirms the evidence of a warming trend driven by anthropogenic greenhouse gas emissions. Rising global temperatures have wide-ranging consequences, influencing regional climates worldwide.

In South Asia, including Nepal, studies consistently show a warming trend over the past decades. For example, Klein Tank et al. (2006)conducted an extensive study on changes in daily temperature and precipitation extremes in central and south Asia, analyzing data from 116 meteorological stations. Their findings revealed a notable warming trend in both the cold and warm tails of the daily minimum and maximum temperature distributions between 1961 and 2000, along with indications of disproportionate changes in precipitation extremes relative to the total precipitation trends. Moreover, their analysis of stations with data spanning from 1901 to 2000 indicated that recent trends in minimum temperature extremes align with long-term trends, while trends in maximum temperature extremes are attributed to multi-decadal climate variability. This aligns with global warming trends and underscores the implications for water resources, agriculture, and human health.

Similar warming trends have been observed in India. Kothawale & Rupa Kumar (2005) found significant recent changes in India's surface temperature trends, showing an accelerated warming of 0.22°C/10yr from 1971 to 2003, primarily contributed by maximum temperatures. Additionally, rising temperatures during the monsoon season resulted in a weakened seasonal asymmetry of temperature trends. China, a neighboring country of Nepal, has also experienced warming trends, as demonstrated by You et al. (2011) research. Their study analyzed daily climate extremes in China from 1961 to 2003, revealing significant warming trends in northeastern, northern, and northwestern regions. The research highlighted an increase in warm days and nights, a decrease in cold days and nights, and changes in precipitation patterns, attributed to shifts in large-scale atmospheric circulation. These findings support global and regional warming trends, emphasizing the impact of climate change on local climates in China. These findings corroborate the global and regional warming trends, emphasizing the influence of climate change on local climates.

Our comprehensive analysis of climate data in Nepal aligns closely with observed global and regional warming trends. The noteworthy increase in warm days (TX90p) and warm nights (TN90p) signifies a clear warming trend, holding significant implications for local ecosystems, water resources, and agriculture. Simultaneously, the decrease in cool days (TX10p) and cool nights (TN10p) serves to accentuate the overall warming trajectory, emphasizing the intricate dynamics of climate change. This underscores the critical need for nuanced, localized assessments to grasp the multifaceted nature of these changes. Comparing our findings with existing literature in Nepal, studies by Karki et al. (2020b), Poudel et al. (2020a), and Hamal et al. (2021) consistently report a substantial increase in extreme temperature and mean temperature distributions across the country. This consistency in results across different studies reinforces the robustness of the observed warming trend, substantiating the urgent need for targeted climate adaptation measures.

Shifting our focus to precipitation patterns, our analysis exposes variations in the trend of extreme precipitation in Nepal. The increasing trend in consecutive dry days (CDD) signals prolonged dry spells, posing substantial risks to agriculture, water availability, and ecosystems. Conversely, the trends in consecutive wet days (CWD) exhibit regional variations, indicating potential alterations in extended periods of rainfall. The conflicting trends in the Simple Precipitation Intensity Index (SDII) across stations underscore the spatially heterogeneous distribution of precipitation intensity changes, influencing water availability, erosion, and flood risks. Comparisons with previous studies, such as Karki et al. (2017), Khadka et al. (2020) and Poudel et al. (2022), support our findings on extreme precipitation trends. Additionally, our examination of total annual precipitation (PRCPTOT), maximum 1-day precipitation (Rx1day), maximum 5-day precipitation (Rx5day), R10mm, and R20mm highlights spatial variability. Generally, PRCPTOT exhibits a decreasing trend, aligning with previous studies by Khadka et al. (2020) and Poudel et al. (2022). These consistent findings provide valuable insights into the evolving precipitation patterns in Nepal and contribute to our understanding of the multifaceted impacts of climate change on the region's hydrological systems.

Future projections using CMIP6 models provide insights into the potential trends of precipitation indices in Nepal. Under the SSP245 scenario, there is a projected increase in the duration of consecutive dry days (CDD) across all models. Spatial distribution variations are observed among the models, with certain regions, such as the eastern part of Nepal, projected to experience higher rates of increase. Conversely, the trends in consecutive wet days (CWD) exhibit more variability among the models, with some showing increasing trends in specific regions, while others display a mix of increasing and decreasing trends.

Projections also indicate an increasing trend in annual total precipitation (PRCPTOT) under the SSP245 scenario. Higher rates of increase are projected for the central and eastern regions of Nepal compared to the western region. However, the trends in annual maximum 1-day precipitation (RX1day) vary among the models, with some showing increasing trends, others displaying mixed patterns, and even indicating decreasing trends in certain regions. The rates of increase in RX1day precipitation range from 0.1-0.8 mm per year.

The relationship between crop yield and meteorological factors in Nepal, particularly focusing on wheat production, provides insights into the impact of climate on agricultural outcomes. The analysis reveals varying trends across different districts. Rupandehi and Banke districts show significant increasing trends in wheat crop yield, attributed to improved agricultural practices, irrigation systems, and the adoption of high-yielding wheat varieties. Kailali district exhibits a relatively lower increasing trend, potentially due to regional variations in agronomic practices or other environmental factors.

Correlation analyses indicate a negative relationship between wheat crop yield and excessive rainfall during November and December. Conversely, a positive correlation is observed between wheat crop yield and adequate rainfall during critical growth stages in January and February. These findings underscore the importance of understanding the specific impacts of temperature and precipitation changes on crop yield and highlight the need for region-specific strategies to mitigate adverse effects.

The observed and projected climate trends in Nepal, along with the regional and global context, have significant implications for various sectors. Rising temperatures and changing precipitation patterns can impact agriculture, water resources, and ecosystems. To address these challenges, region-specific adaptation strategies are essential. These may include the adoption of climate-resilient agricultural practices, efficient water management systems, sustainable land use practices, and the development of disaster preparedness and response systems.

In conclusion, the analysis of climate trends in Nepal, incorporating global, South Asia, India, and China trends, provides valuable insights into the changing climate dynamics. The observed warming trend and changing precipitation patterns align with the global and regional climate trends. The implications for water resources, agriculture, and ecosystems in Nepal are significant. Urgent action is required to mitigate the impacts of climate change and promote sustainable practices to ensure a resilient future for Nepal and the surrounding regions.

CHAPTER 6: CONCLUSIONS

The examination of precipitation trends in Nepal spanning from 1980 to 2020 reveals noteworthy spatial variations. While roughly 76% of meteorological stations display a decreasing trend in annual total precipitation (PRCPTOT), these trends lack statistical significance at the 5% level, suggesting a decrease in annual precipitation. In contrast, 24% of stations show an increasing trend in PRCPTOT, also without statistical significance. The countrywide (from quality control 85 stations) average PRCPTOT shows decreasing trend at the rate of 4.16 mm per year. Heavy rainfall events (R95p) exhibit a declining trend at around 69% of stations, indicating a reduction in the frequency of such events. However, only 28% of stations show an increasing trend (not statistically significant at 5%). Precipitation extremes, including consecutive dry days (CDD), consecutive wet days (CWD), and Simple Daily Intensity Index (SDII), reveal mixed trends, pointing to complex changes in precipitation intensity and frequency.

Examining climate projections under different scenarios, under the SSP245 scenario, Nepal is anticipated to experience an increase in consecutive dry days (CDD) and spatially variable changes in consecutive wet days (CWD). Projections indicate an overall increase in annual total precipitation (PRCPTOT), with more pronounced changes in the central and eastern regions. Extreme precipitation events, as indicated by RX1day, R10mm, R20mm, and SDII, are expected to intensify, with variations by region. Under the SSP585 scenario, there is a heightened shift in precipitation patterns, with more consecutive dry days (CDD) in higher-altitude regions and the eastern region. CWD patterns vary across models, with some regions experiencing more consecutive wet days. Projections indicate overall increases in PRCPTOT, with higher rates in the central and eastern regions. Extreme precipitation events are likely to intensify, including R10mm, R20mm, and SDII.

Regarding temperature trends, Nepal has undergone a significant warming trend over the past four decades. Both daily maximum (TXmean) and daily minimum (TNmean) temperatures have consistently increased across the stations. The country-wide average trends for TMm, TXm, and TNm were 0.025°C, 0.030°C, and 0.022°C per year, respectively, and these trends were statistically significant at the 5% level. Warm days (TX90p) and warm nights (TN90p) have increased across most stations, with statistical significance in many cases, indicating a rise in the occurrence of warm temperature extremes. Conversely, cool days (TX10p) and cool nights (TN10p) exhibited decreasing trends in many stations, suggesting a reduction in cooler temperature extremes. The Warm Spell Duration Indicator (WSDI) also showed a substantial increase in the number of warm spell days. In summary, the analysis of precipitation and temperature trends in Nepal suggests a complex and regionally diverse climate response. While warming trends are consistent, precipitation trends exhibit spatial variability and complexity. These findings underscore the need for adaptive strategies and further research to understand the implications for water resources, agriculture, and climate resilience in Nepal.

REFERENCES

Alexander, L., & Herold, N. (2016). *ClimPACT2: Indices and software*.

Alexander, L. V., Zhang, X., Peterson, T. C., Caesar, J., Gleason, B., Klein Tank, A. M. G., Haylock, M., Collins, D., Trewin, B., Rahimzadeh, F., Tagipour, A., Rupa Kumar, K., Revadekar, J., Griffiths, G., Vincent, L., Stephenson, D. B., Burn, J., Aguilar, E., Brunet, M., … Vazquez-Aguirre, J. L. (2006). Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research*, *111*(D5), D05109. https://doi.org/10.1029/2005JD006290

Baidya, S. K., Shrestha, M. L., & Sheikh, M. M. (2008). SOHAM-Nepal. *Journal of Hydrology and Meteorology*, *5*(1), 38–51.

Bocchiola, D., Brunetti, L., Soncini, A., Polinelli, F., & Gianinetto, M. (2019). Impact of climate change on agricultural productivity and food security in the Himalayas: A case study in Nepal. *Agricultural Systems*, *171*(April 2018), 113–125. https://doi.org/10.1016/j.agsy.2019.01.008

Chalise, S., Naranpanawa, A., Bandara, J. S., & Sarker, T. (2017). A general equilibrium assessment of climate change–induced loss of agricultural productivity in Nepal. *Economic Modelling*, *62*(January), 43–50. https://doi.org/10.1016/j.econmod.2017.01.014

Cuo, L., Zhang, Y., Wang, Q., Zhang, L., Zhou, B., Hao, Z., & Su, F. (2013). Climate Change on the Northern Tibetan Plateau during 1957–2009: Spatial Patterns and Possible Mechanisms. *Journal of Climate*, *26*(1), 85–109. https://doi.org/10.1175/JCLI-D-11-00738.1

Donat, M. G., Lowry, A. L., Alexander, L. V., O'Gorman, P. A., & Maher, N. (2016). More extreme precipitation in the world's dry and wet regions. *Nature Climate Change*, *6*(5), 508–513. https://doi.org/10.1038/nclimate2941

Easterling, D. R., Meehl, G. A., Parmesan, C., Changnon, S. A., Karl, T. R., & Mearns, L. O. (2000). Climate Extremes: Observations, Modeling, and Impacts. *Science*, *289*(5487), 2068–2074. https://doi.org/10.1126/science.289.5487.2068

FloodList. (2021). *Nepal – Dozens of Lives Lost After Rain Heavy Rain Triggers Floods and Landslides*.

Frich, P., Alexander, L., Della-Marta, P., Gleason, B., Haylock, M., Klein Tank, A., & Peterson, T. (2002). Observed coherent changes in climatic extremes during the second half of the twentieth century. *Climate Research*, *19*, 193–212. https://doi.org/10.3354/cr019193

GON. (2015). *Agriculture Development Strategy (ADS) 2015 to 2035*.

GON. (2021). *National Adaption Plan (NAP) 2021-2050: Nepal*.

Goswami, B. N., Venugopal, V., Sengupta, D., Madhusoodanan, M. S., & Xavier, P. K. (2006). Increasing Trend of Extreme Rain Events Over India in a Warming Environment. *Science*, *314*(5804), 1442–1445. https://doi.org/10.1126/science.1132027

Hamal, K., Sharma, S., Talchabhadel, R., Ali, M., Dhital, Y. P., Xu, T., & Dawadi, B. (2021). Trends in the Diurnal Temperature Range over the Southern Slope of Central Himalaya: Retrospective and Prospective Evaluation. *Atmosphere*, *12*(12), 1683. https://doi.org/10.3390/atmos12121683

ICIMOD. (2017). *ICIMOD Annual Report*.

IPCC. (2021). IPCC. Climate change 2021: The physi-cal science basis. In *Future Global Climate: Scenario-42 Based Projections and Near-Term Information; Cambridge University Press: Cambridge, UK*.

IPCC. (2023). *Climate change 2023: Synthesis report*.

Karki, R., ul Hasson, S., Gerlitz, L., Talchabhadel, R., Schickhoff, U., Scholten, T., & Böhner, J. (2020a). Rising mean and extreme near-surface air temperature across Nepal. *International Journal of Climatology*, *40*(4), 2445–2463. https://doi.org/10.1002/joc.6344

Karki, R., ul Hasson, S., Gerlitz, L., Talchabhadel, R., Schickhoff, U., Scholten, T., & Böhner, J. (2020b). Rising mean and extreme near-surface air temperature across Nepal. *International Journal of Climatology*, *40*(4), 2445–2463. https://doi.org/10.1002/JOC.6344

Karki, R., ul Hasson, S., Schickhoff, U., Scholten, T., & Böhner, J. (2017). Rising precipitation extremes across Nepal. *Climate*, *5*(1). https://doi.org/10.3390/cli5010004

Katz, R. W., & Brown, B. G. (1992). Extreme events in a changing climate: Variability is more important than averages. *Climatic Change*, *21*(3), 289–302. https://doi.org/10.1007/BF00139728

Khadka, N., Roy, P. D., Sharma, S., Hamal, K., Baniya, B., Luintel, N., & Joshi, B. B. (2020). Spatial and Temporal Analysis of Precipitation and Its Extremities in Seven Provinces of Nepal. *Applied Ecology and Environmental Sciences*, *8*(2), 64–73. https://doi.org/10.12691/aees-8-2-4

Klein Tank, A. M. G., Peterson, T. C., Quadir, D. A., Dorji, S., Zou, X., Tang, H., Santhosh, K., Joshi, U. R., Jaswal, A. K., Kolli, R. K., Sikder, A. B., Deshpande, N. R., Revadekar, J. V., Yeleuova, K., Vandasheva, S., Faleyeva, M., Gomboluudev, P., Budhathoki, K. P., Hussain, A., … Spektorman, T. (2006). Changes in daily temperature and precipitation extremes in central and south Asia. *Journal of Geophysical Research Atmospheres*, *111*(16). https://doi.org/10.1029/2005JD006316

Kothawale, D. R., & Rupa Kumar, K. (2005). On the recent changes in surface temperature trends over India. *Geophysical Research Letters*, *32*(18), n/a-n/a. https://doi.org/10.1029/2005GL023528

Luterbacher, J., Dietrich, D., Xoplaki, E., Grosjean, M., & Wanner, H. (2004). European Seasonal and Annual Temperature Variability, Trends, and Extremes Since 1500. *Science*, *303*(5663), 1499–1503. https://doi.org/10.1126/science.1093877

Manton, M. J., Della-Marta, P. M., Haylock, M. R., Hennessy, K. J., Nicholls, N., Chambers, L. E., Collins, D. A., Daw, G., Finet, A., Gunawan, D., Inape, K., Isobe, H., Kestin, T. S., Lefale, P., Leyu, C. H., Lwin, T., Maitrepierre, L., Ouprasitwong, N., Page, C. M., … Yee, D. (2001). Trends in extreme daily rainfall and temperature in Southeast Asia and the South Pacific: 1961-1998. *International Journal of Climatology*, *21*(3), 269–284. https://doi.org/10.1002/joc.610

Meehl, G. A., & Tebaldi, C. (2004). More intense, more frequent, and longer lasting heat waves in the 21st century. *Science*, *305*(5686), 994–997. https://doi.org/10.1126/SCIENCE.1098704/SUPPL_FILE/MEEHL.SOM.PDF

NOAA. (2021). *Past and future change in global temperature*. https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature#:~:text=According to NOAA's 2021 Annual,0.18 °C) per decade.

Pokharel, B., Wang, S. Y. S., Meyer, J., Marahatta, S., Nepal, B., Chikamoto, Y., & Gillies, R. (2020). The east–west division of changing precipitation in Nepal. *International Journal of Climatology*, *40*(7), 3348–3359. https://doi.org/10.1002/joc.6401

Poudel, A., Cuo, L., Ding, J., & Gyawali, A. R. (2020a). Spatio-temporal variability of the annual and monthly extreme temperature indices in Nepal. *International Journal of Climatology*, *40*(11), 4956–4977. https://doi.org/10.1002/joc.6499

Poudel, A., Cuo, L., Ding, J., & Gyawali, A. R. (2020b). Spatio-temporal variability of the annual and monthly extreme temperature indices in Nepal. *International Journal of Climatology*, *40*(11), 4956–4977. https://doi.org/10.1002/joc.6499

Poudel, A., Cuo, L., Gyawali, A. R., & Li, N. (2022). Spatiotemporal Patterns of Hydrometeorological Extremes over 1986–2015 in Nepal. *Journal of Hydrometeorology*, *23*(4), 573–596. https://doi.org/10.1175/JHM-D-21-0122.1

Seneviratne, S. I., Nicholls, N., Easterling, D., Goodess, C. M., Kanae, S., Kossin, J., Luo, Y., Marengo, J., Mc Innes, K., Rahimi, M., Reichstein, M., Sorteberg, A., Vera, C., Zhang, X., Rusticucci, M., Semenov, V., Alexander, L. V., Allen, S., Benito, G., … Zwiers, F. W. (2012). Changes in climate extremes and their impacts on the natural physical environment. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change*, *9781107025*, 109–230. https://doi.org/10.1017/CBO9781139177245.006

Shrestha, U. B., Shrestha, A. M., Aryal, S., Shrestha, S., Gautam, M. S., & Ojha, H. (2019). Climate change in Nepal: a comprehensive analysis of instrumental data and people's perceptions. *Climatic Change*, *154*(3–4), 315–334. https://doi.org/10.1007/s10584-019-02418-5

Sun, Q., Zhang, X., Zwiers, F., Westra, S., & Alexander, L. V. (2021). A Global, Continental, and Regional Analysis of Changes in Extreme Precipitation. *Journal of Climate*, *34*(1), 243–258. https://doi.org/10.1175/JCLI-D-19-0892.1

Talchabhadel, R., Karki, R., Thapa, B. R., Maharjan, M., & Parajuli, B. (2018). Spatio-temporal variability of extreme precipitation in Nepal. *International Journal of Climatology*, *38*(11), 4296–4313. https://doi.org/10.1002/joc.5669

Thrasher, B., Wang, W., Michaelis, A., Melton, F., Lee, T., & Nemani, R. (2022). NASA Global Daily Downscaled Projections, CMIP6. *Scientific Data*, *9*(1), 1–6. https://doi.org/10.1038/s41597-022-01393-4

WFP. (2018). *World Food Programme Annual performance report for 2017*. *June*, 18–22.

You, Q., Kang, S., Aguilar, E., Pepin, N., Flügel, W.-A., Yan, Y., Xu, Y., Zhang, Y., & Huang, J. (2011). Changes in daily climate extremes in China and their connection to the large scale atmospheric circulation during 1961–2003. *Climate Dynamics*, *36*(11–12), 2399–2417. https://doi.org/10.1007/s00382-009-0735-0

Zhang, X., Wan, H., Zwiers, F. W., Hegerl, G. C., & Min, S. (2013). Attributing intensification of precipitation extremes to human influence. *Geophysical Research Letters*, *40*(19), 5252–5257. https://doi.org/10.1002/grl.51010

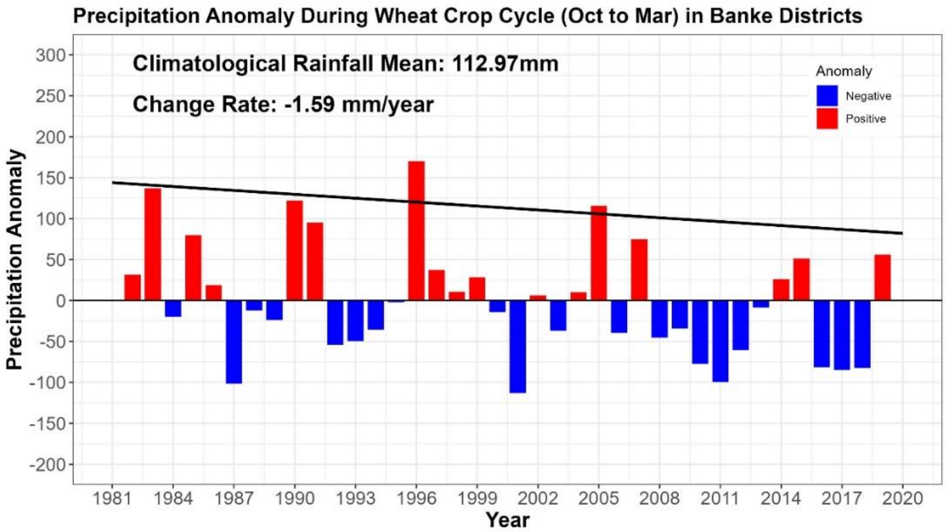
ANNEX

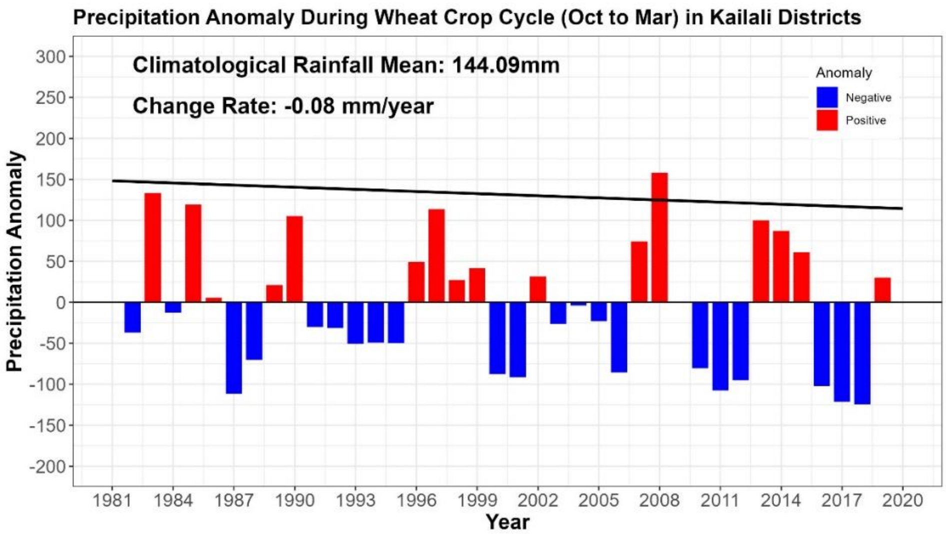
Table: Quality controlled finalized stations' details, including station location elevation, latitude and longitude

S.N	Index. No.	Stations Name	Station Type	Elevation (m)	Longitude	Latitude
1	102	Baitadi	Precipittation	1635	80.41667	29.55
2	103	Patan(West)	Climatology	1266	80.53333	29.46667
3	104	Dadeldhura	Synoptic	1848	80.58333	29.3
4	107	Darchula	Climatology	1097	80.98333	29.26667
5	203	Silgadi Doti	Climatology	1360	81.31667	29.38333
6	204	Bajura	Precipitation	1400	81.11667	28.53333
7	207	Tikapur	Climatology	140	80.55	28.8
8	209	Atariya	Synoptic	187	80.63333	28.86667
9	215	Godavari(West)	Climatology	288	81.28333	29.15
10	217	Mangalsen	Precipitation	1345	80.93333	29.23333
11	218	Dipayal(Doti)	Synoptic	652	82.17961	29.27469
12	303	Jumla	Synoptic	2300	82.15	29.55
13	306	Gam Shreenagar	Precipitation	2133	81.9	29.2
14	308	Nagma	Precipitation	1905	82.21667	29.26667
15	310	Dipal Gaun	Climatology	2310	82.91667	28.93333
16	312	Dunai	Climatology	2058	81.25	28.88333
17	401	Pusma Camp	Climatology	950	81.71667	28.85
18	402	Dailekh	Climatology	1402	81.26667	28.65
19	405	Chisapani(Karnali)	Climatology	225	81.61667	28.6
20	406	Surkhet	Synoptic	720	81.59028	28.11375
21	409	Khajura(Nepaljung)	Agrometeorology	190	81.52278	28.05194
22	416	Nepaljung(Reg.Off)	Climatology	144	81.33778	28.33361
23	417	Ranijaruwa Nursery	climatology	200	81.97492	28.02986
24	419	Sikta	Agrometeorology	195	82.63333	28.3
25	504	Libang Gaun	Precipitation	1270	82.86667	28.1
26	505	Bijuwar Tar	Precipitation	823	82.3	28.13333
27	508	Tulsipur	Climatology	725	82.16667	28.38333
28	511	Salyan Bazar	Climatology	1457	82.2	28.63333
29	513	Chaur Jhari Tar	Climatology	910	82.48333	28.63333
30	514	Musikot(Rukumkot)	Climatology	2100	83.71667	28.78333
31	601	Jomson	Climatology	2744	83.71667	28.78333
32	604	Thakmarpha	Agrometeorology	2566	83.7	28.75
33	614	Kushma	Climatology	891	83.7	28.21667
34	705	Bhairahawa Airpot	Aeronatical	109	83.4205	27.50692
35	706	Dumkauli	Agrometeorology	154	84.21667	27.68333
36	707	Bhairawaha (Agric)	Agrometeorology	120	83.45808	27.52917
37	708	Parasi	Precipitation	125	83.66472	27.53472
38	715	Khanchikot	Climatology	1760	83.15	27.93333
39	716	Taulihawa	Climatology	94	83.06667	27.55
40	725	Tamaghas	Climatology	1530	83.25	28.06667
41	728	Simari	Climatology	728	83.75	27.53333
42	804	Pokhara Airpot	Aeronatical	827	83.97972	28.2
43	808	Bandipur	Climatology	965	84.41667	27.93333

S.N	Index. No.	Stations Name	Station Type	Elevation (m)	Longitude	Latitude
44	809	Gorkha	Agrometeorology	1097	84.61667	28
45	810	Chapkot	Climatology	460	83.81667	27.88333
46	811	Malepatan(Pokhara)	Agrometeorology	856	83.97417	28.21833
47	814	Lumle	Agrometeorology	1740	83.81778	28.29667
48	815	Khairini Tar	Agrometeorology	500	84.1	28.03333
49	817	Damauli	Climatology	358	84.28333	27.96667
50	902	Rampur	Agrometeorology	256	84.35056	27.65389
51	906	Hetauda N.F.I	Climatology	474	85.05	27.41667
52	909	Simara Airpot	Aeronatical	130	84.98333	27.16667
53	911	Parwanipur	Agrometeorology	115	84.96667	27.06667
54	1007	Kakani	Agrometeorology	2064	85.25	27.8
55	1022	Godavari	Climatology	1400	85.4	27.58333
56	1027	Bahrabise	Climatology	1220	85.9	27.78333
57	1029	Khumultar	Agrometeorology	1350	85.33333	27.66667
58	1030	Kathmandu Airport	Aeronatical	1337	85.36667	27.7
59	1038	Dhunibesi	Climatology	1085	85.16417	27.72311
60	1043	Nagarkot	Climatology	2163	85.33333	27.73333
61	1052	Bhaktapur	Precipitation	1330	85.41667	27.66667
62	1057	Pansayakhola	Precipitation	1240	85.11667	28.01667
63	1102	Charikot	Precipitation	1940	86.05	27.66667
64	1103	Jiri	Agrometeorology	2003	86.23333	27.63333
65	1111	Janakpur Airpot	Climatology	90	85.96667	26.71667
66	1118	Manusmara	Climatology	100	85.41667	26.88333
67	1206	Okhaldhunga	Synoptic	1720	86.5	27.31667
68	1213	Udayapur Gadhi	Climatology	1175	86.51667	26.93333
69	1216	Siraha	Precipitation	102	86.21167	26.65611
70	1219	Salleri	Precipitation	2378	86.58333	27.5
71	1222	Diktel	Precipitation	1623	86.8	27.21667
72	1223	Rajbiraj	Climatology	91	86.69861	26.80083
73	1303	Chainpur (East)	Climatology	1329	87.31667	27.29222
74	1304	Pakhribas	Agrometeorology	1680	87.2925	27.04639
75	1307	Dhankuta	Synoptic	1210	87.34583	26.98333
76	1311	Dharan Bazar	Climatology	444	87.28472	26.79194
77	1316	Chatara	Precipitation	183	87.16667	26.81667
78	1319	Biraatanagar Airport	Aeronatical	72	87.26694	26.48333
79	1320	Tarahara	Agrometeorology	200	87.27861	26.69861
80	1405	Taplejung	Synoptic	1732	87.66667	27.35
81	1408	Damak	Precipitation	163	87.70333	26.77056
82	1412	Chandra Gadhi	Precipitation	120	88.06139	26.56389
83	1416	Kanyam Tea Estate	Climatology	1678	88.07833	26.86806
84	1419	Phidim (Panchther)	Climatology	1205	87.75167	27.14361
85	1421	Gaida (Kankai)	Agrometeorology	143	87.86056	26.65083

Precipitation anomaly during wheat crop cycle (October to March) in Banke District and Kailali District





Annual time series of precipitation indices averaged over Nepal in the period of 1980-2020: