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Climatic variability change analysis in Tamor River Basin Projected by CMIP6 Model

Ayush Poudel [a], Utsav Bhattarai [b], Pawan Bhattarai [c]

[a, c] *Department of Civil Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
[b] *Kearneys Spring, Queensland, Australia*
[a] ayushpoudelhimal@gmail.com, [b] utsavbhattarai@gmail.com, [c] nepal.pawan@gmail.com

Abstract
A sound understanding of projected climate is crucial for the effective structural design and planning of adaptation and mitigation measures in combating the adverse effects of climate change. This study projects precipitation, Tmax, and Tmin in the Tamor River Basin (TRB) up to 2100 using CMIP6 GCMs model output under two shared socioeconomic pathways, SSP245 (4.5 Watt/m2) and SSP585 (8.5 Watt/m2). All selected meteorological stations in the basin showed a widespread and robust rising trend of temperature, decrease in precipitation in NF, and increase in FF using the Multi-model Ensemble (MME) of selected GCMs, with very few exceptions. The multi-model ensemble indicated considerable variation in annual precipitation, initially decreasing up to 2.5 % in NF and increasing to 5.73 % at the end of the 21st century. The average annual Tmax across the TRB is projected to increase by 0.37 ℃, .96 ℃, and 1.25℃ in NF, MF, and FF under the SSP245 scenario. Similarly, under SSP585, Tmax will increase by 0.4℃, 1.26℃, and 2.29℃ to the base period. Tmin under SSP245 increases it by 0.2℃, 0.8 ℃ to 1.2℃ in NF, MF, and FF. Similarly, under SSP585, Tmin will increase by 0.4℃, 1.6℃, and 3.0 ℃. From MME analysis, there is no clear changing trend of precipitation, Tmax and Tmin, according to season, but for most of the station, precipitation increases in winter and monsoon season and decreases in pre-monsoon and autumn. As with precipitation, Tmax and Tmin increase in the winter season and decrease in the autumn season. This bias-corrected Projection of Precipitation, Tmax and Tmin may apply to future research on the basin's climate change and hydrological analysis.

Keywords
Climate Change, CMIP6, GCM, SSP, Tamor River Basin (TRB)

1. Introduction

Climate is the long-term pattern of weather in a location, usually averaged over 30 years, but it is more precisely the mean and variability of meteorological variables ranging from months to millions of years. Climate change varies the timing and intensity of rainfall, temperature, and runoff; tests existing infrastructures' coping capacities; and increases the risk of drought and floods, all of which have an impact on the hydrological cycle, both locally and internationally [1] [2]. Understanding the extent and significance of CC-induced alterations in the hydrological cycle and subsequent water availability is of great interest to global environment and water resources managers [3] [4]. Under balance of evidence, global warming is unequivocal, and most of it is very likely due to the increase in atmospheric greenhouse gas concentrations. Observed climate change has extended beyond temperature. However, there are multiple pressures of global change, such as population growth, land use, land cover changes, urbanization, deforestation, and environmental pollution, which in many areas are exacerbated by climate change. Hence, there are concerns about the impacts of changes on water resources. It is reported that there will be an increase in the difference in precipitation between wet and dry regions and seasons (IPCC, 2013). Climate change is affecting rainfall patterns; in high latitudes, precipitation is likely to increase, while it is projected to decrease over large parts of the subtropics. Changes to monsoon precipitation are expected, which will vary by region (IPCC, 2018). The global population is heavily dependent on water resources. Climate change impacts may affect water quality, quantity, and availability.

The studies on the Tamor river basin using CMIP5 showed that maximum and minimum temperature would increase but decrease precipitation. Similarly, studies by [5] on the Koshi river basin showed that CC projection show increasing CC projections show an increasing trend in precipitation and net water yield for most of the basin, except the trans mountain region.

As the Tamor River contributes around one-fifth of the water in the Koshi River, changes in temperature and precipitation will affect the livelihoods of hundreds of millions of people in India and Nepal. They rely on water availability in the Koshi River Basin, which has navigational potential for Nepal. Also, the basin has a high potential for large-capacity hydropower generation. Therefore, studying temporal and spatial change in climatic variability is essential to assess climate change impact.

This study project temperature and precipitation for three future periods, namely near-future (NF:2022-2048), mid-future (MF:2049-2074), and far-future (FF:2975-2100), based on CMIP6 model output under two future scenarios namely SSP245 and SSP585 with seasonal and annual change analysis which will help for adaptation planning.

2. Material and Methods

2.1 Study Area

TRB is located in the eastern part of Nepal, which covers Taplejung, Paanchtar, Terathum and some parts of the Dhankuta district. The latitude and longitude for the TR Blues are between 26°49' to 27°53'N and 87°27'to 88° 3'E, respectively. The Tamar River is a major river in eastern Nepal, which begins around Kanchenjunga. The Tamor and the Arun join the Sun Koshi at Tribenighat to form the giant Saptakoshi, which flows through the Mahabharat range onto the Gangetic plain. The catchment area of the TRBis5877 square kilometer (Source: Watershed area calculation in GIS). The elevation of the catchment area varies from 252 m to 8368 m above the mean sea level, with steep topography having an area of more than 45 percent in slope higher than 50 percent rise. Basin has average annual maximum precipitation around 2340 mm at station no 1403 and minimum precipitation 961 at station 1307 in base period (from 1980 to 2014 A. D). Observed min temp and max temp was -1 °C and 36°C at station 1405 1992 and 1419.Most of the basin is covered by forest, around 48 percent followed by agricultural land, 20 percent of the basin and 14 percent snow/Glacier cover, as shown in Figure 2.The TRB location map is shown in Figure 1

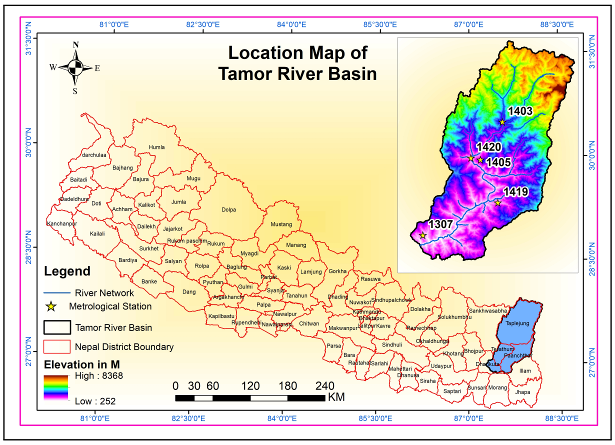

Figure 1: Location and details of the Tamor river basin

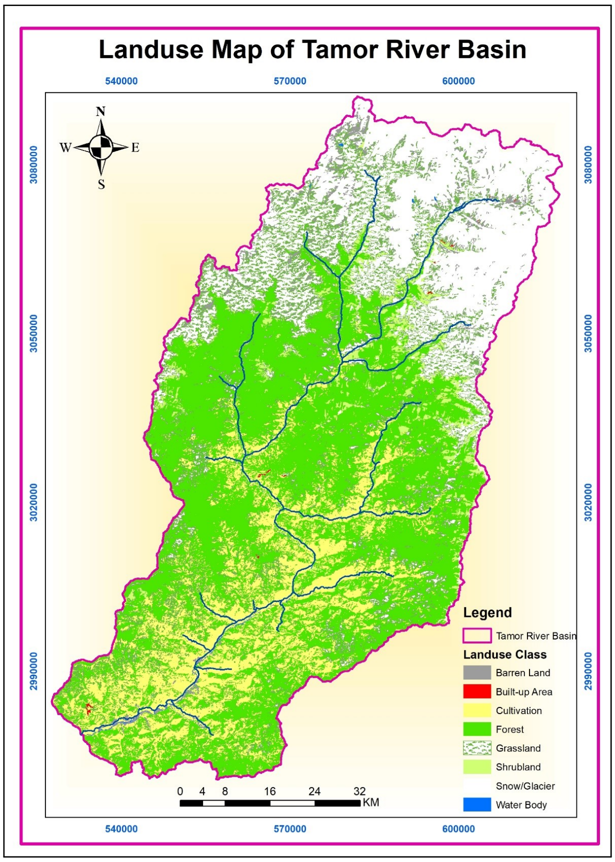

Figure 2: Location and details of the Tamor river basin

Table 1: Meteorological station Details

S.No	Station Name	Index No	District	Latitude	Longitude	Elevation
1	DHANKUTA	1307	Dhankuta	26.98	87.35	1210
2	LUNGTHUNG	1403	Taplejung	27.55	87.78	1780
3	TAPLEJUNG	1405	Taplejung	27.35	87.66	1732
4	PHIDIM	1419	Panchthar	27.15	87.75	1205
5	DOVAN	1420	Taplejung	27.35	87.6	763

2.2 Data Collection

2.2.1 Temperature And Precipitation Data

Meteorological data (precipitation, temperature) were collected from the Department of Hydrology and Meteorology from 1980 to 2014 for eight stations, However Stations that have missing data of more than 15 % were avoided, and only five stations 1307, 1403, 1405, 1419 and 1420 were taken for this study considering the spatial location of station to represent the whole basin. Details of the selected meteorological station are present in the table below 1.

2.2.2 GCMs(CMIP6) Data

For future (2022-2100) projection of temperature and precipitation, CMIP6-GCMs model outputs were collected from World Climate Research Program (WCRP) website (https://esgfnode.llnl.gov/search/cmip6/) under SSP245 and SSP585 scenario. Ten and eight CMIP6 GCM were selected for precipitation and temperature based on different paper reviews.

2.3 Methodological framework

The overall research methodology is shown in the figure below. The principal activities in this study are the acquisition of observed data, GCMs data set, filling of missing data, selection of best GCMs, selection of best-performed bias correction method, and projection of climatic variables. The missing data are filled by the Normal Ratio and Long-Term Average methods for precipitation and temperature, respectively.

2.3.1 GCMs Selection

Based on no different lecture review, 10 GCMs for precipitation and 8 GCMs for Tmax and Tmin were selected to form a pool of raw GCMs that participated in the CMIP6. Taking several GCMs helps to minimize the uncertainty present. The performance rating was assigned to each GCM. Details are listed in the table below. The average rating was calculated for all GCMs at selected station.

Table 2: Performance rating table for Raw GCMs

Rating	NSR	RSR	PBIAS	Ratings
Very Good	0.75-1.00	0.00-0.50	<10	5
Good	0.55-0.75	0.50-0.6	10-15	4
Satisfactory	0.40-0.55	0.60-0.70	15-25	3
Unsatisfactory	0.25-0.40	0.70-0.80	25-35	2
Poor	<=0.25	>0.80	>=35	1

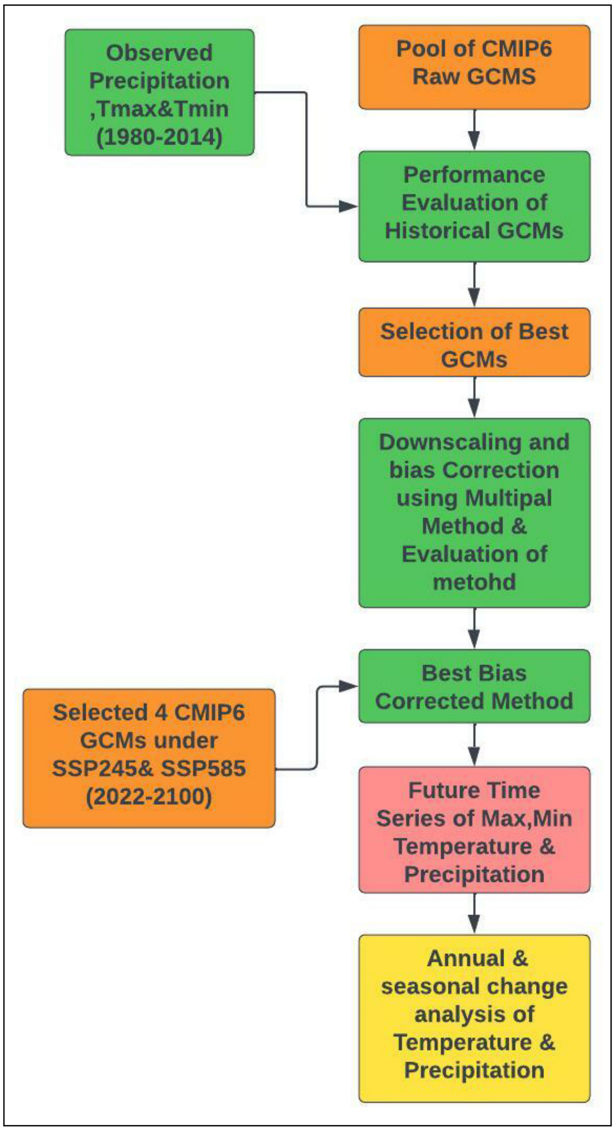

Figure 3: Methodological Framework for this study

2.3.2 Bias Correction Methods

The GRMs have coarser resolution with approximate grid sizes of 150-300 km and therefore need to downscale further and correct for biases before applying with hydrological models for climate impact assessments (Cook et al., 2018). Using the difference in mean and variability between GCM and reference period data, the bias correction approach adjusts the anticipated raw daily GCM output.

Table 3: Performance rating of GCM

Rating	NSR	RSR	PBIAS	Ratings
Very Good	0.75-1.00	0.00-0.50	<10	5
Good	0.55-0.75	0.50-0.6	10-15	4
Satisfactory	0.40-0.55	0.60-0.70	15-25	3
Unsatisfactory	0.25-0.40	0.70-0.80	25-35	2
Poor	<=0.25	>0.80	>=35	1

3. Results and Discussions

3.1 Selected GCMS for Multi –Model Ensemble

Based on three performance metrics (i.e., RSR, PBIAS, and NSE), the rating for each GCM in the pool was assigned, and the highest rating for four GCMs, namely MRI-ESM2-0, BCC-CSM2-MR, NorESM2-MM, and MPI-ESM1-2-LR was selected for precipitation similarly INM-CM4-8, INM-CM5-0, NorESM2-MM and ACCESS-CM2 for Tmax and ACCESS-CM2, EC-Earth3, IPSL-CM6A-LR, NorESM2-MM for Tmin. Details rating of GCMs is shown in fig below

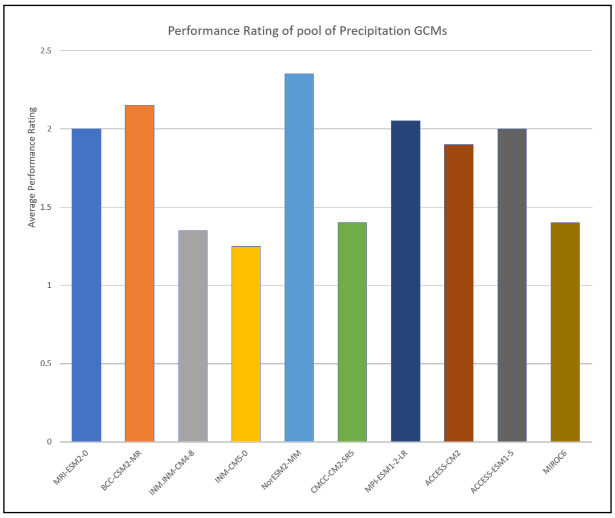

Figure 4: Performance rating of Raw GCMs for Precipitation

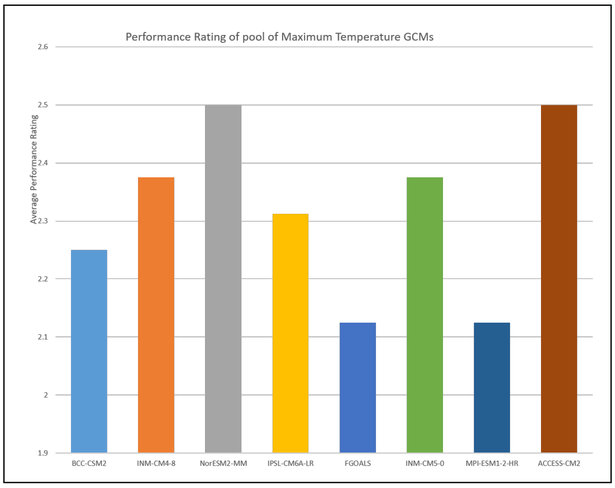

Figure 5: Performance rating of Raw GCMs for Tmax

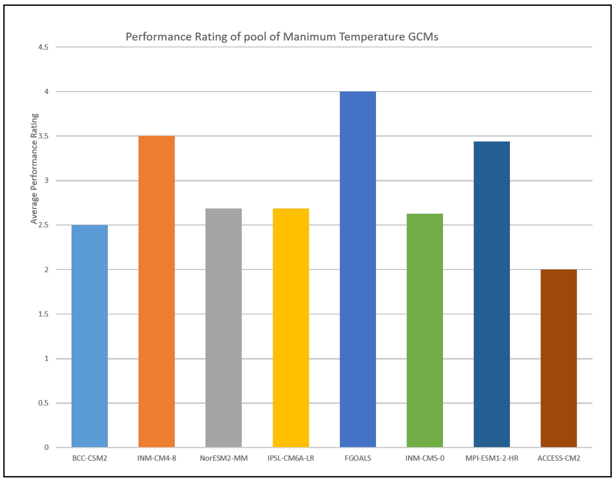

Figure 6: Performance rating of Raw GCMs for Tmin

3.2 Selected Bias Correction Method

Thirteen bias correction methods were applied to correct biases in the selected historical raw GCMs. The biases present in raw GCMs were reduced substantially after applying these methods. Then bias-corrected GCMs daily data were compared with observed data collected from DHM to calculate three performance metrics NSE, RSR, and PBIAS. Bernoulli Weibull was the best bias correction method for precipitation, similar Non-Parametric Quantile Mapping using robust empirical quantile–tri cube for Tmax and Tmin. The bias correction method for historical GCMs output improved much improvement. Before and after bias correction for Precipitation, Tmax and Tmin at sample station 1307 are shown in fig below

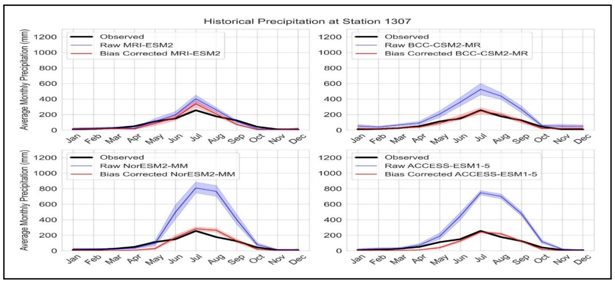

Figure 7: Before and After bias correction of historical precipitation of selected GCMs at station 1307

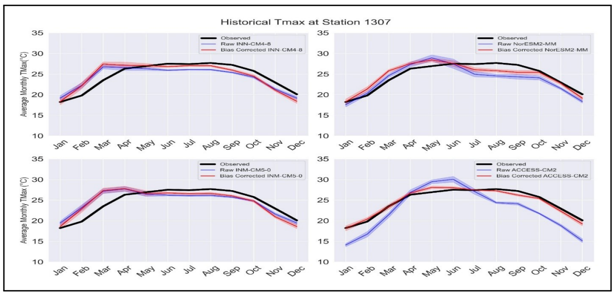

Figure 8: Before and After bias correction of historical Tmax of selected GCMs at station 1307

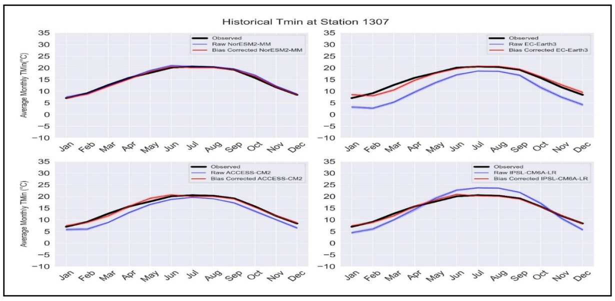

Figure 9: Before and After bias correction of historical Tmin of selected GCMs at station 1307

3.3 Projected Future Temperature and Precipitation

SSP245 and SSP585 future emission scenarios were used to forecast temperatures and precipitation (2022-2100) for selected meteorological stations in TRB. For Tmax and Tmin, the anticipated annual temperature time series tends to rise as this century draws closer. For all of the chosen GCMs and MME, scenario SSP585 exhibits a greater rate of temperature increase than SSP245 does. No clear pattern of future annual temperature and precipitation changes was observed in the future. The rate of change in future temperature and precipitation differs for different models.

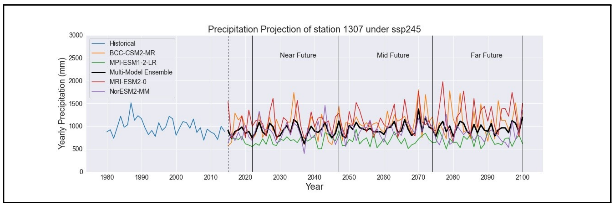

Figure 10: Precipitation Projection of station 1307 under ssp245

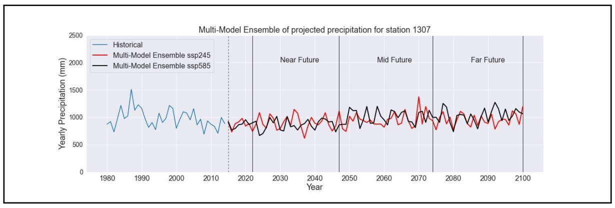

Figure 11: Multi-Model Ensemble of projecteed precipitation for station 1307

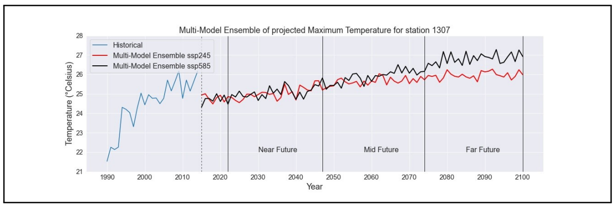

Figure 12: Multi-Model Ensemble of projected Maximum Temperature for station 1307

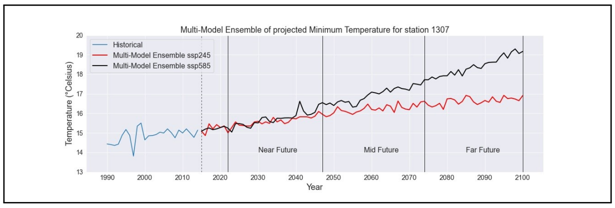

Figure 13: Multi-Model Ensemble of projected Minimum Temperature for station 1307

3.4 Projected Change in Annual Temperature and Precipitation

The spatial distribution of the projected changes in the annual mean of Tmax and Tmin and the annual sum of precipitation over the TRB for three future periods under two scenarios, SSP245 and SSP585, were analyzed. The multi-model ensemble indicated a 2.5% decrease in annual precipitation in the near future, 1.22% increase in mid future, and 0.19 % increase in the far future for the SSP245 scenario, while -5.32% decrease in the near future, 4.89% in mid future and 5.73 % increase in far future for SSSP585 scenario.

There is no evident variation in rainfall according to the four seasons. In some stations, there is an increase in precipitation in some seasons, but at the same time, in some stations, it is decreasing. Details of annual change in precipitation in TRB are shown in the table 4.

Table 4: Annual Change in Precipitation [%]

Scenario	Time	1307	1403	1405	1419	1420
	NF	-7.98	0.54	-2.31	-2.77	0.01
SSP245	MF	-2.57	3.43	1.15	1.06	3.03
	FF	-2.63	1.87	-0.13	0.28	1.57
	NF	-11.81	-1.32	-4.78	-5.83	-2.88
SSP585	MF	3.45	5.45	4.17	5.19	6.19
	FF	5.02	6.31	5.26	5.79	6.28

The multi-model ensemble indicated Maximum temperature under the SSP245 scenario is projected to increase, ranging from 0.59 °C to 0.73°C for NF, 0.14 °C to 1.24 °C for MF, and 0.45 °C to 1.52 °C for FF expect for station 1403 where -0.5 °in NF. Similarly, the maximum temperature under SSP585 is projected to increase, ranging from 0.62 °C to 0.77° C for NF, 0.51 °C to 1.54 °C for MF, and 1.7 °C to 2.58°C for FF expect, as like in SSP245 in NF of 1403 station temperature is decrease by 0.48°C in NF of SSP585. Details of annual change in Tmax in TRB are shown in the table below. 5.

Table 5: Annual Change in Tmax [°C]

Scenario	Time	1307	1403	1405	1419
	NF	0.59	-0.50	0.73	0.66
SSP245	MF	1.20	0.14	1.26	1.24
	FF	1.51	0.45	1.51	1.52
	NF	0.62	-0.48	0.77	0.67
SSP585	MF	1.46	0.51	1.53	1.54
	FF	2.37	1.70	2.51	2.58

The multi-model ensemble indicated Minimum temperature under the SSP245 scenario is projected to increase, ranging from 0.7°C to 0.8°C for NF, 1.3°C to 1.5°C for MF, and 1.7°C to 1.9°C for FF expect station no 1403 where it decreases by 1.5°C, 0.8°C and 0.4°C in NF, MF and FF respectively. Similarly, the minimum temperature under the SSP585 scenario is projected to increase concerning the historical period, ranging from 0.8 °C to 1 °C for NF, 1.9 °C to 2.3°C for MF, and 1.4°C to 3.9 °C for FF, expect station 1403, where Tmin decrease by -1.3°C in NF and 0.1°C in MF. Details of annual change in Tmax in TRB is shown in the table below 6.

Table 6: Annual Change in Tmin [°C]

Scenario	Time	1307	1403	1405	1419
	NF	0.7	-1.5	0.7	0.8
SSP245	MF	1.4	-0.8	1.3	1.5
	FF	1.8	-0.4	1.7	1.9
	NF	0.9	-1.3	0.8	1.0
SSP585	MF	2.1	-0.1	1.9	2.3
	FF	3.6	1.4	3.3	3.9

Table 7: Seasonal change in percentage of precipitation

	Period	DJF	MAM	JJAS	ON
	Historical	50.4	336.1	1751.8	105.8
	NF	37.89	-18.54	2.86	-13.86
SSP245	MF	59.30	-9.13	5.15	-27.20
	FF	32.87	-9.31	3.86	-27.63
	NF	37.60	-15.11	0.02	-12.89
SSP585	MF	32.32	-11.56	8.42	-16.01
	FF	46.39	2.40	5.78	-8.74

The various other studies done for this region showed similar type of result

3.5 Projected Change in Seasonal Temperature and Precipitation

Change in precipitation and temperature is analyzed in four seasonal basins, namely winter (DJF), pre-monsoon (MAM), monsoon (JJAS), and autumn (ON). From MME analysis, there is no clear pattern according to season; in DJF, precipitation decreases in some stations and increases in others. Also, the increase/decrease percentage is different for different stations. However, for most stations, precipitation increases in winter and monsoon seasons and decreases in pre-monsoon and autumn. The maximum increase is 61.129 % in the post-monsoon season at station 1403 and maximum decrease in precipitation is 69.8% in autumn at station 1307. Seasonal change in percentage of precipitation for sample station 1403 is shown in the table below 7

Like in precipitation change, Change Tmin also vary with the different station. The maximum increase in Tmax by 4.8 °C in FF at station 1307 in winter and the maximum decrease in Tmax by 1.8 8°C in NF at station 1403 in autumn. Similarly maximum increase in Tmin by 4.85 °C in FF at station 1405 in the winter season and a maximum decrease in Tmin by 1.87 °C in NF at station 1403 in the Pre-monsoon season. Seasonal change by °C in Tmax and Tmin for sample

Table 8: Seasonal change by °C in Tmax & Tmin

Scenario	Time	DJF	MAM	JJAS	ON
	Tmin				
	NF	-1.04	-1.87	-1.56	-1.46
SSP245	MF	-0.19	-0.85	-0.99	-1.48
	FF	0.34	-0.04	-0.72	-1.69
	NF	-0.88	-1.85	-1.33	-1.31
SSP585	MF	0.67	-0.29	-0.15	-0.77
	FF	2.58	1.47	1.18	-0.05
	Tmax				
	NF	-0.3	-0.4	-0.2	-1.5
SSP245	MF	0.6	0.6	0.3	-1.6
	FF	0.9	1.4	0.5	-1.8
	NF	0.4	-1.3	-0.1	-1.3
SSP585	MF	1.3	0.1	1.0	-1.1
	FF	2.7	1.6	2.1	-0.6

station 1403 is shown in the table below 8.

4. Conclusions

This study projected future temperature, both Tmax and Tmin, and Precipitation in TRB under two SSPs, SSP245 and SSP585, based on CMIP6 GCMs. Four GCMs from a pool of ten were identified and selected based on their performance matrix and associated ratings. The outputs of the selected GCMs were bias-corrected using thirteen and nine methods for precipitation and temperature, respectively. The most suitable method was Bernoulli Weibull for precipitation and Non-parametric Quantile Mapping using the robust empirical quantiles-tri club for Tmax and Tmin based on its performance. Therefore, bias-corrected results from this method were selected for preparing an MME to project future temperatures and precipitation. The future climate was projected for three future periods, namely, NF (2022-2048), MF (2049-2074), and FF (2075-2100). The result obtained from trend analysis of mean annual temperature data indicated a significant warming trend in Tmax and Tmin, and Annual precipitation also increased in the future with significant seasonal change. There is no clear pattern in percentage change in precipitation in TRB; it varies according to the station, scenario, and future time. The maximum decrease in station 1307 and maximum increase in station 1420 for both SSP245 and SSP 585 Scenario. For basin, precipitation will decrease in NF by 5.32 % and increase up to 5.73 in both scenarios. Tmax minimum increase in station 1403 by -.5 °C to 1.7 °C in the future and maximum increase up to 2.58 °C in annual average in FF with SSP585 scenario. Similarly, as in Tmax, Tmin will decrease in station 1403 by a maximum of 1.5°C in NF and a maximum increase up to 2.58 °C in FF in station 1419 on an average annual basis. According to this analysis, the TRB's temperature will likely rise dramatically. Mountainous areas are particularly affected by the warming trend, which has a significant impact on the area covered in snow and glaciers. Although there will be a significant change in precipitation with the season, precipitation will decrease in NF and increase in FF. Therefore, runoff and water availability will be highly influenced, resulting in several hydrological disasters in the basin. The appropriate mitigation and adaptation methods should be developed to lessen the effects of global warming. The findings of this study may apply to future research on the basin's climate and hydrological analysis.

Acknowledgments

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