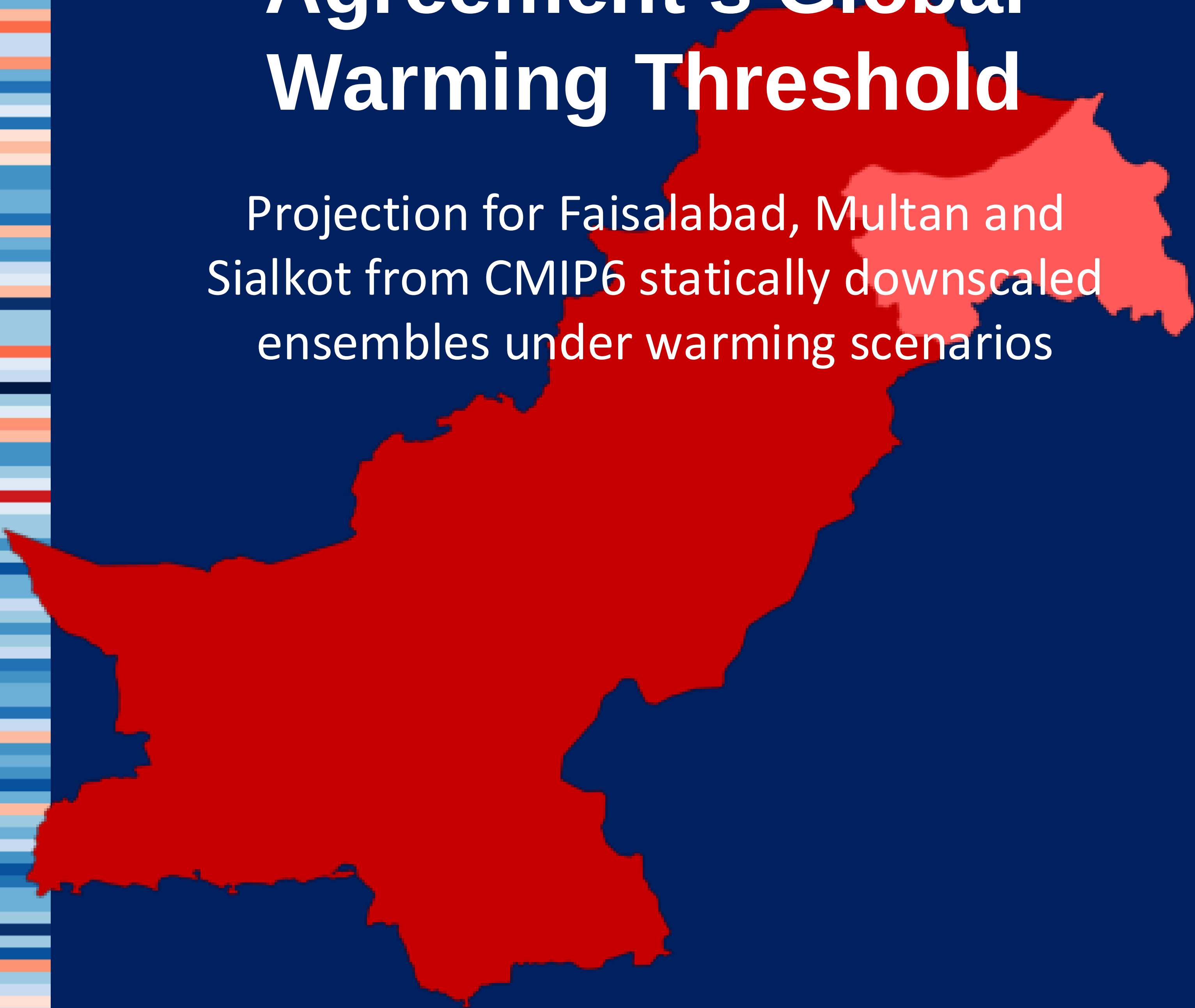
Climate Change in Punjab: Crossing the Paris Agreement's Global Warming Threshold

Projection for Faisalabad, Multan and Sialkot from CMIP6 statically downscaled ensembles under warming scenarios



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Executive Summary

This technical assessment delivers a meticulous, multimodal evaluation of future climate for Faisalabad, Sialkot, and Multan, leveraging statistically downscaled CMIP6 ensembles (16 models) under SSP245 (moderate mitigation) and SSP585 (high-emission) scenarios. Employing advanced bias-correction and spatial disaggregation techniques, the study generates city specific climate projections across three temporal horizons: near term (2015–2040), mid future (2041–2070), and far future (2071–2100). These empirically grounded insights equip policymakers to pre-emptively address region-specific vulnerabilities and institutionalize evidence-based climate adaptation frameworks in Punjab.

In **Faisalabad**, downscaled CMIP6 ensemble projections for the period 2015–2040 reveal consistent thermohydrological shifts. Specifically, projected maximum temperatures increase by 2.6 °C under SSP245 and 2.8 °C, repectively, under SSP585, while minimum temperatures rise by1.9 °C and 2.3 °C, Concurrently, precipitation regime shifts, demonstrating a 19% deficit under SSP245 (2015-2040) followed by an additional 5% reduction under SSP585.

In **Multan**, a differential thermal amplification is observed with SSP245 yielding 1.4°C maximum temperature and 0.6°C minimum temperature increase, while SSP585 exacerbates warming to 1.6°C (T. max) and 1.0°C (T. min). Hydrological projections reveal significant precipitation enhancement, manifesting the region exhibits pronounced pluvial tendencies, with SSP245 generating 17.3% precipitation surplus and SSP585 producing extreme rainfall (45.9% increase) by the 2040 horizon.

In **Sialkot** the CMIP6 ensemble projections reveal scenario divergent thermal responses: such as invariant maximum temperature rise observed 1.0°C under both SSP245 and SSP585 contrasted against differential minimum temperature 0.9°C & 3.0°C respectively Hydrologically, the region exhibits anti-phased precipitation behavior SSP245 produces an 11.8% deficit while SSP585 triggers initial pluvial conditions (10.2% increase) followed by heightened interannual variability.

By the end of the century, temperature anomalies are anticipated to reach up to 6.8°C in Faisalabad, 5.6°C in Multan, and 4.8°C in Sialkot under SSP585, substantially amplifying the frequency and duration of extreme heat events. These thermal extremes will exacerbate urban heat island effects, intensify energy demand, compromise public health, and threaten agricultural productivity. The analysis reveals an unequivocal escalation in both maximum and minimum temperatures across all study regions (Faisalabad, Multan, Sialkot), with projected warming intensifying under high-emission scenario (SSP585 Overall, Multan is projected to become the wettest, Faisalabad shows dramatic long-term increases, and Sialkot exhibits the most unpredictable rainfall shifts, particularly under high emission scenarios.

These findings underscore the imperative for robust adaptation and mitigation frameworks tailored to the specific climate vulnerabilities of each urban center. Priority interventions must integrate heat resilient urban design (cool pavements, green roofs), hydrodynamic flood control systems, climate adapted crop varieties, and heat-health early warning systems to address projected thermal and hydrological extremes. Furthermore, aggressive greenhouse gas mitigation measures remain essential to constrain long-term climate risks and avoid irreversible damage to critical ecosystems and socioeconomic systems across Punjab.

CHAPTER 1

Future Extremes: Temperature and Precipitation Projections for three cities of Punjab

Setting the Stage

In the twenty-first century, climate change has emerged as a significant global challenge, owing to its profound environmental and socioeconomic impacts. During the recent decades, the human activities such as burning fossil fuels, industrial emissions, land-use changes, and population growth have significantly increased greenhouse gas concentrations in the atmosphere, resulting in more frequent and severe extreme weather events. At the same time, forests are being cut down for expanding cities and industries, reducing our planet's ability to absorb CO_2 and driving up its levels even further.

In the last three decades, fossil fuel combustion has been responsible for nearly 90% of all human-caused CO_2 emissions[1.] This has driven a global temperature rise of about 1°C above pre-industrial levels, with an average increase of 0.15°C per decade during the latter half of the 20th century[2.] These changes are altering local climate patterns and intensifying extreme hydrological events, including droughts3. Climate extremes have grown more intense, frequent, and prolonged in recent decades. While these events affect regions worldwide, some areas are particularly vulnerable due to their geographic and climatic conditions. Over the past few decades, the duration and severity of extreme weather events have increased a trend expected to get more worse due to rising anthropogenic influences. Regions with diverse terrain, such as semi-arid and arid zones are more vulnerable to climatic risks.[4.]

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[1] Climate Change 2021: The Physical Science Basis. Working Group I Contribution to the IPCC Sixth Assessment Report

2 Bekele, D., Alamirew, T., Kebede, A., Zeleke, G., & M. Melesse, A. (2019). Modeling climate change impact on the Hydrology of Keleta watershed in the Awash River basin, Ethiopia. Environmental Modeling & Assessment, 24, 95-107.

[3] Thomas, T., Goyal, S., Goyal, V. C., & Kale, R. V. (2018). Water availability under changing climate scenario in Ur River basin. In Climate Change Impacts: Select Proceedings of ICWEES-2016 (pp. 213-229). Springer Singapore

4Intergovernmental Panel on Climate Change (IPCC), 2013. Climate change 2013: the physical science basis. In: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

As pr IPCC 6th Assessment report, heatwaves, heavy rainfalls, droughts, and other extreme weather events grow more severe with each incremental 0.5°C rise in global temperatures[5].

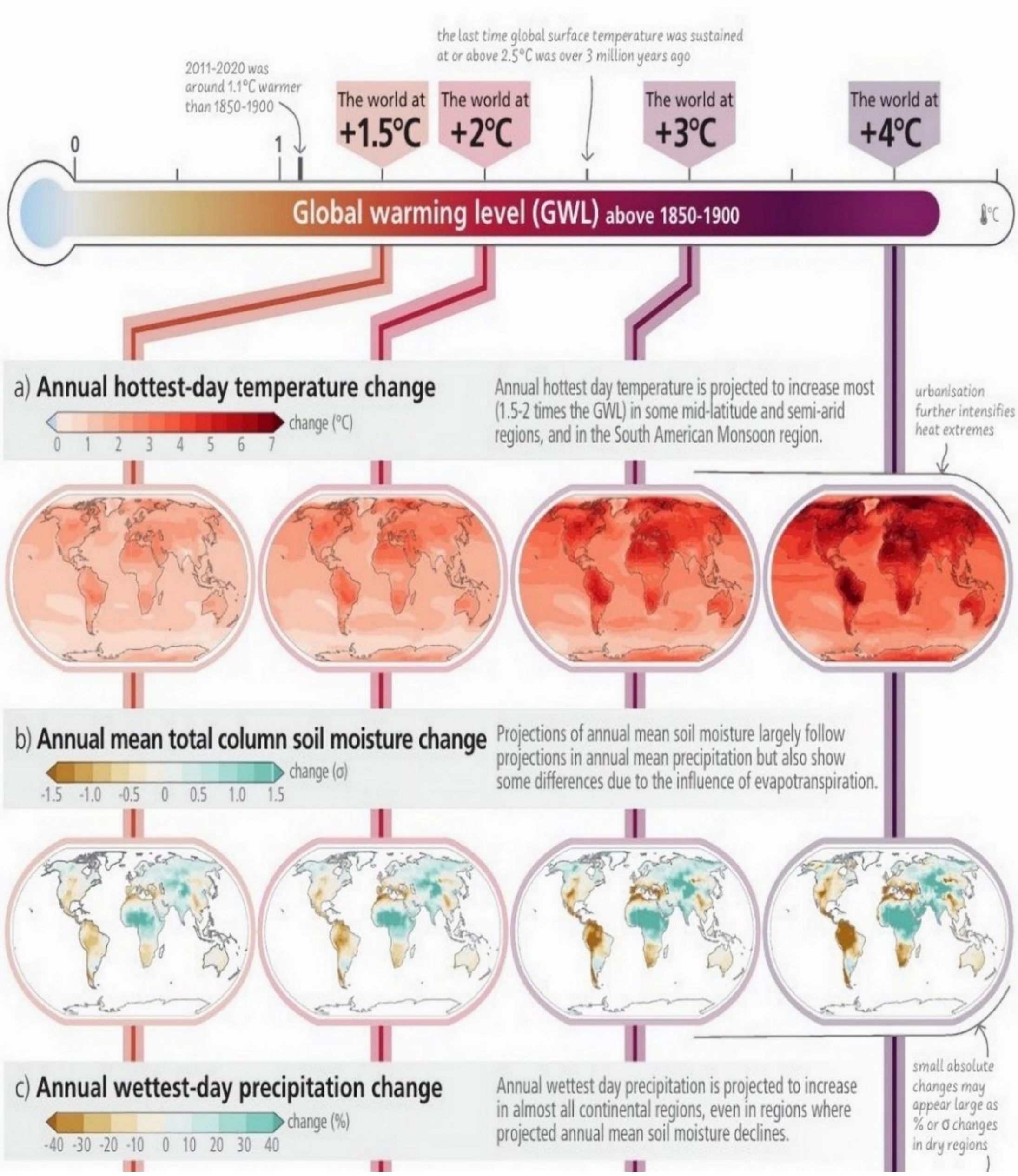

Figure 1: Projected changes of annual maximum daily temperature, annual mean total column soil moisture CMIP and annual maximum daily precipitation at global warming levels of 1.5°C, 2°C, 3°C, and 4°C relative to 1850-1900 (IPCC 6th Assessment Report

[5] IPCC, 2022: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844

In 2024, Asia recorded either its warmest or second-warmest year in observed history, marked by intense and persistent heatwaves across the region[6]. Oceanographic conditions exacerbated climatic extremes, with record-high sea surface temperatures (SSTs) and extensive marine heatwaves impacting marine ecosystems and coastal communities. Notably, sea level rise in the Pacific and Indian Ocean basins surpassed the global mean, amplifying inundation and erosion risks for vulnerable low-lying regions[7] .

Extreme climate events are more likely to occur in places with varied terrain, such as semi-arid and dry regions. Pakistan, has semi-arid to desert climate, is currently experiencing an increasing change in climatic extreme events like heatwaves, intense floods and droughts[8,9].

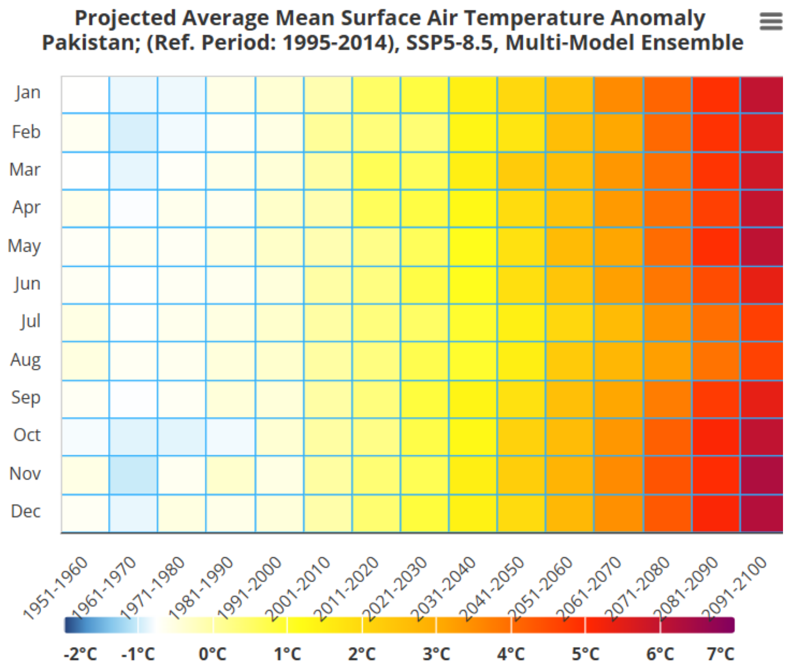

Figure 2: Projected Change in Annual Mean Surface Air Temperature from Multimodal Ensemble [10]

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6 https://wmo.int/publication-series/state-of-climate-asia-2024.
7 https://wmo.int/publication-series/state-of-climate-asia.
8Muhammad, H.U.R., Ashfaq, A., Aftab, W., Manzoor, H., Fahd, R., Wajid, I., Md, A.I.F., Vakhtang, S., Muhammad, A., Asmat, U., Abdul, W., Syed, R.S., Shah, S., Shahbaz, K., Fahad, S., Manzoor, H., Saddam, H., Wajid, N., 2017. Application of CSM-CROPGRO Cotton model. for cultivars and optimum planting dates: evaluation in changing semi arid climate. Field Crop Res. https://doi.org/10.1016/j.fcr.2017.07.007.

9 Muhammad, T., Shakeel, A., Fahad, S., Ghulam, A., Sajjad, H., Zartash, F., Wajid, F., Muhammad,M., Muhammad,H.U.R., Muhammad, A.K., Muhammad, A., Carol, J.W., Gerrit, H., 2018. The impact of climate warming and crop management on phenology of sunflower-based cropping systems in Punjab. Pak. Agric. For. Meteorol. 256–257, 270–282. Nasim, W., Amin, A., et al., 2018. Future risk assessment by estimating historical heat wave trends with projected heat accumulation using SimCLIM climate model in Pakistan. Atmos. Res. 205, 118–133.
[10] https://climateknowledgeportal.worldbank.org/country/pakistan/climate-data-projections

Pakistan has consistently ranked among the top ten most climate-vulnerable countries in the *German Watch Climate Risk Index 2022*, underscoring the urgency for localized, evidence-driven climate governance.

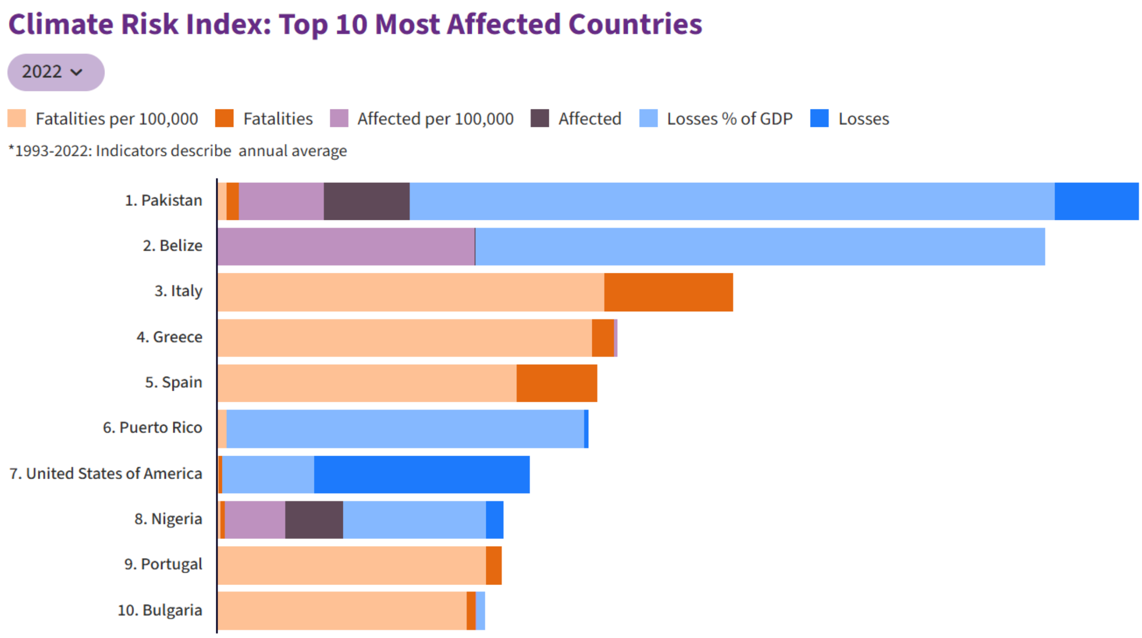

Figure 3: Climate Risk Index 0 Top 10 most affected countries showing Pakistan at top

Punjab, Pakistan's most populous and economically significant province, stands at the frontline of the country's climate crisis.

As Pakistan's agricultural and economic powerhouse, Punjab is increasingly exposed to the intensifying impacts of climate change. The province is already experiencing extreme and unpredictable weather patterns—prolonged droughts, off-season rainfall, and recurring heatwaves that are undermining agricultural productivity, depleting water resources, and threatening public health.

According to the *Climate Resilient Punjab Vision and Action Plan 2024*, the province contributes over 54% to the national GDP, yet remains highly vulnerable to climate extremes including floods, droughts, and heatwaves[11]. Recent years have seen increasing temperature anomalies, erratic precipitation, and catastrophic smog levels that have repeatedly placed Punjab's cities among the world's most polluted.

[11] Climate Change Book (3)_compressed.pdf

Thus, data on Pakistan's projected catastrophic climate changes is urgently needed, in order to develop the efficient adaptation of policies and strategies.

GCMs (Global circulation models) which are primary tool, used to simulate the historical, current and future climate forecasts, the climate impacts and GCMs are considered as most reliable numerical models, formulated on fluid dynamics, physics and various other fundamental rules. GCMs can be selected on their ability to simulate the temperatures and precipitation. These GCMs simulations were released in different phases under the umbrella of CMIP (Coupled Model Intercomparison Project)[12] .

Projections of climate change throughout the twenty-first century have been analysed using global climate models (GCMs) from the sixth phases of the Coupled Model Intercomparison Project (CMIP6), coordinated by the World Climate Research Programme (WCRP). These simulations incorporate a consistent set of historical radiative forcings spanning the period from 1850 to 2014. For future climate scenarios (2015–2100), emission trajectories are derived from standardized frameworks, including Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSPs), which serve as input for modelling potential climatic outcomes. These factors encompass a wide array of potential outcomes that may influence future susceptibility and exposure to climate change. Climate-related risks and impacts are commonly evaluated across three key time horizons: near-future (2021–2040), mid future (2041–2060), and far future (2081–2100). Shared Socioeconomic Pathways (SSPs) provide policymakers with a robust framework to assess a wide range of future scenarios, enabling the development of targeted strategies for climate change mitigation and adaptation.

Statistical downscaling involves establishing robust statistical relationships between large-scale meteorological variables typically sourced from Global Climate Models (GCMs) and localized, in-situ observations. These relationships are most often derived using one of two methods: the Perfect Prognosis (PP) approach, which relies on historical observations, and the Model Output Statistics (MOS) approach, which adjusts GCM outputs using observed data. Once calibrated, these relationships are applied to project future climate scenarios. Compared to dynamic downscaling methods, statistical downscaling is significantly less computationally intensive. Numerous studies have successfully employed both statistical downscaling and

12 Maraun, D.; Widmann, M. Statistical Downscaling and Bias Correction for Climate Research; Cambridge University Press: Cambridge, UK, 2018

CORDEX dynamic downscaling, particularly using regression-based models to simulate climate projections under Shared Socioeconomic Pathway scenarios SSP245 and SSP585.

1.1 Experimental Design and Data

1.1.1 Study Areas

This study evaluates Punjab's climate projections of temperature and precipitation over three selected urban centers i.e. Faisalabad, Sialkot, and Multan based upon distinct **Koppen-Geiger climate classification.**

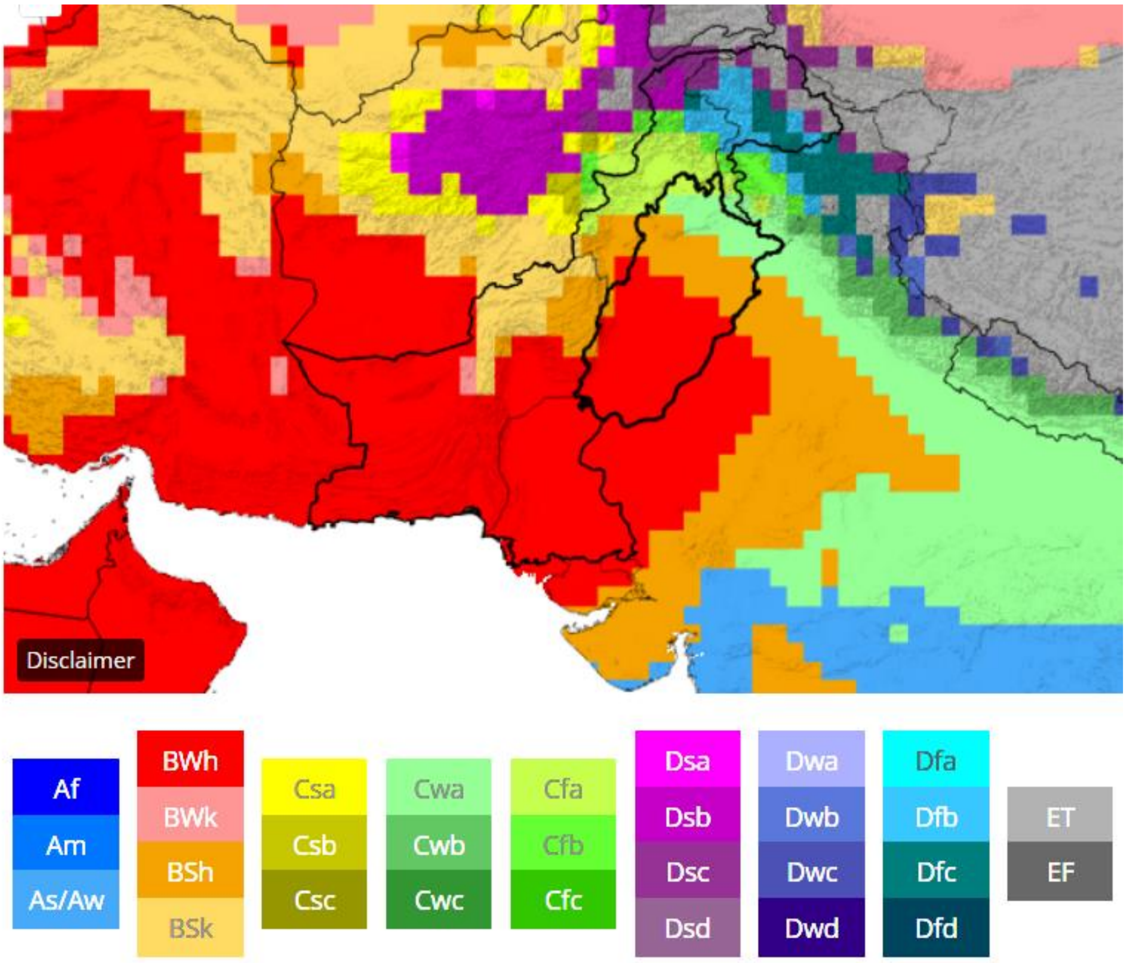

Figure 4: Pakistan's climate under the Köppen-Geiger system (1991–2020): showing Hot , arid (BWh) and temperate (Cwa) regions[13] .

- **Faisalabad - BSh** climate (Hot Semi-Arid)
- **Sialkot - Cwa** (Humid subtropical dry winter climate)

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[13] https://climateknowledgeportal.worldbank.org/country/pakistan

- **Multan** – **BWh** (Hot Desert Climate)

The above-mentioned cities encounter multiple climate stressors i.e. increase of urban heat resulting from intensified built environments, continuous change in the land use patterns, and increased sensitivity to climate extreme events like heat waves, unstable precipitation patterns, droughts and urban flooding. The purpose of this research is to analyse the climatic responses in Punjab, generating reliable specific zone-specific information about the meteorological parameter's projections with continuous climate change.

1.1.2 Climate Data Sets

I. Observed Climatology Data 1908-2014 (Required for the validation and evaluation)

- Maximum temperature
- Minimum temperature
- Rainfall
- Climate Normal (**Climate Normal** represent averages of climatological variables, such as temperature and precipitation, calculated over a span of three decades, serve as a reference point for assessing current climate conditions).

CMIP6 Historical Data (for validation and evaluation against observed)

- Historical Maximum Temperature (1980-2014)
- Historical Minimum Temperature (1980-2014)
- Historical Precipitation (1980-2014)

II. CMIP6 Future Projection Data (for future projection of temperature and precipitation)

- Temperature and Precipitation Data under Scenario SSP245 (2015-2100) -
- Temperature and Precipitation Data under Scenario SSP585 (2015-2100)

CMIP6 models data

The following 16 GCMs multimodal are used to generate the projections under climate scenarios (SSP245 AND SSP585) are listed in Table 1. Ensemble of these models is used to predict temperature and precipitation using CMhyd model.

Table 1: GCMs employed in this study[14]

WCRP World Climate Research Programme CMIP6

Sr. No	Model	Institute	Nominal Resolution (km)
1.	BCC-CSM2-MR	Beijing Climate Centre - China	100
2.	INM-CM-4-8	Institute of Numerical Modeling, Russian Academy of Science, Russia	100
3.	MIROC6	Japan Agency of Marine-Earth Science and Technology, Japan	250
4.	MPI-ESM1-2-LR	Max Planck Institute for Meteorology, Germany	250
5.	GFDL-CM4	NOAA Geophysical Fluid Laboratory, USA	100
6.	ACCESS-ESM1-5	Commonwealth Scientific and Industrial Research Organisation - Australia	250
7.	CanESM5	Canadian Centre for Climate Modeling and Analysis, Canada	500
8.	EC-Earth3	European Consortium of national meteorological services and research institutes	100

[14] ESGF Data Node DKRZ: https://esgf-metagrid.cloud.dkrz.de/

9	EC-Earth3-Veg	European consortium of national meteorological services and research institutes	100
10	NESM3	Nanjing University of Information Science and Technology, China	250
11.	MRI-ESM2-0	Meteorological Research Institute, Japan	100
12.	FGOALS-g3	Chinese Academy of Sciences, China	250
13.	GFDL-ESM4	NOAA Geophysical Fluid Laboratory, USA	100
14.	NorESM2-LM	NorESM Climate modeling Consortium, Norway	250
15.	NorESM2-MM	NorESM Climate modeling Consortium, Norway	100
16.	INM-CM5-0	Institute of Numerical Modeling, Russian Academy of Science, Russia	100

The notation **r1i1p1f1** ("r" is realization, "i" initialization, "p" physics version, and "f" forcing version), a standard variant of CMIP6 model is used. The bilinear interpolation technique is applied to interpolate the model's data at 0.5°resolution to avoid the disparities between the model simulations [15].Climate models frequently exhibit systematic deviations from observed time series, making bias correction indispensable. Bias correction techniques are applied to transform the GCMs output through multiplicative scaling or additive adjustments for the alignment of statistical simulations against observational data during a defined reference period.

[15] Zhang, Y., Hao, Z., & Zhang, Y. (2023). Agricultural risk assessment of compound dry and hot events in China. *Agricultural Water Management*, *277*, 108128.

1.1.3 CMhyd Tool

The **CMhyd** model is used to downscale and apply bias correction to General Circulation Model (GCM) outputs, refining them to finer temporal and spatial scales for better representation at specific locations. Thus, GCM data must undergo downscaling and bias correction to enhance regional climate assessments at gauge locations. CMhyd offers various techniques for downscaling and bias-correcting temperature and precipitation data for specific areas. To better understand future climate conditions, temperature and precipitation projections from **16 GCMs** under different Shared Socioeconomic Pathways (SSPs) were statistically downscaled for three cities across three future periods:

- Near future (2015–2040)
- Mid future (2041–2070)
- Far future (2071–2099)

This study focuses on two SSP scenarios: SSP245 and SSP585

1.1.4 Bias Correction

Bias correction is a common practice in climate impact modeling to improve the reliability of climate change projections. As a crucial first step in impact studies, Global Climate Model (GCM) outputs undergo preprocessing, including bias correction, to minimize uncertainties. This ensures more accurate future climate projections and supports the development of effective adaptation strategies for the global community. Following bias correction methods are applied during the processing of GCMs data.

Precipitation bias correction

- Linear Scaling (LS) Multiplicative
- Delta Change Correction (DC) Multiplicative
- Precipitation Local Intensity Scaling
- Power Transformation (PT) of precipitation
- Distribution mapping of Precipitations

Temperature bias correction

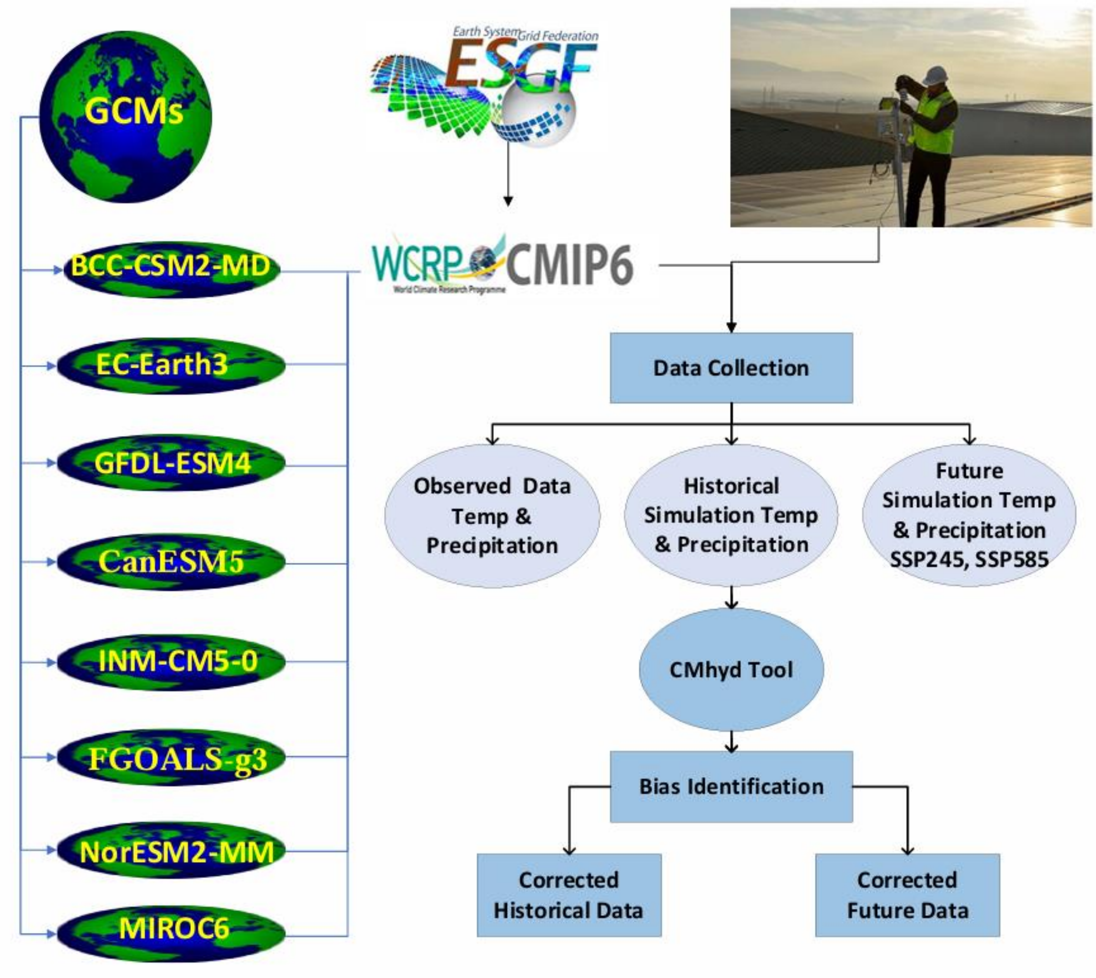


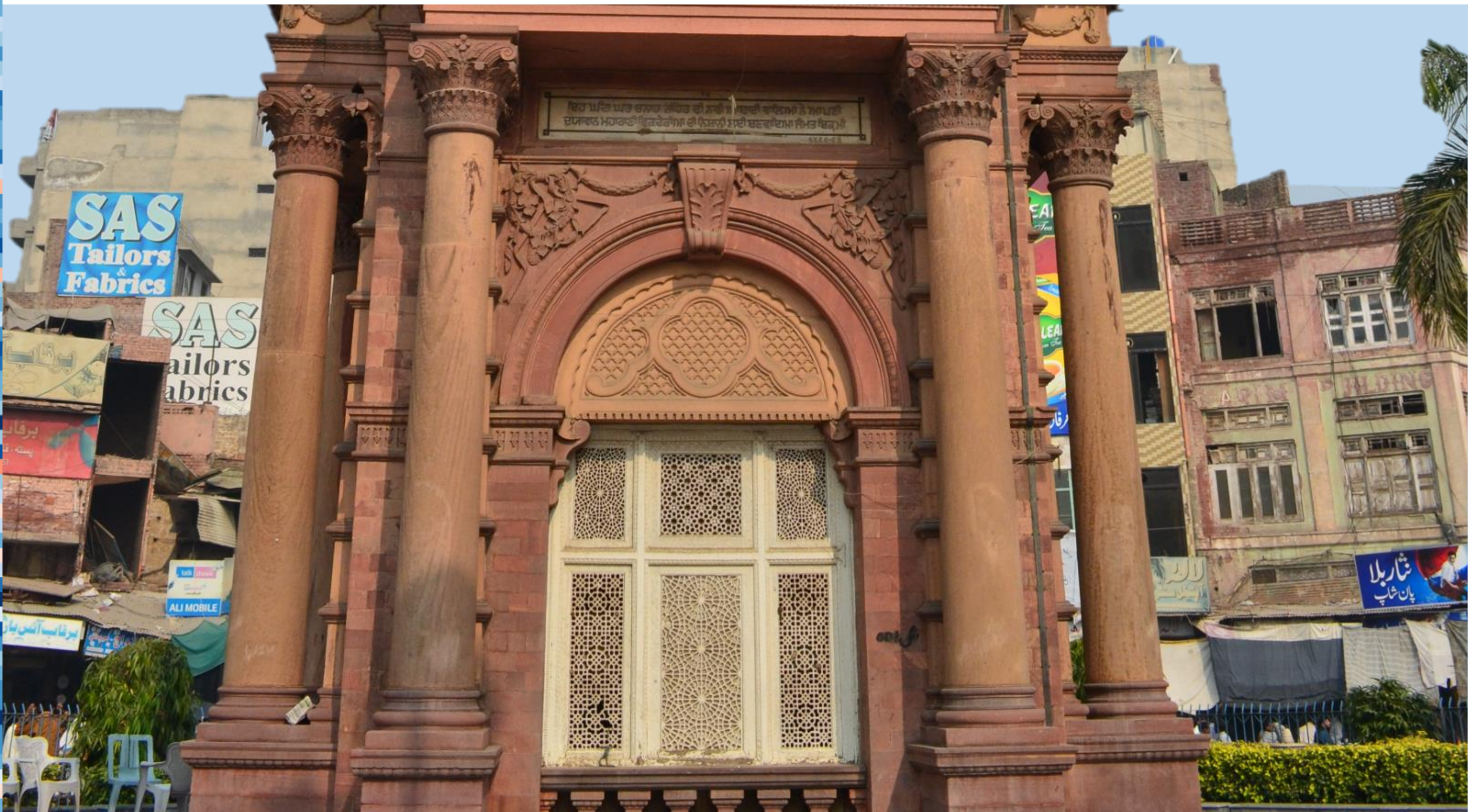
Figure 5: Framework for Correcting Biases in Downscaled Climate Data Derived from GCM

- Linear Scaling (LS) Additive
- Delta Change Correction (DC) Additive
- Variance Scaling of Temperature
- Distribution Mapping of temperature

This method is in line with the IPCC's recommendations, which emphasize that using statistical downscaling and bias adjustment techniques can greatly improve the regional relevance and accuracy of climate model results, making them essential for guiding policy and assessing impacts.

FAISALABAD

Future Temperature & Precipitation Outlook



CHAPETER 2

2. FAISALABAD – Future Temperature and Precipitation Outlook Under Warming Scenarios

Given its predominance in agriculture and extreme climate vulnerability, Faisalabad is an crucial area for climate projections. As the "Manchester" of Pakistan and a significant cotton-wheat belt it is facing erratic monsoon rains. escalating temperatures, and extended droughts that threaten crop yields and water security. It is extremely vulnerable to changing precipitation patterns because of its level terrain and reliance on canal irrigation. The rapid urbanization and industrial activities further increase heat stress and air pollution. Positioned in Punjab's arid-semiarid transition zone, Faisalabad serves as a crucial case study for modeling the impacts of climate change on food production, water resources, and urban resilience.

2.1 Thirty years modelled maximum and minimum temperature projections

The maximum temperature projections for Faisalabad under climate scenarios SSP 245 and SSP 585 show substantial increase across three periods: Near future (2015–2040) Mid future (2041–2070), and far future (2071–2100) as depicted in Figure 6 and Table 2. Under SSP245, a temperature increases of 2.6°C is observed, while SSP585 results in a rise of 2.8°C The upward trend intensifies during the mid-century period (2041–2070) where values reach 3. 6°C (SSP 245) and 4. 1°C (SSP 585), representing the strong early warning of heat stress. Ensembles modelled forecasts for the period 2071–2100 represents maximum temperature increase of 6. 0°C under SSP 585 and 4. 3°C under SSP245.

Table 2: Variation in thirty years maximum temperature under SSP 245 SSP 585 Scenario

Sr. No.	Years	Variation in maximum temperature under SSP 245	Variation in maximum temperature under SSP 585
1.	2015-2040	2.6°C	2.8°C
2.	2041-2070	3.6°C	4.1°C
3.	2071-2100	4.3°C	6°C

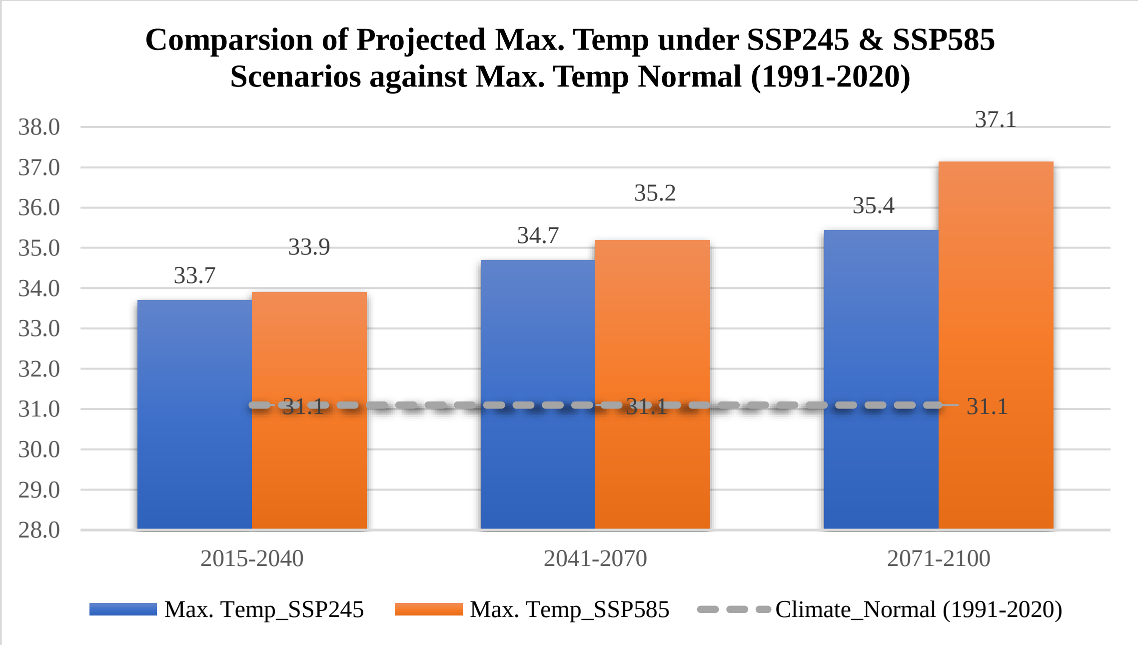


Figure 6: Comparison of thirty years Projected Maximum Temperature against climate Normal

Thirty years modelled minimum temperature Projections

Table 3: Variation in 30 years minimum temperature under SSP245 and SSP 585 Scenario

Sr. no	Years	Variation in 30 years minimum temperature under SSP 245	Variation in 30 years minimum temperature under SSP 585
1.	2015-2040	1.9°C	2.3°C
2.	2041-2070	3.0°C	3.9°C
3.	2071-2100	3.7°C	5.9°C

The (Table 3) details the anticipated increases in minimum temperatures under SSP 245 and SSP585 across three future time frames. The temperatures are projected to rise by 1.9°C by 2040, 3.0°C by 2070, and 3.7°C by 2100 under SSP 245 scenario. Conversely, SSP 585 predicts more severe warming, with increases of 2.3°C by 2040, 3.9°C by 2070, and a drastic 5.9°C by 2100.

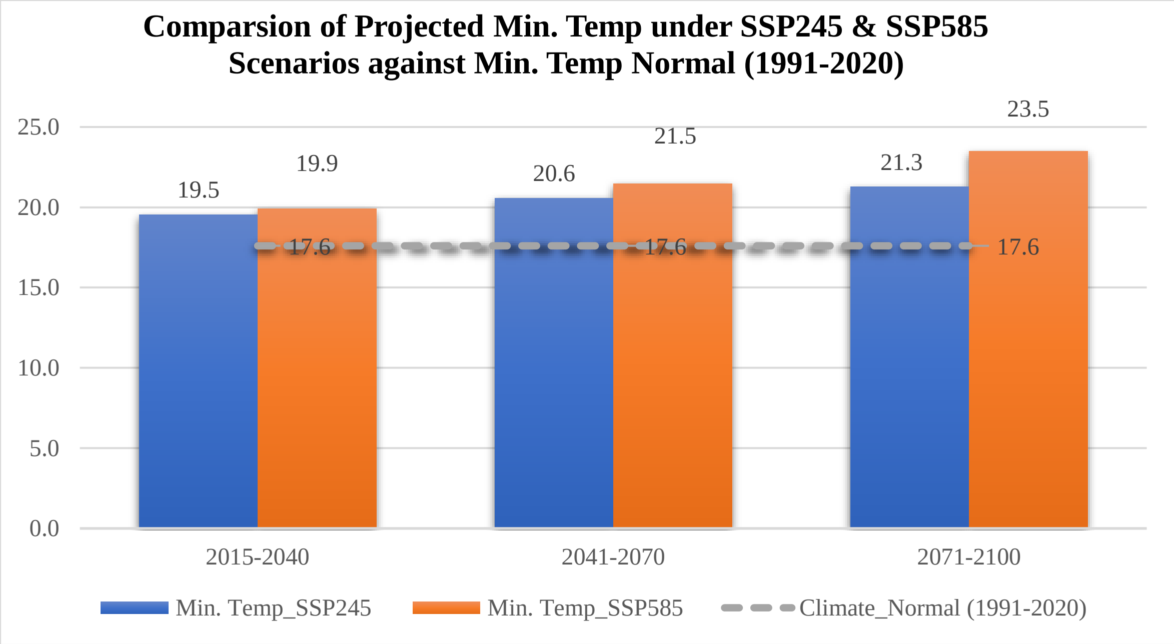


Figure 7: Comparison of thirty years Projected minimum Temperature against climate Normal

2.2 Decadal modelled maximum and minimum temperature Projections

Under the SSP245 scenario, decadal trends indicate an average temperature increase ranging from 2.4 °C to 4.6 °C. Under SSP585, projected increases lie between 2.6 °C and 6.8 ° (Figure 8) and (Table 4).

Table 4: Projected Decadal Maximum Temperature increase under SSP245 and SSP 585

Sr. No	Years	Variation in decadal minimum temperature change under SSP 245	Variation in decadal minimum temperature change under SSP 585
1.	2015-2030	2.4°C	2.6°C
2.	2031-2040	2.8°C	2.9°C
3.	2041-2050	3.2°C	3.4°C
4.	2051-2060	3.7°C	4.0°C
5.	2061-2070	4.0°C	4.8°C
6.	2071-2080	4.1°C	5.4°C
7.	2081-2090	4.3°C	6°C
8.	2091-2100	4.6°C	6.8°C

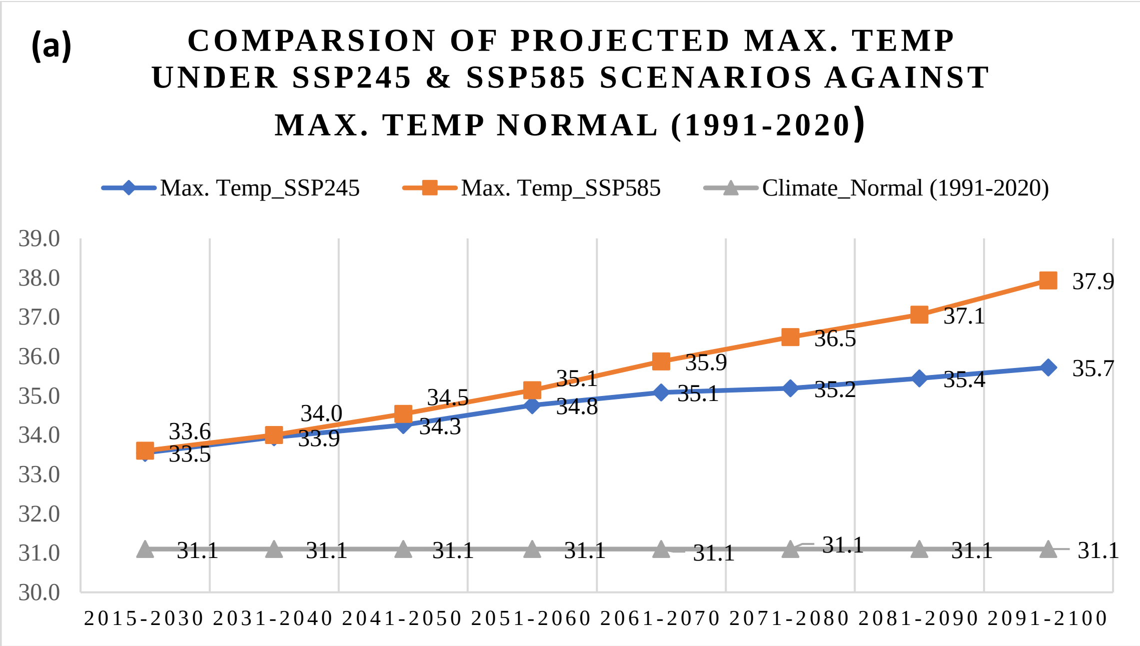


Figure 8: Comparison of decadal Projected Maximum Temperature against climate Normal

Table 5: Projected Decadal Minimum Temperature increase under SSP245 and SSP585 Scenario.

Sr. No	Years	Projected Minimum temperature increases under SSP245	Projected Minimum temperature increase under SSP585
1.	2015-2030	1.8°C	2.4°C
2.	2031-2040	2.2°C	2.7°C
3.	2041-2050	2.5°C	3.2°C
4.	2051-2060	3.1°C	3.8°C
5.	2061-2070	3.5°C	4.6°C
6.	2071-2080	3.5°C	5.2°C
7.	2081-2090	3.7°C	5.8°C
8.	2091-2100	3.9°C	6.6°C

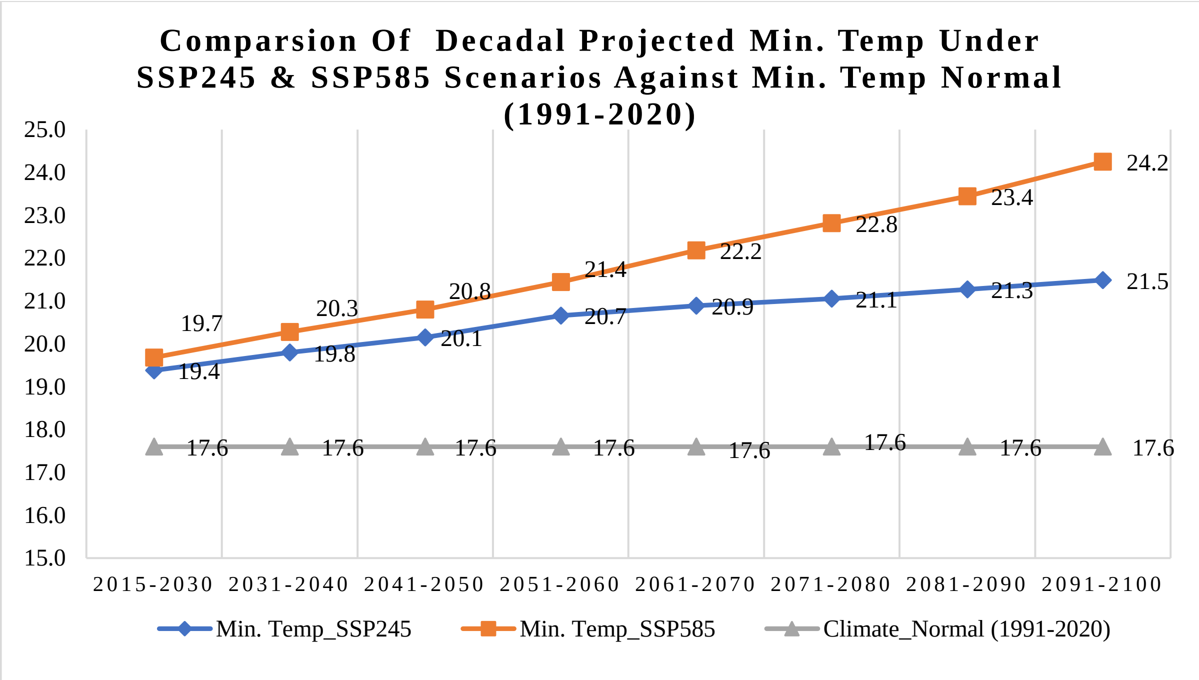


Figure 9: Comparison of Decadal Projected Minimum Temperature Against Minimum Temperature Climate Normal.

It is noted that by the end of century in far future, the warming is projected to be more than double that of the minimum temperature. This data underscores GHG emissions result in significantly higher temperature increase, particularly in the latter part of the century. Even with moderate mitigation efforts, warming exceeds critical thresholds, highlighting the urgent need for climate action to limit severe impacts on ecosystems, agriculture, and human health.

2.3 Projected Increase in Extreme Hot Days frequency during the 21st Century under SSP245 and SSP585 Scenarios in Faisalabad

Hot days are defined as days when local maximum temperature of a region reaches certain threshold (climate normal). [16,17]

The analysed data indicates a consistent increase of number of hot days in April, May, and June under the SSP 245 scenario in (Figure 10, 11 & 12). The precipitous increase of hot days has been observed in April. Hot days are increasing gradually between 2015 and 2040, followed by double in the middle of the century and at the end of century they are gradually decreasing.

[16] PMD (2022). *Climate of Pakistan* & annual reports
[17] https://www.ncei.noaa.gov/products/land-based-station/us-climate-normals

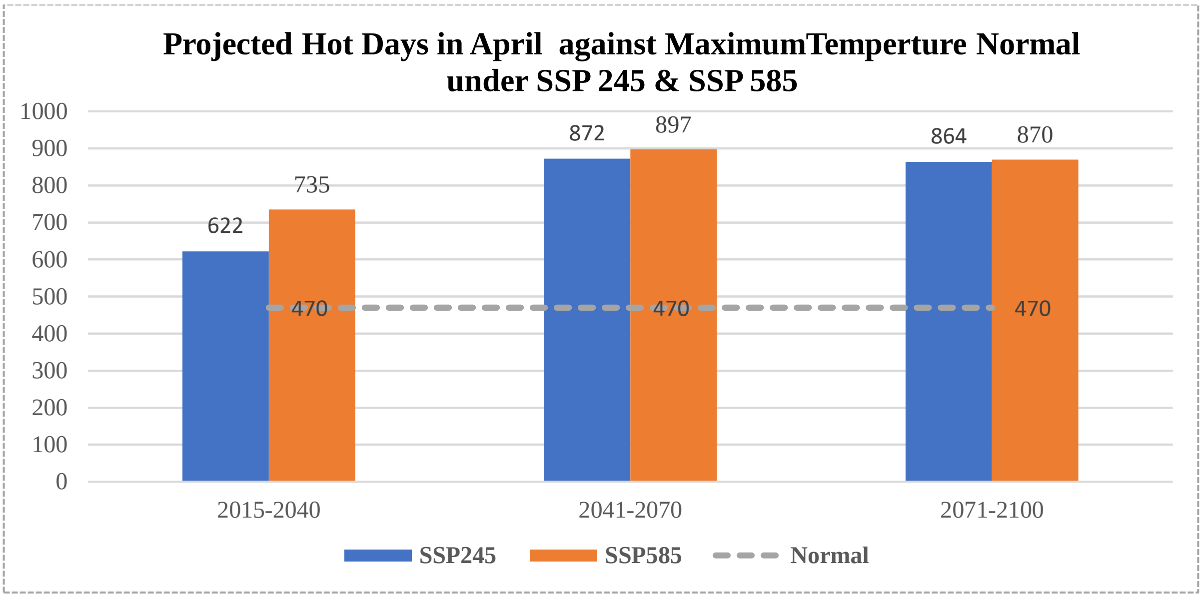


Figure 10: Projected Hot Days in April against Temperature Normal

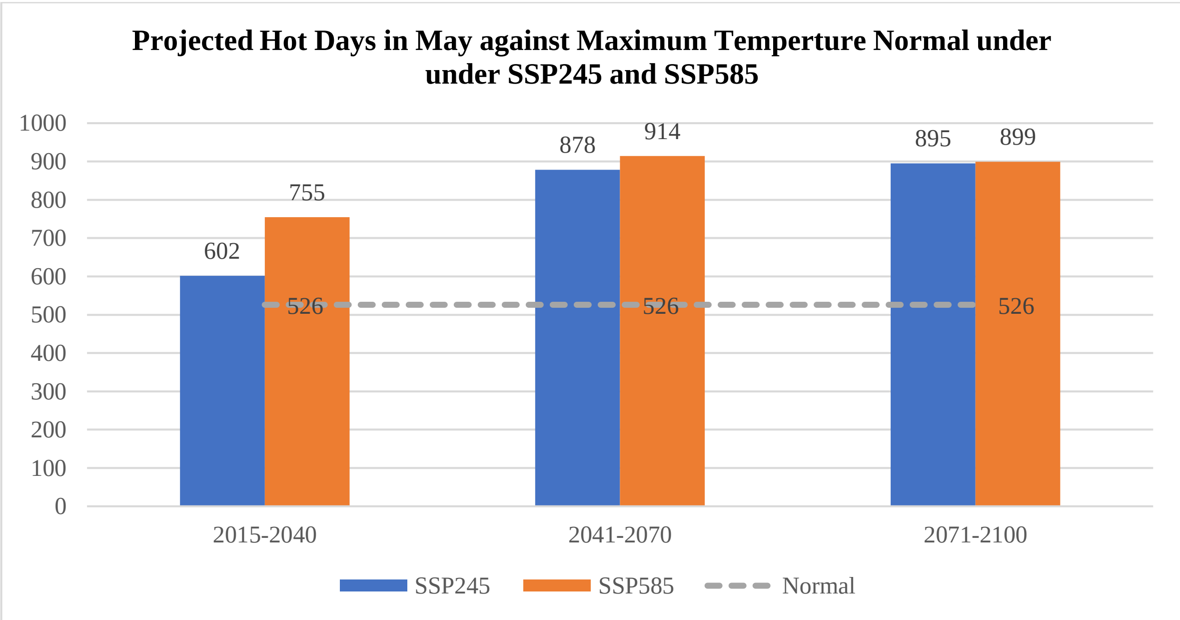


Figure 11: Projected Hot Days in May against Temperature Normal

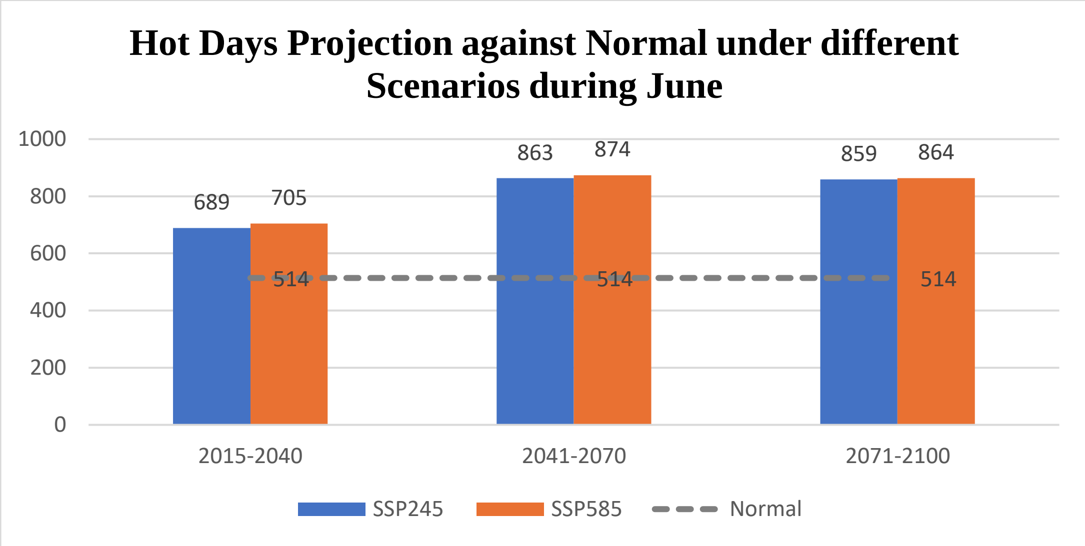


Figure 12: Projected Hot Days in June against Temperature Normal

2.4 Ensembled 30 Years Precipitation Projections under SSP245 and SSP585 Scenario

Faisalabad, a major agricultural and industrial hub of Pakistan, is experiencing shifts in precipitation patterns owing to climate change. This research analyses projected rainfall trends under two climate scenarios (SSP245 and SSP585) compared to the 30-year precipitation climate normal (1991-2020).

The thirty years average modelled precipitation is presented in the (Table 6) and (Figure 13). Under the SSP245 scenario, the projected 30-year average precipitation shows a slight decline to approximately 323 mm about 19% below the normal precipitation levels during the near-term period (2015–2040). The rainfall is only 5% (380mm) less than on average under the SSP585.

Table 6: Projected 30 years average rainfall modelled projections under SSP245 and SSP 585 Scenarios in Faisalabad

Sr no.	Years	Projected 30 years average Precipitation (mm) under SSP 245 Scenario	Projected 30 years average Precipitation (mm) under SSP 585 Scenario	% Change in precipitation under SSP245 against climate normal (401mm)	% Change in precipitation under SSP585 against climate normal (401mm)
1.	2015-2040	323	380	↓ −19%	↓ −5%

2.	2041-2070	470	494	↑ +17%	↑ +23%
3.	2071-2100	850	944	↑ +112%	↑ +135%

Both scenarios are projected about 470 mm and 494 mm by the middle of the century (2041–2070), respectively. There is a shift observed towards more precipitation during the mid-century period (2041–2070), with SSP245 predicting a 17% increase and SSP585 a 23% increase. However, the hydrological cycle intensifies significantly in the late-century period (2071–2100), with precipitation increasing by 112 % under SSP245 and 135 % under SSP585, underscoring the escalation of extreme rainfall events under both emission scenarios. These patterns highlight the increasing risks to the climate, especially in the second half of the century, if greenhouse gas emissions are not controlled.

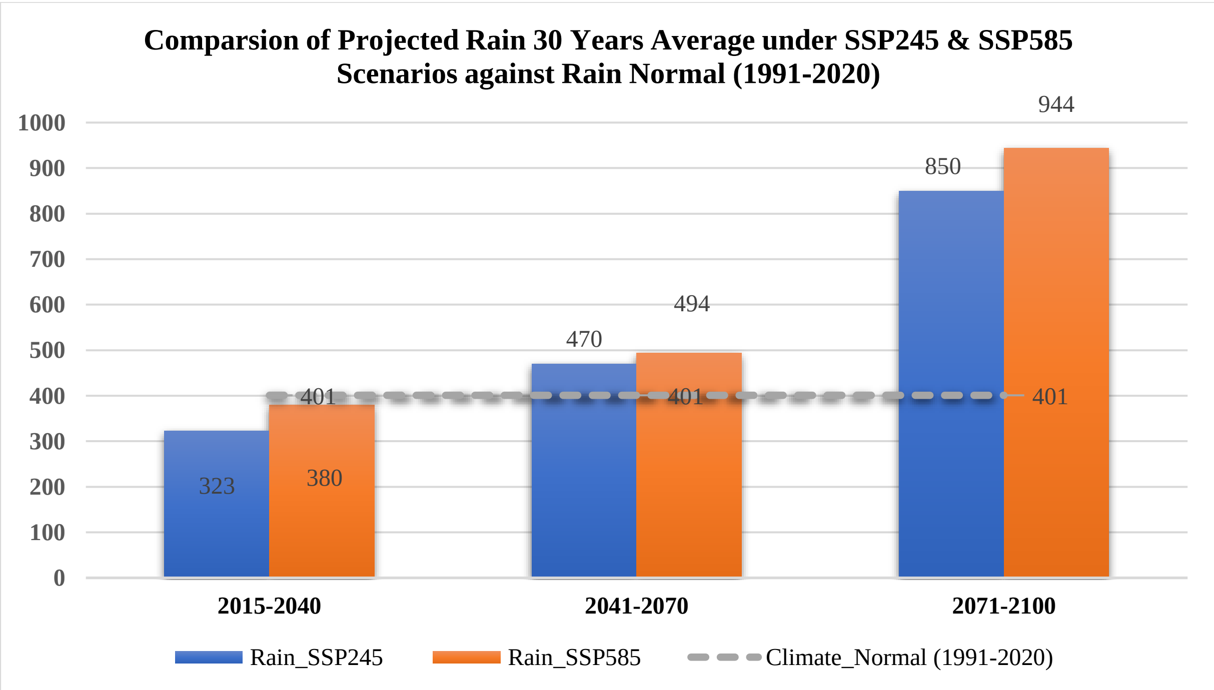


Figure 13: Comparison of decadal precipitation under SSP245 & SSP585 Scenarios against precipitation Normal in Faisalabad

2.5 Ensembled Decadal Precipitation Projections under SSP245 and SSP585 Scenario

Decadal comparisons of Faisalabad's expected rainfall under the SSP245 and SSP585 scenarios show substantial differences from the climate normal (1991–2020). Both scenarios point to rainfall levels in the early decades (2015–2030) that are either near or marginally below the precipitation normal, as we move towards mid-century decades (2041–2070), precipitation gradually increases, with SSP585 exhibiting a more noticeable upward trend than SSP245. This implies that increased greenhouse gas emissions may hasten the intensification of rainfall.

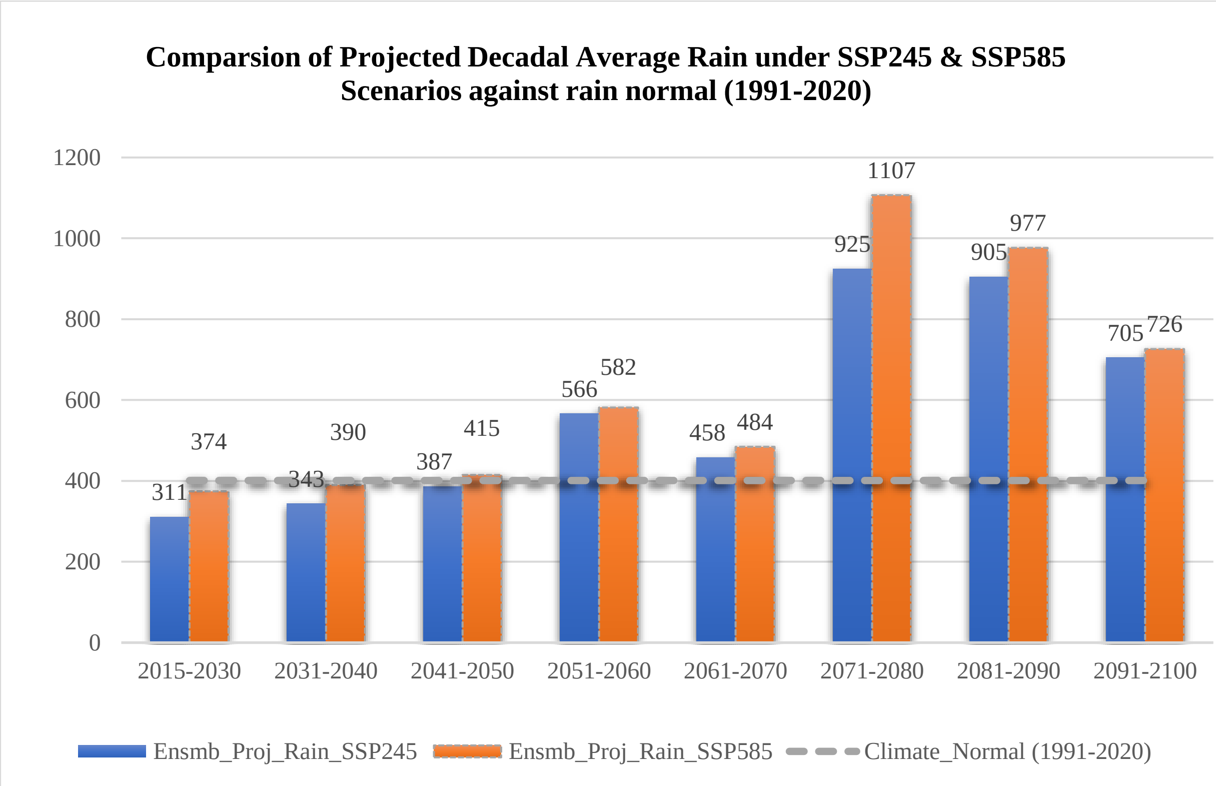
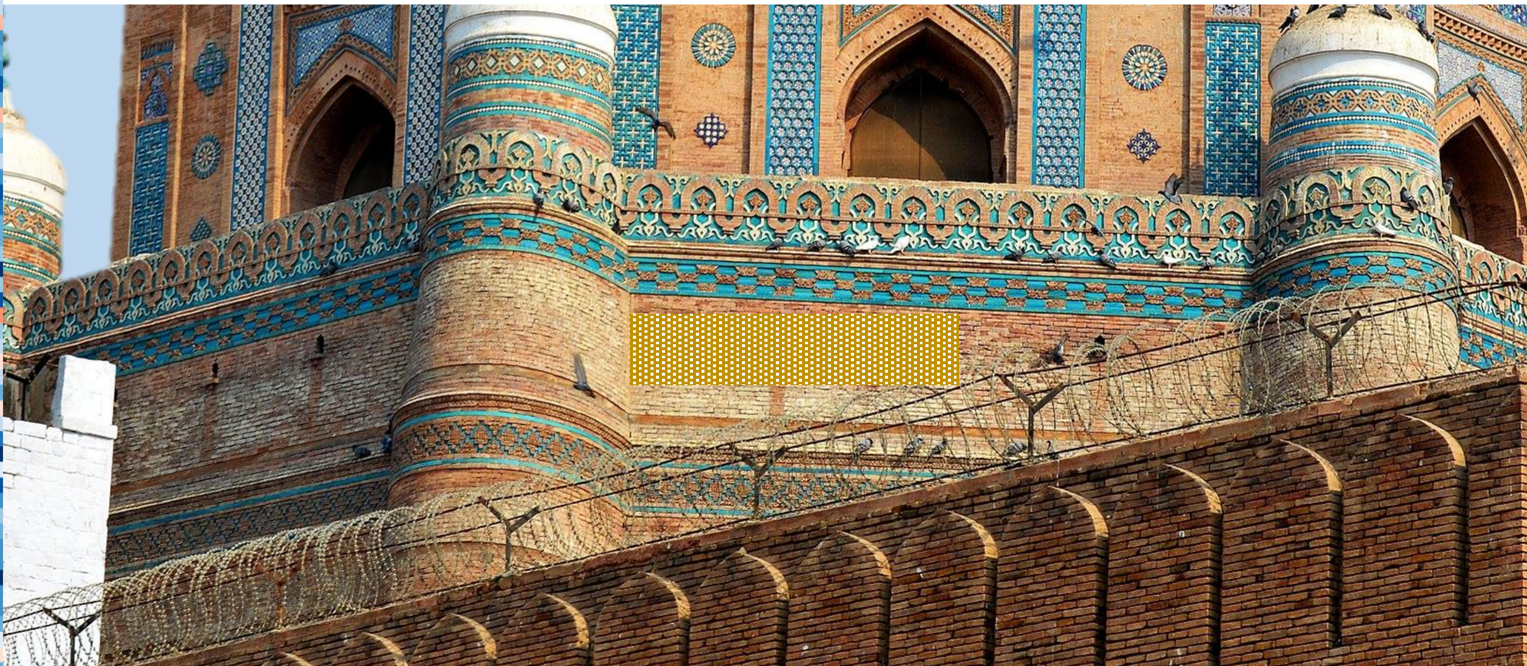


Figure 14: Comparison of decadal averaged precipitation under SSP245 & SSP585 Scenarios against precipitation normal in Faisalabad

The predictions considerably differ by the end of the twenty-first century (2071–2100). Even more extreme precipitation occurs under SSP585, surpassing the normal by 135 percent, while rainfall increases significantly under SSP245, possibly surpassing the baseline by over 100 percent. These patterns show that Faisalabad is increasingly vulnerable to periods of intense precipitation and potential flooding, especially when unmitigated high-emission pathways are in place. The study emphasizes the significance of climate adaptation plans since the SSP585 scenario could have more detrimental effects on Faisalabad and cause both short-term fluctuations and long-term increases in rainfall. In order to improve flood resilience and water management systems in the area, policymakers and urban planners need to take these projections into account.

MULTAN

Future Temperature & Precipitation Outlook



CHAPTER 3

Multan – Future Temperature and Precipitation Outlook Under Warming Scenarios

Multan stands out as a climate hotspot, characterized by its severe arid conditions, record-setting heatwaves, and an agricultural system that heavily relies on delicate riverine ecosystems. As one of the hottest cities in Punjab, where temperatures can soar above 50°C, it illustrates the intensification of the urban heat island effect amid swift urban development. Situated in South Punjab's cotton-mango belt, the shifting monsoon patterns and the flow of the Indus River present existential challenges for farmers. Due to climate change, mango production has dropped by almost 60% this season[18]. Prolonged droughts and erratic precipitation patterns amplify the risk of desertification, while the historical dependence on groundwater is now threatened by depletion. The intersection of extreme thermal stress, water scarcity, food insecurity and the vulnerability of cash crops in Multan positions it as a crucial for assessing climate impacts on agricultural cities in arid zones. This underscores the need to analyse the combined influence of climate change, including projected decadal and 30-year maximum and minimum temperature trends, as well as precipitation patterns in this area.

3.1 Modelled Maximum and Minimum 30 YEARS Temperature Projections under SSP245 and SSP585 Scenario in Multan

The increase of maximum temperature is analysed for thirty years and decadal under two climate change scenarios SSP245 and SSP585 for three 30-year periods 2015-2040, 2041-2070, and 2071-2100 are illustrated in Figure 15(a) & Figure 15(b) and (Table 7&8). According to the SSP245 scenario, temperatures are predicted to rise 1.4°C in the near future (2015-2014), 2.4° by the middle of the century (2041–2070), and 3.1°C at the end of the century (2071–2100). Conversely, SSP585 scenario projects substantial warming increase of 1.6°, 2.9°, and 4.8° for the same time periods. These projections are close together until after 2070 where divergence started with SSP585 resulting in far greater temperatures rising than initially predicted.

[18] https://dailytimes.com.pk/935257/climate-change-causes-60-decline-in-mango-production/

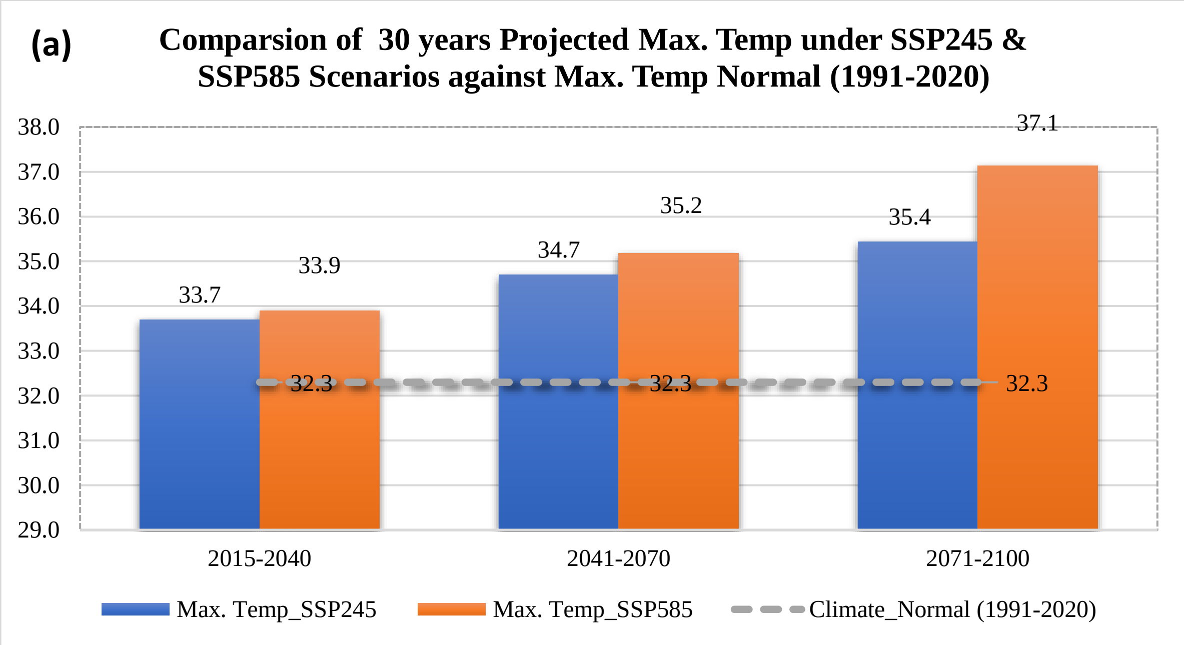


Figure 15: (a) Comparison of 30 years Projected Max. Temp under SSP245 & SSP585 Scenarios against Max. Temp Normal (1991-2020) in Multan

Table 7: Projected 30 years maximum temperature under SSP245 and SSP585 scenario in Multan

Sr. No.	Years	Variation in 30 years maximum temperature under SSP 245	Variation in 30 years maximum temperature under SSP 245
1.	2015-2040	1.4°C	1.6°C
2.	2041-2070	2.4°C	2.9°C
3.	2071-2100	3.1°C	4.8°C

Table 8: Simulated Maximum Temperature Increase Under SSP245 SSP585 Scenario in Multan

Sr. no	Years	Variation in 30 years minimum temperature under SSP 245	Variation in 30 years minimum temperature under SSP 245
1.	2015-2040	0.6°C	1.0°C
2.	2041-2070	1.7°C	2.6°C
3.	2071-2100	2.6 °C	4.6°C

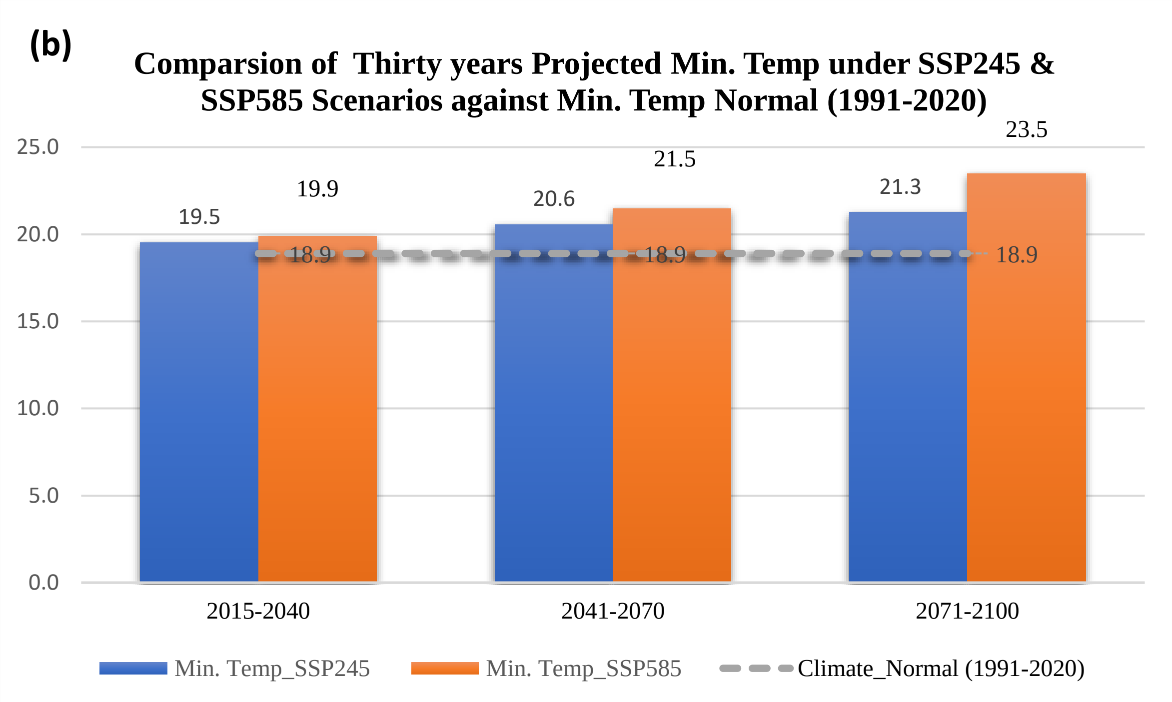


Figure 16: (b) Comparison of Projected thirty years Minimum. Temp under SSP245 & SSP585 Scenarios against Max. Temp Normal (1991-2020)

Figure 15 (b) shows the thirty years predicted minimum temperature over Multan. The predictions are computed across time periods: 2015 to 2040, 2041 to 2070, and 2071 to 2100. In contrast, under SSP585 scenarios which represents extreme warming, the projected minimum temperature increases are approximately 1°C in the first period, followed by increase of 2.6°C and 4.6°C in subsequent by the end of century, substantially surpassing the projected trends.

3.2 Modelled Decadal Maximum and Minimum Temperature Projections under SSP245 and SSP585 Scenario in Multan

Decadal projections of maximum and minimum temperature, from 2015-2100 are presented in the Table 9 and 10. During the near-term (2015-2030), SSP245 and SSP585 show similar warming trends of 1.2 to 1.3°C, indicating that slight temperature increase in Figure 17 (a).

Table 9: Projected decadal maximum temperature under SSP 245 and under SSP 585 Scenario

Sr. No	Years	Variation in decadal maximum temperature under SSP 245	Variation in decadal maximum temperature under SSP 585
1.	2015-2030	1.2°C	1.3°C
2.	2031-2040	1.6°C	1.7°C
3.	2041-2050	2.5°C	2.2°C

4.	2051-2060	2.5°C	2.8°C
5.	2061-2070	2.8°C	3.6°C
6.	2071-2080	2.9°C	4.2°C
7.	2081-2090	3.3°C	4.8°C
8.	2091-2100	3.4°C	5.6°C

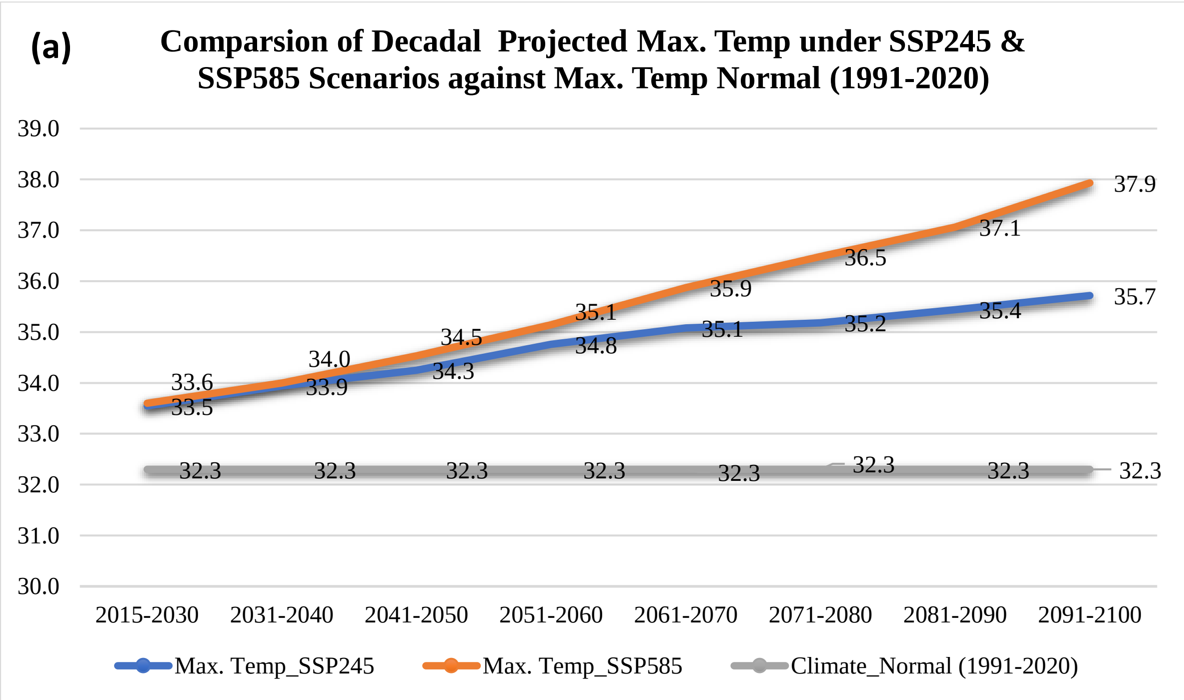


Figure 17: (a) Comparison of Decadal Projected Max. Temp under SSP 25 & SSP 585 Scenario against Max. Temp Normal (1991-2020) in Multan.

Under the SSP245 scenario, decadal trends indicate an average temperature increase ranging from 1.2°C to 3.4 °C. Under SSP585, projected increases lie between 1.3°C and 5.6°C.

A projected 5 to 6°C increase in maximum temperature by 2100, it can be anticipated that it may lead to irreversible tipping points, extreme heatwaves, ecological collapse, and, among other disastrous climate consequences, under the SSP585 scenario. Despite being less drastic, the SSP245 scenario still predicts dangerous temperatures that would put stress on ecological and human systems. The nonlinear acceleration of warming projected under SSP585 post 2070 indicates the onset of concerning climatic feedback loops, which may render the management of maximum temperature rises increasingly vital.

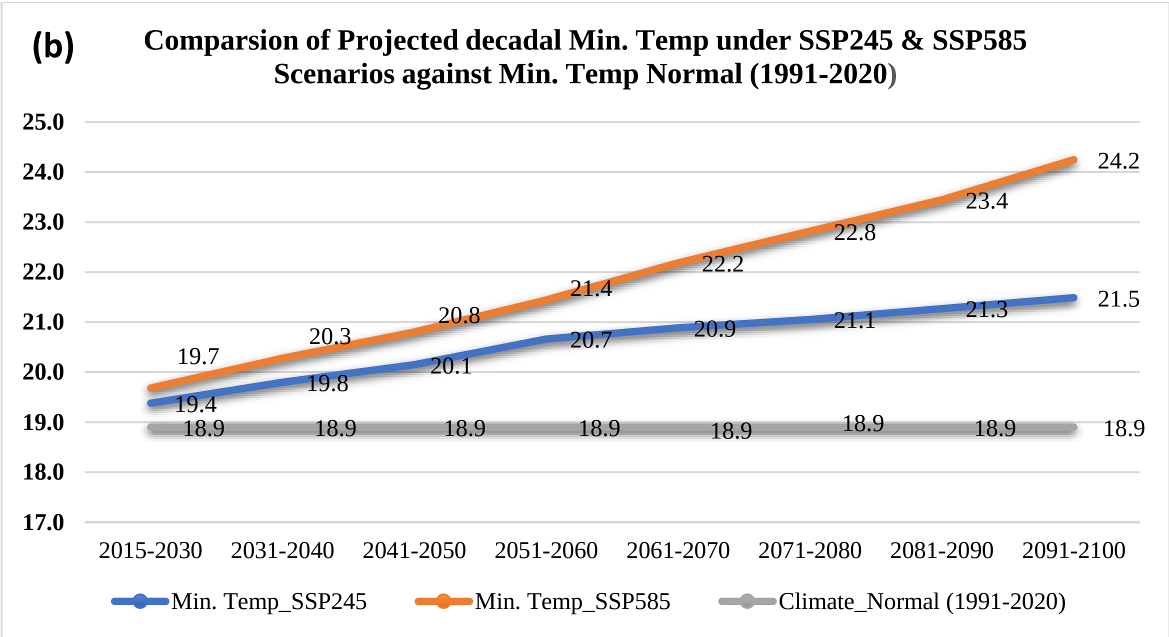


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Figure 18: (b) Comparison of Decadal Projected Minimum Temp under SSP25 & SSP585 Scenarios against Minimum Temp. Normal (1991-2020).

Table 10: Projected decadal minimum temperature under SSP 245 and under SSP 585 scenario

Sr. No	Years	Projected Minimum temperature increase under SSP245	Projected Minimum temperature increase under SSP585
1.	2015-2030	0.5°C	0.8°C
2.	2031-2040	0.9°C	1.4°C
3.	2041-2050	1.2°C	1.9°C
4.	2051-2060	1.8°C	2.5°C
5.	2061-2070	2.0°C	3.3°C
6.	2071-2080	2.2°C	3.9°C
7.	2081-2090	2.4°C	4.5°C
8.	2091-2100	2.6°C	5.3°C

Minimum temperature under SSP 245 has been shown in Figure 18(b), increasing to 0.5°C in 2015–2030 to 2.6°C by 2091–2100. Conversely, SSP 585 warming increase is more noticeable, starting at 0.8°C between 2015 and 2030 and ending at 5.3°C at the end of the century.

3.4 Projected Increase in Extreme Hot Days frequency during the 21st Century under SSP245 and SSP585 Scenarios in Multan

The predicted hot days in Multan, with maximum temperatures above hot days normal, is expected to increase intensely during the spring season and early summer months between 2015 and 2100, (Table 11) with particularly notable increases is observed under SSP 585 scenario. Under the SSP245 scenario, the near-term period (2015–2040) is projected to have between 700 and 879 hot days in April. In contrast, the SSP585 scenario predicts a higher range of 717 to 895 hot days. Notably, both scenarios indicate a significant increase compared to the baseline normal of 532 hot days.

Table 11: Projected Hot days in June, July, August in Multan

		April		May		June	
Sr. No.	**Years**	**Hot days under SSP245**	**Hot days under SSP 585**	**Hot days under SSP245**	**Hot days under SSP585**	**Hot days under SSP245**	**Hot days under SSP 585**
		April Temp Normal **532**		May Temp normal **504**		June temp normal **420**	
1.	2015-2040	700	717	656	670	435	450
2.	2041-2070	879	895	872	881	576	668
3.	2071-2100	870	870	889	504	683	824

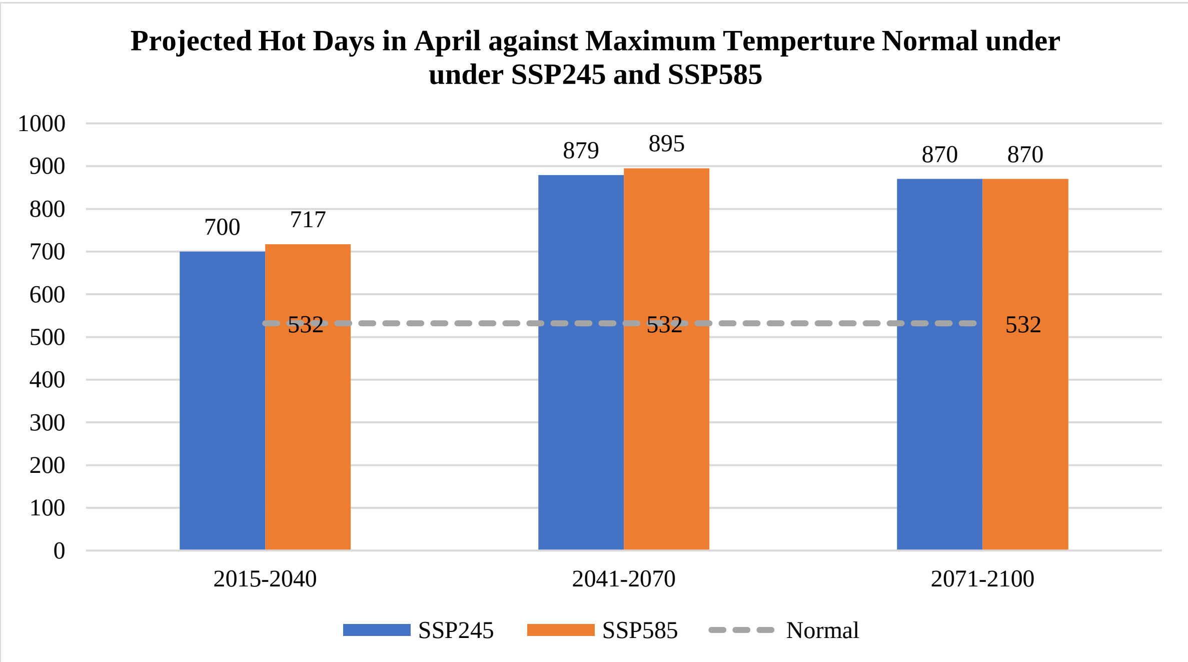

Figure 19: Projected Hot Days in April against Temperature Normal in Multan

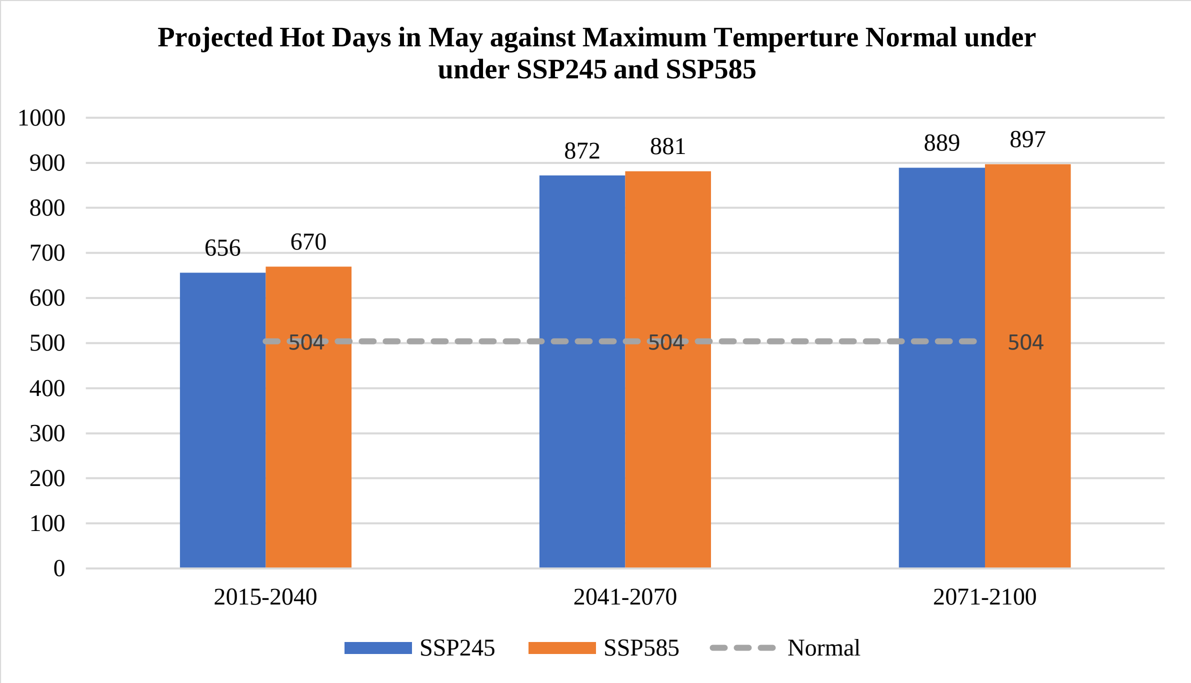

Figure 20: Projected Hot Days in May against Temperature Normal in Multan

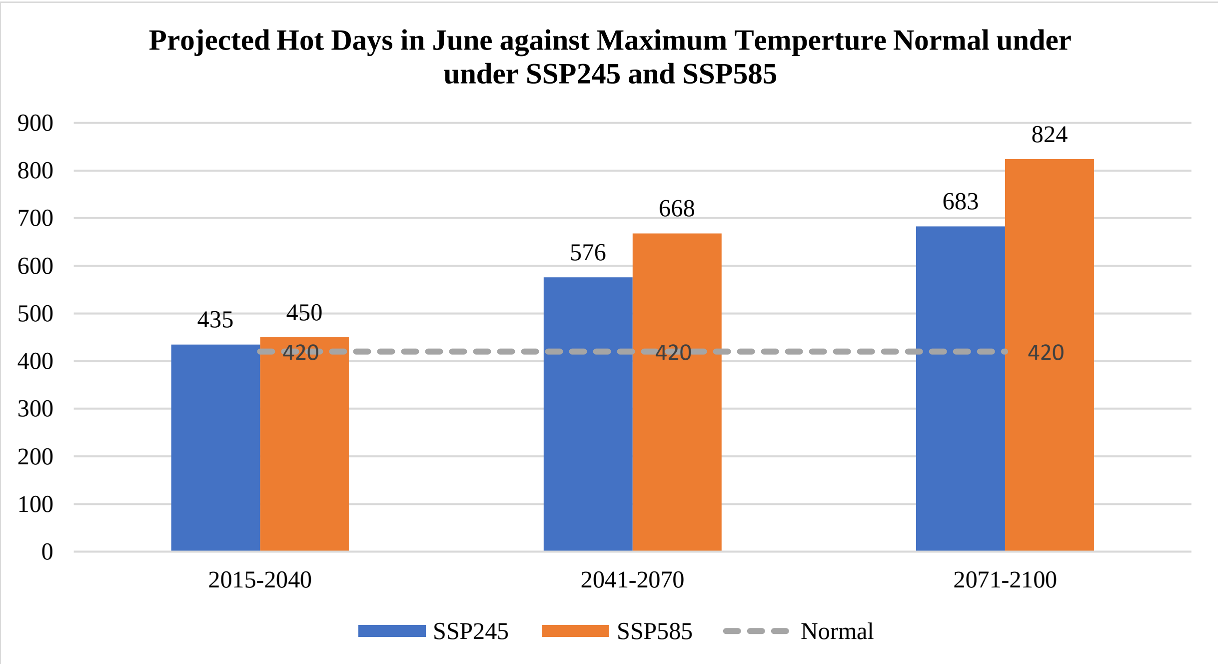

Figure 21: Projected Hot Days in June against Temperature Normal in Multan

In May, the number of hot days in the near-term (2015–2040) is expected to, reaching between 656 and 872 under the SSP245 scenario and between 670 and 891 under SSP585. Nevertheless, the anticipated drop to 504 hot days during the period of 2071–2100 under SSP 585 appears to be anomalous, potentially indicating a data error or a change in scenario. This (Figure 21) illustrates the projected number of hot days in June exceeding the maximum temperature normal under two climate scenarios (SSP245 and SSP585) compared to the maximum hot days

June normal. In the near future (2015–2040), the SSP245 scenario projects 435 hot days slightly above the hot days normal of 420. Meanwhile, SSP585 scenario predicts a similar increase, with 450 hot days. However, the disparity becomes pronounced in the long-term (2021-2100), where SSP585 projections escalate to 820 hot days, about double than normal demonstrating the severe implications of unmitigated emissions. These projections highlight the significant impact of current policy decisions on future heat extremes, with aggressive emission reductions greatly diminishing the frequency of perilous hot days by the century's end. The trend underscores the rising severity of heat extremes linked to elevated emission pathways, stressing the immediate necessity for mitigation actions

This trend of increasing hot days aligns with the larger-scale climate projections for Pakistan that show increased frequency and intensity of heatwaves, rising mean annual temperatures, and greater frequency of hot extremes under SSP scenarios[19]. In particular, many studies have investigated the number of days during which alarming heat indices (exceedingly more than 35 °C) are experienced in Pakistan, may increase 16 to 30 hot days under SSP 224and and 20 to 39 days under SSP 585 at the end of the century. This has critical impacts on food security and agriculture (crop stress and reduced yields), public health (exposure to extreme heat events), and energy systems (increased demand for cooling). The significant difference between outcomes under the multiple SSP scenarios underscores that GHG emissions mitigation is very significant while increases in hot days are substantial under SSP 245. In the far future, the projections suggest that the Multan would experience an extreme climate hazard from hotter extremes under SSP 585 scenario[20],[21].

3.6 Ensembled 30 Years Precipitation Projections under SSP245 and SSP585 Scenario

Multan has a hot desert (BWh) climate with sparse and erratic rainfall. Annual precipitation is low typically between 150–200 mm and most of it arrives during the monsoon season (July–September). However, rainfall is minimal except monsoon, winters may bring light drizzles or occasional frost-triggered showers, but summer months are overwhelmingly dry and scorching

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[19] Wells, C., Petty, C., Saggioro, E., & Cornforth, R. J. (2023). *Pakistan climate change impact storylines based on existing literature* (Technical Report WITR0923/01). Walker Institute, University of Reading. https://doi.org/10.5281/zenodo.8359360

[20] Ullah, S., You, Q., Ullah, W., Sachindra, D. A., Ali, A., Bhatti, A. S., & Ali, G. (2023). Climate change will exacerbate population exposure to future heat waves in the China-Pakistan economic corridor. *Weather and Climate Extremes*, *40*, 100570.

[21] Baig, M. A., Cui, P., Ullah, S., Bazai, N. A., Wei, R., Ali, M., ... & Purohit, S. (2025). Evaluation and Projection of Temperatures Over Pakistan: Insights from the Downscaled NEX-GDDP-CMIP6 Models. Earth Systems and Environment, 1-21.

hot. (Figure 22) and (Table 12) illustrated the thirty years precipitation projections over Multan. The SSP245 scenario predicts a 17% increase to 271 mm, while the high-emission SSP585 pathway shows a more dramatic 46% rise to 337 mm during the 2015-2040. The significant divergence has been observed during the midcentury (2041-2070), the precipitation under SSP245 stabilizes to 3.5%, whereas under SSP585 rainfall has continue to increase 61% (373) against the precipitation normal. A substantial shift has been observed in far future (2071-2100) with 31% (302mm) increase under SSP245 and soaring increase of 94% (449mm) above precipitation normal under SSP 585 scenario.

Table 12: Projected 30 years average rainfall modelled projections under SSP245 and SSP 585 Scenarios in Multan

Sr. no.	Years	Projected 30 years average Precipitation (mm) under SSP 245 Scenario	Projected 30 years average Precipitation (mm) under SSP 585 Scenario	% Change in precipitation under SSP245 against climate normal (231mm)	% Change in precipitation under SSP585 against climate normal (231mm)
1.	2015-2040	271	337	↑17.3 %	↑ 45.9 %
2.	2041-2070	239	373	↑ 3.5 %	↑ 61 %
3.	2071-2100	302	449	↑ 30.7 %	↑ 94.4 %

The projected precipitations results are in line with CMIP6 model predictions that call for more precipitation throughout semi-arid South Asia, including the central regions of Pakistan. Rising flood risks during upcoming monsoon seasons are highlighted by the increasing rainfall, especially in high-emission scenarios. Comprehensive adaptation strategies, such as improved drainage infrastructure, flood mitigation systems, and adaptable agricultural practices that can handle both water surplus and scarcity, are required due to this changing precipitation pattern. The forecasts underscore the vital significance of proactive adaptation planning to increase Multan's resilience against shifting rainfall patterns as well as climate mitigation initiatives to reduce extreme scenarios.

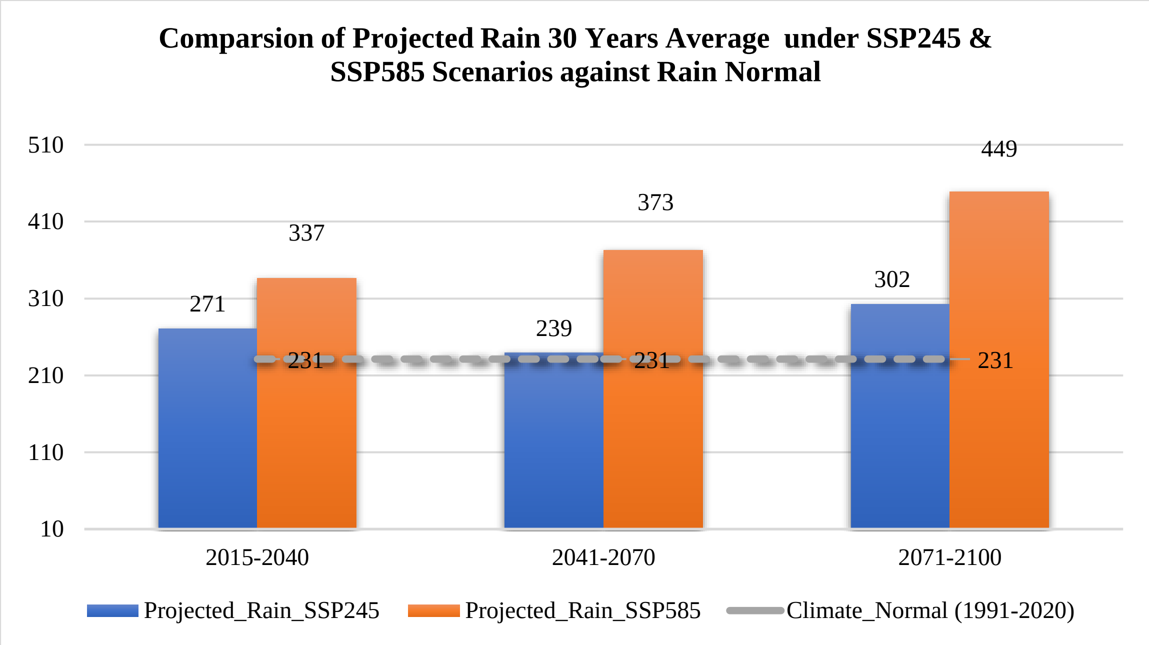

Figure 22: Comparison of decadal Averaged precipitation under SSP245 & SSP585 Scenarios against precipitation normal in Multan

3.6 Ensembled Decadal Precipitation Projections under SSP245 and SSP585 Scenario

The (Figure 23) illustrates projected decadal rainfall for Multan under two future climate scenarios, SSP245 and SSP585 against the historical climate normal (1991–2020), which is approximately 231 mm. Under SSP245, rainfall is projected to remain relatively close to the climate normal throughout most of the century, however some decades are showing modest increases, with peak value 325 mm during 2071–2080. Whereas, projections under SSP585 indicate significant increased precipitation during 2041–2050 (528 mm) and 2071–2080 (505 mm), showing the potential for more intense rainfall extreme events under SSP 585 pathways. After 2080, rainfall under SSP585 slightly decreases but this decrease is still above the precipitation climate normal. These patterns highlight a possible intensification and variability of precipitation in Multan, particularly under higher emissions, with important implications for water resource management and climate adaptation strategies in the area.

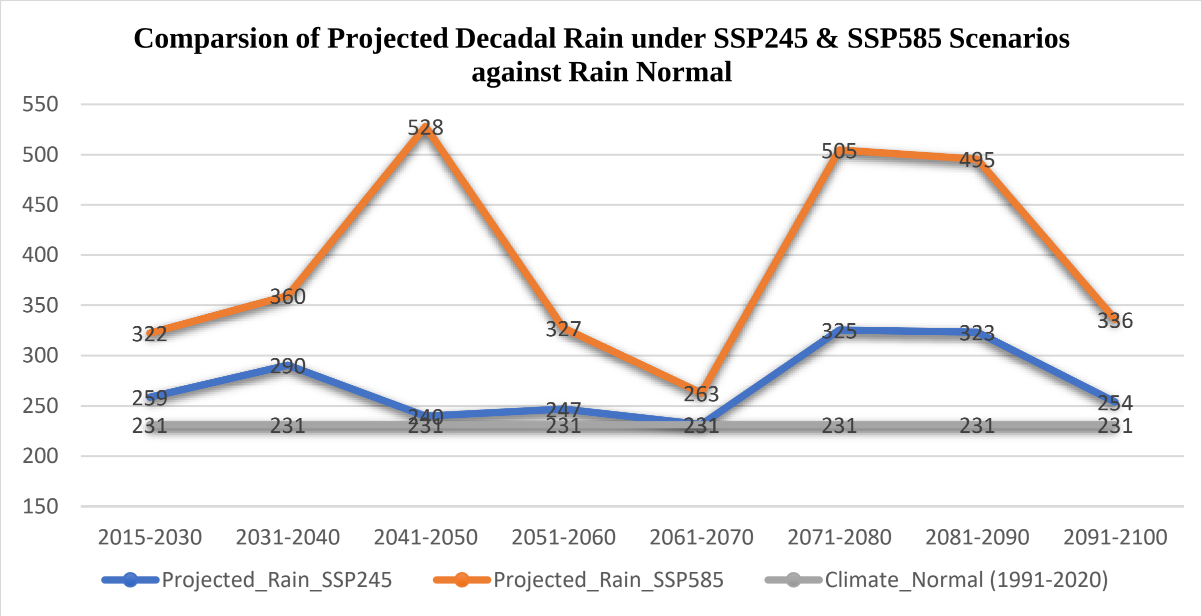

Figure 23: Comparison of 30 years Averaged precipitation under SSP245 & SSP585 Scenarios against Precipitation Normal in Multan

SIALKOT

Future Temperature & Precipitation Outlook

CHAPTER - 4

Sialkot – Future Temperature and Precipitation Outlook Under Warming Scenarios

The socioeconomic significance, susceptibility to extreme weather, and distinct transitional climate of Sialkot make it an essential site for climate research. Because of its location between semi-arid and humid regions, rendering it an excellent location for forecasting future risks due to its unpredictable monsoons, severe flooding, and increasing heatwaves. As an essential agricultural and industrial centre, the wheat and rice production in Sialkot is jeopardized by changing rainfall patterns and temperature fluctuations, while urban development exacerbates local warming. Additionally, its closeness to the Himalayan glaciers ties its water resources to melting trends. These elements position Sialkot as a crucial area for evaluating climate effects and guiding adaptation measures in South Asia.

4.1 Modelled Maximum and Minimum 30 YEARS Temperature Projections under SSP245 and SSP585 Scenario in Sialkot

The projected increase in Sialkot's maximum temperatures is presented in Figure 24 and Table 13, under two climate scenarios SSP245 and SSP585 spanning three future periods: 2015-2040, 2041-2070, and 2071-2100. During the near term (2015-2040), both climate scenarios indicate a 1.0°C increase, showing the signs of warming. By mid-century (2041-2070), SSP245 projects a 1.7°C increase, while SSP585 projected slightly higher at 1.8°C, signalling a gradual divergence. Between 2071 and 2100, the distinction becomes more apparent, indicating 2.4°C under SSP245 and 2.5°C under SSP585. Ultimately, prolonged high emissions clearly result in larger temperature increases for Sialkot.

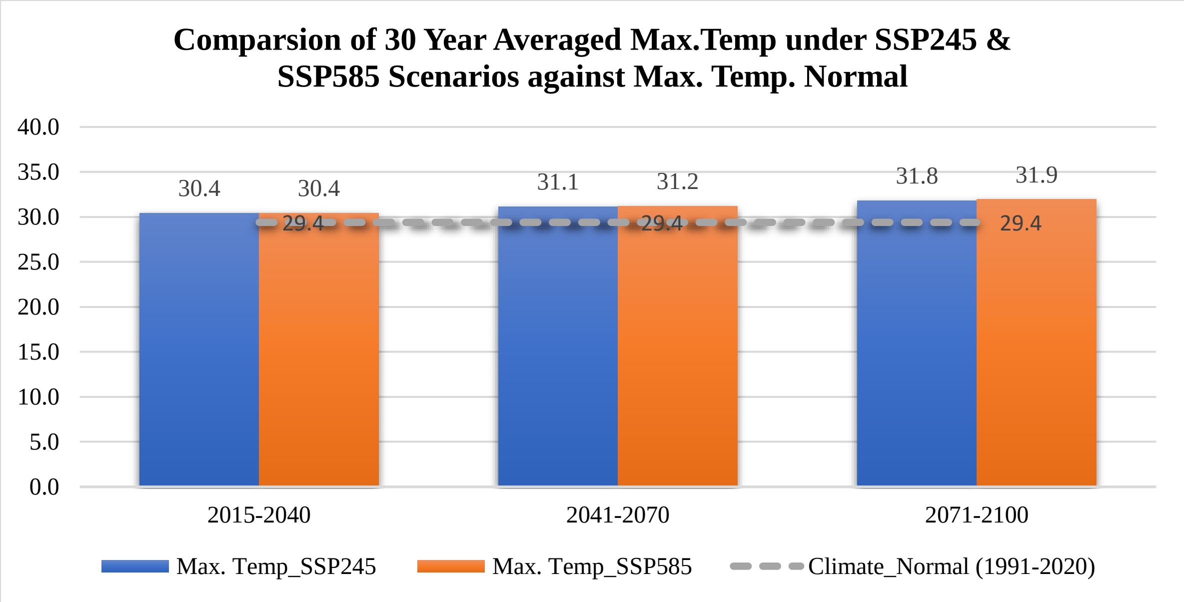

Figure 24: Comparison of 30 year Averaged Maximum Temp. under SSP245 & SSP585 Scenarios against Maximum Temp Normal in Sialkot

Table 13: Projected 30 years maximum temperature change under SSP245 and SSP585 scenario in Sialkot

Sr. No.	Years	Projected Maximum Temperature increase under SSP 245 Scenario	Projected Maximum Temperature increase under SSP 585 Scenario
1.	2015-2040	1.0 °C	1.0 °C
2.	2041-2070	1.7 °C	1.8°C
3.	2071-2100	2.4 °C	2.5 °C

The (Table 14) and (Figure 25) shows how minimum temperatures in Sialkot are expected to increase over time under two climate scenarios SSP245 and SSP585. The climatic assessments projections have been done across three periods: 2015-2040, 2041-2070, and 2071-2100. Under the SSP245 scenario, minimum temperatures are predicted to increase by 0.9°C from 2015 to 2040, then rise to 1.8°C by mid-century, and reach around 2.4°C by 2100. On the other hand, the SSP585 scenario shows much steeper increase of 3.0°C in the near future, 4.0°C mid-century, and around 4.8°C by the end of the century the warming of silakot.

Table 14: Projected 30 years minimum temperature change under SSP245 and SSP585 scenario in Sialkot

Sr. No.	Years	Projected Minimum Temperature increase under SSP 245 Scenario	Projected Minimum Temperature increase under SSP 585 Scenario
1.	2015-2040	0.9 °C	3.0 °C
2.	2041-2070	1.8 °C	4.0 °C
3.	2071-2100	2.4 °C	4.8 °C

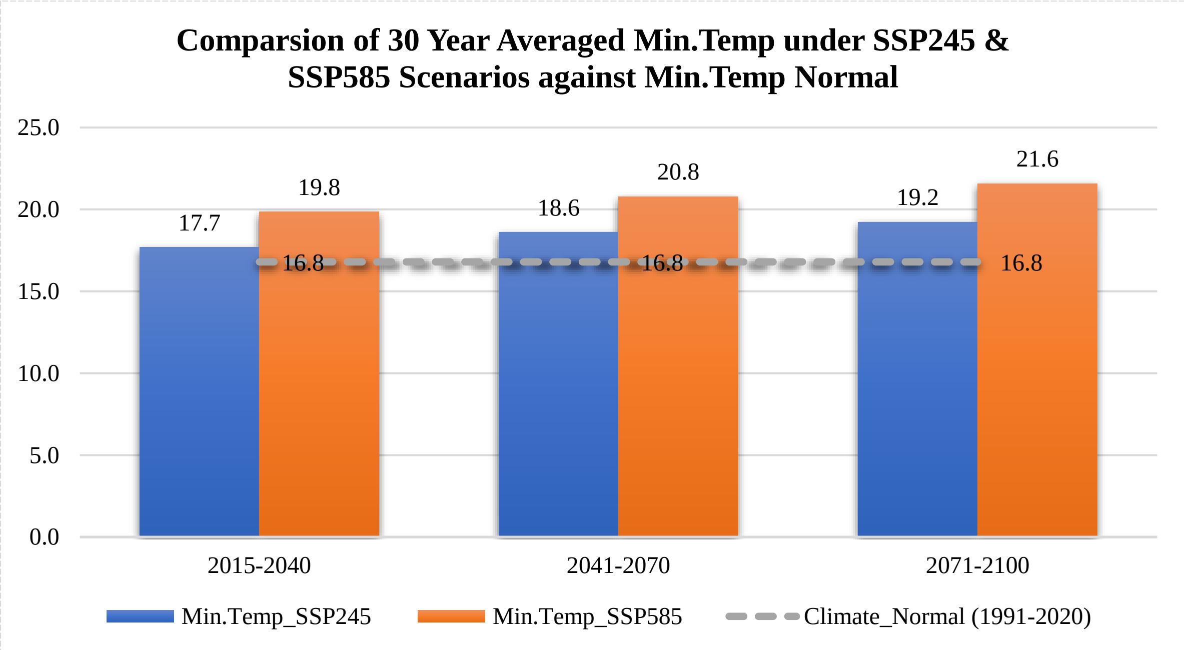

Figure 25: Comparison of 30-year Averaged Max. Temp. under SSP245 & SSP585 Scenarios against maximum Temperature Normal

4.2 Modelled Decadal Maximum and Minimum Decadal Temperature Projections under SSP245 and SSP585 Scenario in Sialkot

Decadal maximum temperatures under SSP245 and SSP 585 are presented in Figure 26. The maximum temperature are forecasted to increase gradually from 30.3°C in 2015–2030 to 32.1°C by 2091–2100. Under SSP585, the rise in maximum temperature project is almost the same as of SSP 245, with an increase to 32.2°C by the century's end. Throughout the period, these projected temperatures remain significantly higher than the historical climate normal of 29.4°C, indicating consistent warming regardless of the emission scenario, with more pronounced increases under high-emission pathways

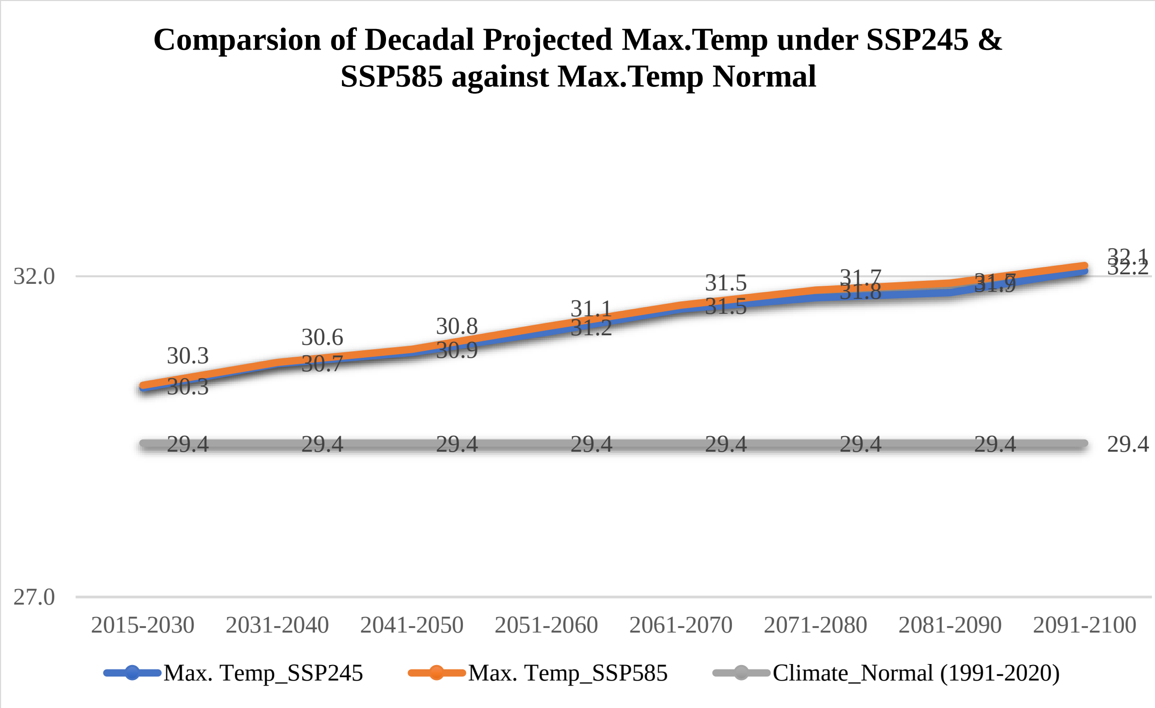

Figure 26: Comparison of Decadal Average Max. Temp. under SSP245 & SSP585 Scenarios against Temp Normal

Table 15: Projected decadal maximum temperature under SSP 245 and under SSP 585 scenario.

Sr. No	Years	Variation in decadal maximum temperature under SSP 245	Variation in decadal maximum temperature under SSP 585
1.	2015-2030	1.2°C	1.3°C
2.	2031-2040	1.6°C	1.7°C
3.	2041-2050	2.5°C	2.2°C
4.	2051-2060	2.5°C	2.8°C
5.	2061-2070	2.8°C	3.6°C
6.	2071-2080	2.9°C	4.2°C
7.	2081-2090	3.3°C	4.8°C
8.	2091-2100	3.4°C	5.6°C

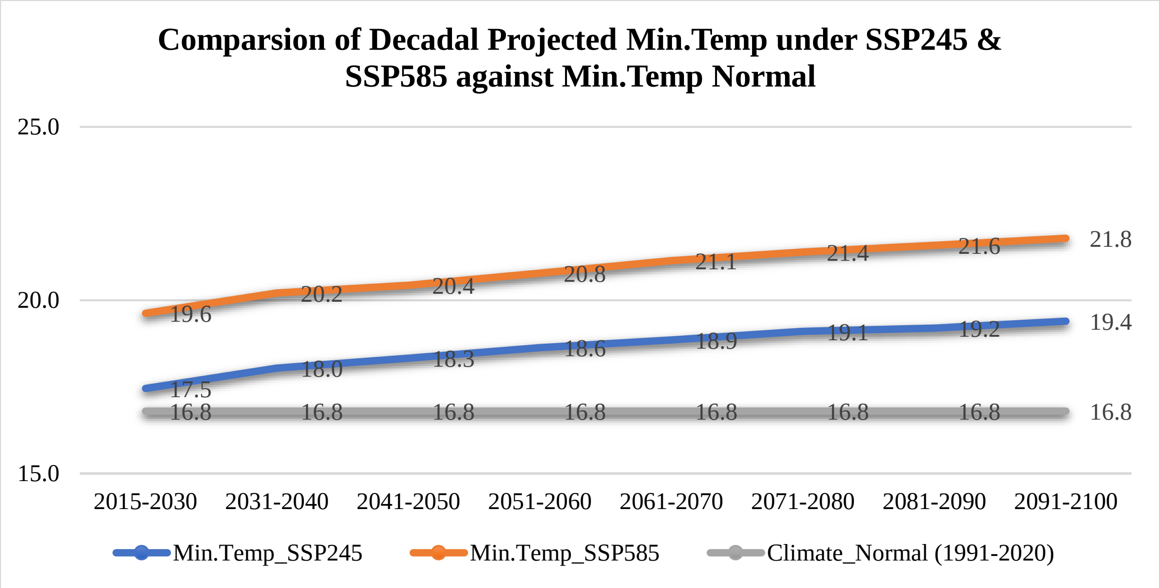

Figure 27: Comparison of Decadal Averaged minimum temp. under SSP245 & SSP585 Scenarios against Temp Normal

Table 16: Projected minimum temperature under SSP 245 and SSP 585 scenario.

Sr. No	Years	Variation in decadal minimum temperature under SSP 245	Variation in decadal minimum temperature under SSP 585
1.	2015-2030	1.2°C	1.3°C
2.	2031-2040	1.6°C	1.7°C
3.	2041-2050	2.5°C	2.2°C
4.	2051-2060	2.5°C	2.8°C
5.	2061-2070	2.8°C	3.6°C
6.	2071-2080	2.9°C	4.2°C
7.	2081-2090	3.3°C	4.8°C
8.	2091-2100	3.4°C	5.6°C

A comprehensive comparison of projected minimum temperatures is presented in the (Figure 27) under two climate scenarios SSP245 and SSP585 relative to minimum temperature climate normal (1991–2020). The minimum temperatures are projected from 2015 to 2100. The difference against the climate normal in near future is less under SSP245. From mid century onwards, SSP585 predicts much warmer minimum temperatures than SSP245 and climate normal, demonstrating the risks of unmitigated greenhouse gas emissions.

The growing difference between the two scenarios emphasizes how important emission reductions and climate policies will be in tackling the climate extremes. While SSP585 cautions about the perils of inaction and projects extreme warming by 2100, SSP245 illustrates the advantages of moderate mitigation. This analogy emphasizes how urgently global climate action is required to avert the most disastrous consequences of warming temperatures.

4.3 Projected Increase in Extreme Hot Days frequency during the 21st Century under SSP245 and SSP585 Scenarios in Sialkot

The projected hot days are computed under two climate scenarios SSP245 and SSP 245. The anticipated increase of hot days has been observed in April, May, and June across near, mid and far future (2015–2040, 2041–2070, and 2071–2100). The days are analysed against the hot days normal (historical baseline), April: 201 days, May: 237 days, June: 388 days. As per data presented in the Figure 28,29,30 and Table 17, SSP245 predicts that hot days would grow from 225 in 2015–2040 to 554 by 2071–2100 in April, whereas SSP585 predicts an even more pronounced increase from 250 to 584 throughout the same time frame respectively. During May and June, similar trends are observed, with June having the hottest days because of its inherently warmer temperature. The contrast between SSP245 and SSP585 demonstrates how, especially in the latter part of the twenty-first century, increased greenhouse gas emissions cause extreme heat events to occur more frequently

Table 17: Projected Hot days in Sialkot under SSP 245 and SSP 585 Scenario.

		April		May		June	
Sr. No.	**Years**	**Hot days under SSP245**	**Hot days under SSP 585**	**Hot days under SSP245**	**Hot days under SSP585**	**Hot days under SSP245**	**Hot days under SSP 585**
		April hot days Normal 201 days		**May hot days normal 237 days**		**June hot days normal 388 days**	
1.	2015-2040	225	250	273	308	403	423
2.	2041-2070	352	387	457	463	656	670
3.	2071-2100	554	584	589	596	734	738

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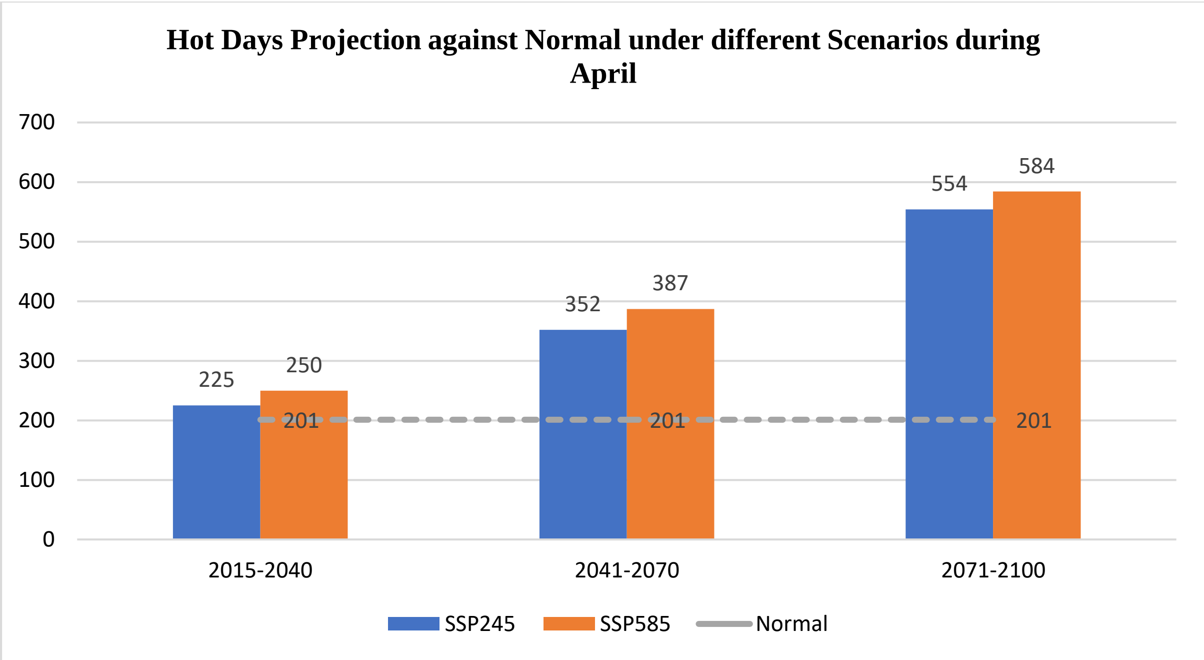

Figure 28: Hot days projection in April against normal under SSP 25 and SSP 585 scenarios.

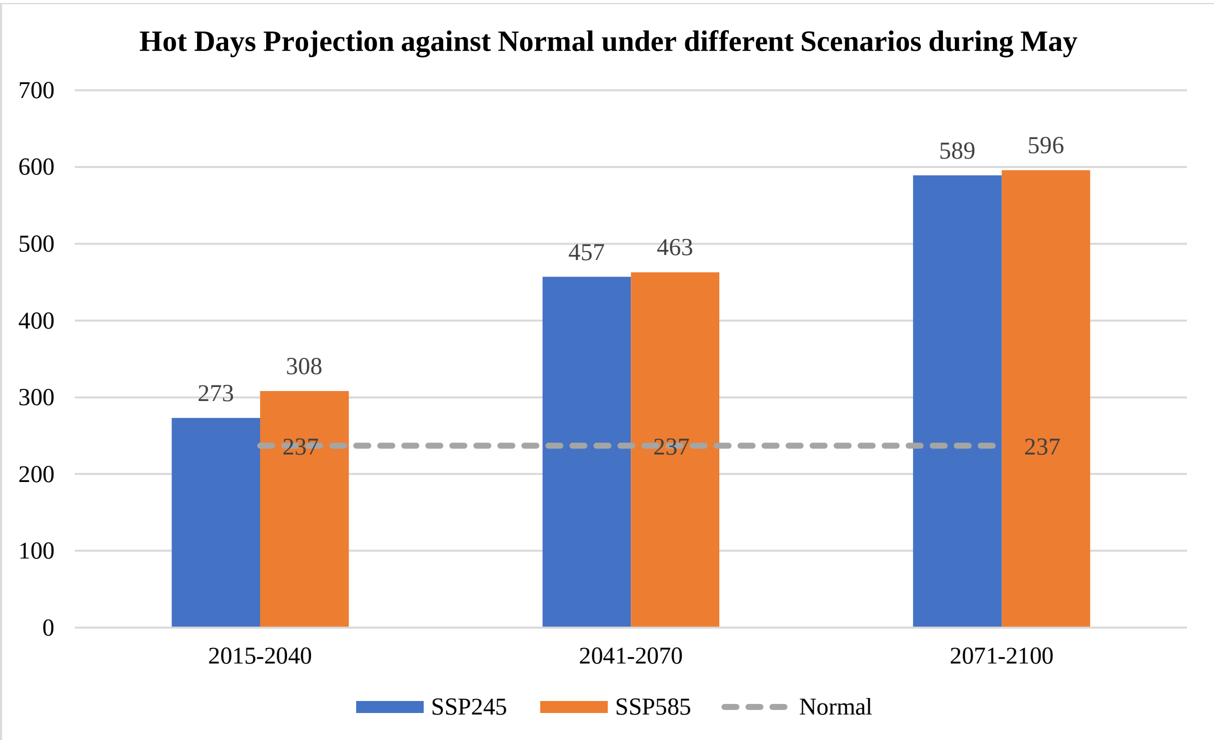

Figure 29: Hot days projection in April against normal under SSP 25 and SSP 585 Scenarios

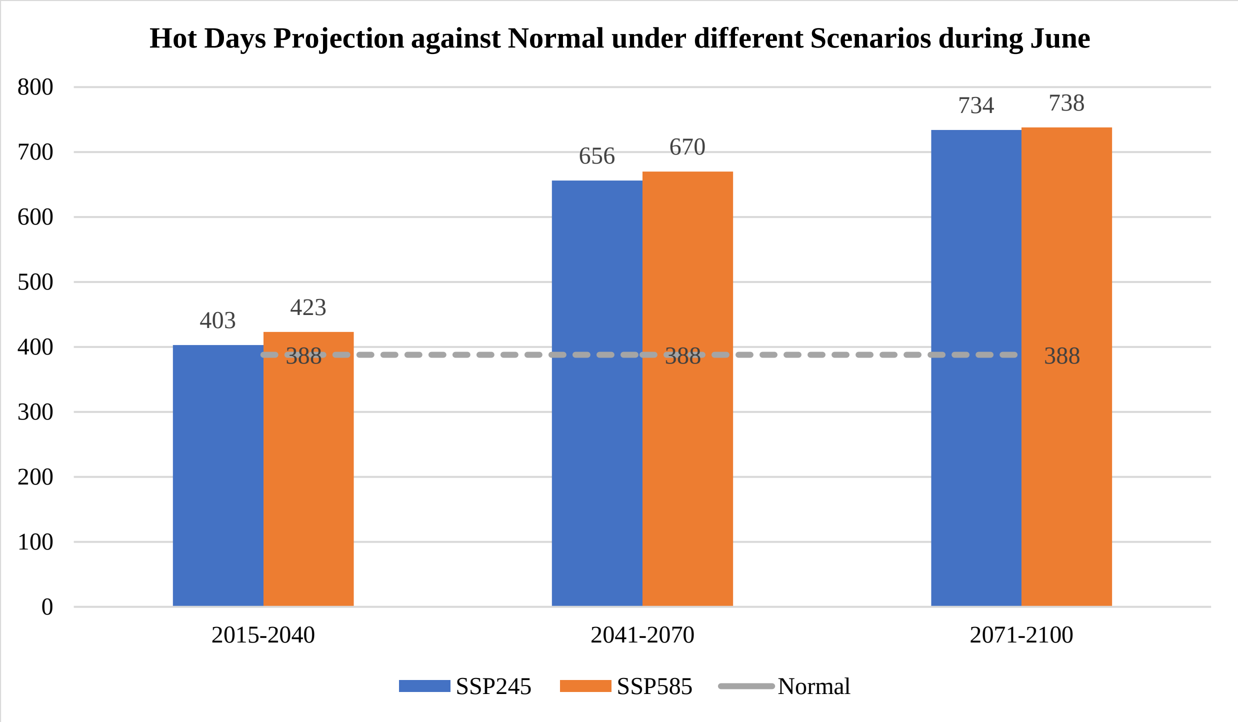

Figure 30:Hot Days projection in April against normal under SSP 245 and SSP585 scenarios

4.4 Ensembled 30 Years Precipitation Projections under SSP245 and SSP585 Scenario

The dataset showed in (Figure 31) and (Table 18) evaluates modelled precipitation projections under climate scenarios SSP245 and SSP585 relative to the 1991–2020 precipitation climate normal of 1,008 mm. The percentage deviations highlight notable changes in precipitation trends, with important implications over different time horizons. Under SSP 245 precipitation projection showed drought conditions from moderate to severe. In the near future (2015-2040), the precipitation pattern is showing steady decrease with 11.8% showing the early warning of onset of drought conditions. The decreasing trend of precipitation intensifies between 2041–2070, with 29.5 % below the precipitation normal, depicted the risk of drought condition. The decline peaks in the 2071–2100, with a 32.2 % shortfall, which could critically affect agriculture, freshwater availability, and ecosystem health.

Table 18: Projected 30 years average rainfall modelled projections under SSP245 and SSP 585 Scenarios in Sialkot

Sr. no.	Years	Projected 30 years average Precipitation (mm) under	Projected 30 years average Precipitation (mm) under SSP 585 Scenario	% Change in precipitation under SSP245 against	% Change in precipitation under SSP585 against climate normal (1008 mm)

		SSP 245 Scenario		climate normal (1008mm)	
1.	2015-2040	889	1111	↓-11.8 %	↑ 2.1%
2.	2041-2070	711	866	↓-29.5 %	↓ -20.4%
3.	2071-2100	683	1267	↓-32.2%	↑ 16.5%

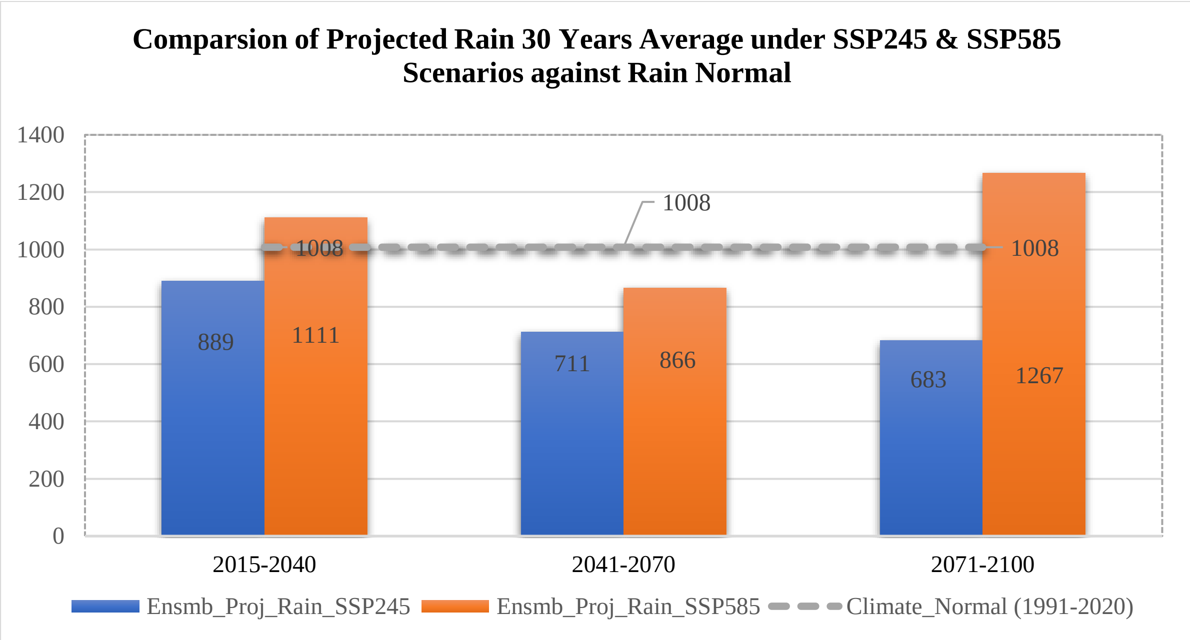

Figure 31: Comparison of 30 years Averaged precipitation under SSP245 & SSP585 Scenarios against Precipitation Normal in Sialkot

Decadal analysis of Modelled precipitation under SSP 245 and SSP 585 is presented in figure 27 against the perception normal. The decal patterns of precipitation in each decade are showing deviation form the normal under SSP245 and SSP 585 scenario.

The (Figure 31) shows projected rainfall trends from 2015 to 2100, broken down into decadal intervals. Each interval (e.g., 2015-2030, 2011-2040, etc.) likely shows how rainfall patterns are expected to deviate from the rainfall normal under the two scenarios. SSP 585 scenario is showing less drastic shifts than SSP245 scenario which shows less precipitation than rainfall normal in the mid future and far future period.

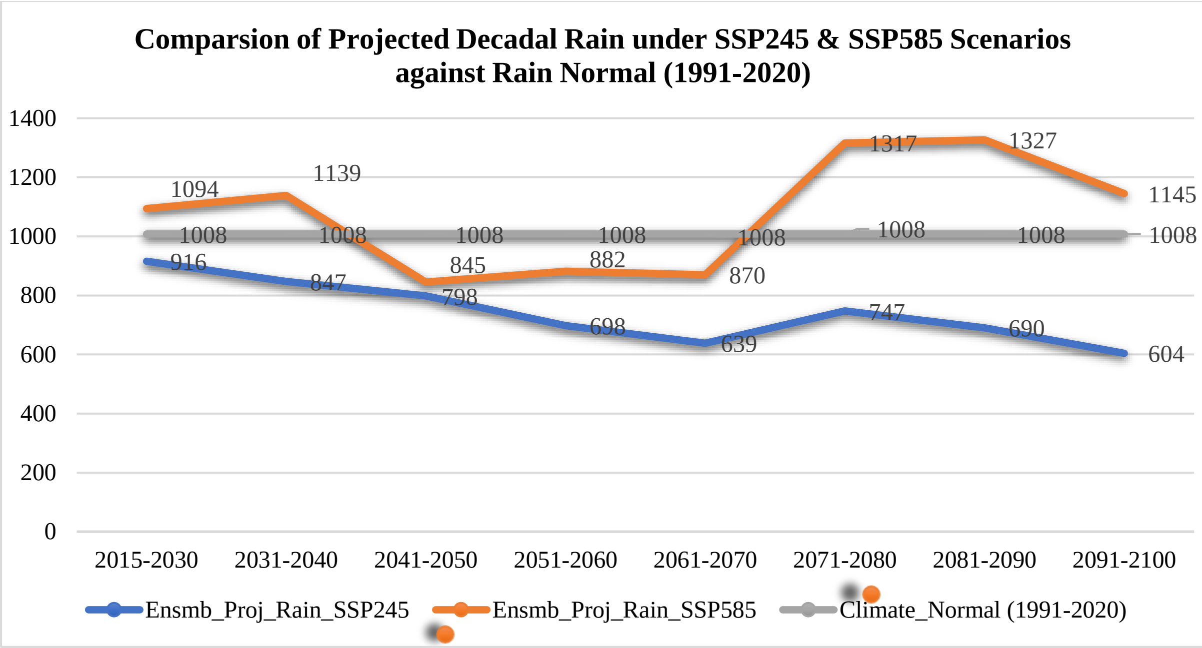

Figure 32: Comparison of Decadal Averaged precipitation under SSP245 & SSP585 Scenarios against Precipitation Normal in Sialkot

The observed decline of 11.8% average and sharp intensification to 29.5 to 32.2% by the end of this century is closely correlated with CMIP6-based assessment conducted by Asif et al. (2024) for Pakistan's northern highlands, which showed projections of 21.4% drop in annual precipitation under SSP245 in near and mid future 2021–2050[22]. Similarly, a targeted analysis of the Potohar Plateau under the SSP245 scenario projects a decline in annual and rabi-season rainfall at a rate of approximately 16.6 mm per decade (4.3% reduction). These findings align with baseline estimate of an 11.8% decline, further reinforcing the observed trend of increasing aridity[23].

[22] Asif, M., Anjum, M. N., Azam, M., Hussain, F., Afzal, A., Kim, B. S., Maeng, S. J., Kim, D., & Iqbal, W. (2024). Climate-Driven Changes in the Projected Annual and Seasonal Precipitation over the Northern Highlands of Pakistan. *Water*, *16*(23), 3461. https://doi.org/10.3390/w16233461.

[23] Rasool, G., Anjum, M. N., Kim, D. Y., Azam, M., Hussain, F., Afzal, A., Maeng, S. J., & Min, K. C. (2024). Projecting Climate Change Impact on Precipitation Patterns during Different Growth Stages of Rainfed Wheat Crop in the Pothwar Plateau, Pakistan. *Climate*, *12*(8), 110. https://doi.org/10.3390/cli12080110