

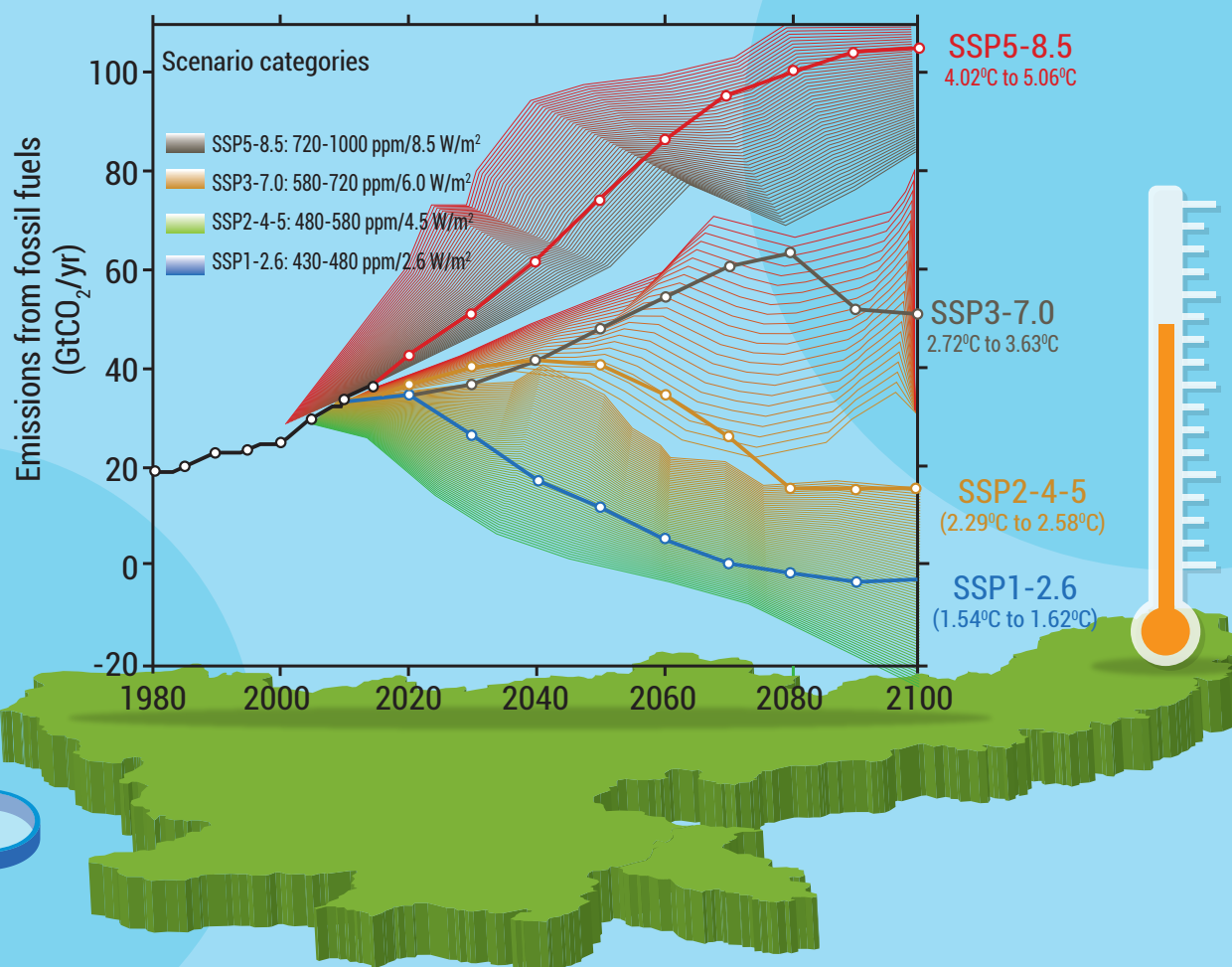


विज्ञान एवं प्रौद्योगिकी विभाग
DEPARTMENT OF
SCIENCE & TECHNOLOGY



District Level Climate Projection for Jharkhand

The Climate Countdown!



Department of Forest, Environment & Climate Change
Government of Jharkhand

Message from the Secretary



Climate change has become one of the most perilous threats not only to economic development but also to the entire earth's ecosystem and its existence. One of the main causes is the steady rise in the earth's mean temperature due to large-scale emissions of GHG gases, primarily from fossil fuel-based industrial activities.

Although we are now aware that temperatures are rising across the globe, this rise is not uniform across regions. It depends on various factors such as vegetation cover, the presence of seas and water bodies, the intensity of industrial activities, and other anthropogenic activities. Additionally, the impact of climate change on various sectors of the economy, regions, and society is expected to vary significantly in different parts of the globe. This variation will be determined by both global and local factors and will depend on the socio-economic path the world follows in the coming days.

The district and block-level climate data sets and their projections are particularly important for the state of Jharkhand, as it has been identified as the most climate-vulnerable state in India by the Department of Science & Technology (DST), Government of India. This localized projection data, including variables such as temperature and rainfall, will help assess the overall climate risk to specific regions, sectors, and communities in particular blocks/districts. It will play a vital role in formulating localized climate policies, budget allocations, and identifying appropriate adaptation measures to address both current and future climate risks.

I commend the efforts made by the officers of the State Forest & Climate Department, climate modellers, researchers, and members of the state climate change cell involved in this modeling and projection exercise. Their work in making this projection data available to all departments is commendable, and I hope it will aid various departments and the climate change cell in their future efforts.

Finally, I wish to express my hope that this initiative, taken up by the Jharkhand State Forest Department with funding support from the Department of Science and Technology (DST), Government of India, under the National Mission on Strategic Knowledge for Climate Change (NMSKCC), will not only strengthen the capacities of the State Climate Change Cell in climate modelling and projections of important climatic variables but will also help in policy formulation. The data presented in this report will be a vital tool for the state government and officials to understand future climate risks, enabling informed decision-making on climate change and localized adaptation planning.

Aboobacker Siddique P, IAS

Secretary: Department of Forest, Environment & Climate Change, Jharkhand

Foreword



The science of climate change is now very clear, and we know that the earth's temperature is increasing at an alarming rate across the globe. This makes it necessary to understand the expected rise in temperature and variations in other climatic parameters in advance, especially at the local level.

Jharkhand is serious about understanding the implications of climate change and planning actions to address its challenges. The state already has a state-level climate change action plan in place and has implemented several important mitigation and adaptation measures in various areas with the help of the United Nations Development Program (UNDP) and NABARD. Further studies and research will help strengthen the state action plan, enabling micro-level and targeted actions in climate change adaptation, mitigation planning, and resource allocation.

In particular, these district-level climate projections will help in understanding the possible variations in two main climatic variables: temperature and rainfall across the state. They will assist decision-makers in planning appropriate adaptation measures in advance to reduce and manage the adverse impacts of climate change.

I am pleased to know that this study has been supported by the Department of Science & Technology, Government of India, and is being executed by the Climate Change Cell of the Department of Forest, Environment & Climate Change. I would like to thank them for their funding support, inputs, and encouragement, and I also expect their continued support for such studies and capacity-building efforts in the field of climate change in the future.

I further congratulate and thank the APCCF, CAMPA, members of the state climate change cell, and independent researchers who have contributed to the modeling exercise and the preparation of this report.

Satyajit Singh, IFS

Principal Chief Conservator of Forests (PCCF) & Head of Forest Force (HoFF)
Department of Forest, Environment & Climate Change, Jharkhand

Acknowledgement



This “District Level Climate Projection Report” is part of a larger project titled “Block Level Climate Vulnerability Assessment and Preparing District-Level Adaptation Planning for the State of Jharkhand,” which has been funded by the Department of Science and Technology (DST), Government of India, as part of a capacity-building program under the National Mission on Strategic Knowledge for Climate Change (NMSKCC), one of the eight missions of the National Action Plan on Climate Change (NAPCC).

On behalf of the Department of Forest, Environment & Climate Change, Government of Jharkhand, I would like to sincerely thank the Climate Change Program (CCP) of the SPLICE Division/Team, Department of Science and Technology (DST), Government of India, especially Dr. Susheela Negi, who is leading the program at the national level and supporting this much-needed study and capacity-building effort on climate change at the state level.

I am grateful to the Principal Chief Conservator of Forests (HoD), who has consistently encouraged us and has been the motivating force behind this study and capacity-building program at both the department and state levels. I also sincerely appreciate the confidence that our senior colleagues from the department have shown in the team and the state climate change cell to complete this exercise.

On behalf of the Department of Forest, Environment & Climate Change, Government of Jharkhand, I would like to acknowledge, with sincere gratitude, the efforts of Prof. N.H. Ravindranath of IISc Bengaluru for his inputs and suggestions on the projection exercise and data, which helped finalize the report.

I sincerely acknowledge and appreciate the efforts made by Vijay Shankar and Kunal Jain for running various GCM and RCM models, putting tremendous effort into modeling and projection work with very limited computing resources, and shaping this report. I would also like to extend my thanks to all supporting staff of the Forest, Environment & Climate Change Department. This report could not have been completed without their enthusiasm and cooperation.

Ravi Ranjan, IFS
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List of Abbreviations

AR6	: Sixth Assessment Report (by the IPCC)
AOGCM	: Atmosphere-ocean General Circulation Model
CORDEX	: Coordinated Regional Downscaling Experiment
CHELSEA	: Climatologies at High Resolution for the Earth's Land Surface Areas
CMIP3	: Coupled Model Intercomparison Project Phase 3
CMIP5	: Coupled Model Intercomparison Project Phase 5
CMIP6	: Coupled Model Intercomparison Project Phase 6
DECK	: Diagnostic, Evaluation and Characterization of Klima
DST	: Department of Science and Technology
EBM	: Energy Balance Models
FAR	: First Assessment Report (by the IPCC)
SAR	: Second Assessment Report (by the IPCC)
TAR	: Third Assessment Report (by the IPCC)
AR4	: Fourth Assessment Report (by the IPCC)
AR5	: Fifth Assessment Report (by the IPCC)
GCM	: General Circulation Models/ Global Climate Models
GHG	: Greenhouse Gas
IAM	: Integrated Assessment Model
IAMC	: Integrated Assessment Modeling Consortium
IPCC	: Intergovernmental Panel on Climate Change
ISIMIP	: Inter-Sectoral Impact Model Intercomparison Project
NAPCC	: National Action Plan on Climate Change
NOAA	: National Oceanic and Atmospheric Administration
PPM	: Part Per Million
PMCCC	: Prime Minister's Council on Climate Change
RCM	: Regional Climate Models
RCP	: Representative Concentration Pathway
SAPCC	: State Action Plan on Climate Change
SPA	: Shared climate Policy Assumptions
SRES	: Special Report on Emissions Scenarios
SSP	: Shared Socioeconomic Pathway
UNFCCC	: United Nations Framework Convention on Climate Change
WRCP	: World Climate Research Programme
WGCM	: Working Group on Coupled Modeling

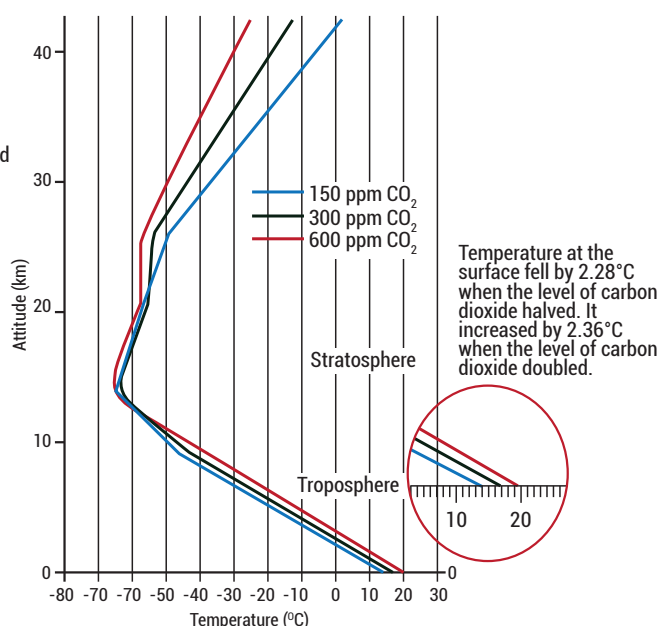
1. Introduction

Understanding the scientific reasons and methods is an essential part of the global temperature rise and impacts of climate change science. Although in the last 100 years various scientists and research institutes have worked on finding the cause of temperature rise, in the modern time, Nobel Laureate Syukuro Manabe's pioneer scientific work with physical models of Earth's climate has undoubtedly established that increased concentrations of carbon dioxide, a Greenhouse Gas (GHG), led to the increase in earth's surface temperatures. His pioneering research in the 1960s laid the foundation for modern climate models. Along with Syukuro Manabe's, Klaus Hasselmann's contributions include a model linking weather and climate, demonstrating the reliability of climate models despite weather variability. He also developed methods to identify specific signals, or "fingerprints," left by natural phenomena and human activities, proving that human emissions of carbon dioxide are driving temperature increases.

Figure 1: Co-relation between increase in CO₂ emission and temperature

Carbon dioxide heats the atmosphere

Increased levels of carbon dioxide lead to higher temperatures in the lower atmosphere, while the upper atmosphere gets colder. Manabe thus confirmed that the variation in temperature is due to increased levels of carbon dioxide; if it was caused by increased solar radiation, the entire atmosphere should have warmed up.



The IPCC's Sixth Assessment Report, has clearly summarized the relative influence of all things known to affect Earth's average surface temperature: The likely range of total **human-caused global surface temperature increase from 1850–1900 to 2010–2019 is 0.8°C to 1.3°C**, and other **human drivers (principally aerosols) contributed a cooling of 0.0°C to 0.8°C**, **natural (solar and volcanic) drivers changed global surface temperature by –0.1°C to +0.1°C**, and **internal variability changed it by –0.2°C to +0.2°C**.

According to the National Oceanic and Atmospheric Administration's (NOAA) the combined land and ocean temperature has increased at an average rate of 0.11° Fahrenheit per decade since 1850, or about 2° F in total. The rate of warming since 1982 is more than three times as fast: 0.36° F (0.20° C) per decade.

- 2023 was recorded as the warmest year since global records began in 1850.
- It was 2.12 °F (1.18 °C) above the 20th-century average of 57.0°F (13.9°C).
- It was 2.43 °F (1.35 °C) above the pre-industrial average (1850-1900).

However, though the past records are available, the future warming will depend on how much carbon dioxide and other greenhouse gases we emit in the coming decades and what measures and policy framework we adopt to reduce the GHG emission. To better anticipate the future warming and potential impacts of climate change at the regional and sub-national levels, information about the main drivers of future change including expected rise in GHG emission, temperature and variation in rainfall, socio-economic circumstances, and various policy instruments are required.

This study is an effort to do short term (2021-2040), medium term (2040-2060) and long term (2060-2100) projection of the two main climatic variables i.e. temperature and precipitation using various global climate modelling under various climate forcing, emission concentration and socio-economic assumptions at the district and block level for the state of Jharkhand. The study will help the state and its various departments to plan better adaptation and mitigation strategies which will further help the different layers of society to cope up with the threats of climate change. The methodology, scenarios and dataset used for preparing this climate projection report has been discussed in detail followed by the projection data for each district in the subsequent chapters. The block level projection data will be presented in a separate report due to large data set.

2. Executive Summary

Though it has been scientifically proved that earth's surface temperature is increasing, the warming has not been uniform across the globe. A few regions are warming more rapidly than the other regions. Also increase in the average surface temperature of earth and degree of global warming in the past is based on the real time data observed and evidences collected from the various meteorological centers located across the world, the real challenge lies in the prediction of various climatic variables, like temperature and rainfall, land use pattern for the future. Here the role of climate modelling starts and its play vital role in projecting future trend of various climatic variables. This study and report provide multi-model and multi-scenario temperature and precipitation projections for the state of Jharkhand for the period 2021–2100 based on latest climate data set available globally.

2.1 Model, Dataset, Scenarios and Variables

The two main climatic variables i.e. possible increase in temperature and variation in rainfall has been projected for the state at district and block levels (All 24 Districts and 260 Blocks,). These two variables have been projected using the WorldClim database and 14 Global Circulation/Climate Models (GCMs) inbuilt in Coupled Model Intercomparison Project Phase (CMIP6) framework under SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 scenarios. Projection has been done for four temporal brackets i.e. 2021-2040, 2041-2060, 2061-2080, and 2081-2100.

WorldClim database has been used for projection which provide high-resolution data based on various Global Climate Models (GCMs) and emission scenarios. The district and block level projection and analysis has been done for the entire state of Jharkhand creating the ensemble for four SSP scenarios. For temporal changes of temperature, the historical monthly T_{max} time series was decomposed into seasonal and trend elements. While modelling, below conventions have been followed.

- Special Resolution/Grid size: 2.5 minutes or ~20 sq. km (at equator)
- Temporal Coverage: 2021-2040, 2041-2060, 2061-2080, and 2081-2100.
- SSP Scenarios: Includes SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5.
- Model Used: 14 GCM model ensemble (CMIP6 farmwork).

The below climatic variables have been modelled for four future scenarios.

- T_{max} - maximum monthly temperature
- T_{min} - minimum monthly temperature
- P_{rec} - total monthly rainfall
- B_{ioc} - 19 annual bioclimatic variables derived from the primary variables.

2.2 Outcome of Projection

Figure below shows the sate wide distribution of projected maximum temperature under various scenarios. It is evident that in the SSP5-8.5 scenario, majority of districts will experience a temperature rise in the range of 4 to 5 °C by the end of the year 2100. Heat map suggests that the width of the distribution of the temperature rise increases substantially from the SSP1-2.6 to SSP5-8.5. from 2021 to 2100

Figure 2 : Expected Temperature (Tavg) distribution in SSP 1-2.6_2081-2100_ensemble

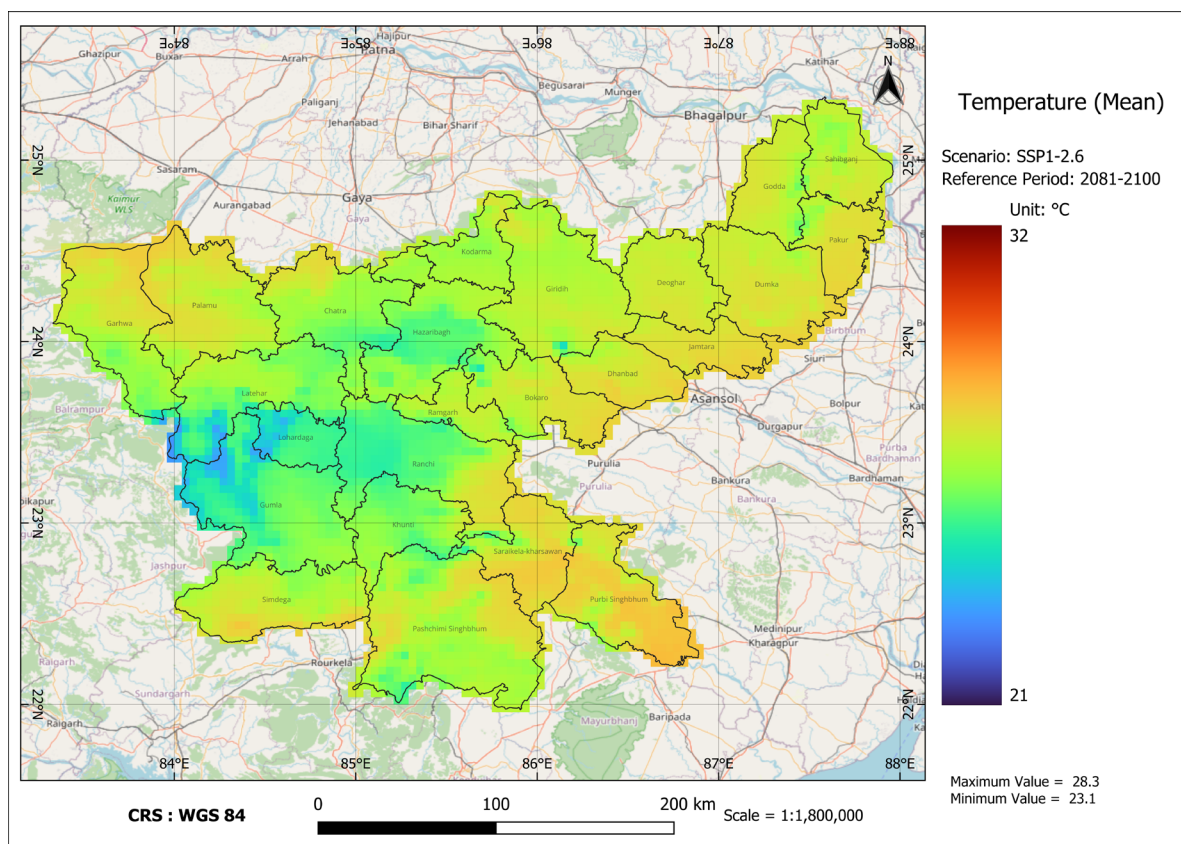
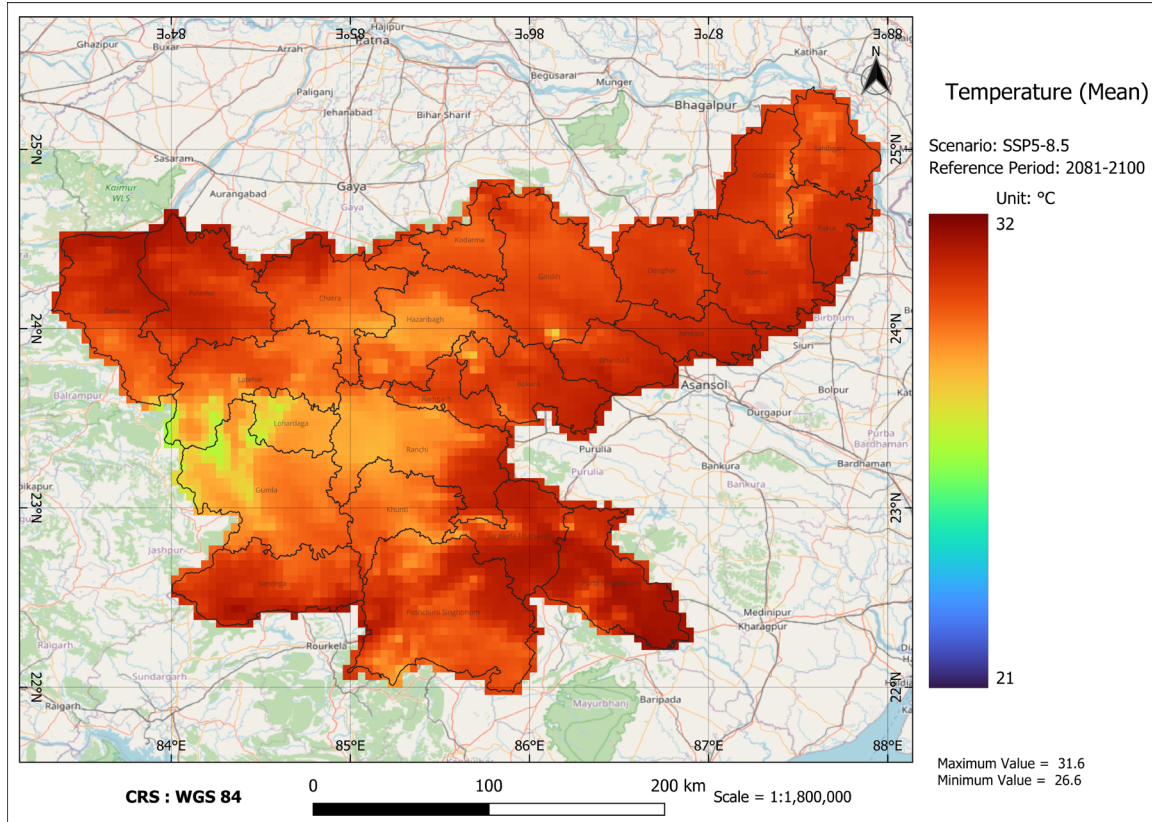
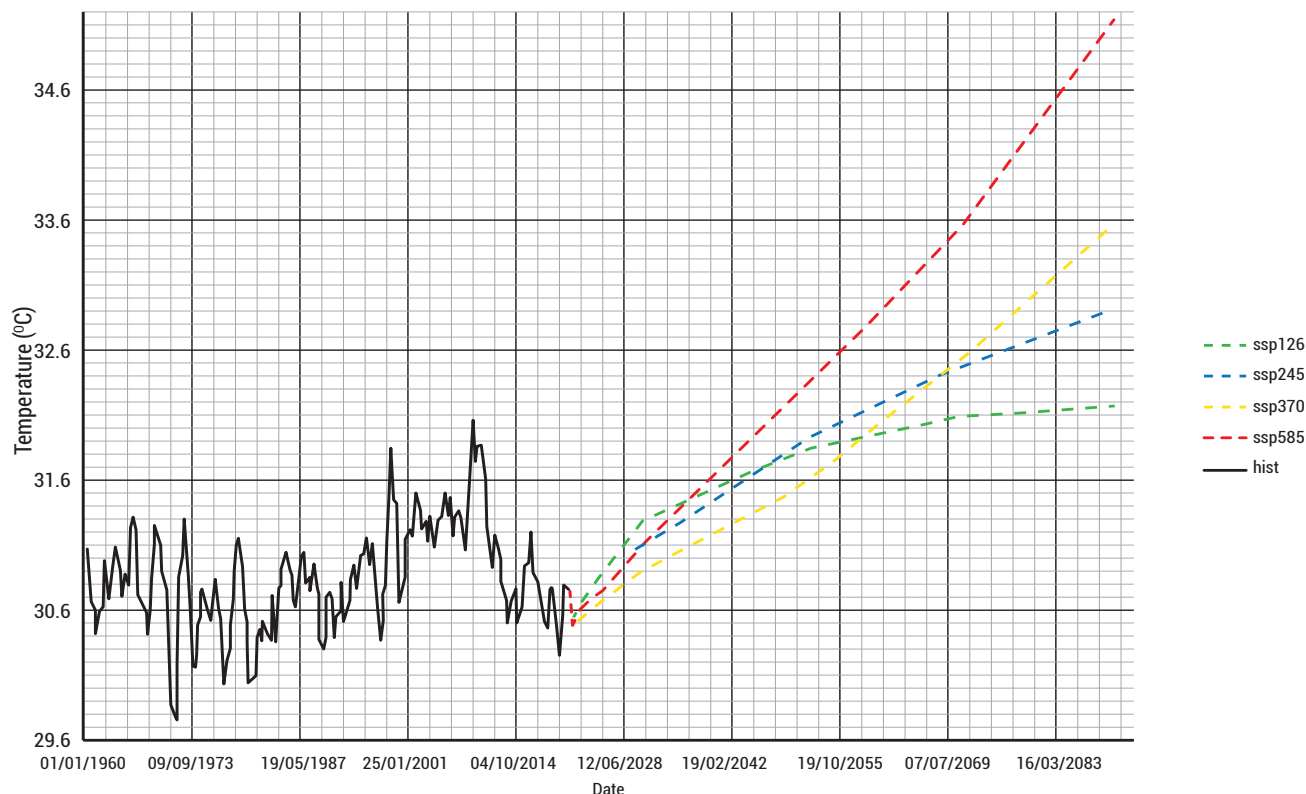


Figure 3 : Expected Temperature (Tavg) distribution in SSP 5-8.5_2081-2100_ensemble



The historical and projected temperature and precipitation trend is shown the below graph.

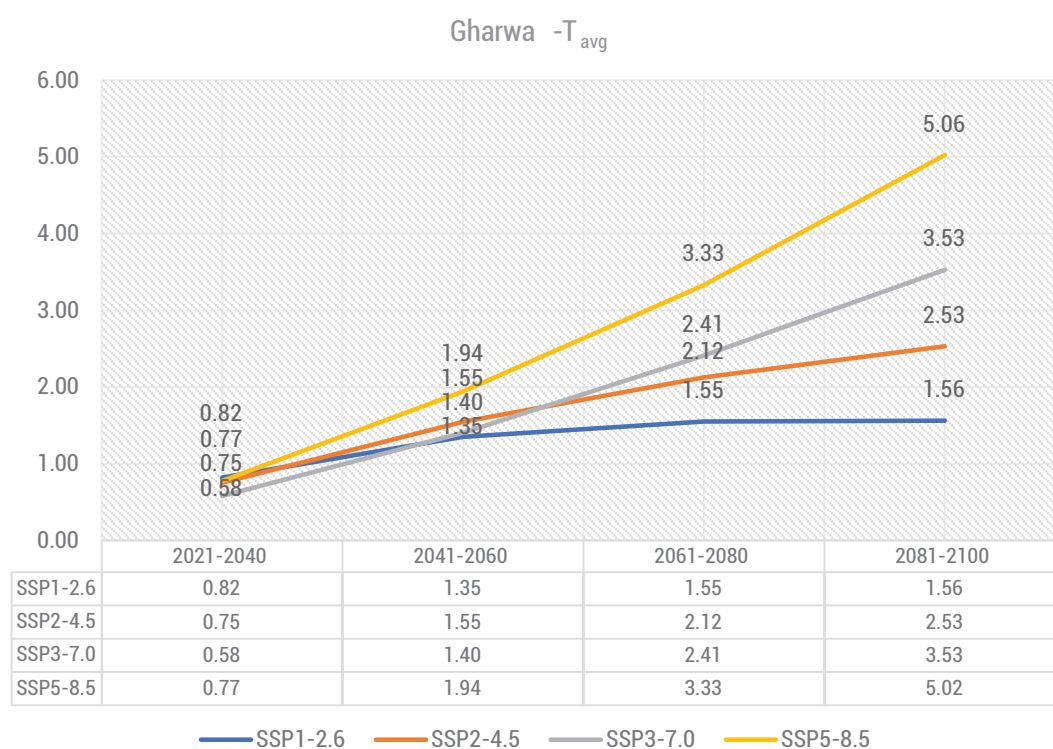
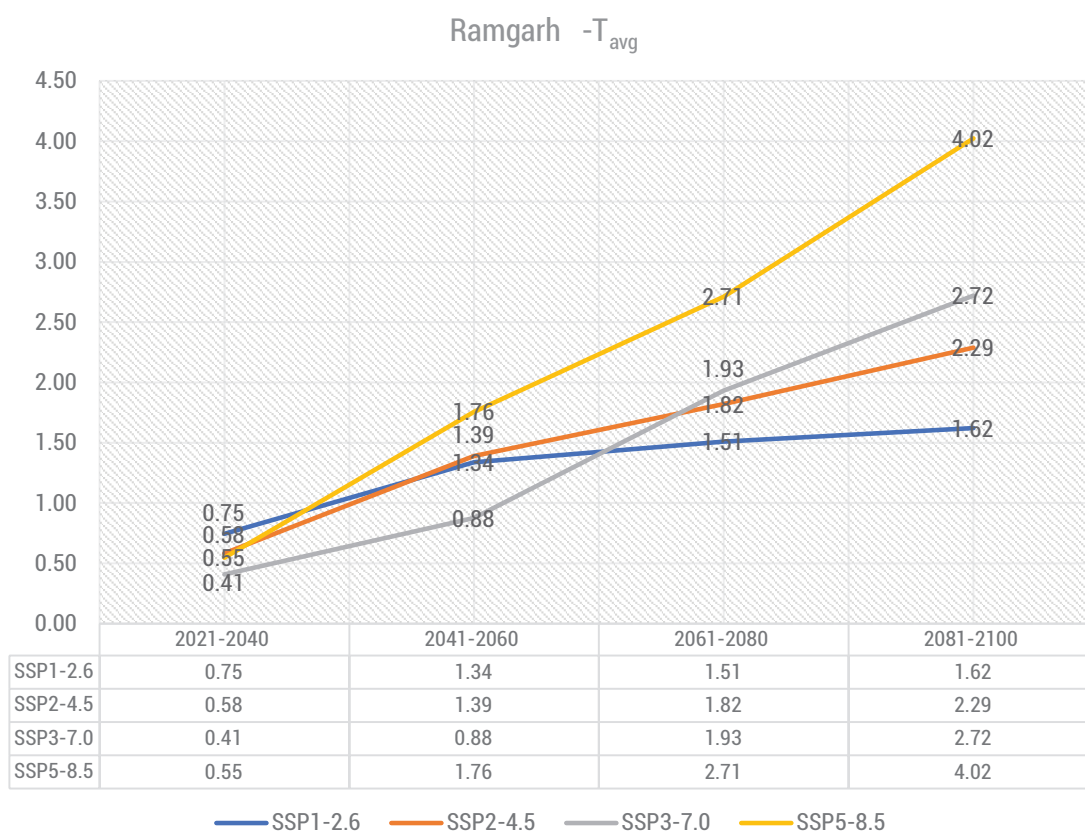
Figure 4 : CMIP6 model-based time series of temperature & precipitation anomalies (historical and projections) from 1970 to 2100 for all SSPs scenarios.



2.2.1 Variation in Temperature

Result show that on the spatial scale, the variation in the temperature rise among all blocks of a particular district does not vary significantly under a particular scenario but it varies significantly among districts. Under the various scenarios (between SSP1-2.6 and SSP5-8.5), mean warming in the state is likely to increase in the range of **0.40–88°C by 2040s, 1.32 –2.01°C by 2060s 1.55–3.44°C by 2080s, and 1.54–5.06°C by 2100s** relative to pre-industrial times. The minimum average temperature within the district boundary, temperature may rise minimum by **1.54° C (SSP1-2.6) in East Singhbhum** and maximum by **5.06° C (SSP5-8.5) in Garhwa district** by the end of the end of the **year-2100**.

Temperature rise is expected to be maximum in the north-western and western districts (**5.06 Degree Centigrade**) of the state which includes Garhwa, Palamau, Latehar, Lohardaga, Gumla and Simdega. Temperature rise is expected to be minimum for Ramgarh district (**4.02 Degree Centigrade**). Detailed projection for all 24 districts have been provided in the section-5 of this report.

Figure 5 : Expected temperature rise under different scenario for hottest district-Gharwa.**Figure 6 : Expected temperature rise under different SSP scenario for coolest district-Ramgarh.**

2.2.2 Variation in Rainfall

CMIP6 model ensemble-based projection indicates that there is a continuous increase in the annual precipitation change (%) in all four scenarios with respect to the pre-industrial baseline. Though precipitation is expected to increase almost all over the state, north-eastern districts such as Pakur, Sahebganj, Dumka, and Godda expect the highest increase in almost all four scenarios. The increase is expected to be minimal in East Singhbhum and West Singhbhum.

As noted in the temperature trends in each of the four temporal brackets, SS1-2.6 experiences the least increase in precipitation, while SSP5-8.5 experiences the highest precipitation increase, and the precipitation changes are larger for each subsequent period i.e. short, mid, and long-term. The figure below shows the state-level distribution of precipitation changes under all four SSP scenarios by 2100s from the CMIP6 model ensemble.

Figure 7: Expected rainfall pattern_SSP1-2.6 scenario_ 2081-2100/2090

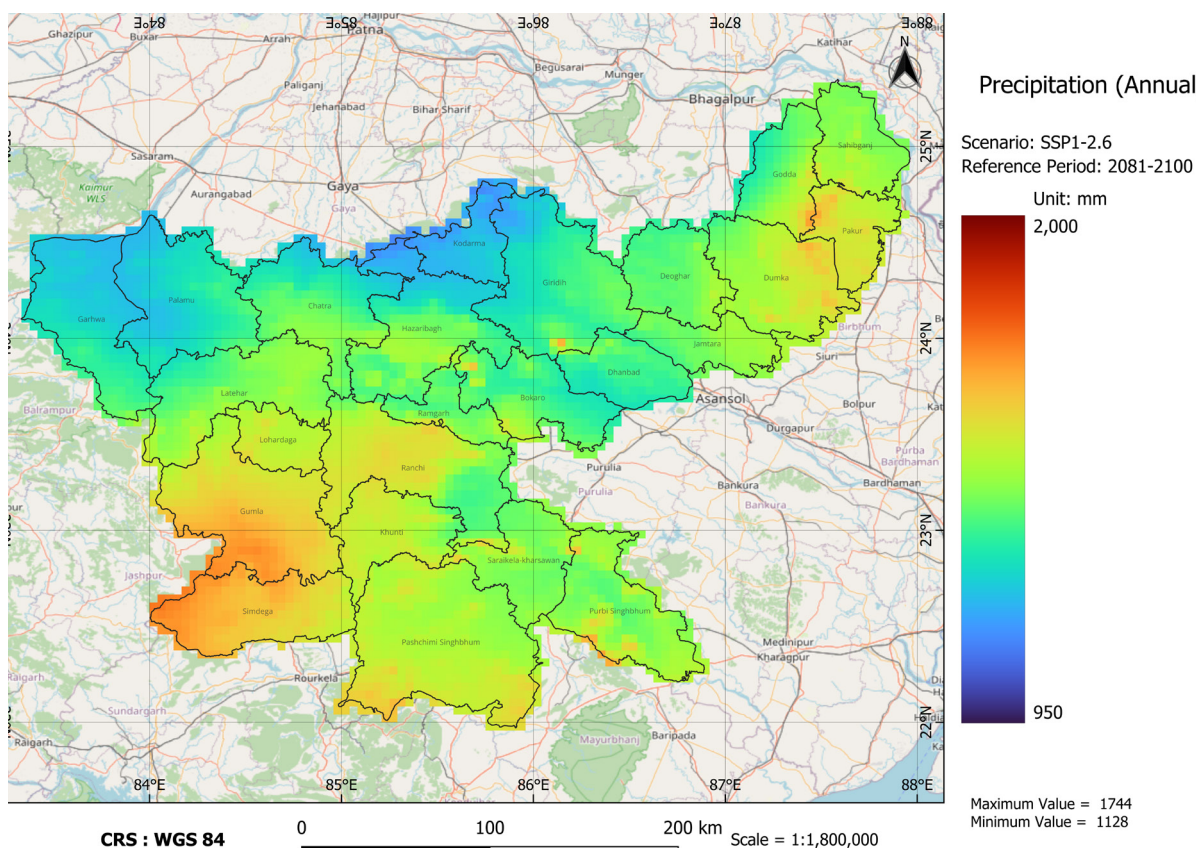
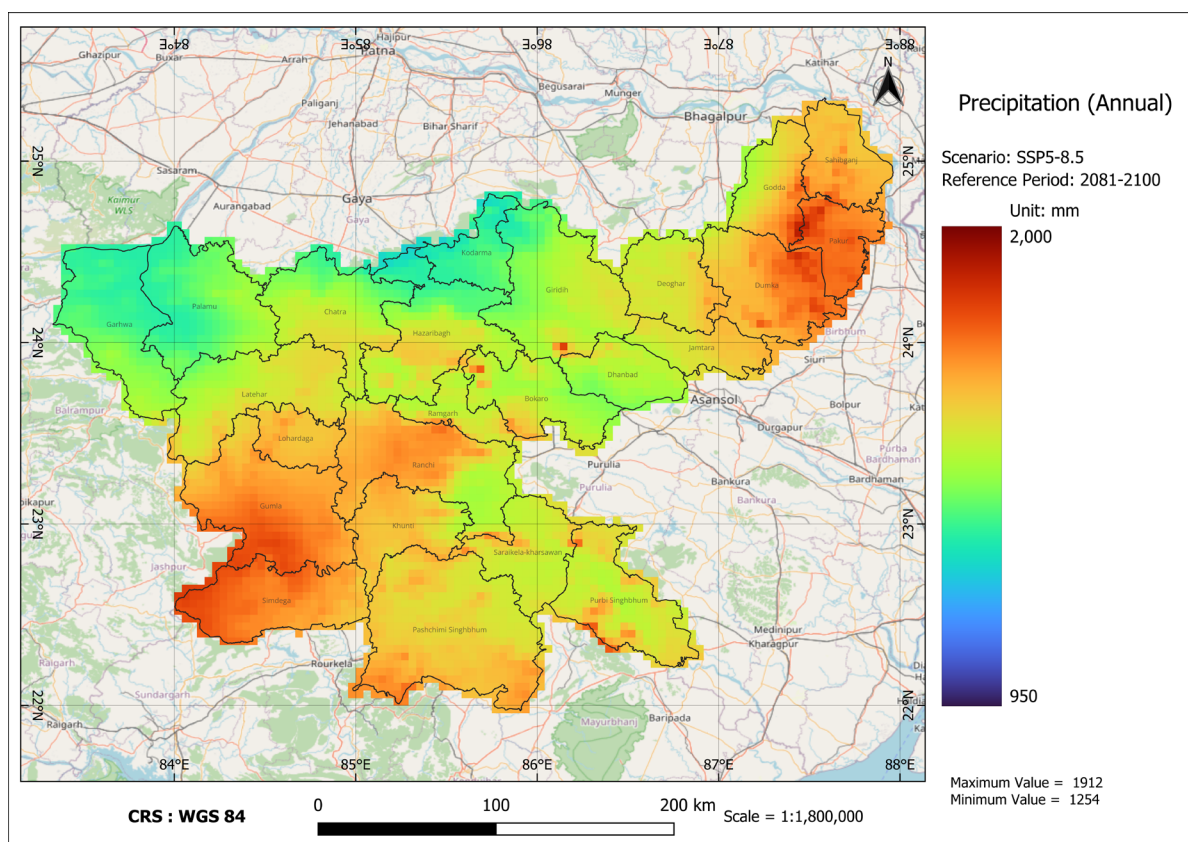


Figure 8: Expected rainfall pattern_SSP5-8.5 scenario_ 2081-2100/2090



Trend shows that overall annual precipitation is projected to increase by 14% to 44% under different scenarios by 2100. While the projected change in SSP1-2.6 is approx. 14%, change in SSP5-8.5 scenario is the max of approx. 25% for almost all districts. In the rest of the two scenarios, the change is between SSP1-2.6 and SSP5-8.5. The projection for two districts where the increase is expected to be maximum and the minimum is given below.

Figure 9: Expected variation in Rainfall(mm) -Pakur district

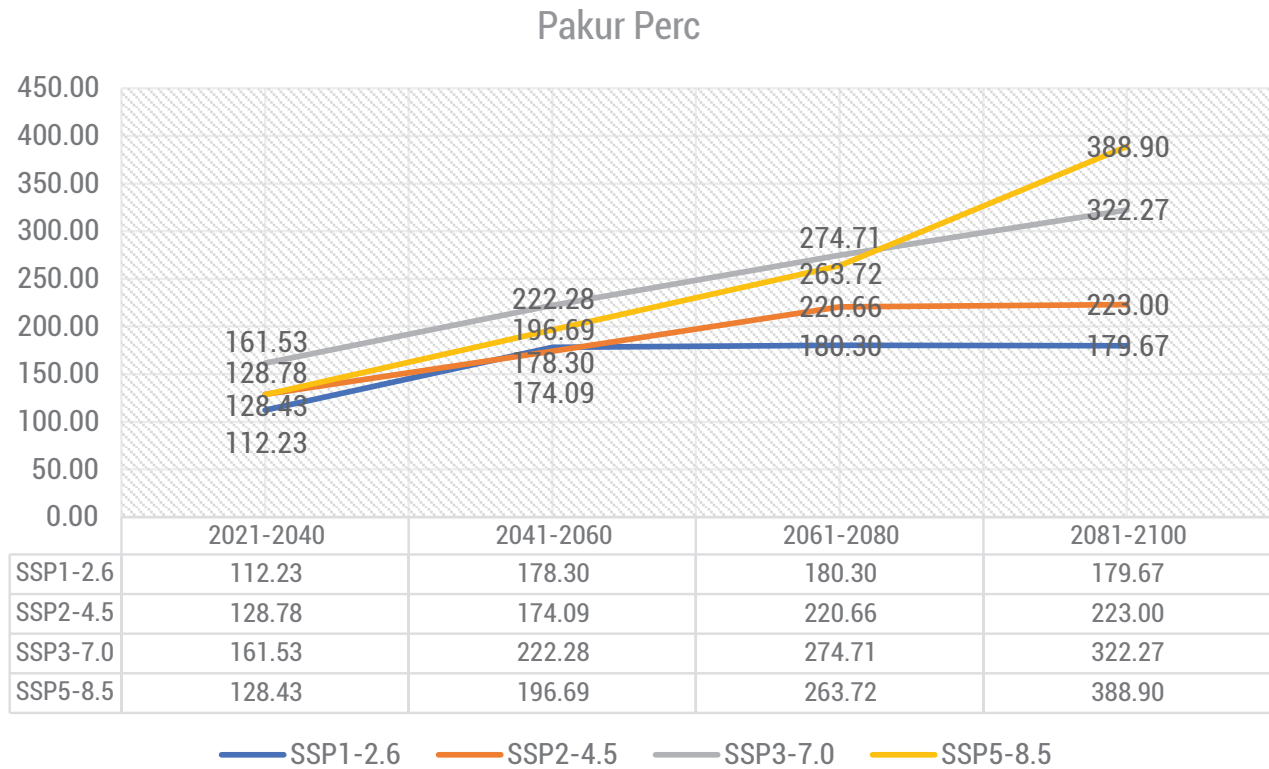
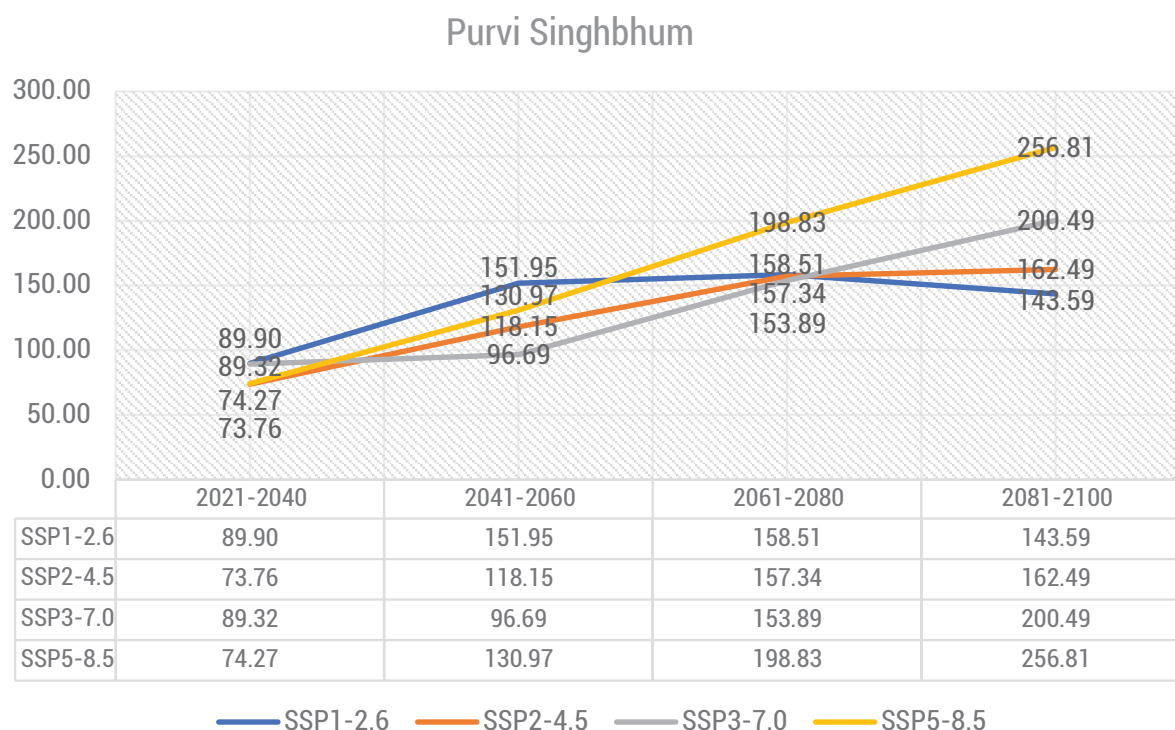


Figure 10: Expected variation in Rainfall(mm) -East Singhbhum district



3 Project Background and Objective

Observing the threat of climate change on its various sectors of the economy, region, and population, India came up with an ambitious and comprehensive policy and planning level vision document called **"National Action Plan on Climate Change (NAPCC)"**. **"The National Action Plan on Climate Change was launched by the Government of India on June 30th June 2008"**, under the guidance of the Prime Minister's Council on Climate Change (PMCCC). The plan was designed to help India adapt to and mitigate the effects of climate change. The NAPCC includes eight national missions, which are:

- 1) National Solar Mission
- 2) National Mission for Enhanced Energy Efficiency
- 3) National Mission on Sustainable Habitat
- 4) National Water Mission
- 5) National Mission for Sustaining Himalayan Ecosystem
- 6) Green India Mission
- 7) National Mission for Sustainable Agriculture
- 8) National Mission on Strategic Knowledge for Climate Change

Various Missions were delegated to the different departments to prepare the sector specific policy, action/implementation planning, setting the goal and starting the implementation work. **The Department of Science & Technology under the Ministry of Science & Technology** was entrusted with the responsibility of coordinating two out of these eight national missions on climate change. These are:

- 1) National Mission for Sustaining Himalayan Ecosystem (NMSHE)
- 2) National Mission on Strategic Knowledge for Climate Change (NMSKCC)

Objectives of both of these missions (NMSHE and NMSKCC) was to focus on building national Science & Technology capacities in the areas of climate change. While the main objective of NMSHE is to develop a capacity to scientifically assess the vulnerability of the Himalayan region to climate change and continuously assess the health status of the Himalayan ecosystem, NMSKCC focuses on building human and institutional Science & Technology capacities in climate change and developing strategic knowledge in the key areas of climate change science, adaptation and mitigation.

The current study is a part of “**National Mission on Strategic Knowledge for Climate Change (NMSKCC)**” and its primary objective is to conduct micro-level vulnerability assessments in Jharkhand and develop a deep understanding of short-term, midterm, and long-term physical and transitional risks of the climate change the to which a particular geography, sector of economy and population is exposed. The study has been funded by the Department of Science and Technology and is being executed by the State Forest Department.

This study will have various important components which include block-level projection of various climatic variables such as temperature and precipitation under various scenarios, ranking of all districts and blocks based on their vulnerability indices, and preparing block level adaptation plan. The main objective of the study is as below.

- **Short term, Mid-term and Long-term Climate Projections:** To get short term, Mid-term and Long-Term trend and projection of vital climatic variables like temperature, rainfall and vegetation cover.
- **Decentralized Climate Planning:** Conduct block-level vulnerability assessments for detailed insights and targeted interventions. Develop district-specific climate action plans focusing on key vulnerable sectors.
- **Policy and Institutional Strengthening:** Strengthen policies to promote green finance and climate risk management. Enhance effective implementation coordination among state agencies, NGOs, and local communities.
- **Data and Research:** Invest in robust data collection and monitoring systems to track climate impacts and adaptation progress. Encourage research on local climate impacts and innovative adaptation solutions.
- **Capacity Building:** Conduct training programs for local officials and communities on climate adaptation and resilience. Promote public awareness campaigns to engage communities in climate action initiatives.

3.1 Objective

The primary objective of this localized and micro-level climate modelling and projection is to know and analyse the future trends and variation/fluctuations of main climatic variables under different socio-economic scenarios and emission concentration and the net change in climate concerning temperature (both minimum and maximum), and rainfall across the state on spatial finer and temporal scales.

The main aims of this study are to:

- i. Formulate sectoral /departmental climate mitigation and adaptation policy for the state.
- ii. To prepare localized (block and district level), sectoral, and short-term & long-term adaptation strategy and plan.
- iii. To prioritize sectoral and localized (block and district level) short term mitigation actions and formulate long-term mitigation strategies.

4 Climate Modelling

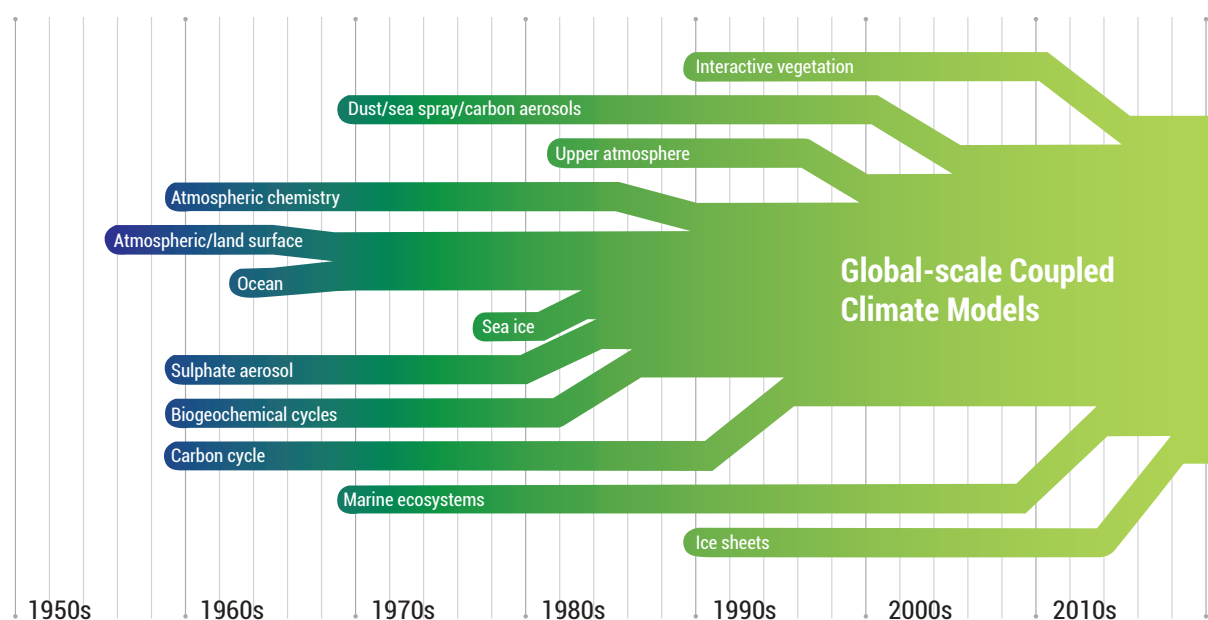
Climate models have become critical tools for predicting future warming and climate variability. These models integrate various climate projections and socio-economic scenarios to assess potential future impacts of climate change and help identify vulnerable regions, and sectors, guiding the development of targeted adaptation and mitigation interventions.

At the most basic level, climate models use physical equations to represent the processes and interactions driving Earth's climate. These cover the atmosphere, oceans, land, and ice-covered regions of the planet. Scientists put the fundamental physical equations of the Earth's climate into a computer model, which is then able to reproduce results. The most basic numerical climate models are *Energy Balance Models (EBMs)*. Indeed, EBMs do not simulate the climate but instead consider the balance between the energy entering the Earth's atmosphere from the sun and the heat released back out to space. The only climate variable they calculate is surface temperature.

A step ahead of EBMs is Radiative Convective Models, which can calculate the temperature and humidity of different layers of the atmosphere. The next level up is General Circulation Models (GCMs), also called Global Climate Models, which simulate the physics of the climate itself. This means they capture the flow of air and water in the atmosphere and the oceans, as well as the heat transfer. Early GCMs only simulated one aspect of the Earth system such as in "atmosphere-only" or "ocean-only" models but they did this in three dimensions(3D), incorporating many kilometres of height in the atmosphere or depth of the oceans in dozens of model layers.

More sophisticated "*coupled*" models have brought these different aspects together, linking together multiple models to provide a comprehensive representation of the climate system. Coupled Atmosphere-Ocean General circulation models (or "AOGCMs") can simulate, the exchange of heat and freshwater between land and ocean surface and the air above. The figure below shows how modellers have gradually incorporated individual model components into global coupled models over recent decades.

Figure 11 : Evolution of global scale coupled climate model.



There are also Regional Climate Models ("RCMs") which do a similar job as GCMs, but for a limited area of the Earth. Because they cover a smaller area, RCMs can generally be run more quickly and at a higher resolution than GCMs. A model with a high resolution has smaller grid cells and therefore can produce climate information in greater detail for a specific area.

RCMs are one way of “downscaling” global climate information to a local scale. This means taking the information provided by a GCM or coarse-scale observations and applying it to a specific area or region. The most recent subset of GCMs now incorporate biogeochemical cycles – the transfer of chemicals between living things and their environment – and how they interact with the climate system. These “Earth System Models” (ESMs) can simulate the carbon cycle, nitrogen cycle, atmospheric chemistry, ocean ecology, and changes in vegetation and land use, which all affect how the climate responds to human-caused greenhouse gas emissions. They have vegetation that responds to temperature and rainfall and, in turn, changes the intake and release of carbon and other greenhouse gases into the atmosphere.

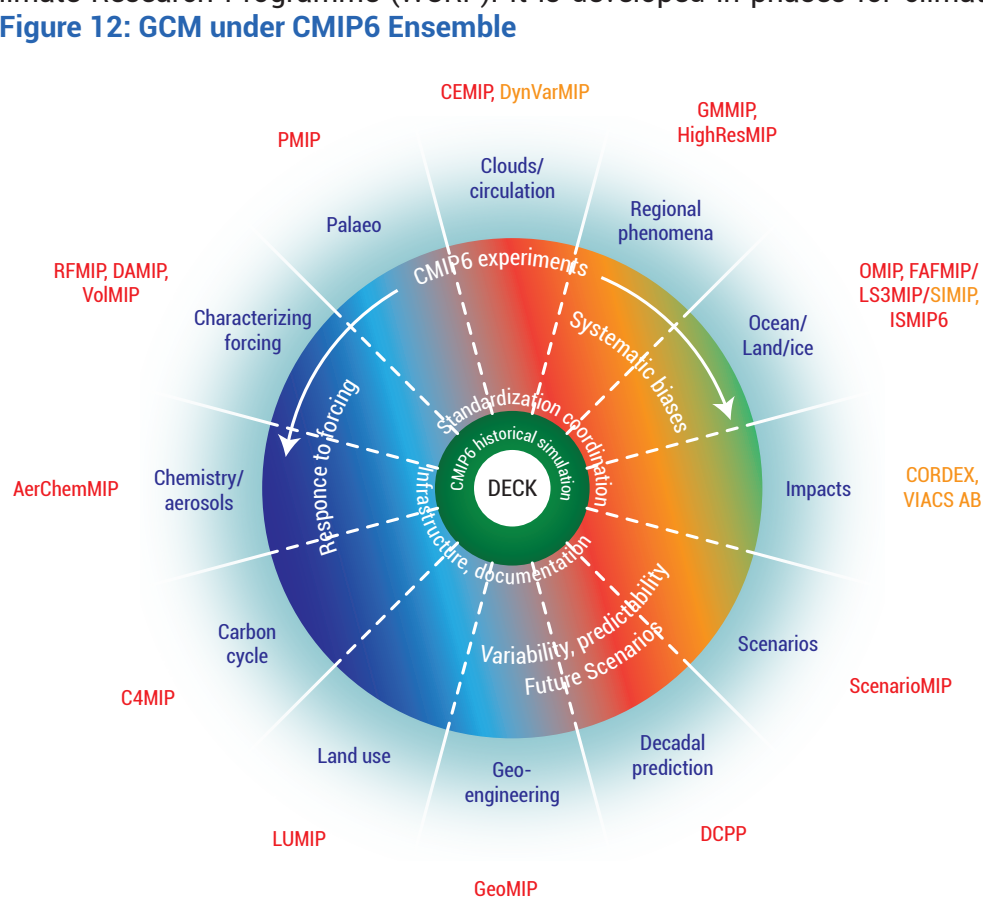
Finally, a subset of climate modeling involves *Integrated Assessment Models (IAMs)*. These add aspects of society to a simple climate model, simulating how population, economic growth, and energy use affect and interact with the physical climate. IAMs produce scenarios of how greenhouse gas emissions may vary in the future. We can then run these scenarios through ESMs to generate climate change projections providing information that can be used to formulate and inform climate and energy policies around the world.

4.1 Coupled Model Intercomparison Project (CMIP)

With so many institutions developing and running climate models across the world, there was a risk that each group approached its modelling in a different way, reducing how comparable their results would be. This is where the concept of Coupled Model Intercomparison Project (“CMIP”) was born. The modern climate modelling work start with the institutionalization of Coupled Model Intercomparison Project (CMIP) in 1995. It is a collaborative framework systematized by the Working Group on Coupled Modelling (WGCM) of the World Climate Research Programme (WCRP). It is developed in phases for climate model experiments, allowing scientists to analyse, validate, and improve GCMs in a systematic way.

The “coupled” in the name means that all the climate models in the project are coupled atmosphere-ocean GCMs. The objective of the Coupled Model Intercomparison Project (CMIP) is to better understand past, present, and future climate changes arising from natural, unforced variability or in response to changes in radiative forcing in a multi-model context.

Since its inception in 1995, CMIP has gone through several updates and each iteration become more sophisticated in the experiments that are being designed. In its early years, CMIP experiments included, for example, modelling the impact of a 1% annual



increase in atmospheric CO₂ concentrations (as mentioned above). In later iterations, the experiments incorporated more detailed emissions scenarios, such as the Representative Concentration Pathways ("RCPs").

CMIP6 is now underway, and more than 33 modelling centers around the world are involved in it currently, the **structure of the CMIP6** has been extended with respect to CMIP5 by providing an equivalent framework named CMIP Diagnostic, Evaluation and Characterization of Klima (DECK) together with a set of Endorsed MIPs to improve the description of those aspects of climate models that are beyond the core set of common experiments included in DECK.

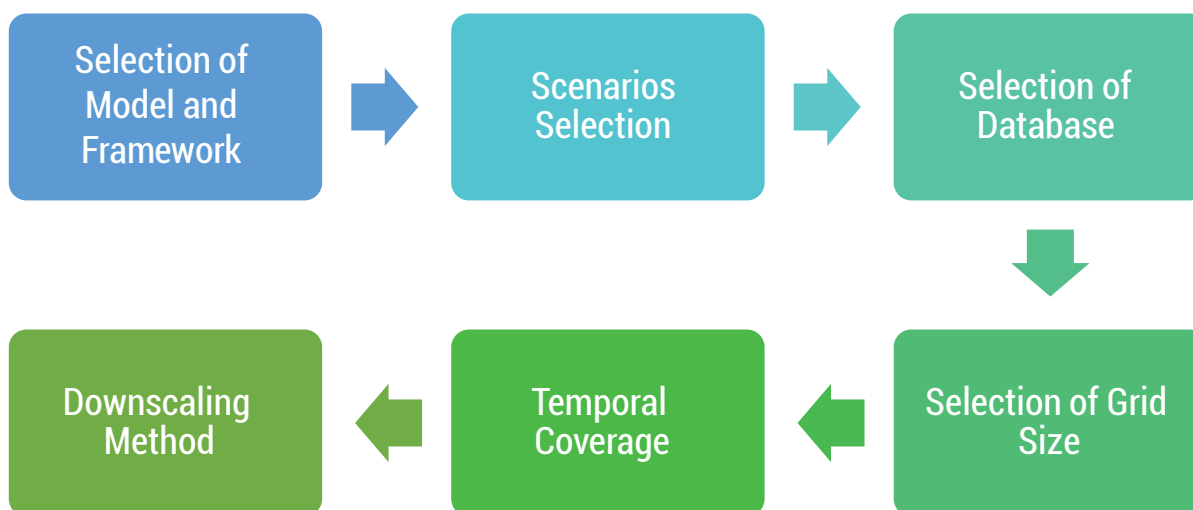
CMIP6 also has a mixed set of future scenarios comprising land use and emissions as required for the future **Shared Socioeconomic Pathways (SSPs)** which have replaced the **Representative Concentration Pathways (RCPs)** from the prior model.

4.2 IPCC Assessment Reports & CMIP

1. **First Assessment Report (FAR, 1990):** The FAR highlighted the growing evidence of human-induced climate change and the need for coordinated international action. It relied on early climate models that provided coarse-resolution projections. At the time of the release of the first assessment report by IPCC CMIP was not in place.
2. **Second Assessment Report (SAR, 1995):** The SAR presented more robust evidence of human influence on climate and introduced the concept of GHG emissions scenarios. The models used in SAR offered improved representations of climate processes and interactions. At the time of the release of the second assessment report by IPCC CMIP was not in place.
3. **Third Assessment Report (TAR, 2001):** The TAR emphasized the importance of understanding climate feedback mechanisms and introduced the concept of radiative forcing. CMIP3 models formed the basis of TAR projections and included more sophisticated representations of physical and biogeochemical processes.
4. **Fourth Assessment Report (AR4, 2007):** The AR4 provided stronger evidence of anthropogenic climate change and its potential impacts. CMIP3 models were also used in AR4 which were further refined, offering better resolution and more accurate projections.
5. **Fifth Assessment Report (AR5, 2013-2014):** The AR5 highlighted the need for urgent climate action to limit Global Warming to 2°C above pre-industrial levels. CMIP5 models were used which incorporated improved representations of aerosols, clouds, and ocean dynamics, providing more detailed projections.
6. **Sixth Assessment Report (AR6, 2021-2022):** The AR6 builds on the advancements of CMIP6 models, which offer higher resolution, improved process understanding, and a broader range of scenarios.

5 Approach & Methodology

For this projection exercise, we have followed six steps approach for arriving at the district and block level projection of the primary climate variables for the state of Jharkhand under different scenarios. All six steps have been described briefly in this section.



5.1 Selection of Models

Since each model has different strengths based on regional focus, data quality, scope, etc, the question of choosing the right model or creating the right ensemble of these models is an active area of research. Typically, taking the ensemble average of well-performing GCMs gives state-of-the-art results when compared to observed data over a given region, beating or closely matching Regional Climate Models (RCMs).

In the case of the state of Jharkhand, we have used the conclusions reached by Mishra et. al, 2014; where the ensemble means of the best GCMs outperformed participating RCMs in the exercise specifically in the performance for the Indian subcontinent.

We have taken the decision to take the ensemble mean of 14 participating GCMs wherever applicable and will be using the ensemble mean for conclusions in this report. Also, though the simulation of large-scale patterns of precipitation has improved somewhat since the AR4, models continue to perform less well for precipitation than for surface temperature.

The list of 14 different CMIP6 models used for projecting the climate variables for the state of Jharkhand is given below.

Table 1 : List of models used for the projection exercise is listed below

GCM Model	Associated CMIP6 modelling center	Release year
HadGEM3-GC31-LL	Met Office, Hadley Centre, UK	2016
INM-CM5-0	Institute for Numerical Mathematics (INM), Russian Academy of Science, Moscow, Russia.	2016
IPSL-CM6A-LR	Institut Pierre-Simon Laplace, France 1	2017
MIROC6	Japan Agency for Marine–Earth Science and Technology, The University of Tokyo), and National Institute for Environmental Studies	2017
MPI-ESM1-2-HR	Max Planck Institute for Meteorology Earth System Model, Germany.	2017
MRI-ESM2-0	Meteorological Research Institute, Japan	2017
BCC-CSM2-MR	Beijing Climate Center, China Meteorological Administration	2017
CMCC-ESM2	Euro-Mediterranean Center on Climate Change Foundation, Italy	2017
UKESM1-0-LL	Met Office and Natural Environment Research Council, UK	2018
FIO-ESM-2-0	The First Institute of Oceanography (FIO) and Qingdao National Laboratory for Marine Science and Technology (QNLN), China	2018
GFDL-ESM4	National Oceanic and Atmospheric Administration (NOAA), Geophysical Fluid Dynamics Laboratory, USA	2018
ACCESS-CM2	Australian Community Climate and Earth System Simulator (ACCESS).	2019
EC-Earth3-Veg	Swedish Meteorological and Hydrological Institute/SMHI, Norrköping, Sweden	2019
GISS-E2-1-G	NASA Goddard Institute for Space Studies, USA	2019

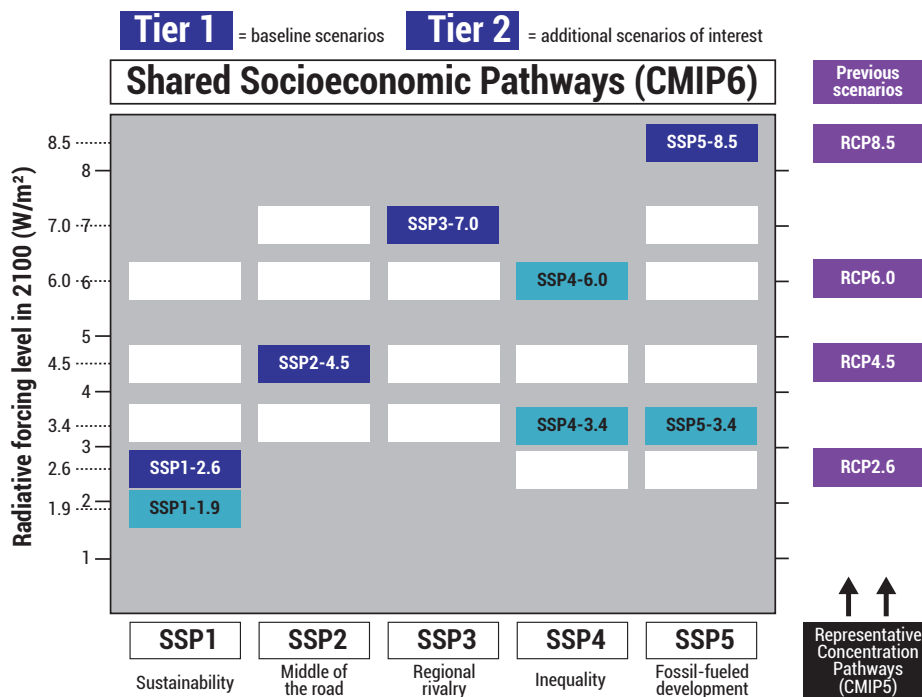
Below are some of the key advancements in CMIP6 models.

- Higher Resolution:** CMIP6 models offer higher spatial and temporal resolution, allowing for more detailed and accurate projections of climate variability and extremes.
- Improved Process Representation:** CMIP6 models incorporate enhanced representations of key physical processes, such as cloud formation, aerosol interactions, and ocean dynamics. These improvements lead to more realistic simulations of the climate system.
- Expanded Scenarios:** CMIP6 includes a broader range of scenarios, combining SSP narratives with RCPs to provide a more comprehensive framework for exploring future climate pathways.
- Better Uncertainty Quantification:** CMIP6 models offer improved methods for quantifying uncertainties, enhancing the robustness of climate projections and facilitating more informed decision-making.
- Inclusion of New Components:** CMIP6 models integrate additional components, such as interactive vegetation, ice sheets.

5.2 Scenarios Selection

The standard sets of time-dependent scenarios used by the climate modelling community as input to global climate model simulations provide the basis for the majority of the future projections presented in IPCC assessment reports. Scenarios provide alternative long-term future outlooks to explore the implications of changes in climatic, environmental, and socio-economic conditions. They have long been identified as a strategic management tool for exploring future changes and associated impacts, devising robust policies and decision-making, and supporting adaptation planning under a degree of uncertainty.

Figure 13: SSP- RCP scenario matrix, utilizing CMIP6



Integrated Assessment Modelling Community (IAMC) has developed a set of standard scenarios that have become more comprehensive with each new generation. The first SA90 scenario was replaced by the IS92 emission scenarios of the 1990s, which was in turn succeeded by the Special Report on Emissions Scenarios in 2000 (SRES), by the Representative Concentration Pathways in 2010 (RCPs), and then augmented by Shared Socioeconomic Pathways (SSPs) in 2017.

While the initial three SA90, IS92, and SRES are emission-based scenarios, RCP was based on the value of climate forcing including emission concentration as considered in SRES, and the latest SSP are "reference pathways describing plausible alternative trends in the evolution of society and ecosystems over a century timescale, in the absence of climate change or climate policies" (O'Neill et al., 2014).

Figure 14: Evolution of Climate Projection Scenario



While this first IPCC first assessment report was based on IS92-based projections were used in the IPCC Second and Third Assessment Reports (SAR and TAR). Projections based on SRES scenarios were used in the IPCC TAR and Fourth Assessment Reports (AR4). The IPCC's Fifth Assessment Report (AR5) focused on four future warming scenarios, known as the Representative Concentration Pathway (RCP) scenarios. SSP -based projections were used in IPCC Sixth Assessment Report (AR6).

For this study and report, we have mainly evaluated RCPs and SSPs scenario. A brief of both scenario and its main features has been discussed before finalizing the composite scenarios that we have considered for the projection in our study.

5.2.1 The RCPs (Representative Concentration Pathways)

The RCPs (Representative Concentration Pathways) “provide information on possible development trajectories for the main climate forcing agents (van Vuuren et al., 2011). They include trajectories for “**radiative forcing**” of the global climate system, a measure of the effect on the energy balance of the system of changes in the composition of atmosphere, such as due to emissions of greenhouse gases. Radiative forcing is usually expressed as a change relative to pre-industrial times in net energy flux into the climate system per unit of area.

Each of the four RCPs has a different forcing at the end of the 21st century and is named according to its forcing level in 2100. Atmospheric carbon dioxide levels for RCP8.5 are similar to those of the SRES A1FI scenario: they rise from current-day levels of 400 ppm to 935 ppm (ppm) by the end of this century. A detailed description of the all four RCP scenarios is mentioned in the below table for better understanding.

Scenario	Description
RCP2.6	Climate Forcing: 2.6 W/m² A “peak and decline” scenario where stringent mitigation and Carbon Dioxide Removal technologies mean atmospheric CO₂ concentration peaks and then falls during this century. By 2100, atmospheric CO₂ reaches around 420 parts per million (ppm) – about 20 ppm above current levels. In this scenario, global temperatures are likely to rise by 1.3-1.9°C above pre-industrial levels by 2100.
RCP4.5:	Climate Forcing: 4.5 W/m² A “stabilisation scenario” where policies are put in place so atmospheric CO₂ concentration levels off around the middle of the century, though temperatures do not stabilise before 2100. These policies include a shift to low-carbon energy technologies and the deployment of carbon capture and storage. In RCP4.5, atmospheric CO₂ sits at 540 ppm by 2100 – roughly 140 ppm higher than now – and the global temperatures are likely to rise by 2-3°C above pre-industrial levels.
RCP6.0	Climate Forcing: 6.0 W/m² A “climate-policy intervention scenario” where emissions peak around 2060 and then decline. CO₂ concentration continues to rise through the rest of the century, but at a slower rate. There are only “very modest” efforts towards mitigation between 2010 and 2060, but improvements in energy intensity and a global market for emissions permits help limit atmospheric CO₂ to 670 ppm by 2100. In RCP6.0, global temperatures by 2100 are likely to be 2.6-3.7°C above pre-industrial.
RCP8.5	Climate Forcing: 8.5 W/m² A scenario of “comparatively high greenhouse gas emissions.” “brought about by rapid population growth, high energy demand, fossil fuel dominance and an absence of climate change policies. This “business as usual” scenario is the highest of the four RCPs and sees atmospheric CO₂ rises to around 935 ppm by 2100. The likely range of global temperatures by 2100 for RCP8.5 is 4.0-6.1°C above pre-industrial levels.

5.2.2 SSP (Shared Socio-economic Pathways)

The SSPs (Shared Socio-economic Pathways) are “reference pathways describing plausible alternative trends in the evolution of society and ecosystems over a century timescale, in the absence of climate change or climate policies” (O'Neill et al., 2014). They also represent the different levels of challenges to mitigation and adaptation: SSP1 (Sustainability – low mitigation and adaptation challenges); SSP2 (Middle of the road – intermediate mitigation and adaptation challenges); SSP3 (Fragmentation/ regional rivalry – high mitigation and adaptation challenges); SSP4 (Inequality – high adaptation and low mitigation challenges); and SSP5 (Conventional/fossil fuelled development – high mitigation and low adaptation challenges).

They outline five plausible social, economic and technical narratives and alternative development pathways that humankind could follow over the next century, in terms of, for example, the level of international co-operation, market freedom, regional equality, and technological development.

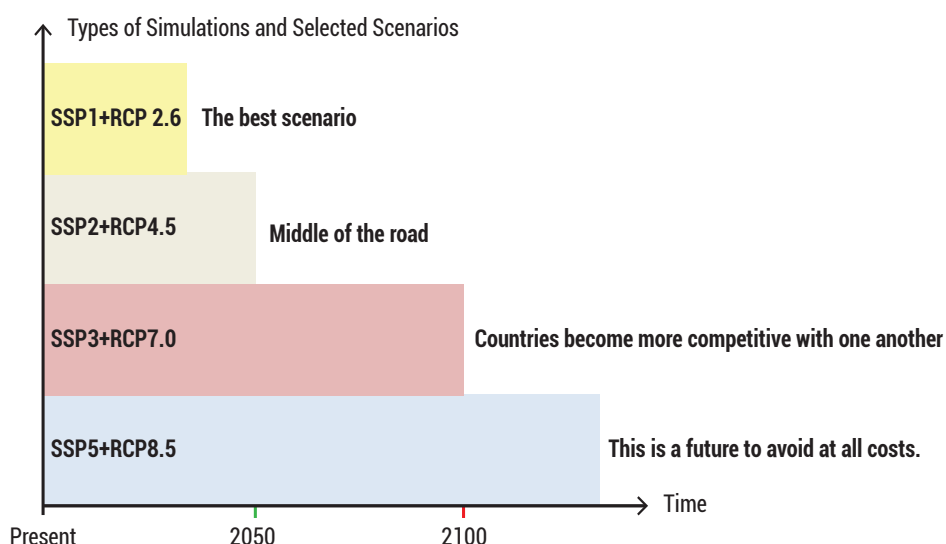
Each scenario has an underlying SSP narrative, as well as consistent assumptions regarding demographics, urbanization, economic growth, and technology development. The qualitative SSP narratives which guide the quantitative differences are given below:

Scenario	Description
SSP1	• “The world shifts gradually, but pervasively, toward a more sustainable path, emphasizing more inclusive development that respects perceived environmental boundaries. • Management of the global commons slowly improves, educational and health investments accelerate the demographic transition, and the emphasis on economic growth shifts toward a broader emphasis on human well-being • Driven by an increasing commitment to achieving development goals, inequality is reduced both across and within countries. Consumption is oriented toward low material growth and lower resource and energy intensity”
SSP2	• “The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. • Development and income growth proceeds unevenly, with some countries making relatively good progress while others fall short of expectations. Global and national institutions work toward but make slow progress in achieving sustainable development goals. Environmental systems experience degradation, although there are some improvements and overall, the intensity of resource and energy use declines. Global population growth is moderate and levels off in the second half of the century. Income inequality persists or improves only slowly and challenges to reducing vulnerability to societal and environmental changes remain”
SSP3	• “A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues. Policies shift over time to become increasingly oriented towards national and regional security issues. • Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development. Investments in education and technological development decline. Economic development is slow, consumption is material-intensive, and inequalities persist or worsen over time. Population growth is low in industrialized and high in developing countries. A low international priority for addressing environmental concerns leads to strong environmental degradation in some regions”

Scenario	Description
SSP4	• “Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. • Over time, a gap widens between an internationally-connected society that contributes to knowledge- and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly educated societies that work in a labour intensive, low-tech economy. Social cohesion degrades and conflict and unrest become increasingly common. • Technology development is high in the high-tech economy and sectors. The globally connected energy sector diversifies, with investments in both carbon-intensive fuels like coal and unconventional oil, but also low-carbon energy sources. Environmental policies focus on local issues around middle- and high-income areas”
SSP5	• “This world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. • Global markets are increasingly integrated. There are also strong investments in health, education, and institutions to enhance human and social capital. • At the same time, the push for economic and social development is coupled with the exploitation of abundant fossil fuel resources and the adoption of resource and energy intensive lifestyles around the world. • All these factors lead to rapid growth of the global economy, while global population peaks and declines in the 21st century. Local environmental problems like air pollution are successfully managed. • There is faith in the ability to effectively manage social and ecological systems, including geo-engineering if necessary”

5.3 Scenario Considered for this study

Historically, most climate change studies focussed on climatic drivers only. However, in integrated assessments, climate scenarios need to be coupled with appropriate socioeconomic scenarios (Nakicenovic and Swart, 2000). Several such scenarios and frameworks have been developed and applied recognising these limitations (e.g., Arnell et al., 2004; Carter et al. 2007; Mahmoud et al., 2009; Moss et al. 2010).



The most notable is the latest global RCP–SSP scenario framework which integrates the climate, socio-economic, and policy components. However, a full application of such a global framework at sub-national scales raises two important challenges in the integrated assessment of interacting human natural systems under uncertain future changing conditions: (i) added complexity in capturing the multiple (i.e., climate-socio-economic-policy) dimensions of change, and (ii) issues of scale.

In this projection exercise, we have presented an SSP-RCP coupled scenario framework that recognizes these challenges based on multi-scale and participatory scenario methods. This pairing of SSPs and RCPs is designed to meet the needs of the impacts, adaptation, and vulnerability, enabling them to couple alternative socioeconomic scenarios with the climate scenarios developed using RCPs to explore the socioeconomic challenges to climate mitigation and adaptation.

Scenario	Description
SSP1-2.6	The best scenario , global CO ₂ emissions are cut severely, but not as fast, reaching net-zero after 2050. It imagines the same socioeconomic shifts towards sustainability as SSP1 but temperatures stabilize around 1.8°C higher by the end of the century.
SSP2-4-5	This is a "middle of the road" scenario. CO ₂ emissions hover around current levels before starting to fall mid-century, but do not reach net-zero by 2100. Socioeconomic factors follow their historic trends, with no notable shifts. Progress toward sustainability is slow, with development and income growing unevenly. In this scenario, temperatures rise 2.7°C by the end of the century.
SSP3-7.0	On this path, emission and temperature rise steadily and CO ₂ emission roughly double from current levels by 2100. Countries become more competitive with one another, shifting towards national security and ensuring their own food supplies. By the end of the century, average temperatures have risen by 3.6°C
SSP5-8.5	This is a future to avoid at all costs. Current CO ₂ emissions levels roughly double by 2050. The global economy grows quickly, but this s growth is fueled by exploiting fossil fuels and energy-intensive lifestyles. By 2100, the average global temperature is a sizzling 4.4°C

5.4 Spatial Resolution/Grid Size

Because of the complexity of the climate system and the limitation of computing power, a model cannot possibly calculate all of these processes for every cubic meter of the climate system. Instead, a climate model divides up the Earth into a series of boxes or "grid cells". A global model can have dozens of layers across the height and depth of the atmosphere and oceans. The size of the grid cells in a model is known as its "spatial resolution". A relatively coarse global climate model typically has grid cells that are around 100km in longitude and latitude in the mid-latitudes. Because the Earth is a sphere, the cells for a grid based on longitude and latitude are larger at the equator and smaller at the poles. However, it is increasingly common for scientists to use alternative gridding techniques – such as **cubed-sphere** and **icosahedral** which don't have this problem.

A high-resolution model will have more smaller boxes and it can produce more specific climate information for a particular region. The figure below shows how the spatial resolution of models improved between the first and fourth IPCC assessment reports. It can be seen how the detail in the topography of the land surface emerges as the resolution is improved.

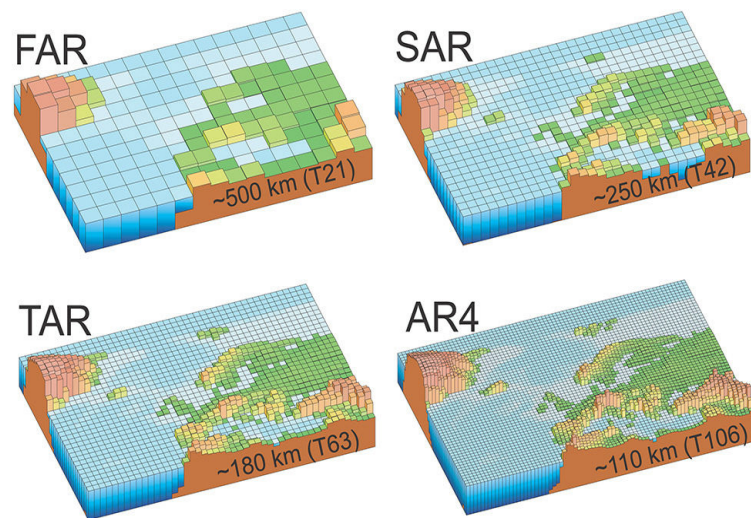
For this projection exercise, on the trade-off between data and processing requirements and usefulness, the resolution of 2.5 minutes or ~20 sq. km (at the equator) has been chosen.

5.5 Temporal Coverage: Future projections up to 2100.

In the real world, time is continuous, yet a model needs to chop time up into bite-sized chunks to make the calculations manageable. In the real scenario, the model takes the climate information it has from the previous and present time steps to extrapolate forward to the next one, and so on through time.

For this projection, we have done short-term, medium-term, and long-term projections and have chosen four temporal brackets every 20 Years i.e. 2021-2040, 2041-2060, 2061-2080, and 2081-2100. The WorldClim models project averages over 20-year periods of 2021-2040, 2041-2060, 2061-2080, and 2080-2100. For variable plots, we have taken class intervals as 2030, 2050, 2070, and 2090 which will analogously refer to the corresponding 20-year time periods from here on.

Figure 15 : Spatial Resolution used in Various IPCC Assessment Report.



5.6 Selection of Database

Various global climate databases have been used in GCMs under CMIP6 framework. While evaluating the various databases to run the model for the state of Jharkhand, we have evaluated below four databases base which seem more relevant because they cover high spatial resolution and provide a projection for SSP-RCP coupled scenarios. A brief comparison of all four databases is given below.

5.6.1 ISIMIP

The grid size is coarser and provide raw outputs of CMIP6 models. It only covers SSP scenarios.

- **Spatial Resolution:** Low/Macro (typically 100-200 km).
- **Temporal Coverage:** Historical (1850-2014) and future projections (2015-2100).
- **Scenarios:** Comprehensive coverage of SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP4-3.4, SSP4-6.0, SSP5-3.4, and SSP5-8.5.

5.6.2 CORDEX

It provides regional downscaled climate projections based on RCM and GCMs from CMIP5 and CMIP6. The focus is regional focus but it poorly covers Indian subcontinent.

- **Spatial Resolution:** Higher (typically 25-50 km).
- **Temporal Coverage:** Future projections up to 2100.
- **SSP Scenarios:** Various SSPs depending on the specific regional model.

5.6.3 WorldClim

Provides high-resolution future climate projections based on various Global Climate Models (GCMs) and emission scenarios. Below are spatial scale, temporal coverage and scenarios covered under this database.

- **Special Resolution:** High (up to 1 km²).
- **Temporal Coverage:** Future projections for 2021-2040, 2041-2060, 2061-2080, and 2081-2100.
- **Scenarios:** Includes downscaled data for SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP 5-8.5.

5.6.4 CHELSA

High-resolution climate data, including future projections statistically downscaled from GCMs. It is very similar to WorldClim but with one SSP scenario less than WorldClim.

- **Resolution:** High (1 km²).
- **Temporal Coverage:** Future projections up to 2100.
- **SSP Scenarios:** Includes SSP1-2.6, SSP2-4.5 and SSP5-8.5.

Given the goal of the sectoral and district-level adaptation planning for the state of Jharkhand is to provide high-quality climate projections for short, medium, and long-term climate hazards, the choice was narrowed down to CHELSA and WorldClim. Both datasets trade temporal resolution in favour of high spatial resolution projections, which matched the objective and goal of this study.

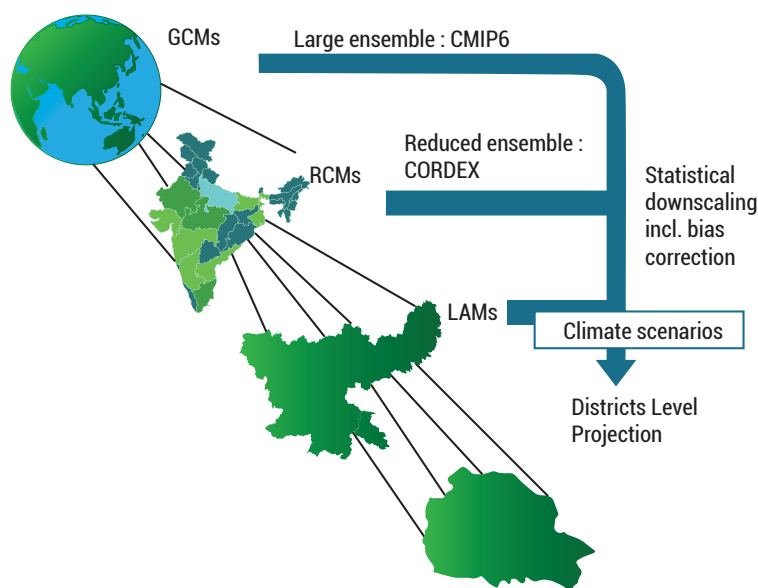
Both data sets combine CMIP6 models with common initial parameters and give bias-corrected outputs. WorldClim has been selected as it had the SSP3-7.0 scenario included additionally. On the trade-off between data and processing requirements and usefulness, the resolution of 2.5 minutes or ~20 sq. km (at the equator) has been chosen.

5.7 Downscaling

One of the main limitations of Global Climate Models (GCM) is that the grid cells are made of typically around 100km in longitude and latitude in the mid-latitudes. Such a coarse resolution means the GCMs miss the geographical features that characterise a particular location. Therefore, for getting projection results at a smaller grid size or spatial resolution of various climatic variables, downscaling is required. Downscaling global climate models to regional and local levels ensures relevance and localised projection of climatic variability enabling more precise planning and adequate resource allocation, fostering resilience in at-risk geography, infrastructures and communities.

We evaluated both methods of downscaling i.e. **“Dynamical downscaling”** which is essentially running regional models (RCM) that are similar to GCMs, but for specific regions. Because these Regional Climate Models (RCMs) cover a smaller area, they can have higher resolution than GCMs and still run in a reasonable time. **Statistical downscaling** which involves using observed data to establish a statistical relationship between the global and local climate. Using this relationship, we can derive local changes based on the large-scale projections coming from GCMs or observations.

In the case of the state of Jharkhand, we have used the conclusions reached by Mishra et. al, 2014; where he has advocated that the ensemble means the best GCMs outperformed participating RCMs in the exercise which was specific for the performance of climate models for the Indian subcontinent.



In this projection exercise, temperature and rainfall data have been downscaled at the grid scale of 2.5m*2.5 m ~ 20 km using the statistical downscaling methodology to get the result at the block level. For the historical (reference) simulations, the model is driven by meteorological data from the Copernicus Climate Change Service.

5.8 The climate variables modelled

The below climatic variables have been projected for future scenarios:

T_{max} - maximum monthly temperature

T_{min} - minimum monthly temperature

P_{rec} - total monthly rainfall

B_{loc} - 19 annual bioclimatic variables derived from the primary variables given above

A summary of the bioclimatic variables is given below.

S. No	Variables
1	Annual Mean Temperature [$^{\circ}\text{C} \times 10$]
2	Mean Diurnal Range [$^{\circ}\text{C}$]
3	Isothermality
4	Temperature Seasonality [standard deviation]
5	Max Temperature of Warmest Month [$^{\circ}\text{C} \times 10$]
6	Min Temperature of Coldest Month [$^{\circ}\text{C} \times 10$]
7	Temperature Annual Range [$^{\circ}\text{C} \times 10$]
8	Mean Temperature of Wettest Quarter [$^{\circ}\text{C} \times 10$]
9	Mean Temperature of Driest Quarter [$^{\circ}\text{C} \times 10$]
10	Mean Temperature of Warmest Quarter [$^{\circ}\text{C} \times 10$]
11	Mean Temperature of Coldest Quarter [$^{\circ}\text{C} \times 10$]
12	Annual Precipitation [mm/year]
13	Precipitation of Wettest Month [mm/month]
14	Precipitation of Driest Month [mm/month]
15	Precipitation Seasonality [coefficient of variation]
16	Precipitation of Wettest Quarter [mm/quarter]
17	Precipitation of Driest Quarter [mm/quarter]
18	Precipitation of Warmest Quarter [mm/quarter]
19	Precipitation of Coldest Quarter [mm/quarter]

The equations used to calculate the bioclimatic variables (where applicable) are:

t = monthly temperature [$^{\circ}\text{C}$]

p = monthly precipitation [mm]

$$\text{Bio 1} : (\sum_{i=1}^{12} t_i) / 12$$

$$\text{Bio 2} : (\sum_{i=1}^{12} (t_{max} - t_{min})) / 12$$

$$\text{Bio 3} : \left(t * \frac{(t_{max} - t_{min})}{t_{max}} - t_{min} \right) * 100$$

$$\text{Bio 4} : \left(\sqrt{\frac{1}{11} \sum_{i=1}^{12} \left(t_i - (\sum_{i=1}^{12} t_i / 12) \right)^2} \right) * 100$$

$$\text{Bio 7} : t_{max} - t_{min}$$

$$\text{Bio 12} : \sum_{i=1}^{12} p_i$$

$$\text{Bio 15} : \frac{\left(\sqrt{\frac{1}{11} \sum_{i=1}^{12} \left(p_i - (\sum_{i=1}^{12} p_i / 12) \right)^2} \right)}{(\sum_{i=1}^{12} p_i) / 12}$$

6 Results & Discussion

Projections of various climatic variables using the global coupled model have evolved in the last 2-3 decades and projected datasets have become an essential tool for understanding future climate scenarios. They are derived from complex GCM and RCM climate models that simulate the interactions between the atmosphere, oceans, land surface, and ice. These datasets help in assessing the potential future threat of climate change in various sectors and regions and enable policymakers to develop informed strategies for climate mitigation and adaptation.

As per the report released by the Department of Science and Technology (DST), Govt. of India, Jharkhand is the most climate-vulnerable state in the country which necessitated this study to understand the climate variability across the state at the micro level. These scenarios-based projections of climatic variables will be effectively used for district-level vulnerability assessment and ranking of blocks and districts according to the climate risk index.

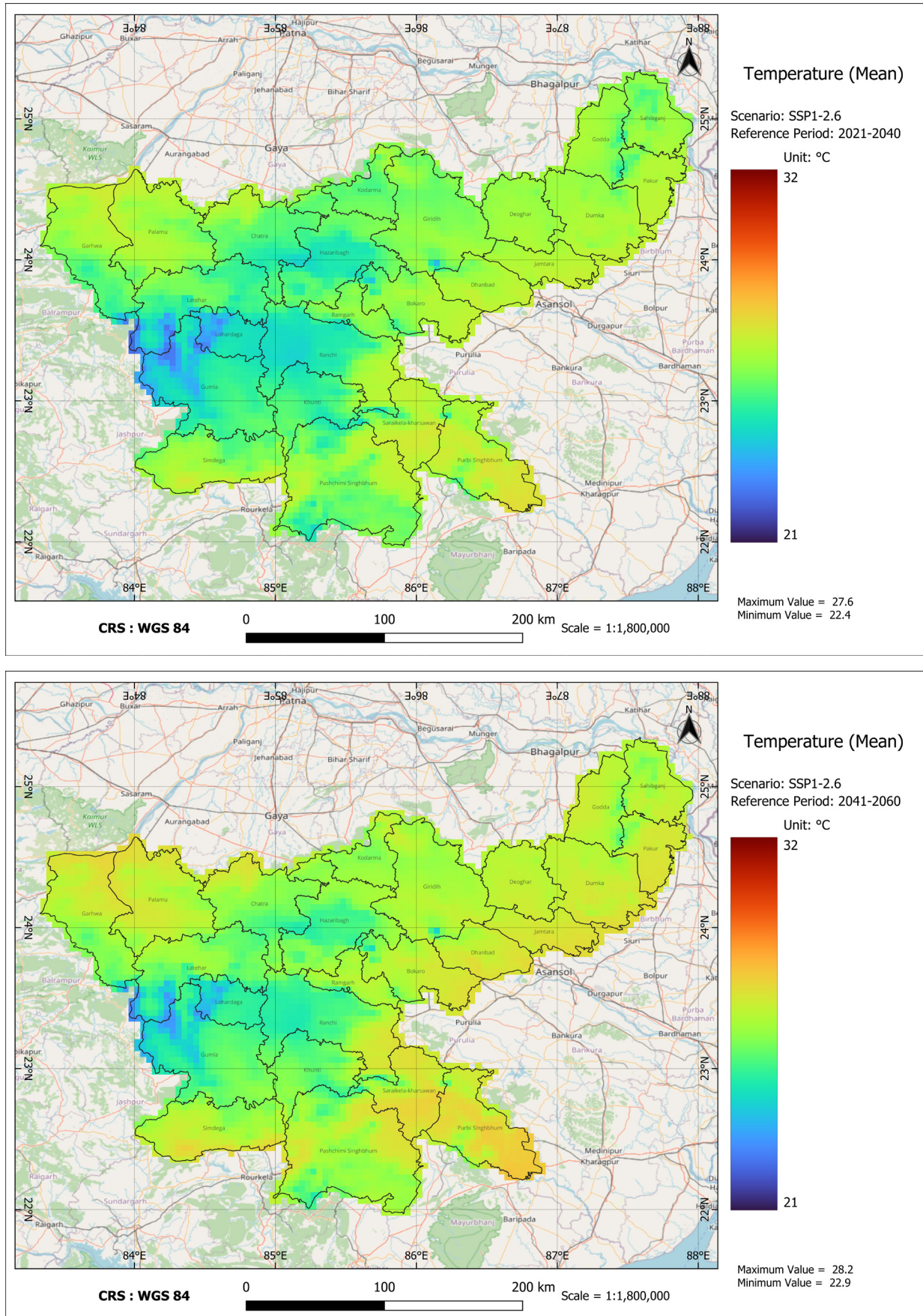
The results demonstrate the importance of spatial analysis for understanding localized climate variability and help in identifying blocks, districts, and sectors that can be severely affected due to variations in rainfall and temperature. Future projection of climatic variables will help recognize the temporal variations, and spatial distribution of various climatic parameters and their impact on agriculture, health, water resources, forests, and society at large for timely intervention and support. This projection dataset will become an important guiding tool for policymakers and various government departments and will provide valuable insights for adaptation, socio-economic planning, and decision-making.

6.1 District & Block Level Results

District and block-level projections have been done for the entire State and results are given in the below sections. It can be observed that the difference in temperature rise under various scenarios for a particular temporal range is not very significant at the block level but very significant at the district level across the seasons and districts.

The increase in temperature is more in the northwestern region of the states. The highest expected increase is in the Palamu and Garhwa districts and the lowest in the Ramgarh district. Districts where the expected rise in temperature is greater are identified as the most vulnerable to drought with the possibility of increases in consecutive dry days, higher maximum temperatures and reduced rainfall. These detailed projection results will be combined with block-level vulnerability factors to derive block-level climate risk indices which will be added to the report at the end of the district-level projections exercise.

Figure 16 : Expected Temperature (Tavg) distribution in SSP 1-2.6 in all four temporal windows



District Level Climate Projection for Jharkhand

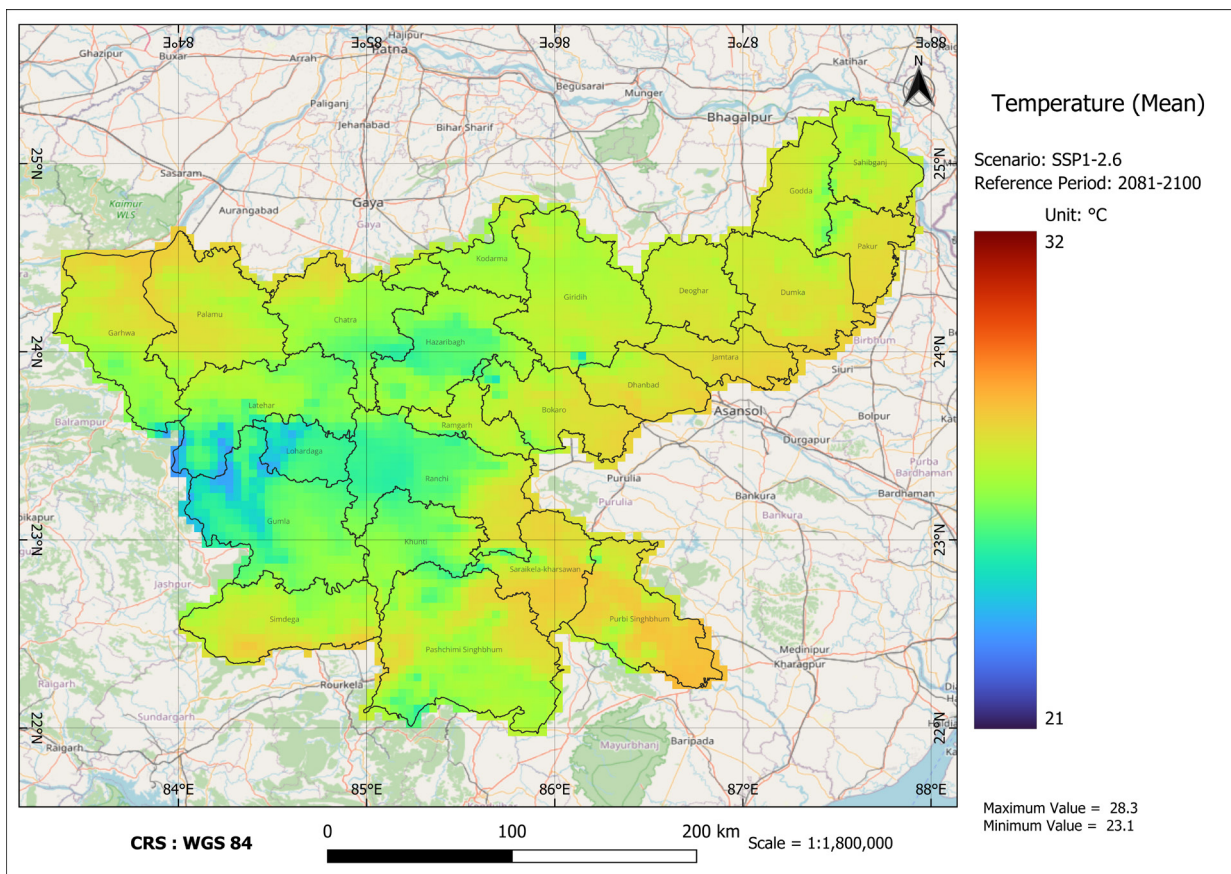
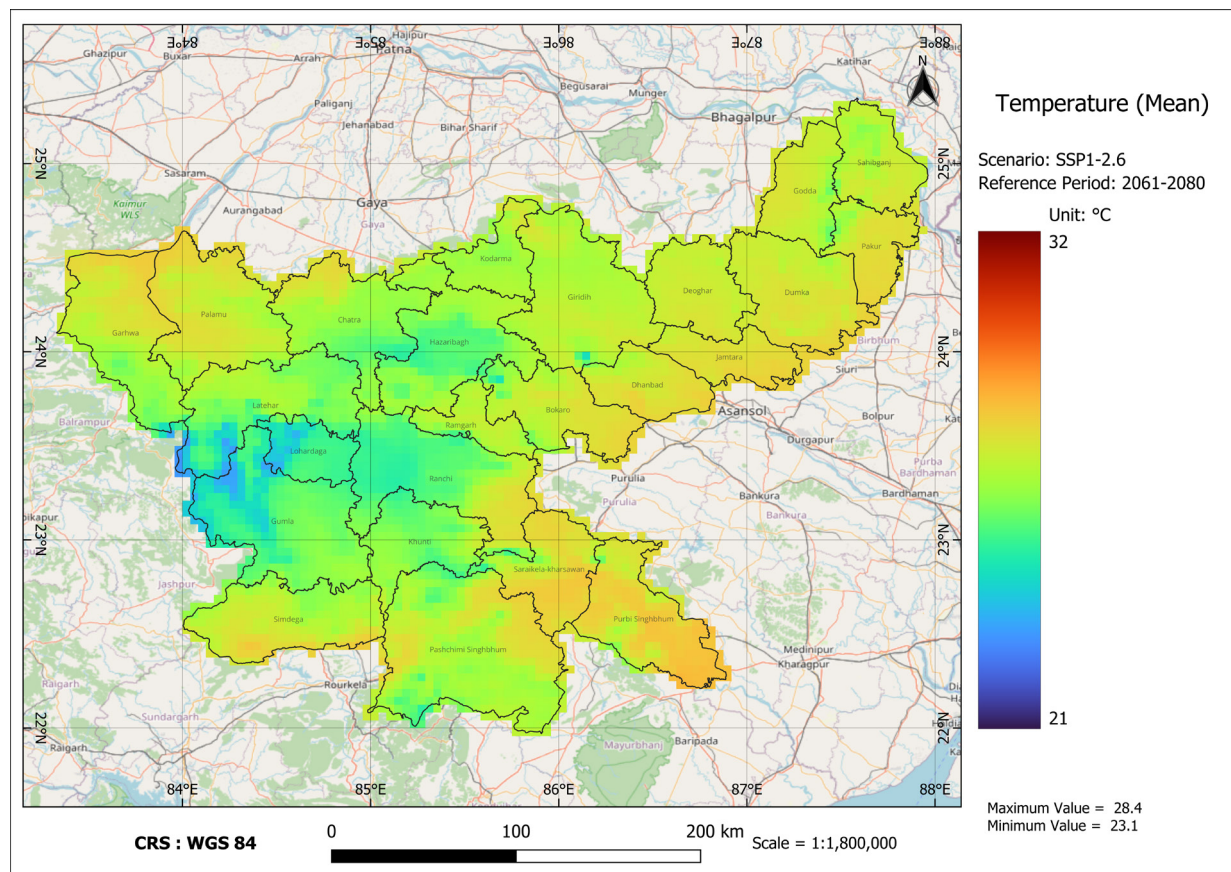
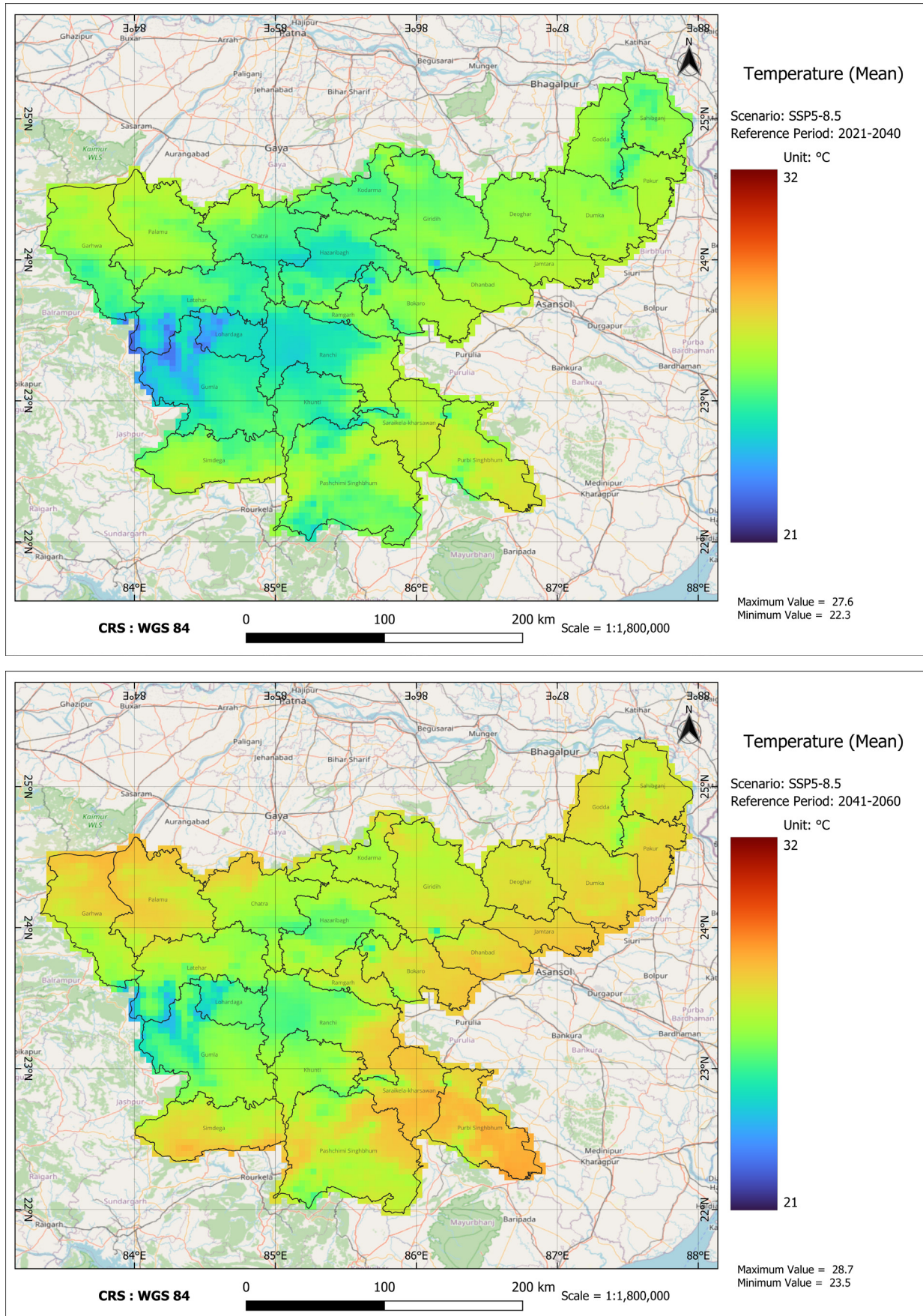


Figure 17 : Expected Temperature (Tavg) distribution in SSP 5-8.5 in all four temporal windows



District Level Climate Projection for Jharkhand

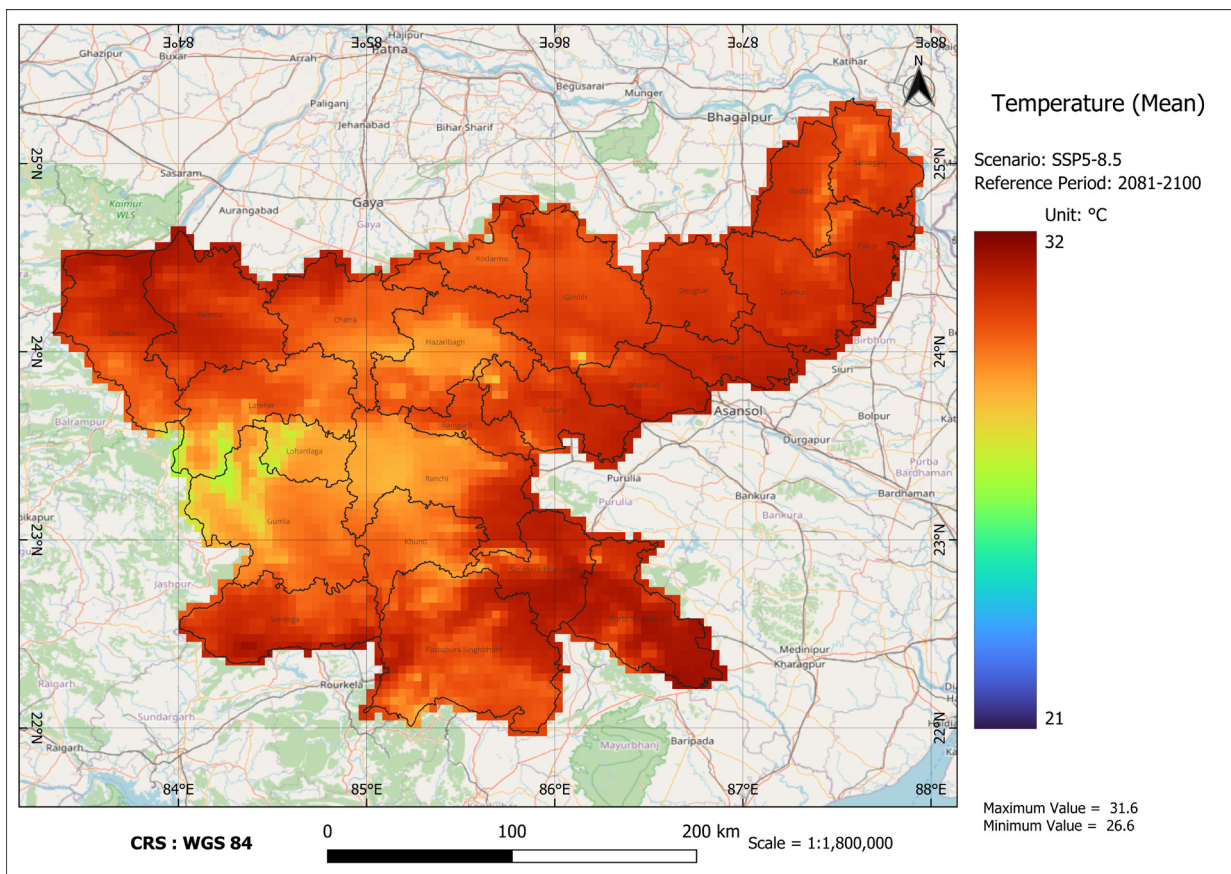
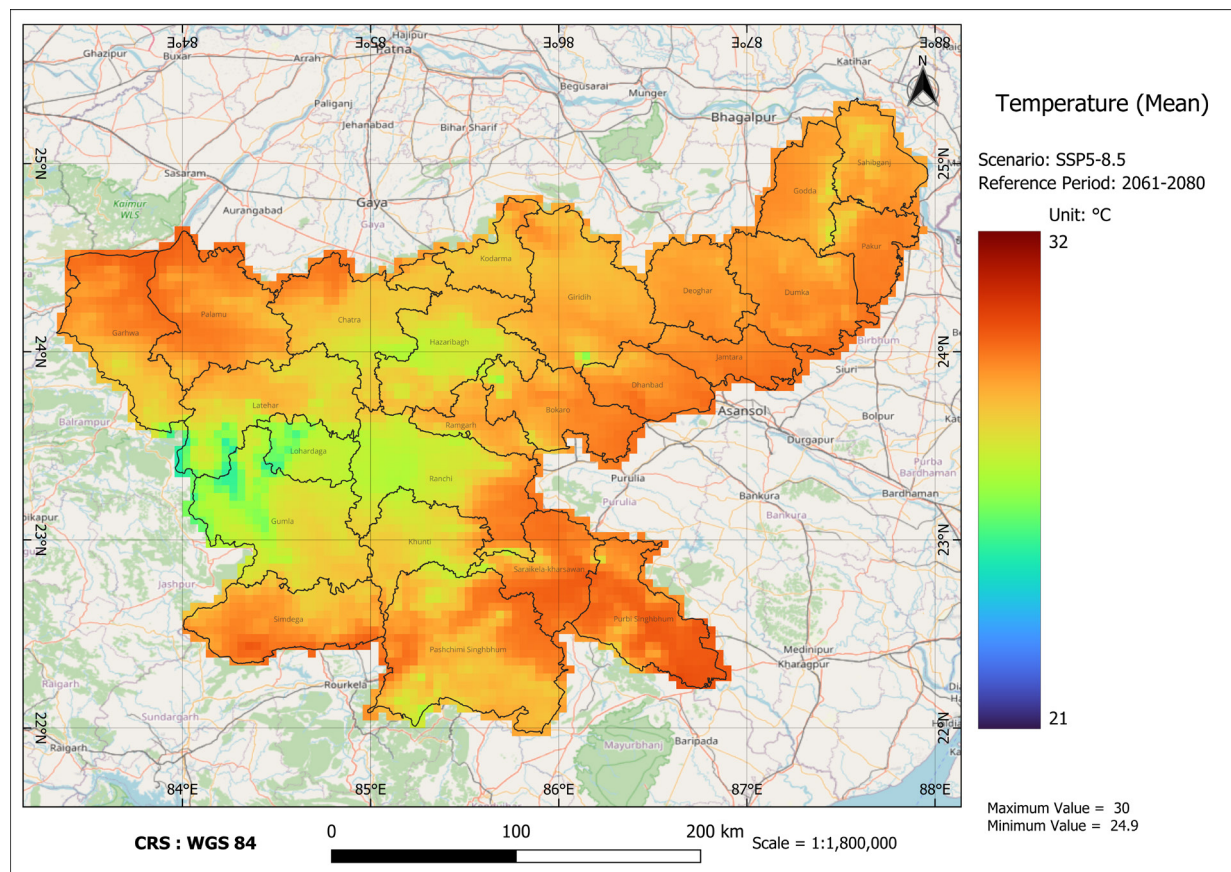
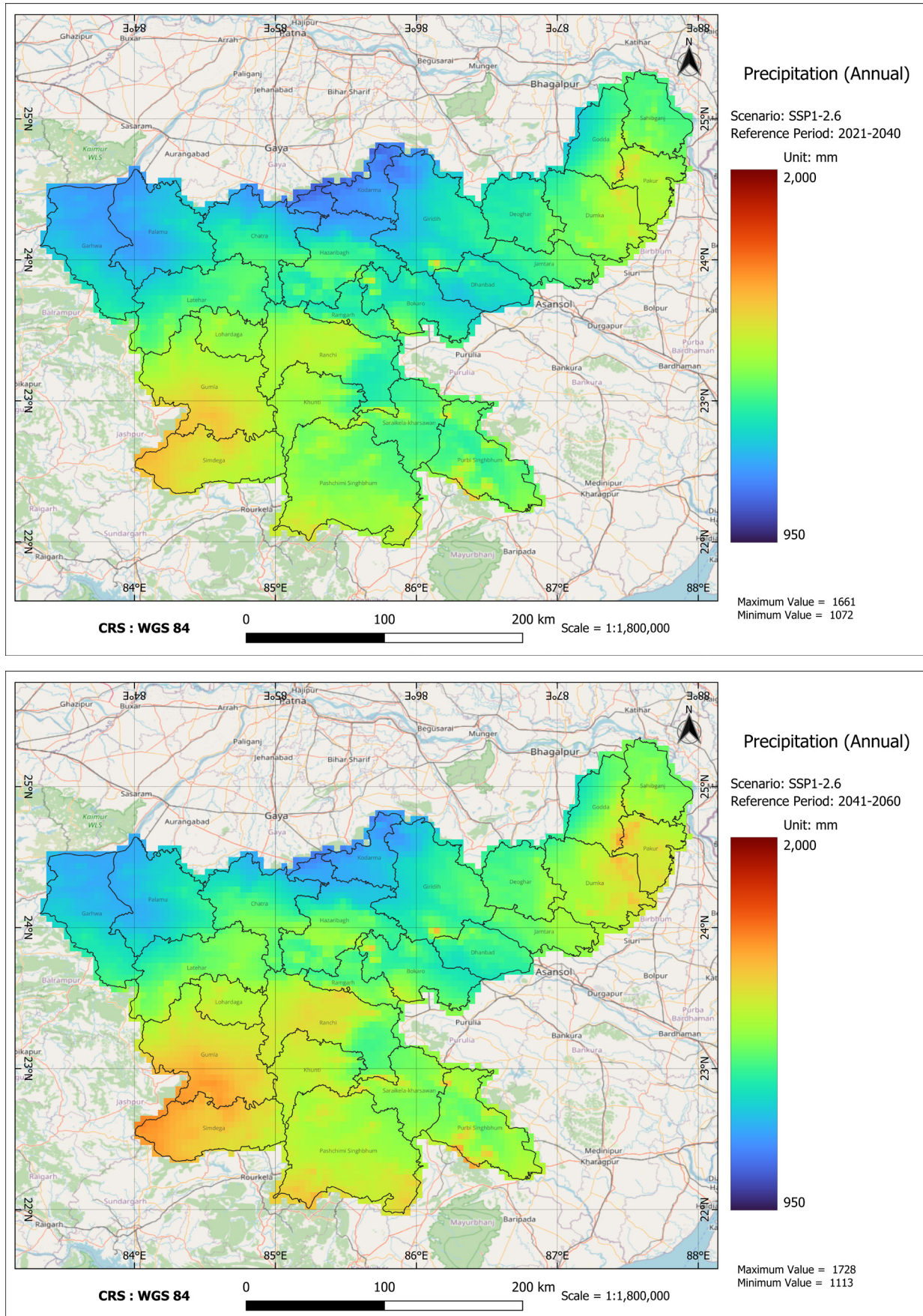


Figure 18 : Expected Rainfall (mm/Annum) distribution in SSP 1-2.6 in all four temporal windows



District Level Climate Projection for Jharkhand

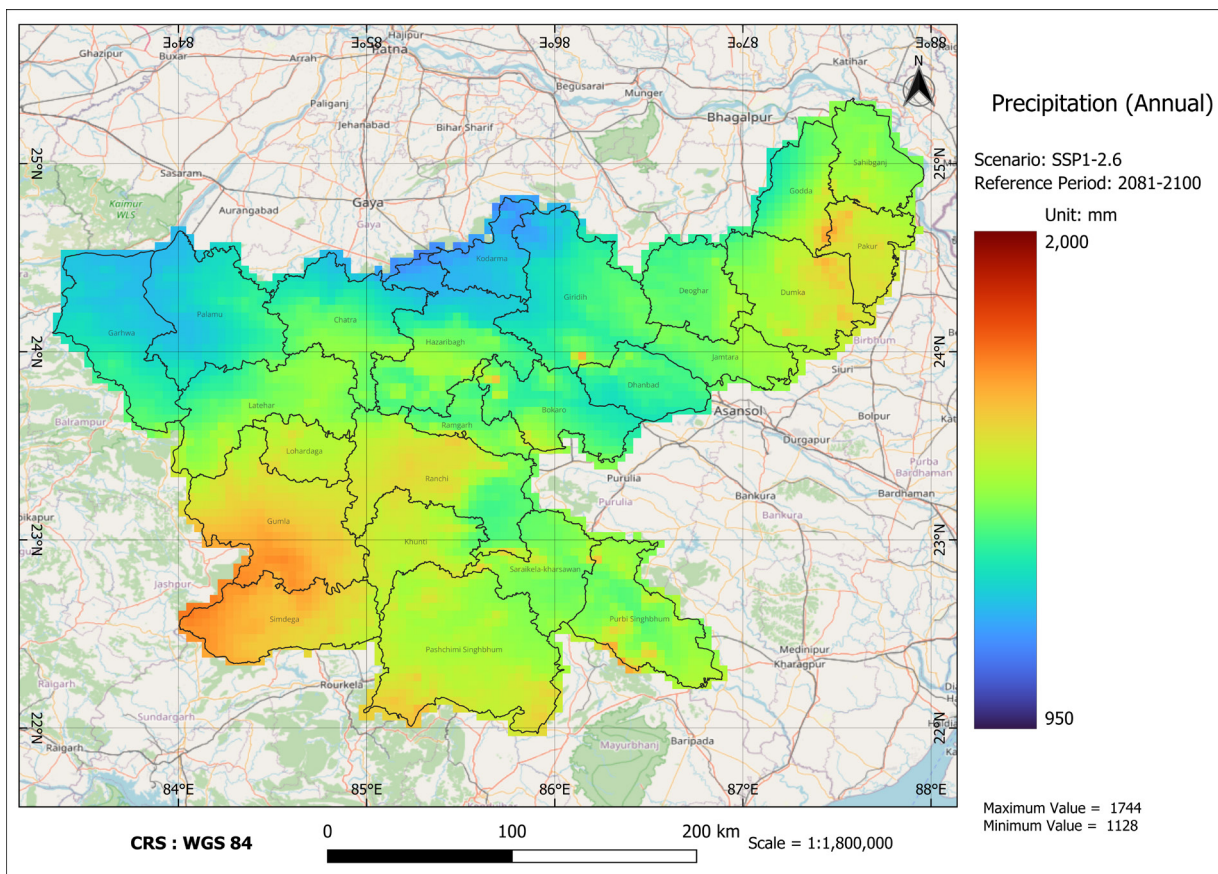
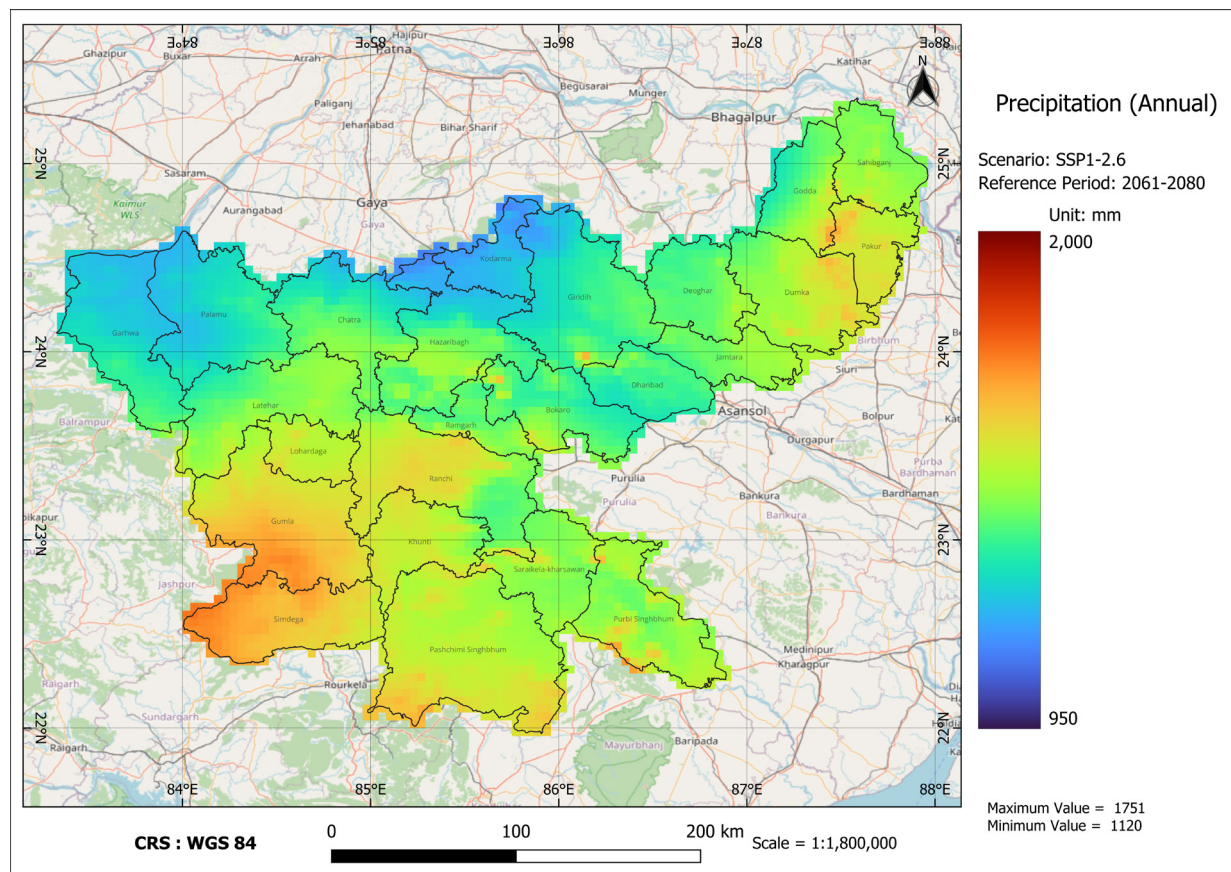
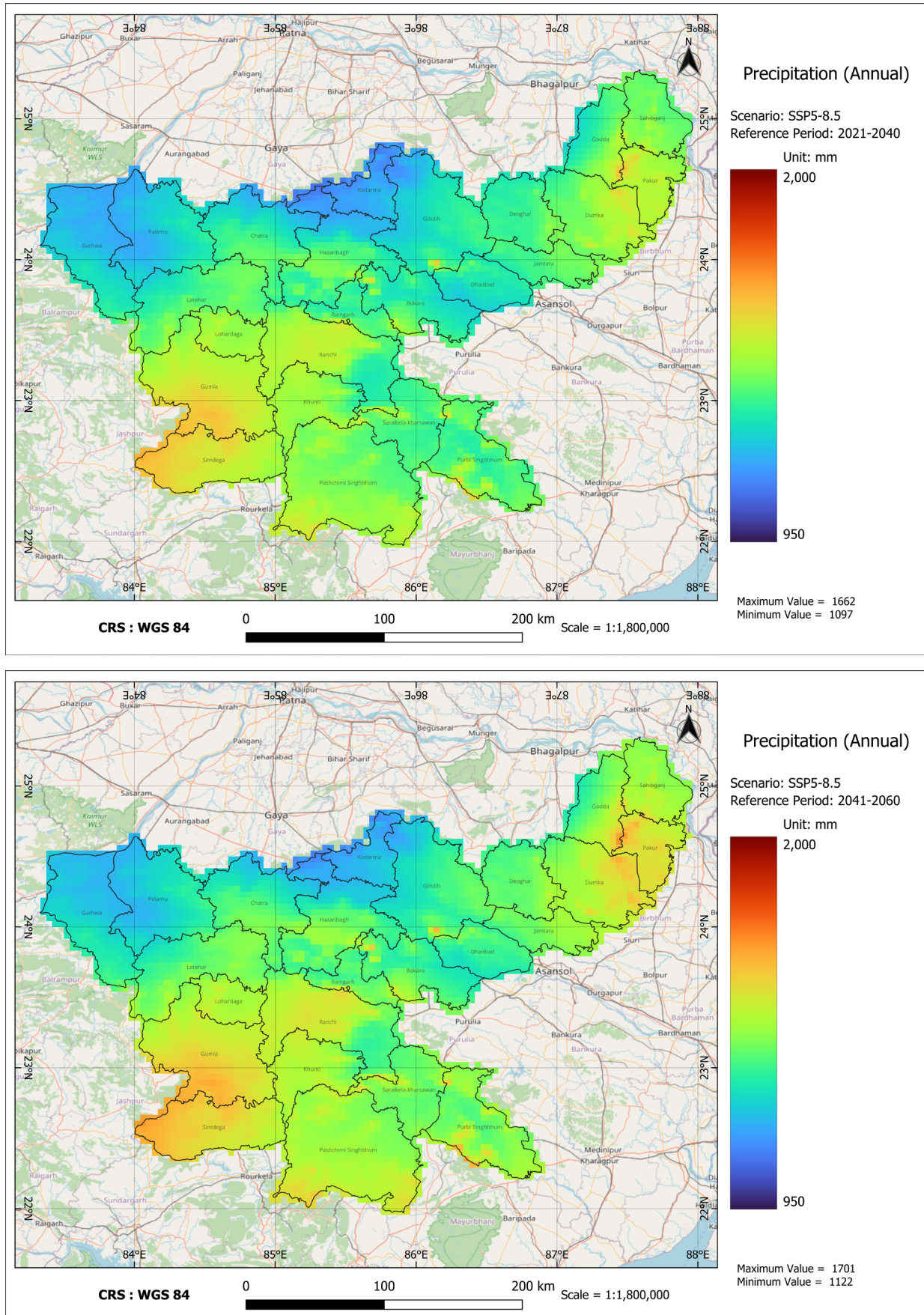
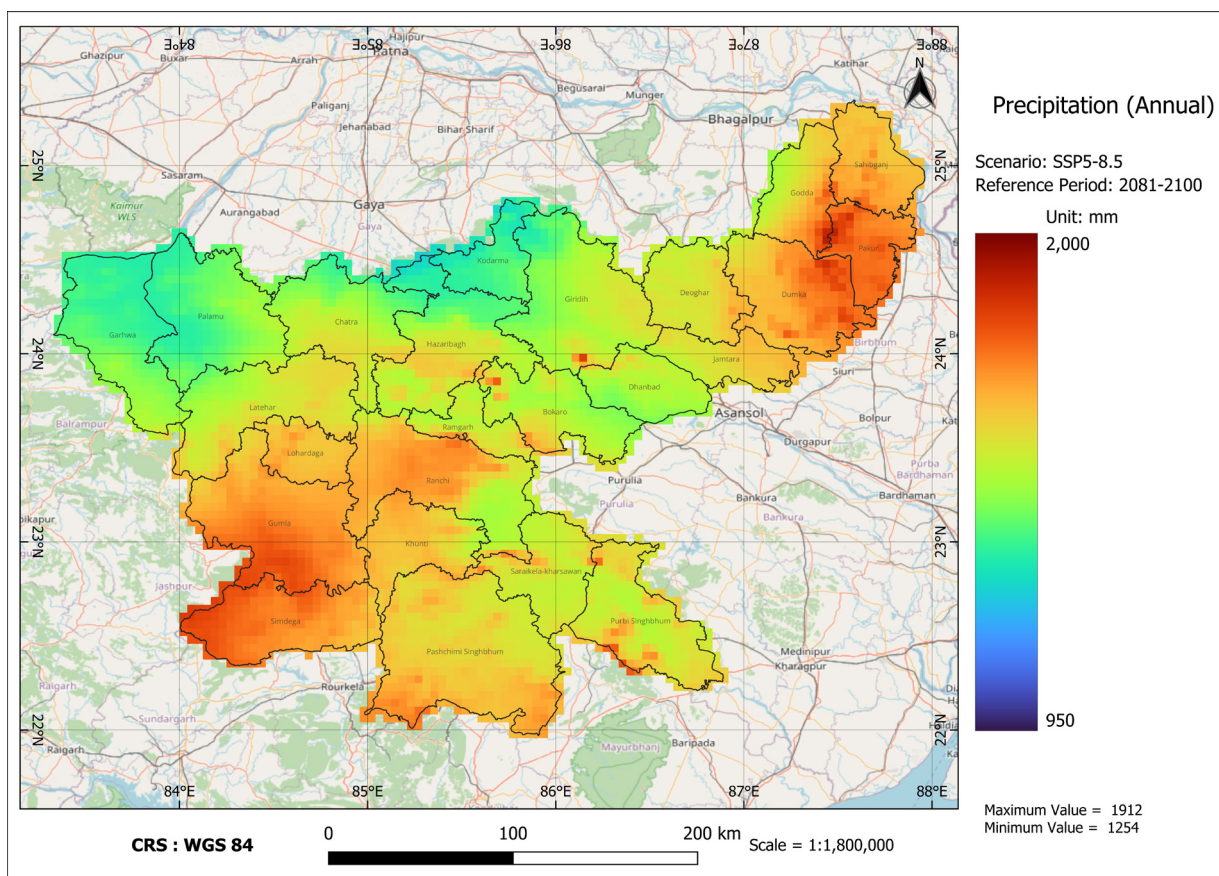
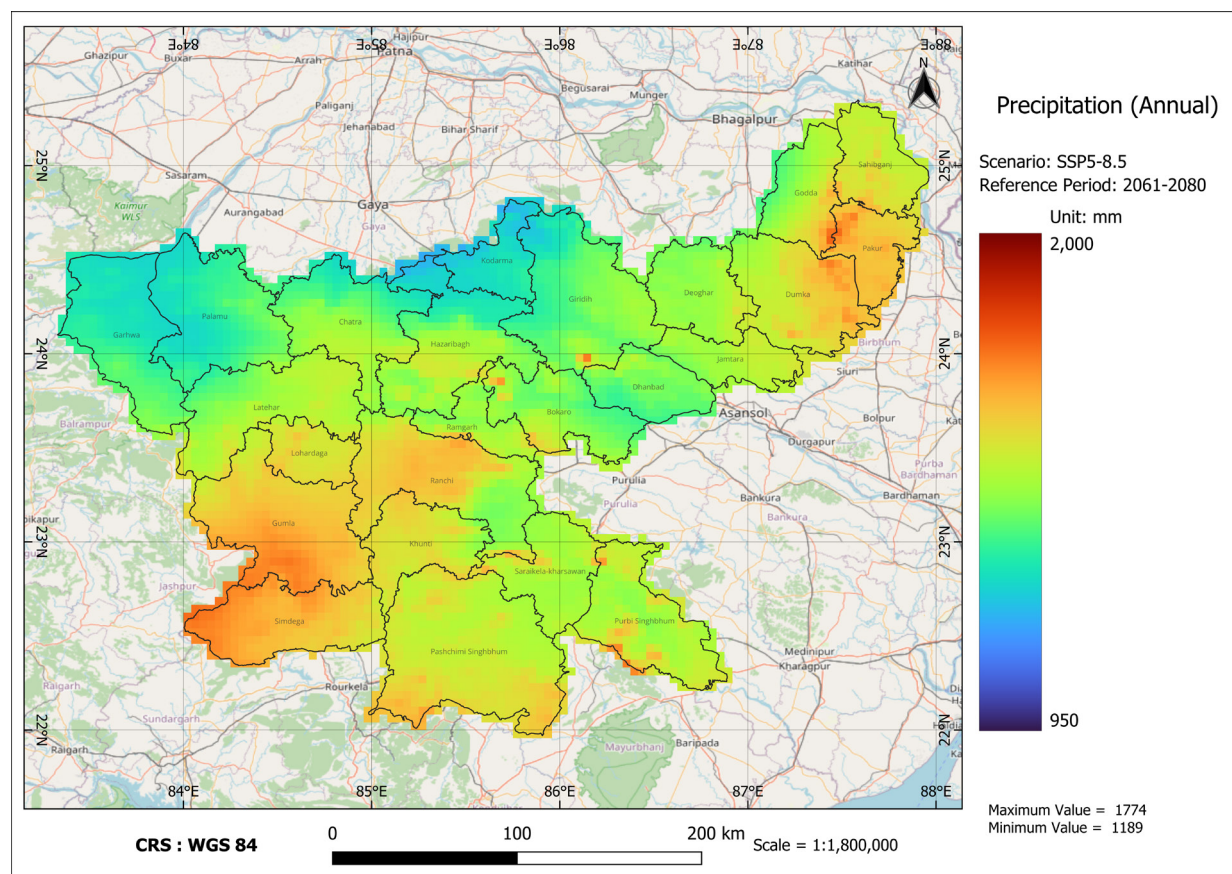


Figure 19 : Expected Rainfall (mm/Annum) distribution in SSP 5-8.5 in all four temporal windows



District Level Climate Projection for Jharkhand



6.1.1 Temperature projection for each district of Jharkhand state.

To enable visualization of changes projected de-seasoned average temperature rise for all the SSP scenarios at decadal level are given below.

Figure 20 : Expected rise in temperature-Bokaro district

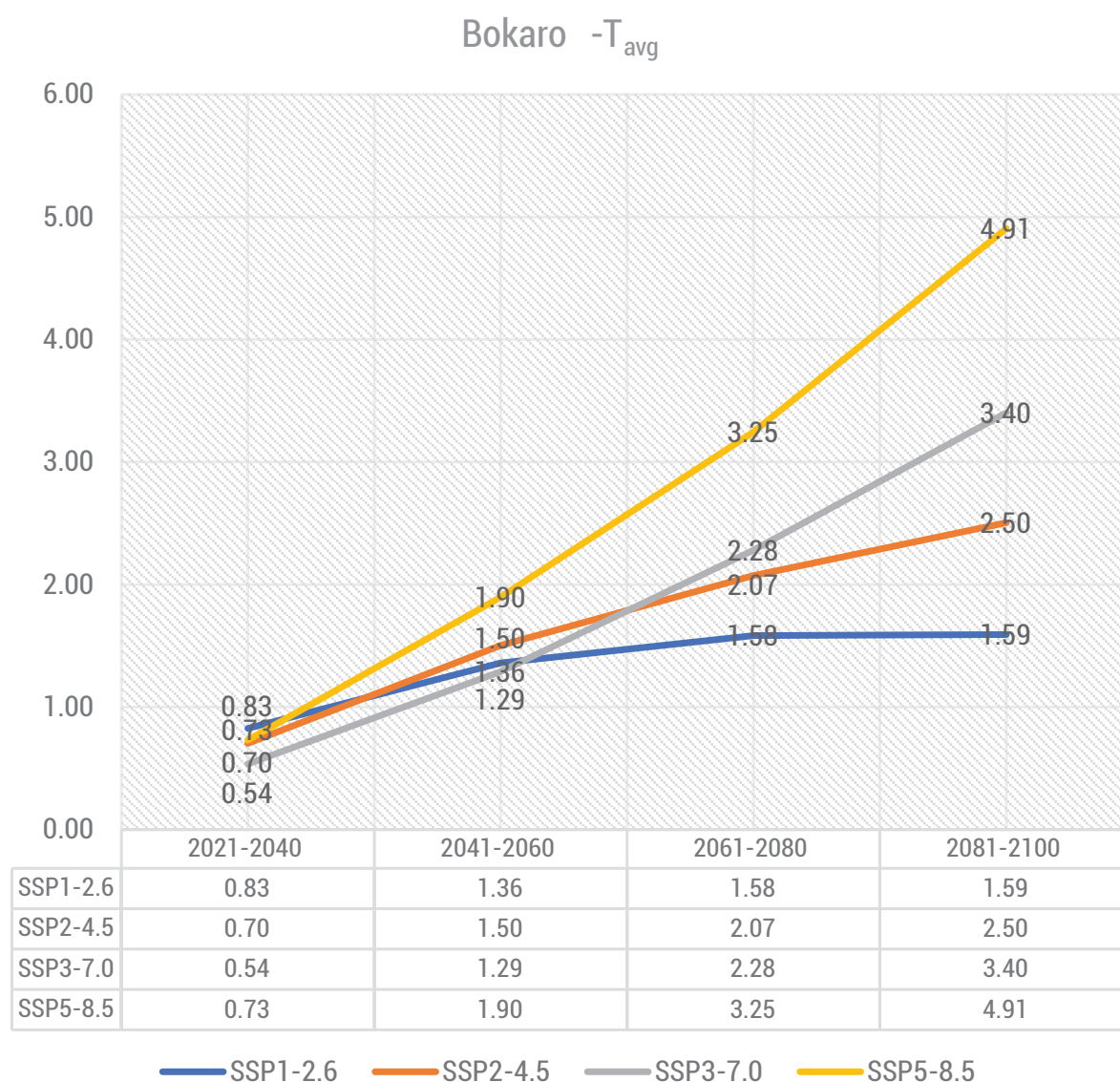


Figure 21 : Expected rise in temperature-Chatra district

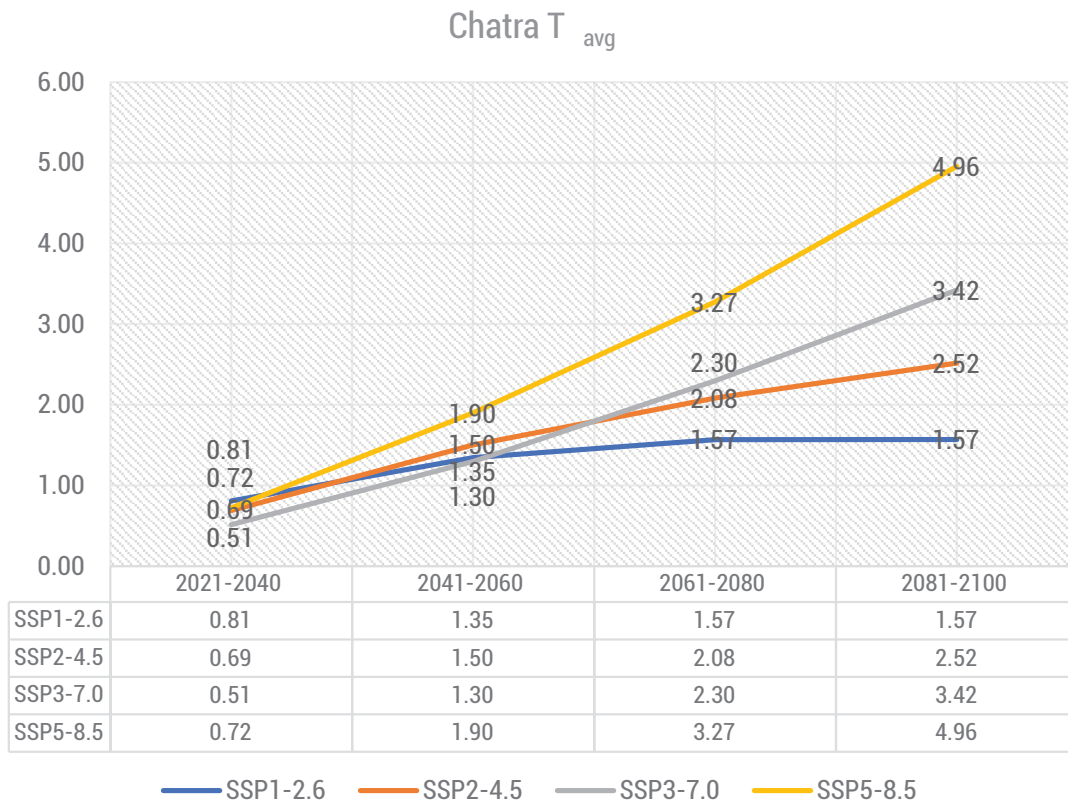


Figure 22 : Expected rise in temperature-Dhanbad district

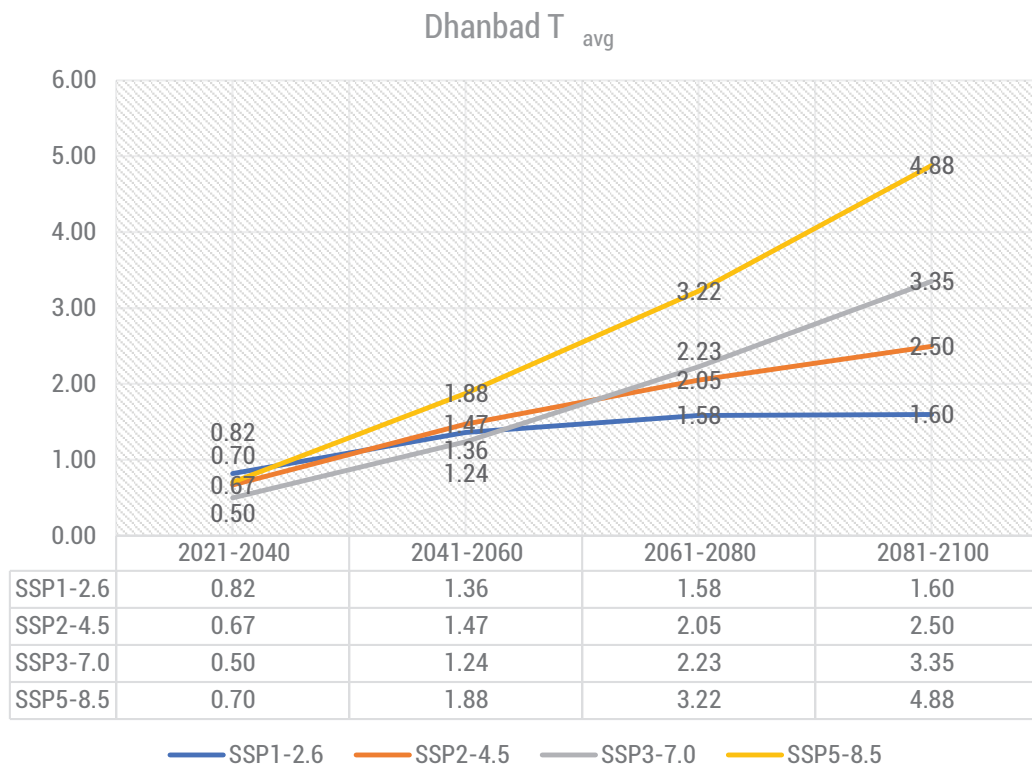


Figure 23 : Expected rise in temperature-Deoghar district

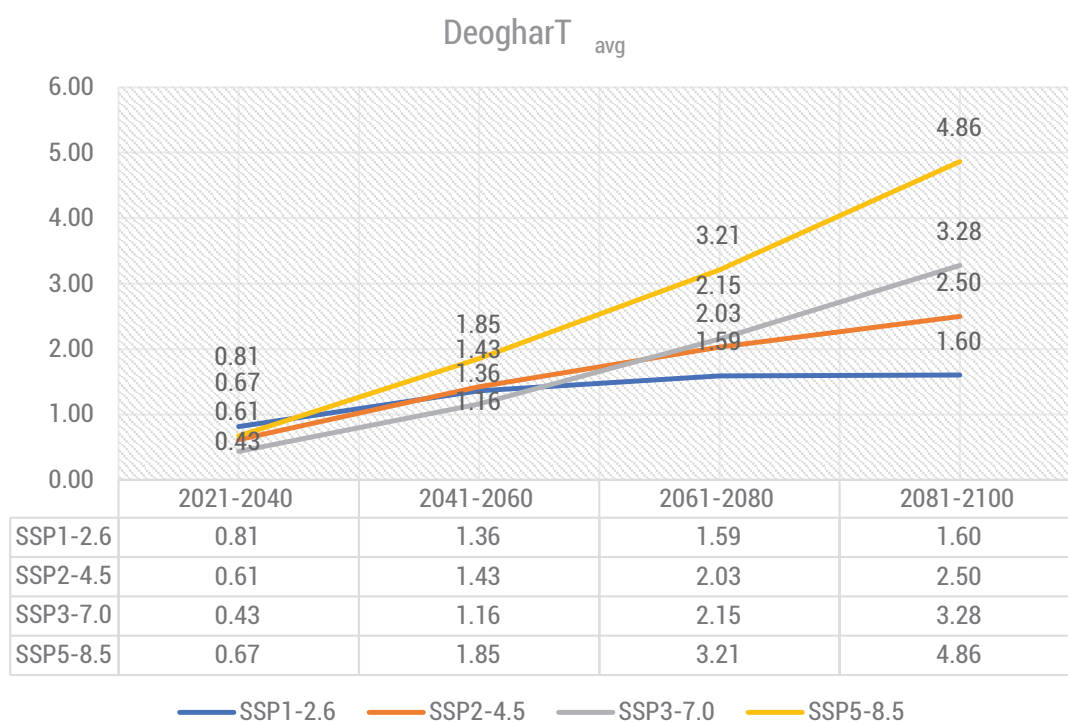


Figure 24 : Expected rise in temperature-Giridih district

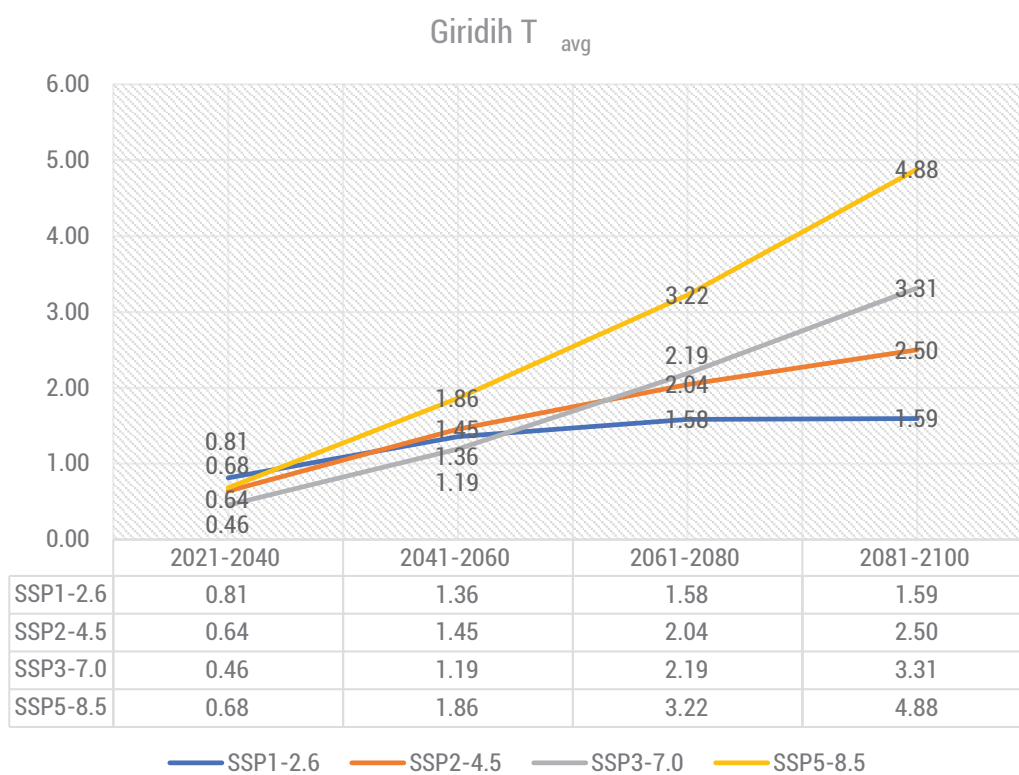


Figure 25 : Expected rise in temperature-Hazaribagh district

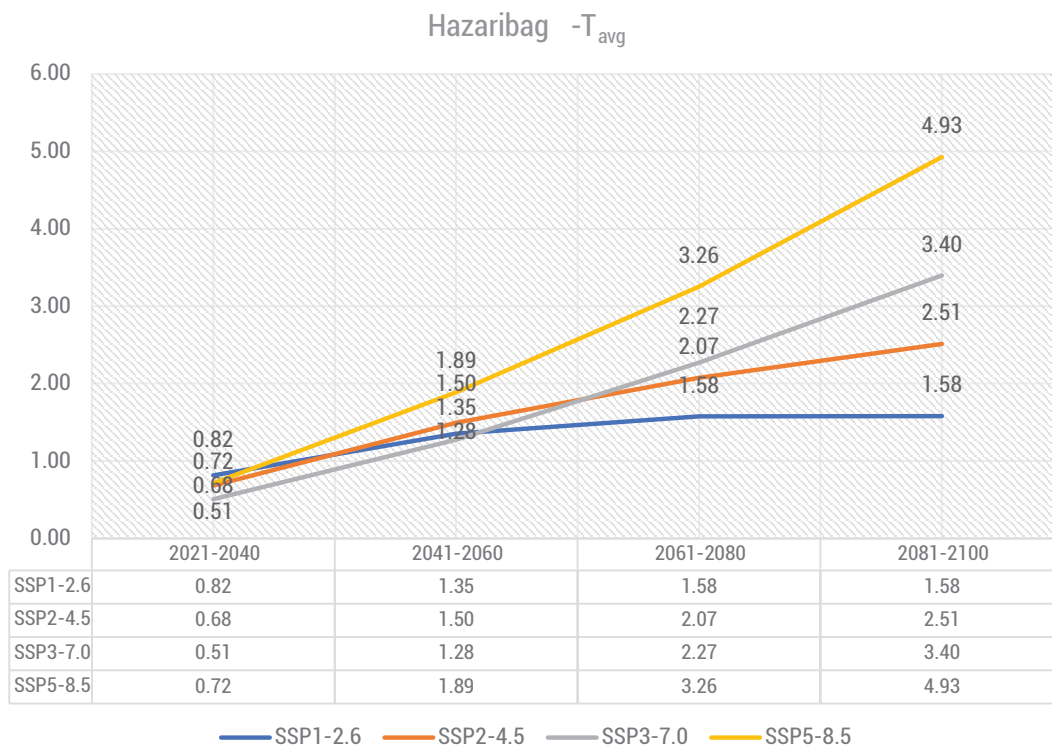


Figure 26 : Expected rise in temperature-Simdega district

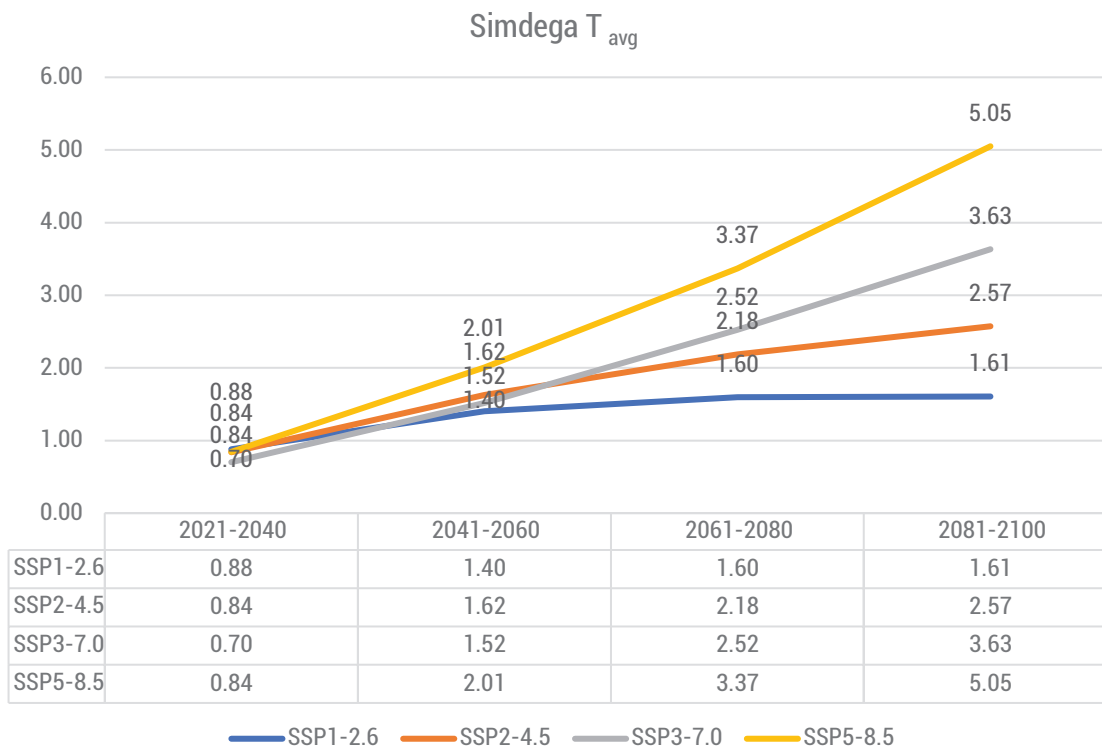


Figure 27 : Expected rise in temperature-Dumka district

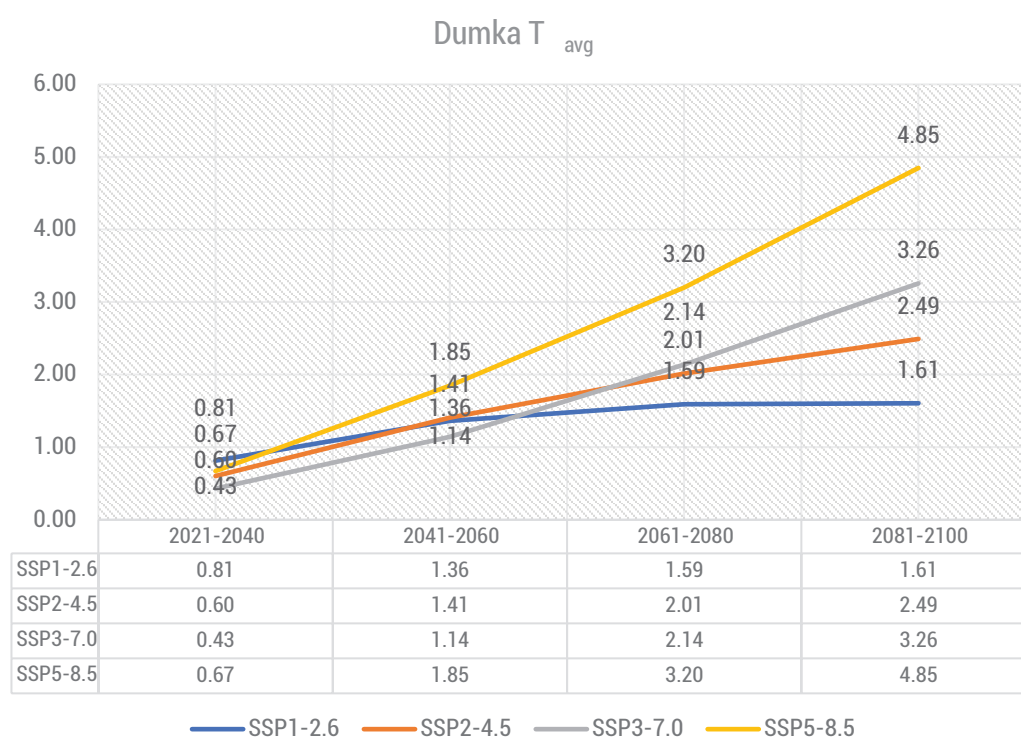


Figure 28 : Expected rise in temperature- East Singhbhum district

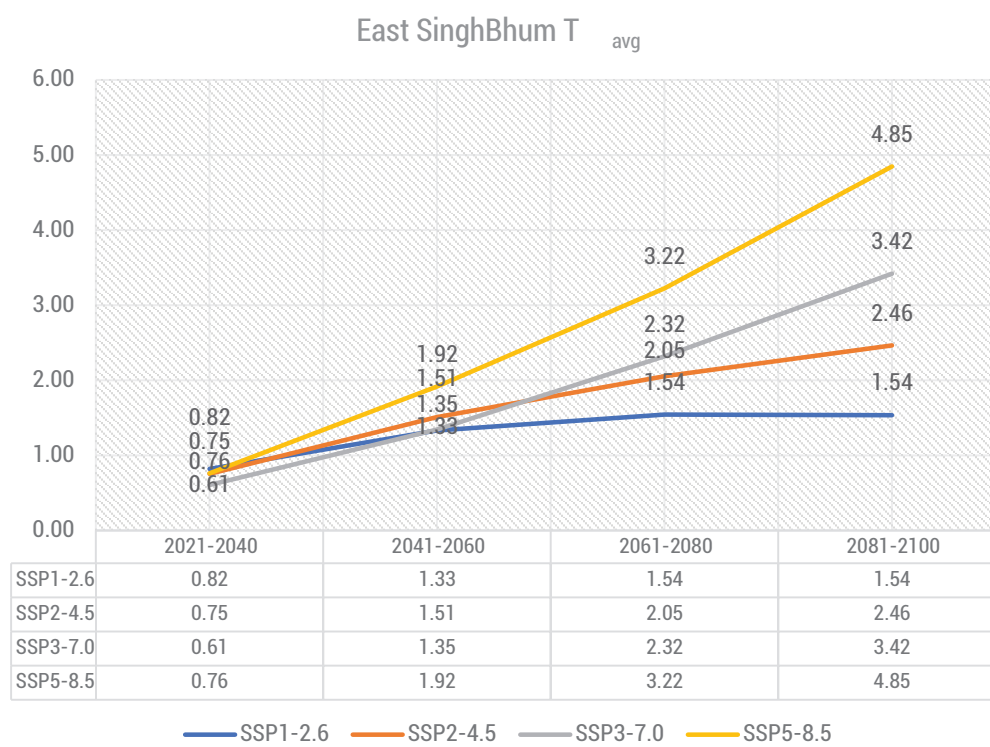


Figure 29 : Expected rise in temperature-Gharwa district

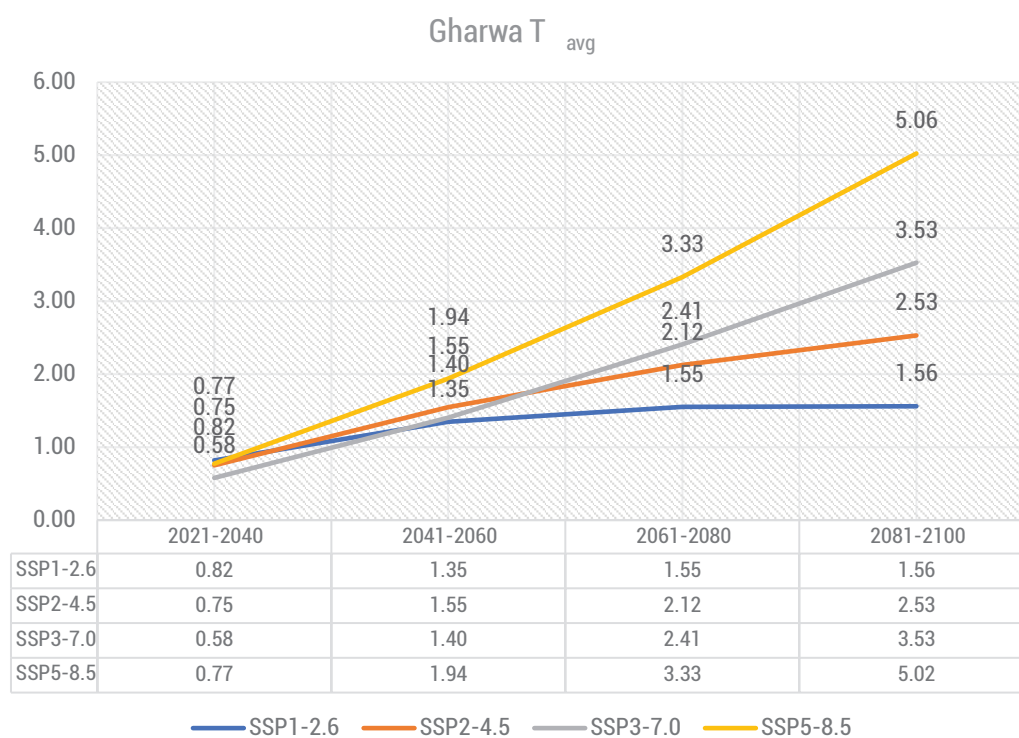


Figure 30 : Expected rise in temperature-Giridih district

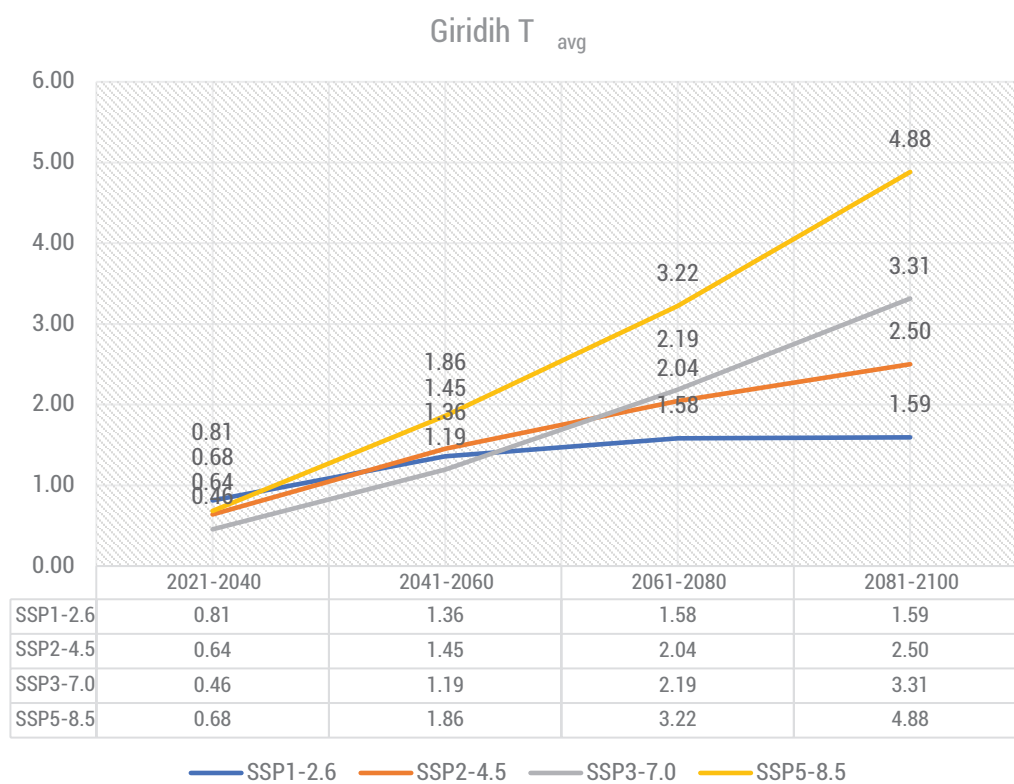


Figure 31 : Expected rise in temperature-Godda district

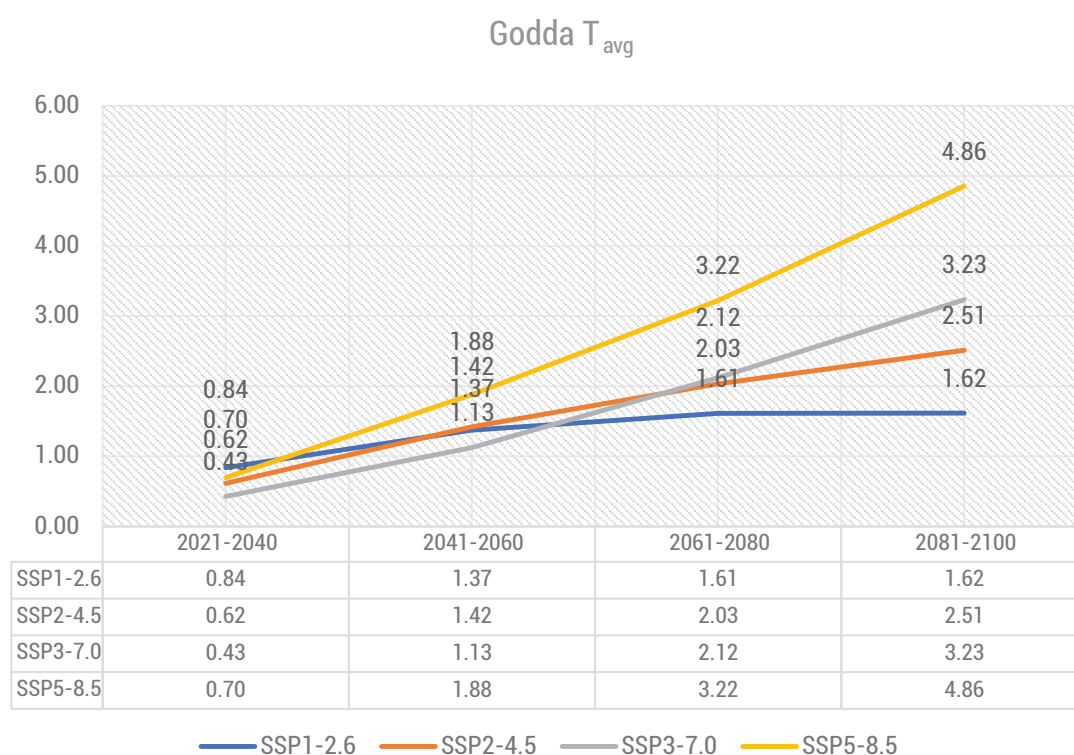


Figure 32 : Expected rise in temperature-Gumla district

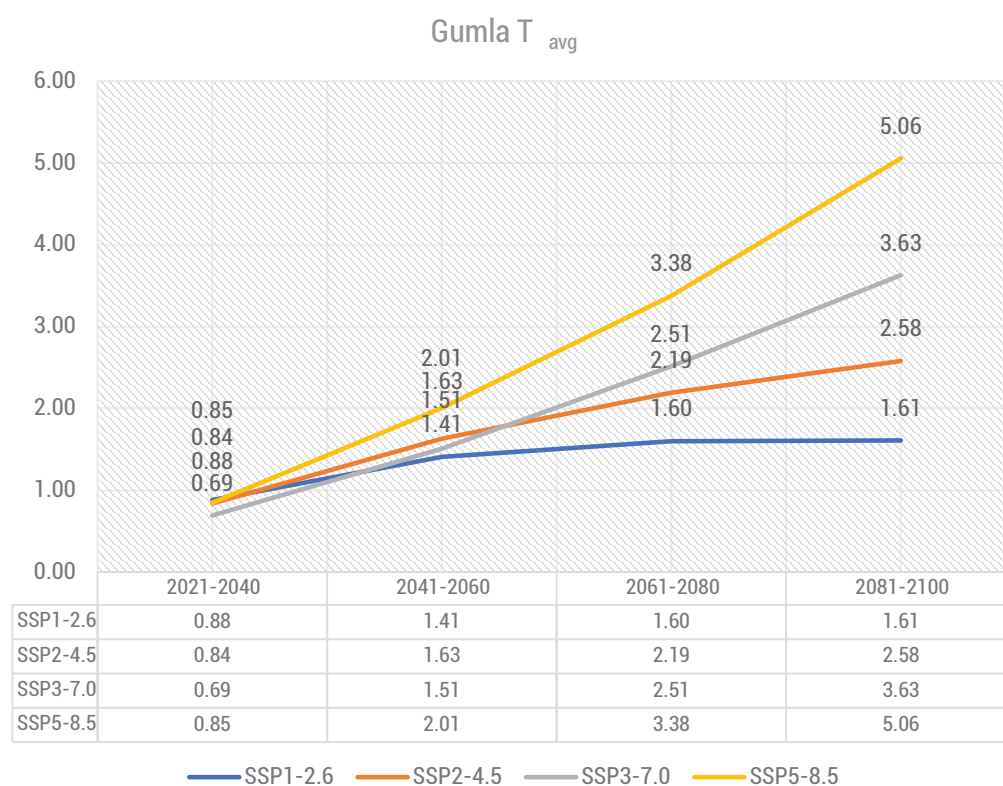


Figure 33 : Expected rise in temperature- Jamtara district

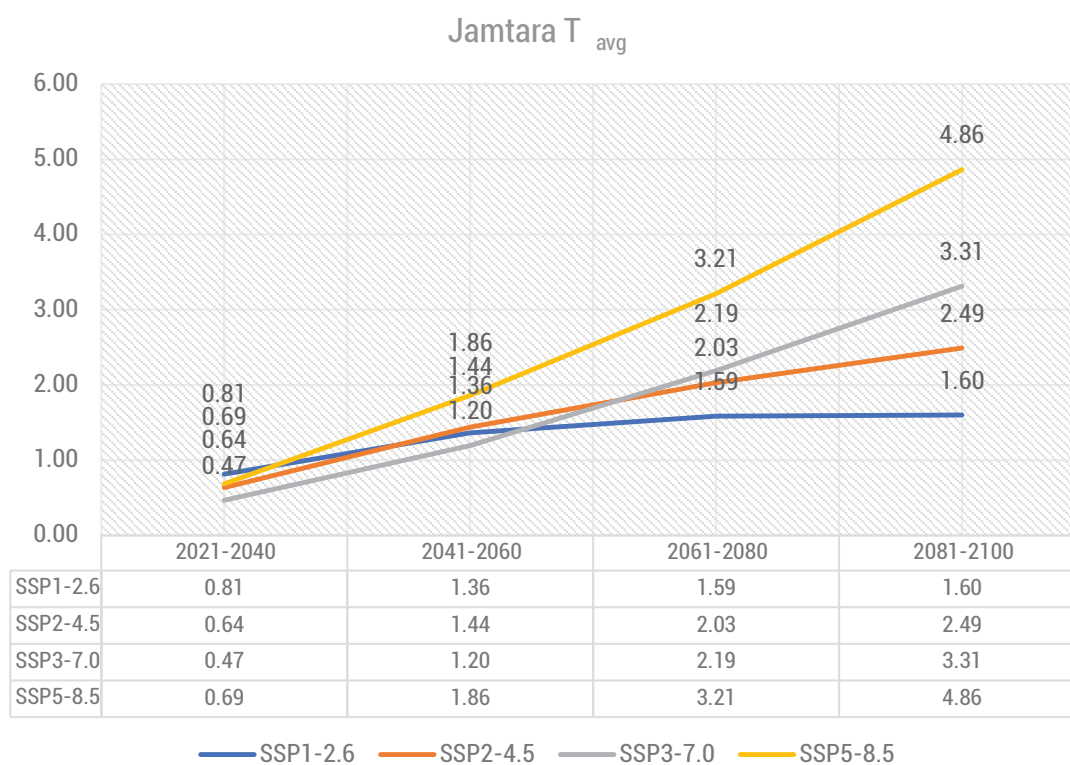


Figure 34 : Expected rise in temperature- Khunti district

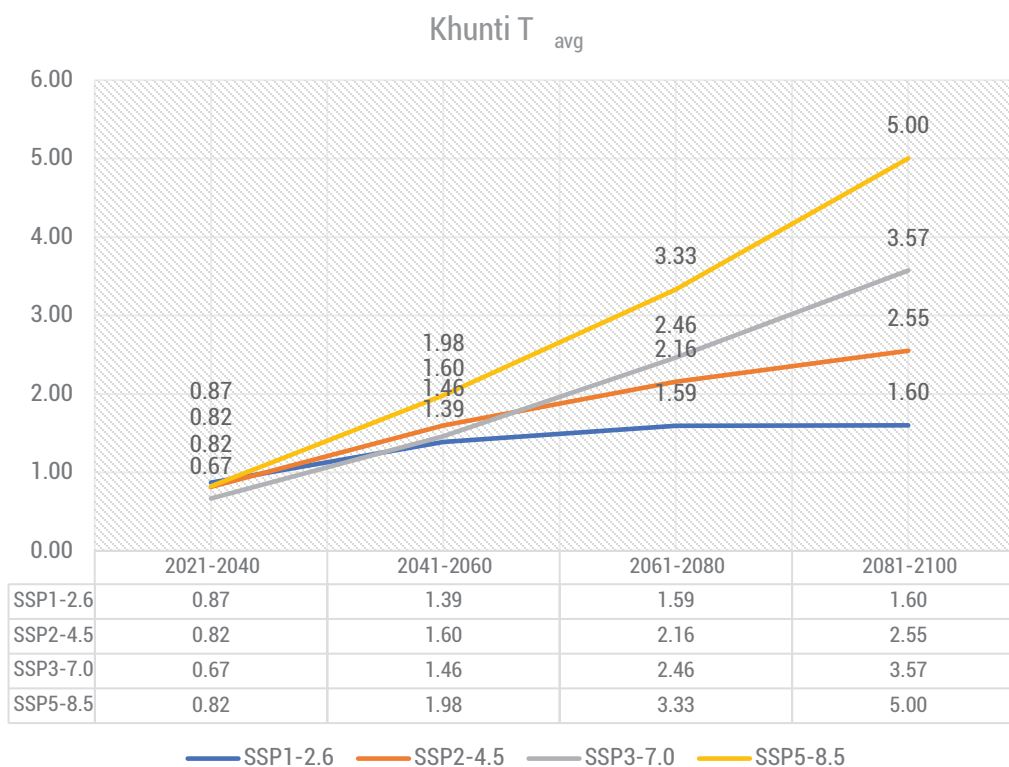


Figure 35 : Expected rise in temperature- Koderma district

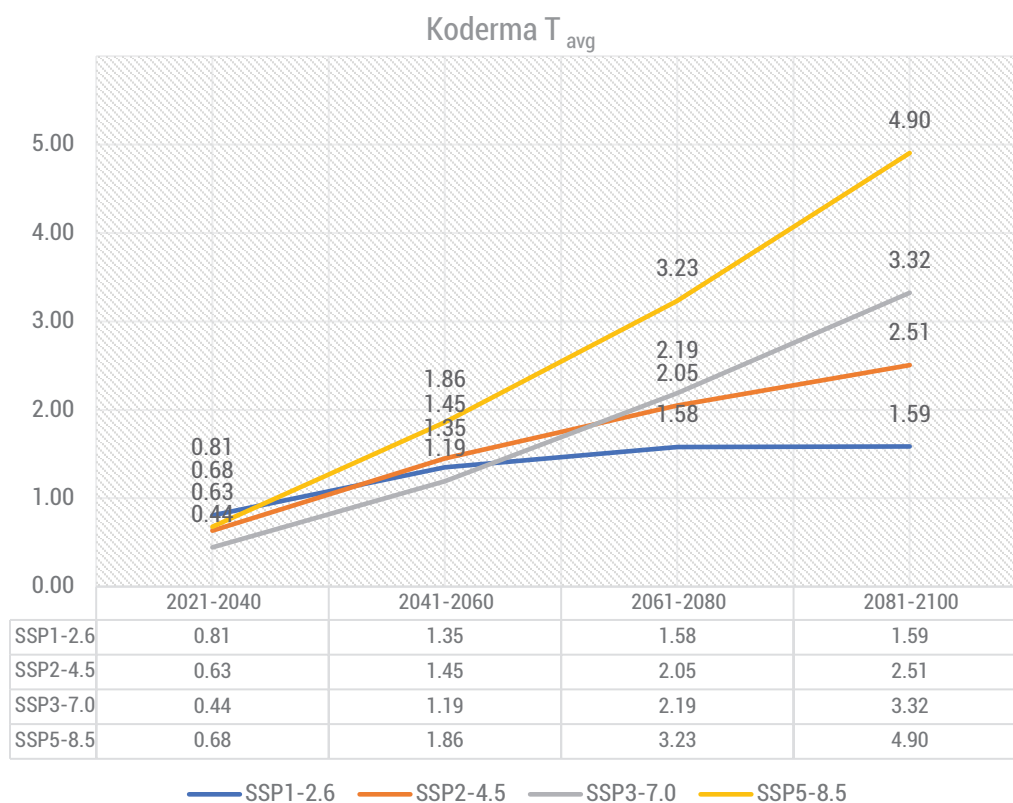


Figure 36 : Expected rise in temperature-Latehar district

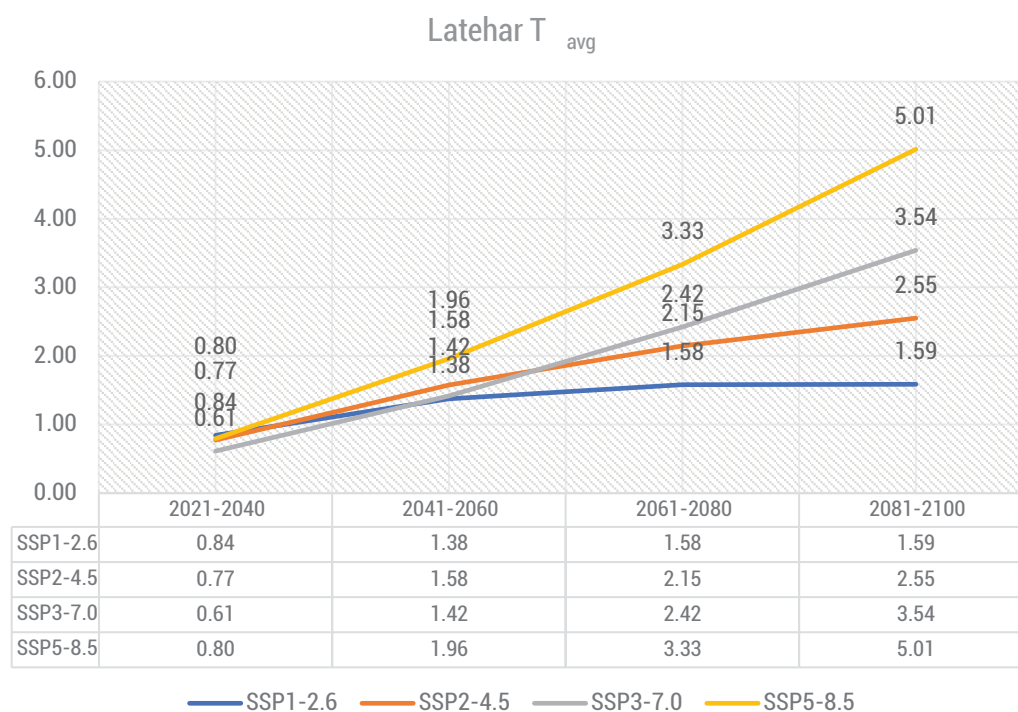


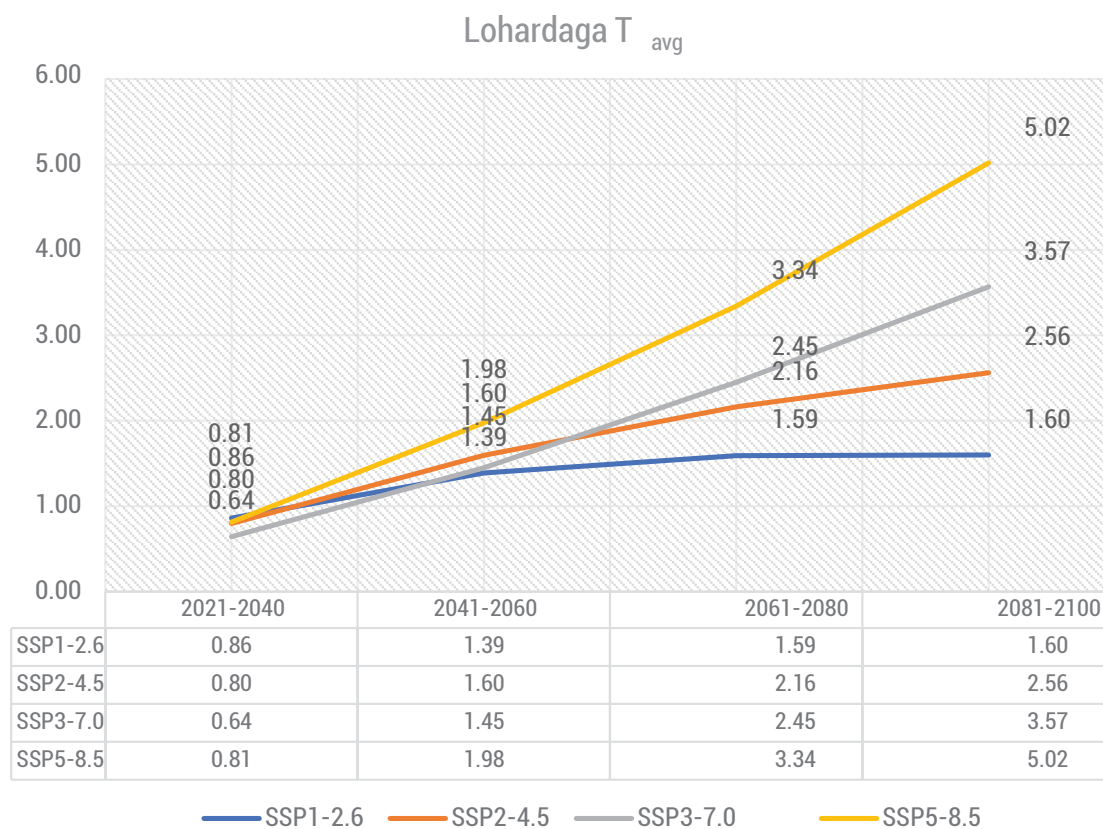
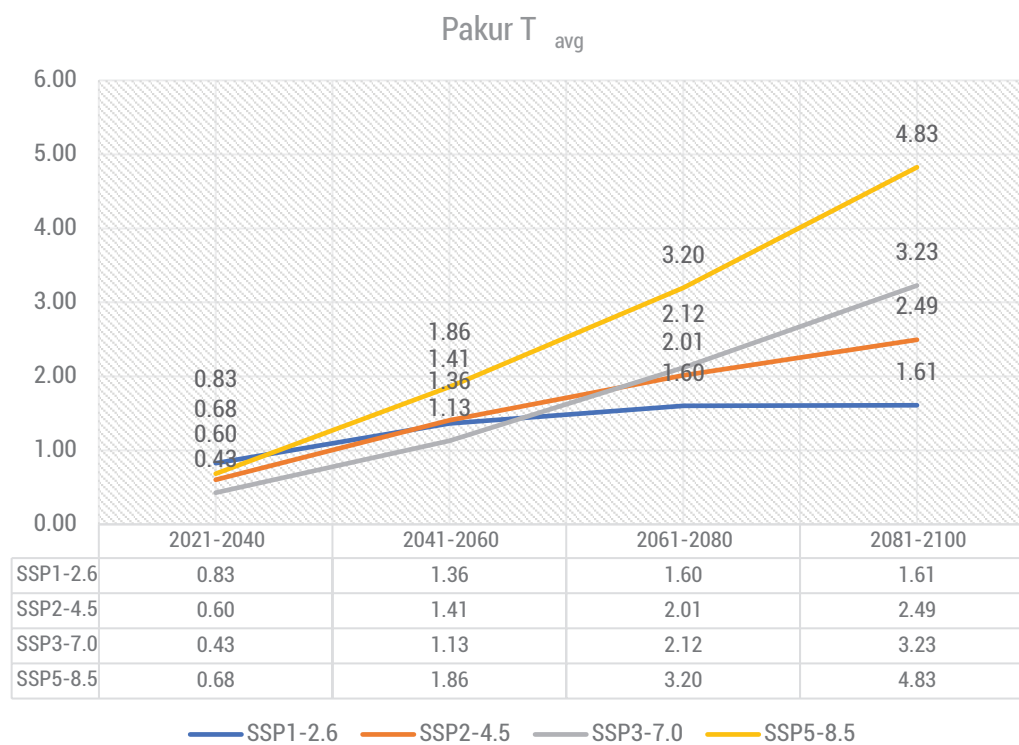
Figure 37 : Expected rise in temperature-Lohardaga district**Figure 38 : Expected rise in temperature-Pakur district**

Figure 39 : Expected rise in temperature-Palamu district

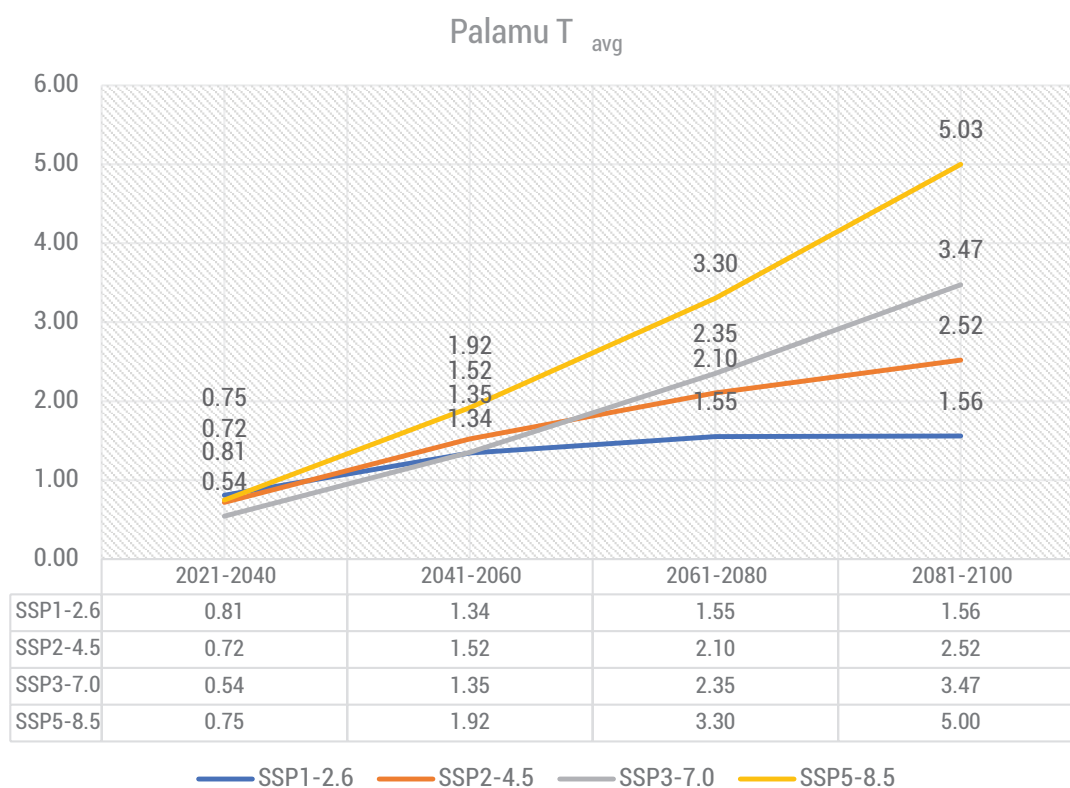


Figure 40 : Expected rise in temperature-Ramgarh district

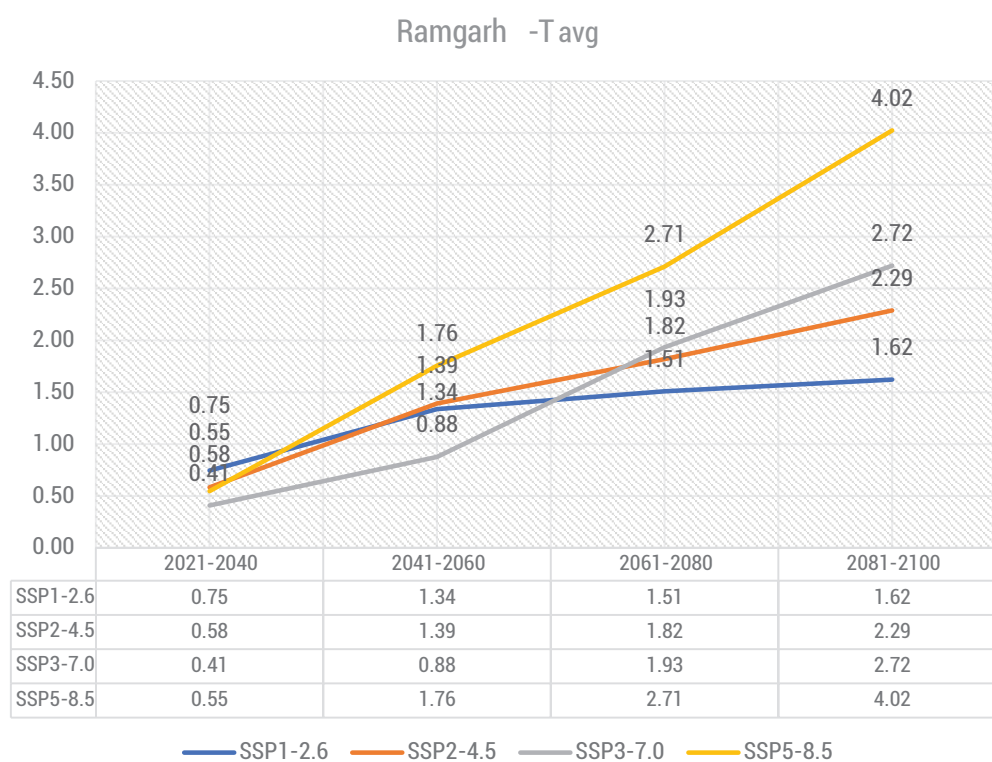


Figure 41 : Expected rise in temperature-Jamtara district

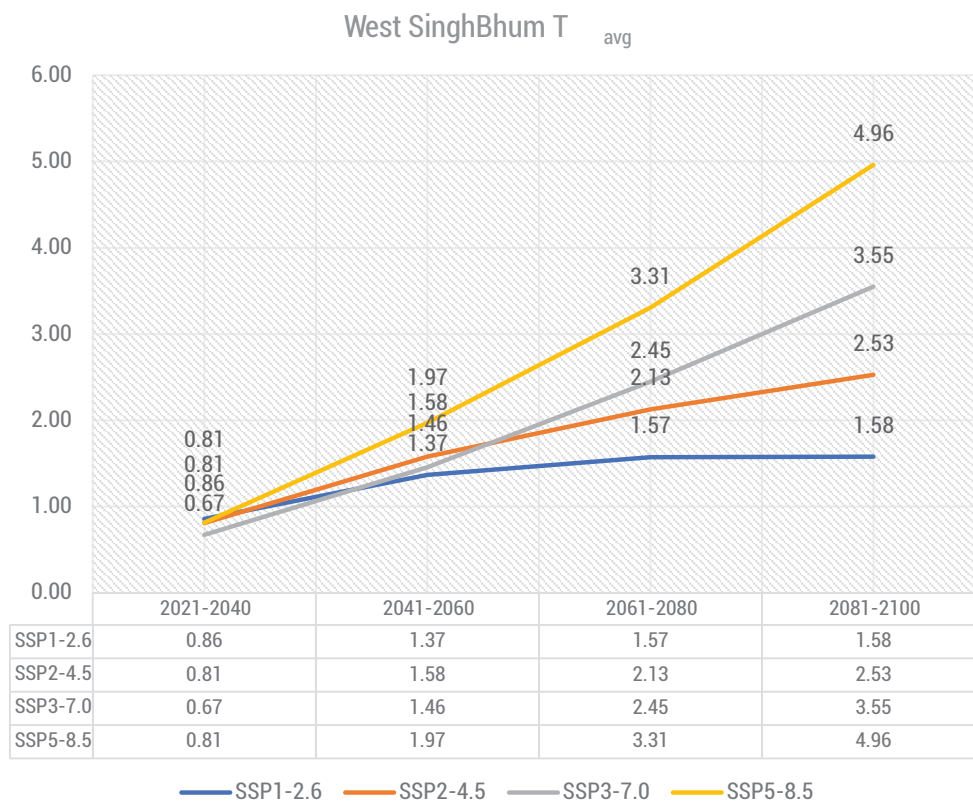


Figure 42 : Expected rise in temperature-Ranchi district

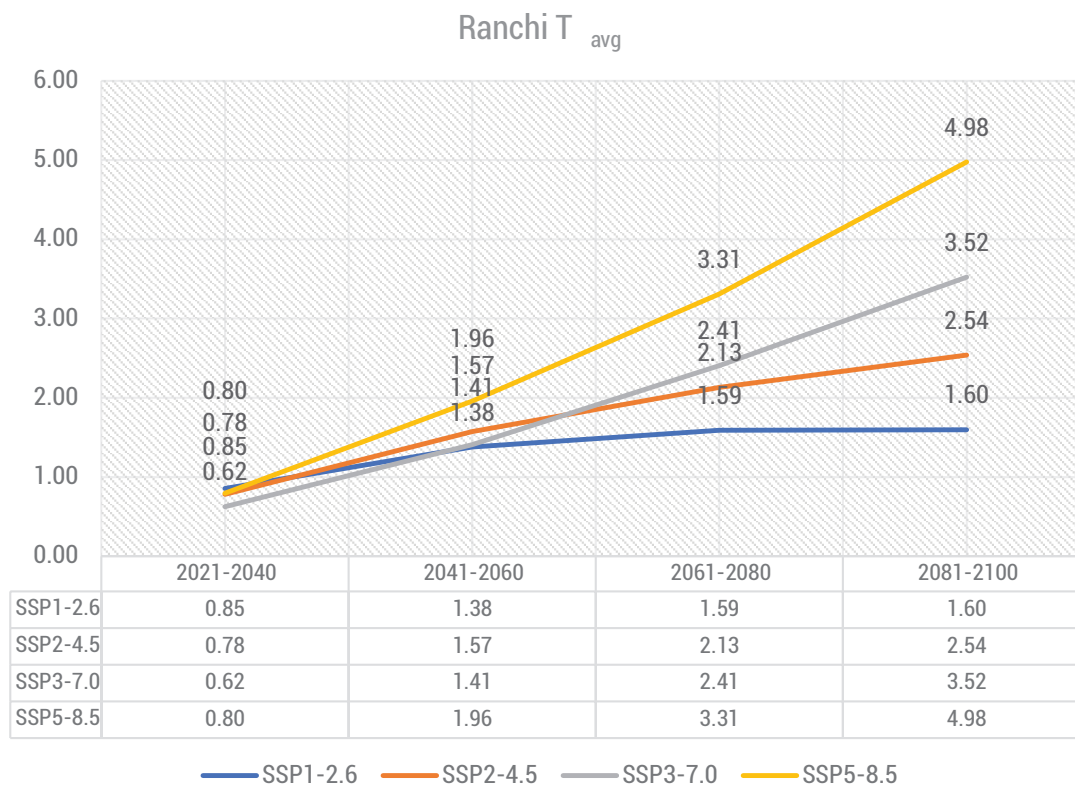


Figure 43 : Expected rise in temperature-Sahebganj district

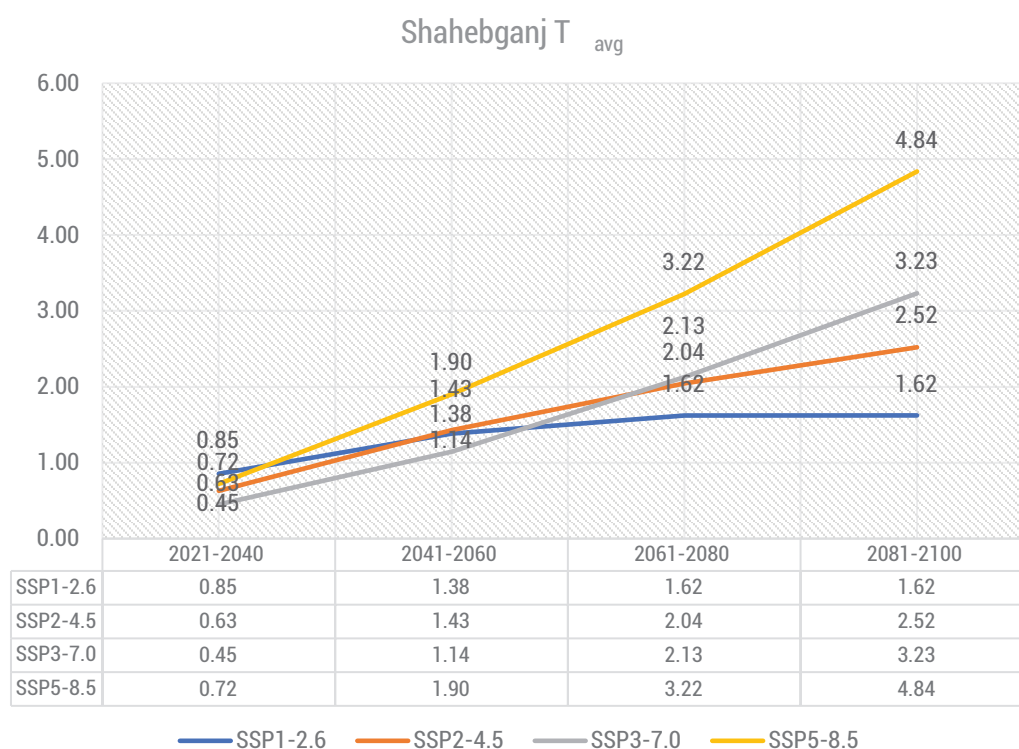
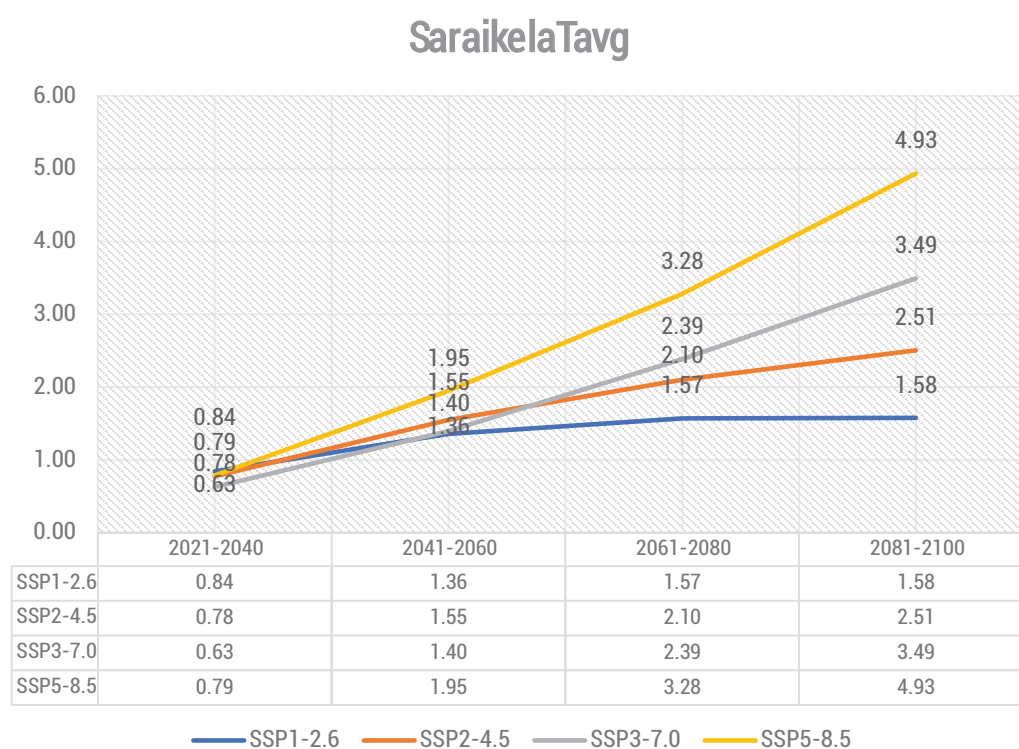


Figure 44 : Expected rise in Temperature-Saraikela district



6.1.2 Precipitation projection for each district of Jharkhand state.

To enable visualization of changes projected de-seasoned average rise in precipitation for all the SSP scenarios at decadal level are given below:

Figure 45 : Expected variation in Rainfall-Bokaro district

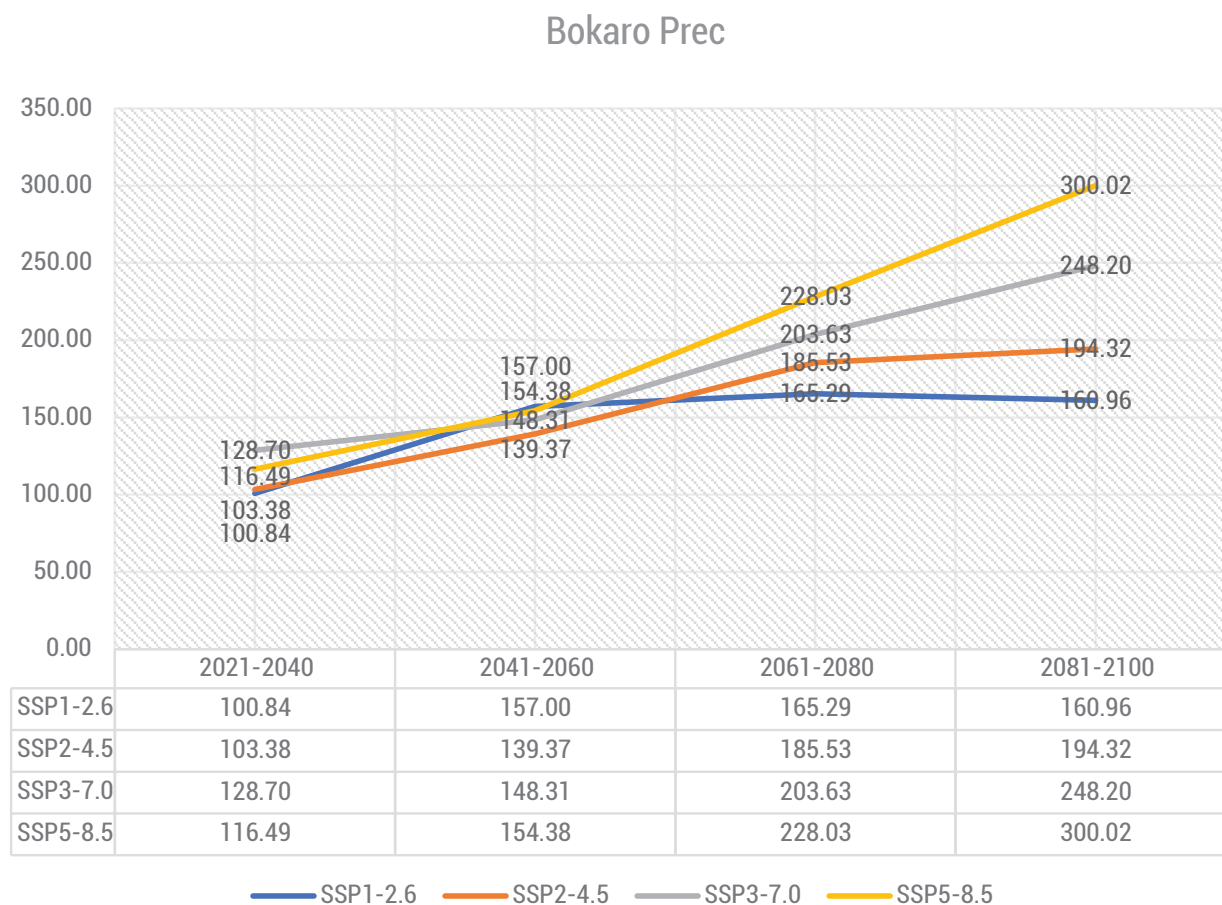


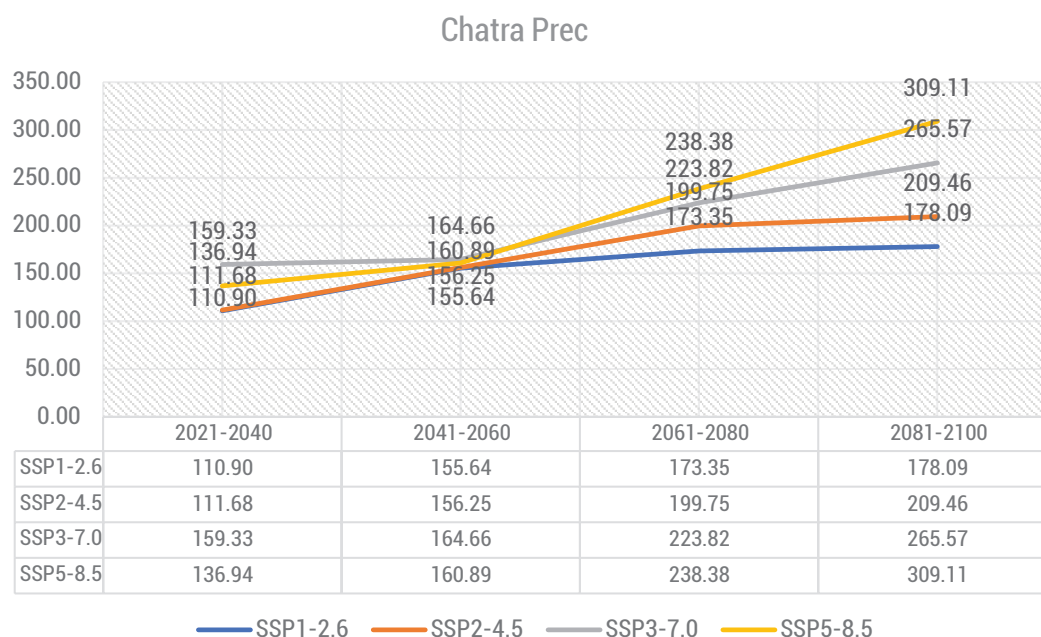
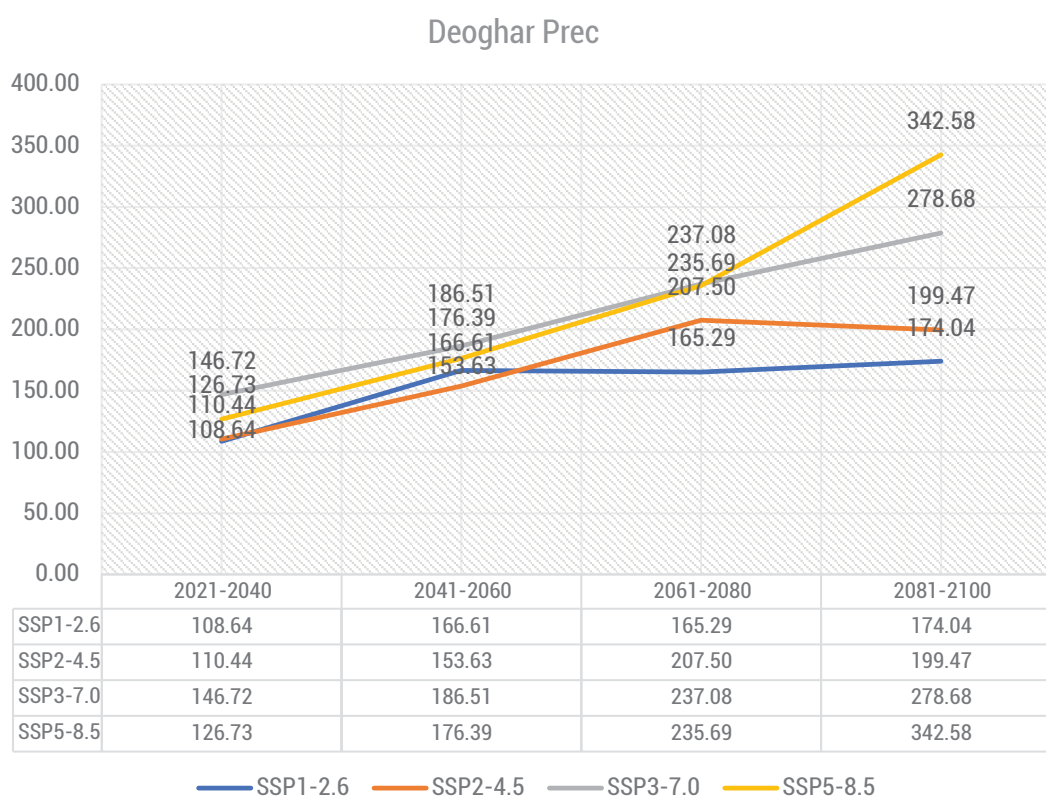
Figure 46 : Expected variation in Rainfall -*Chatra district*Figure 47 : Expected variation in Rainfall -*Deoghar district*

Figure 48 : Expected variation in Rainfall -Dhanbad district

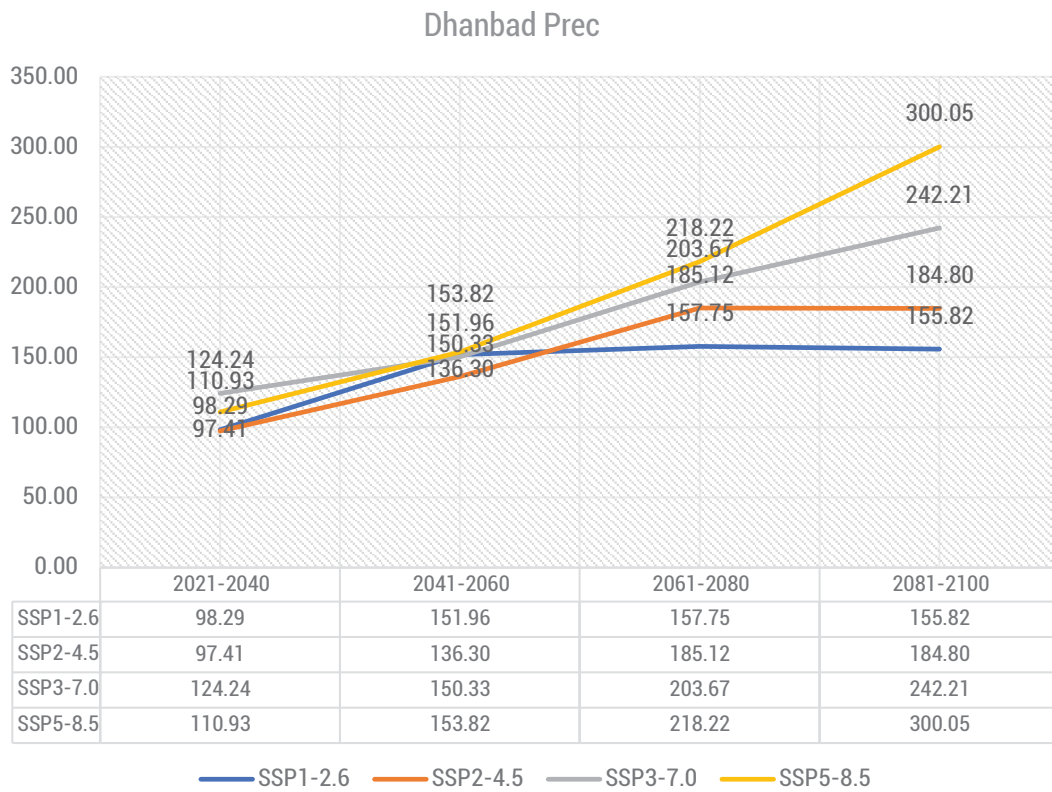


Figure 49 : Expected variation in Rainfall -Dumka district

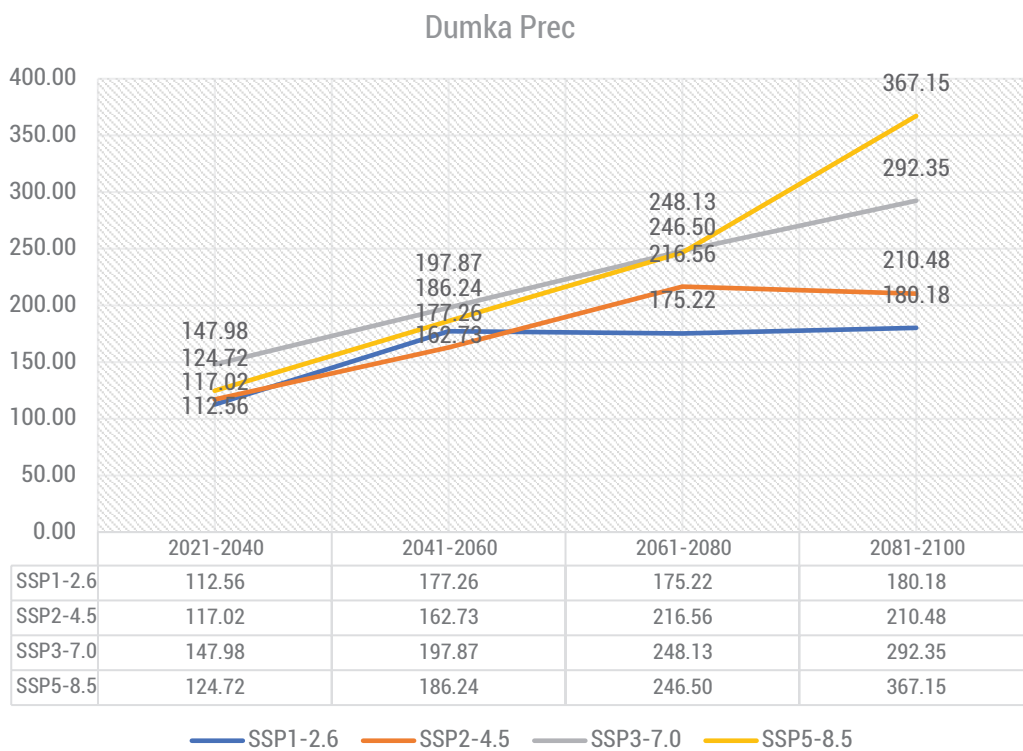


Figure 50 : Expected variation in Rainfall -Garhwa district

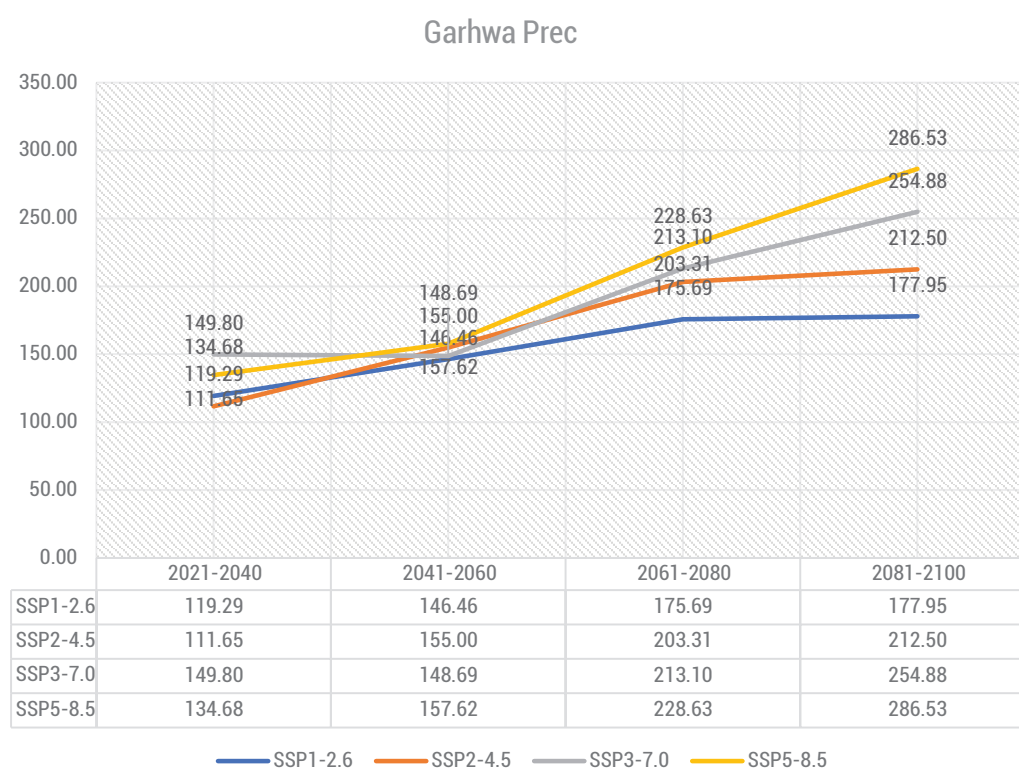


Figure 51 : Expected variation in Rainfall -Giridih district

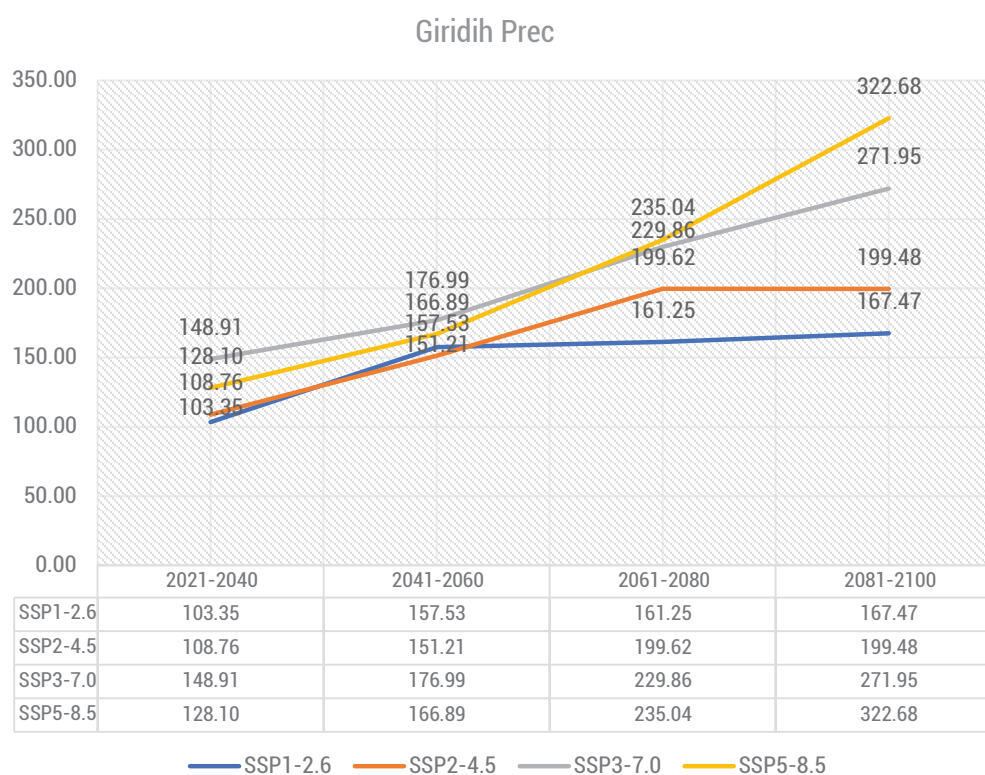


Figure 52 : Expected variation in Rainfall -Godda district

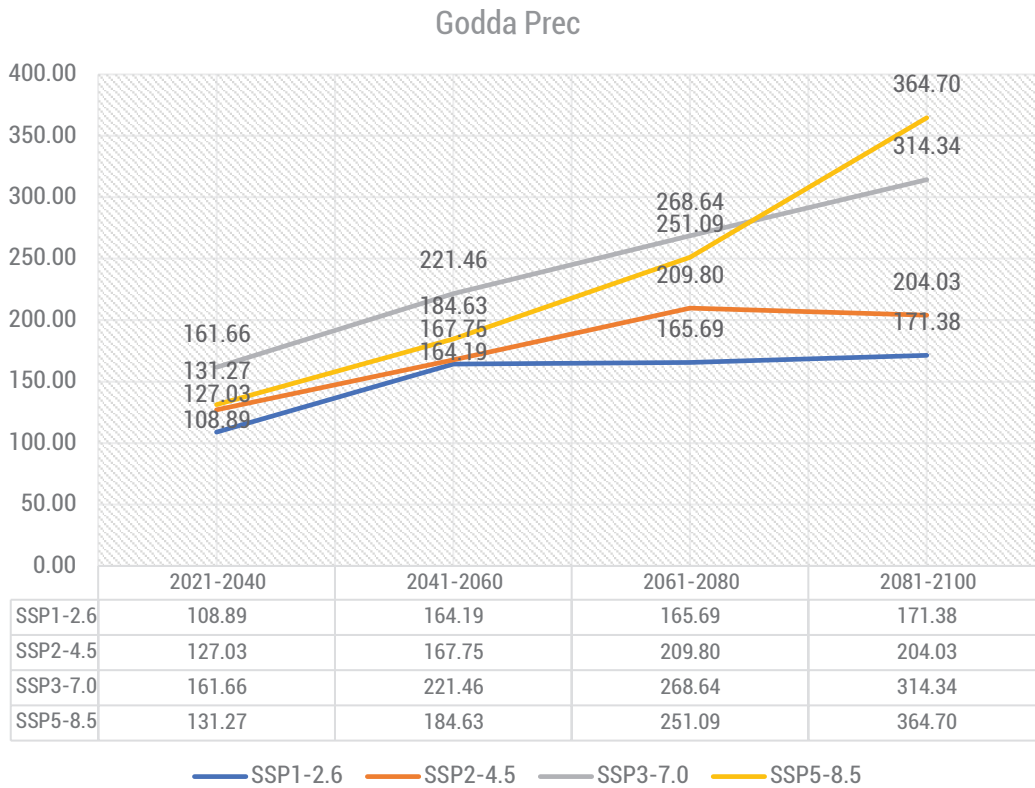


Figure 53 : Expected variation in Rainfall -Gumla district

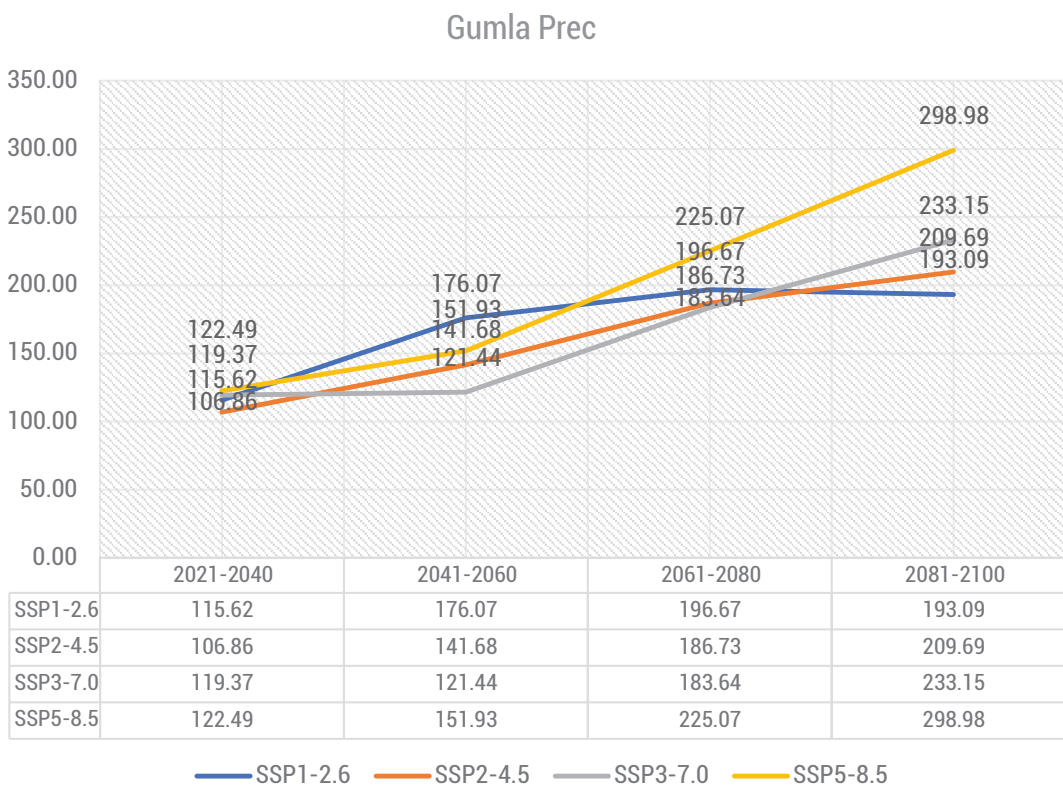


Figure 54 : Expected variation in Rainfall -Hazaribag district

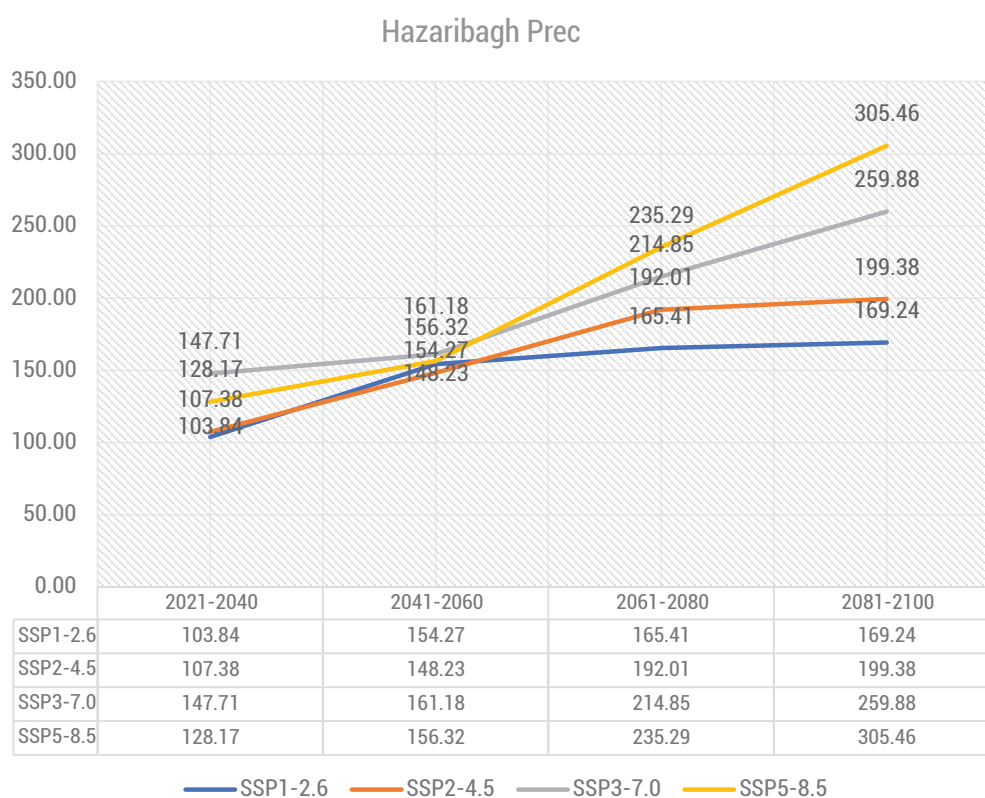


Figure 55 : Expected variation in Rainfall -Jamtara district

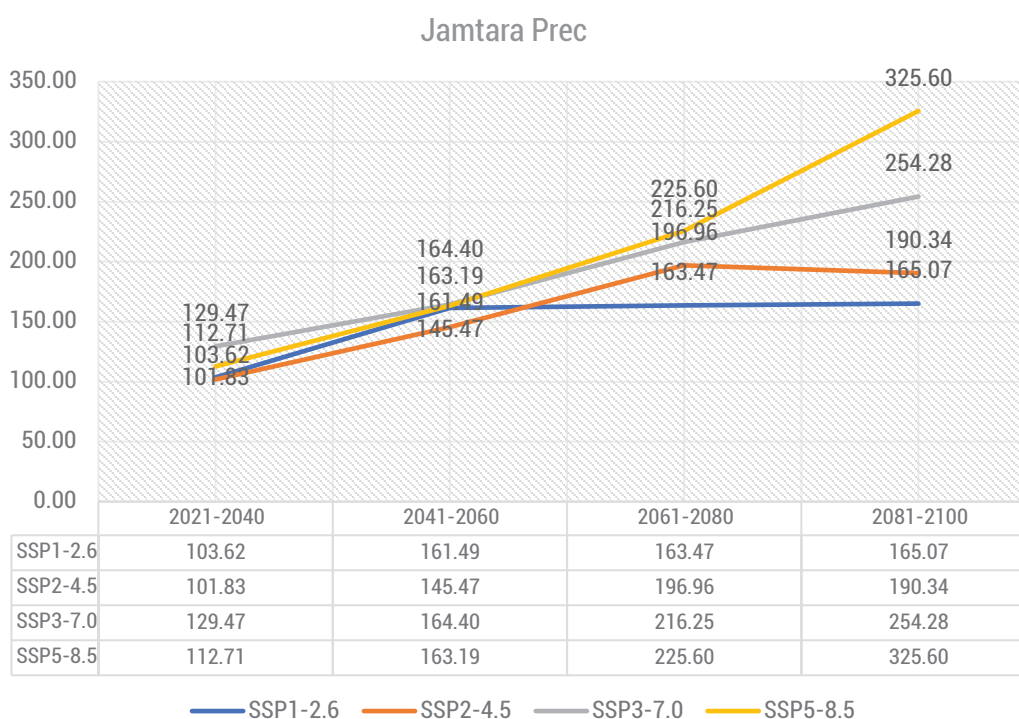


Figure 56 : Expected variation in Rainfall -Khunti district

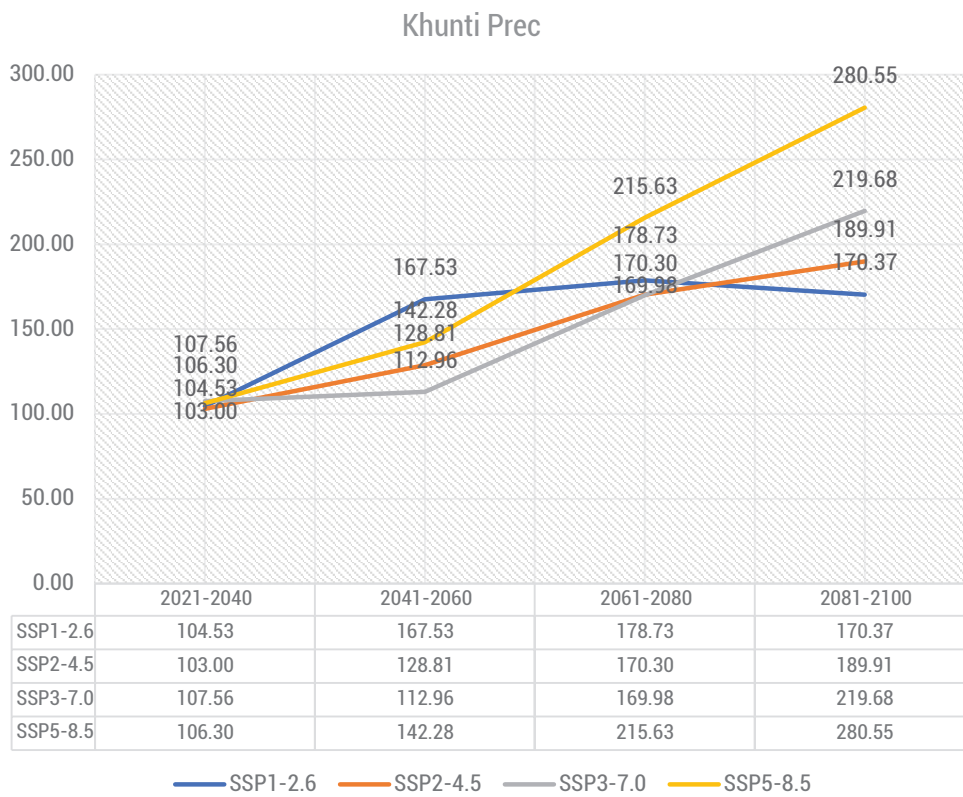


Figure 57 : Expected variation in Rainfall -Khunti district

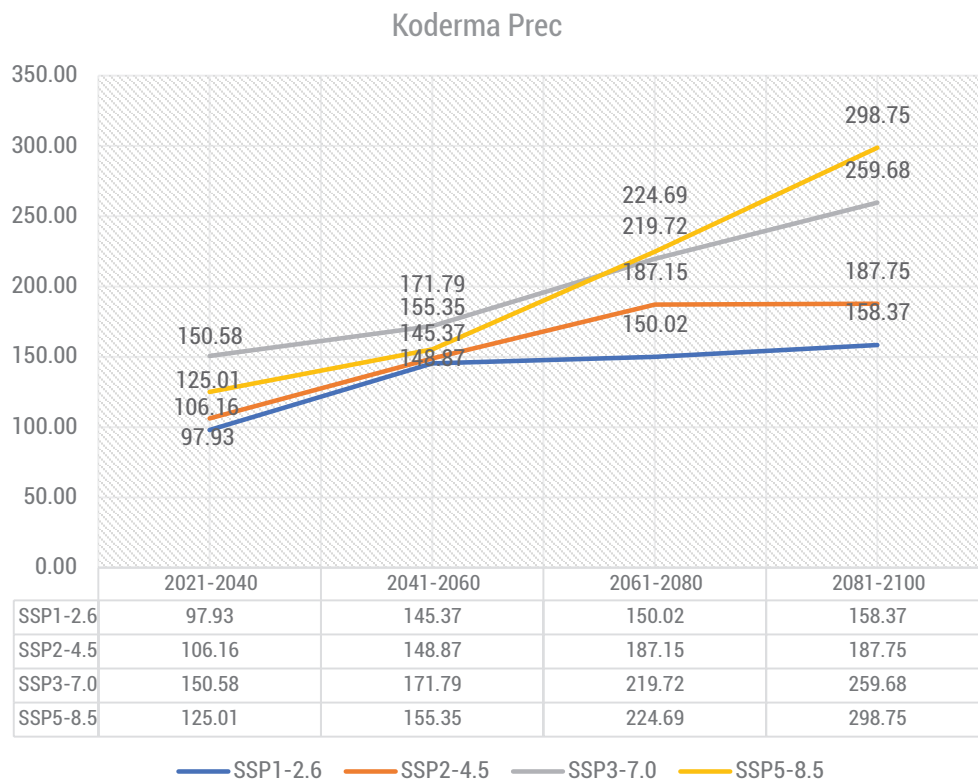


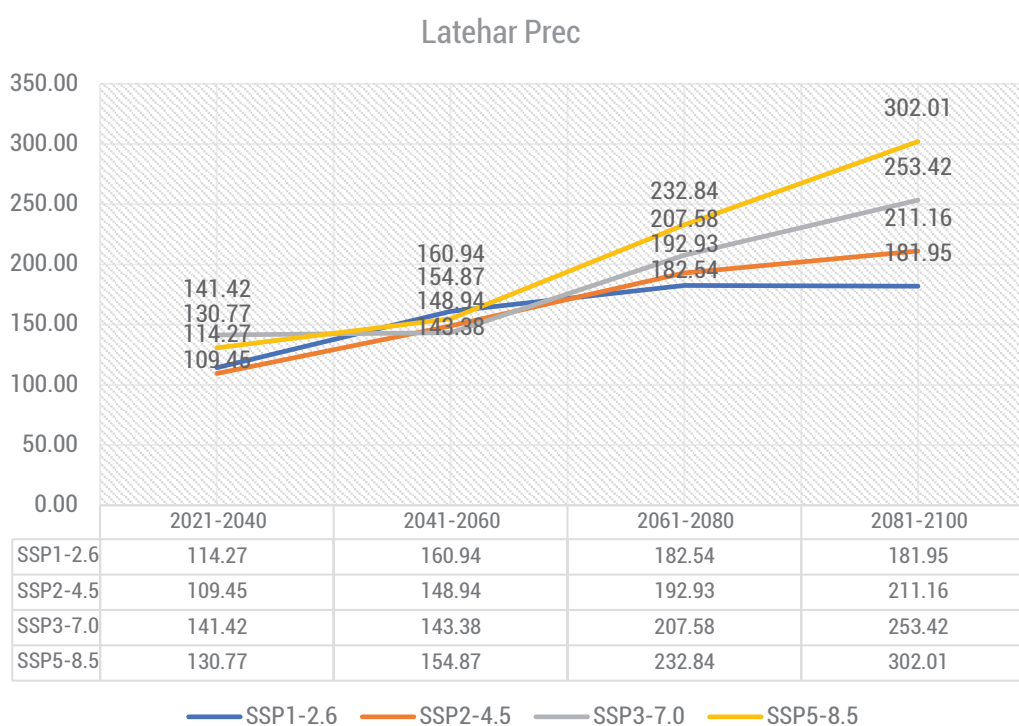
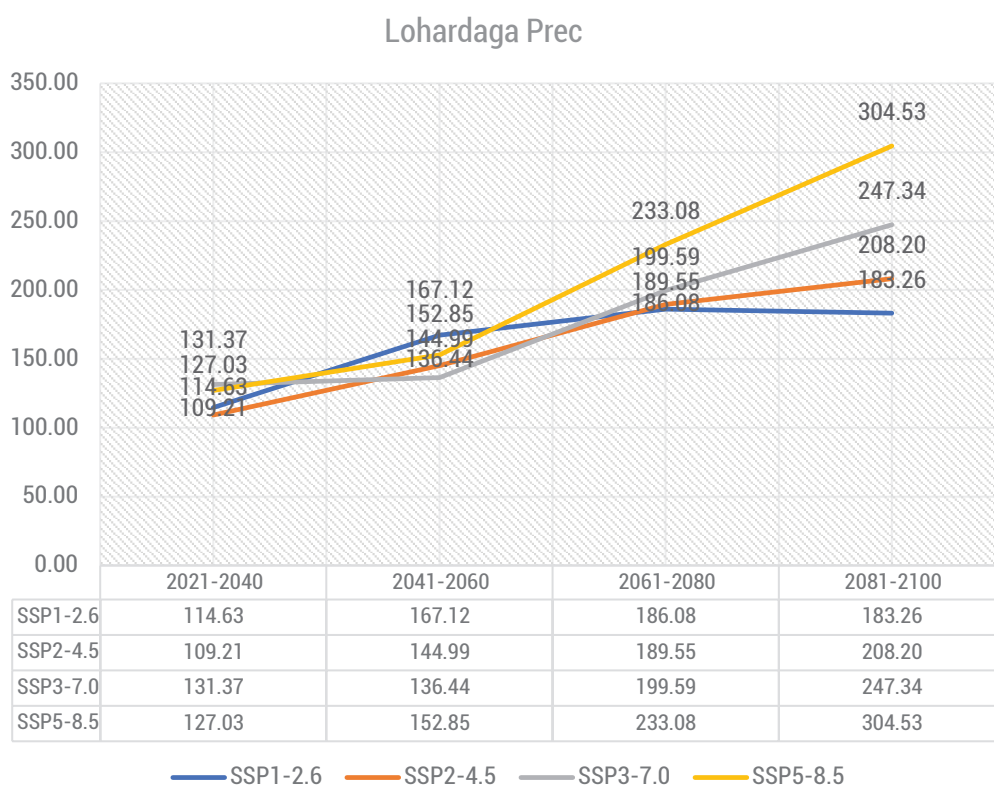
Figure 58 : Expected variation in Rainfall -Latehar district**Figure 59 : Expected variation in Rainfall -Lohardaga district**

Figure 60 : Expected variation in Rainfall -Pakur district

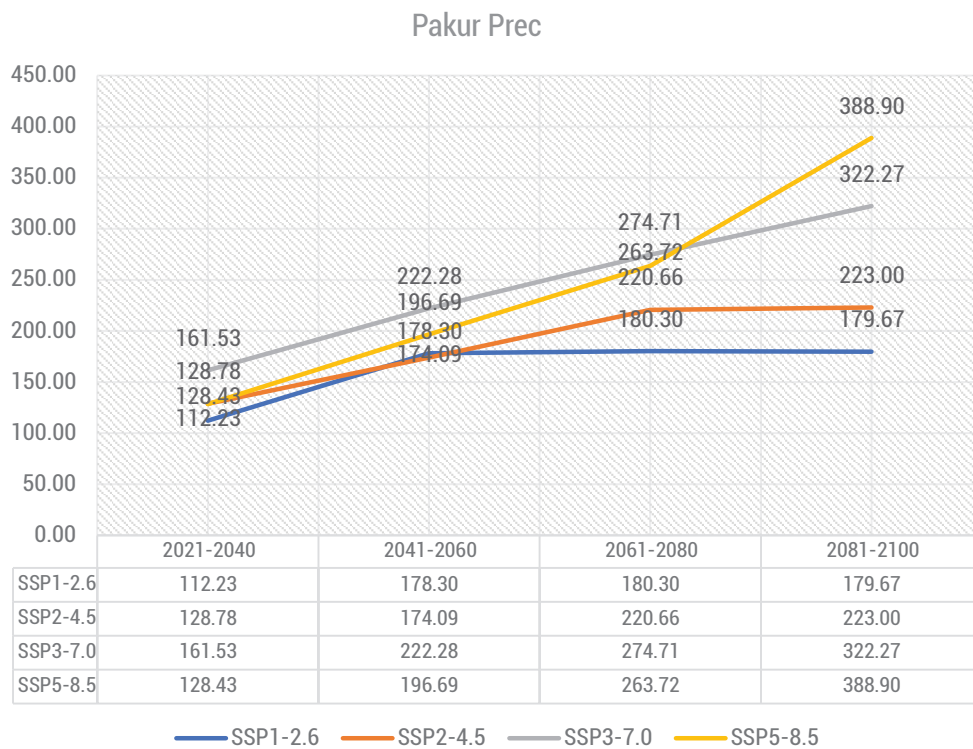


Figure 61 : Expected variation in Rainfall -Palamu district

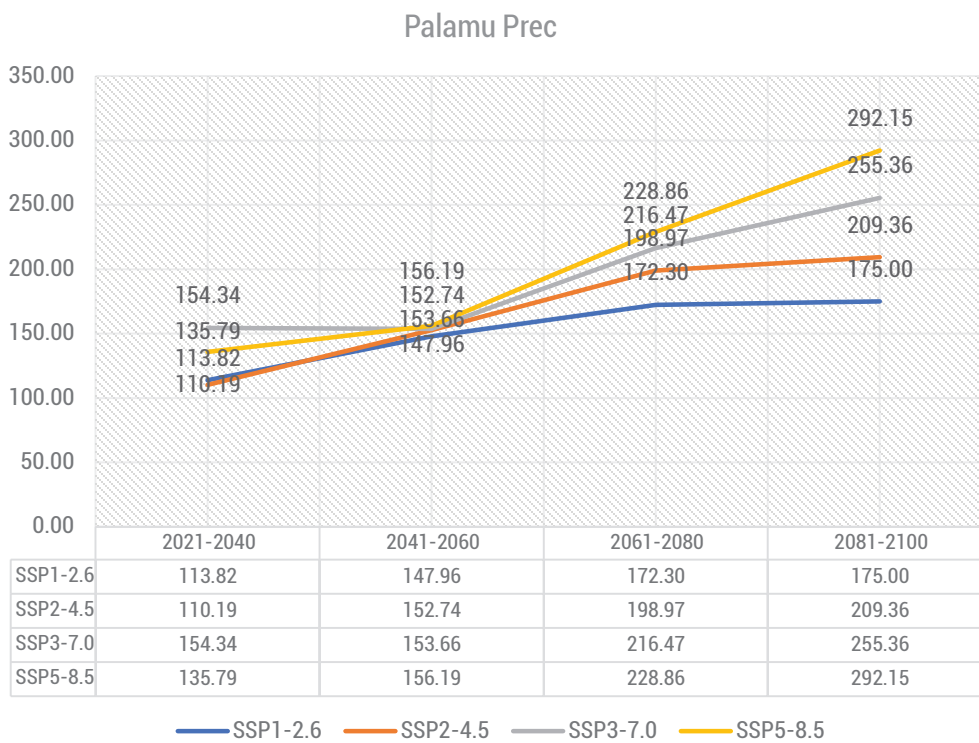


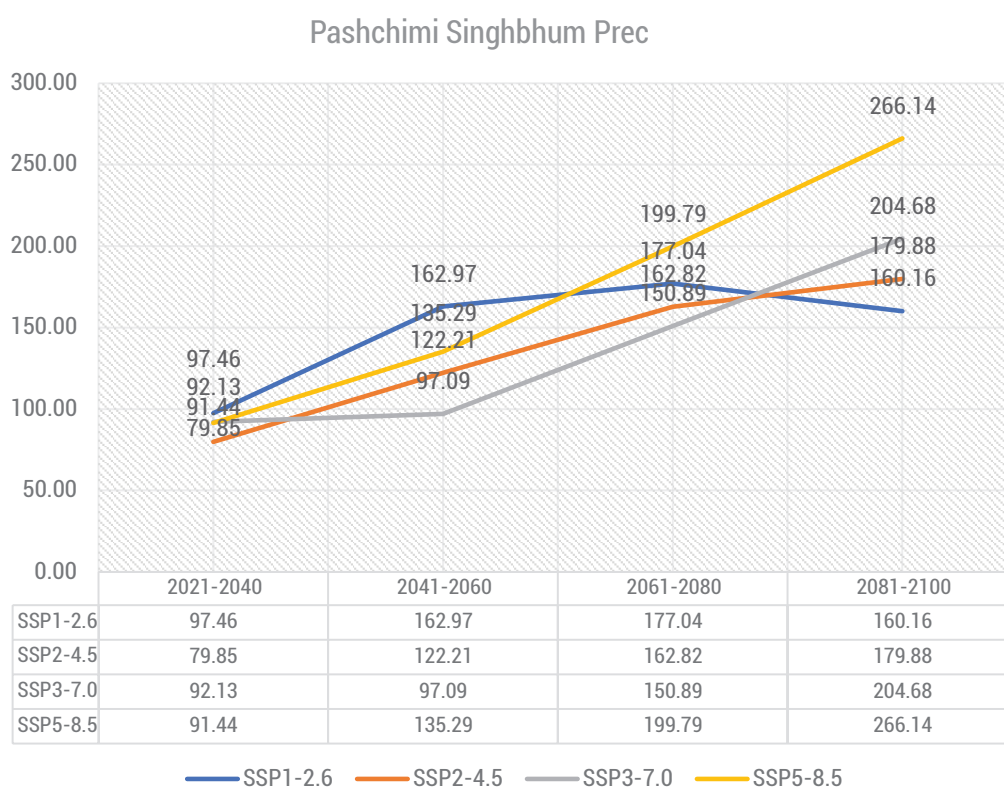
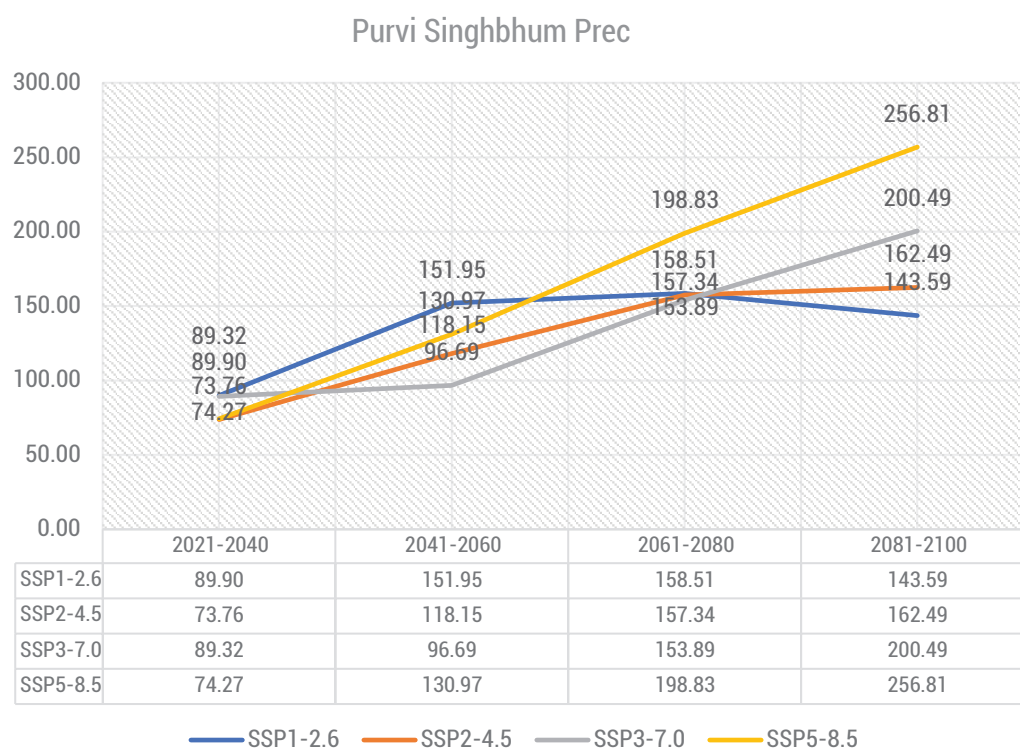
Figure 62 : Expected variation in Rainfall – West Singhbhum district**Figure 63 : Expected variation in Rainfall – East Singhbhum district**

Figure 64 : Expected variation in Rainfall -Ramgarh district

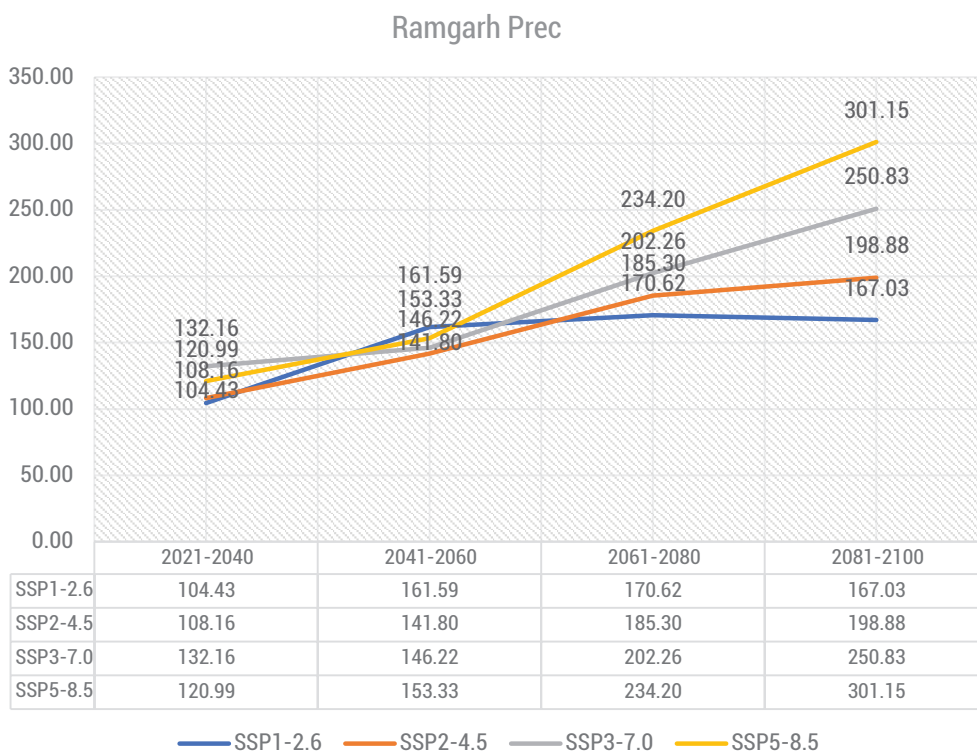


Figure 65 : Expected variation in Rainfall -Ranchi district

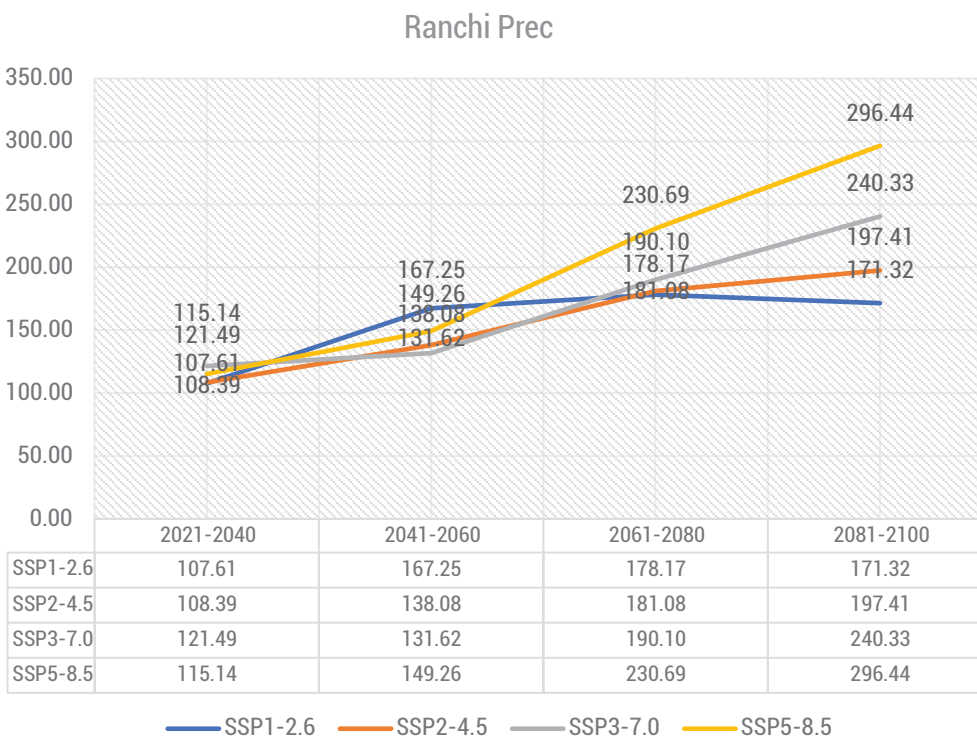


Figure 66 : Expected variation in Rainfall -Sahebganj district

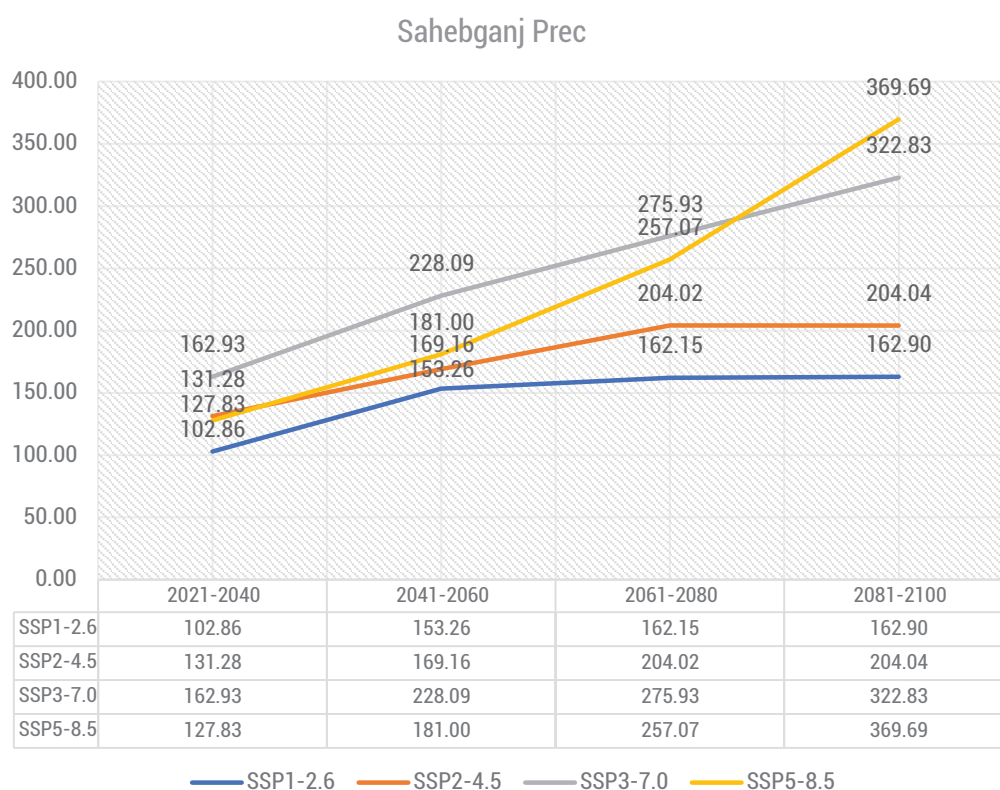


Figure 67 : Expected variation in Rainfall -Saraikela district

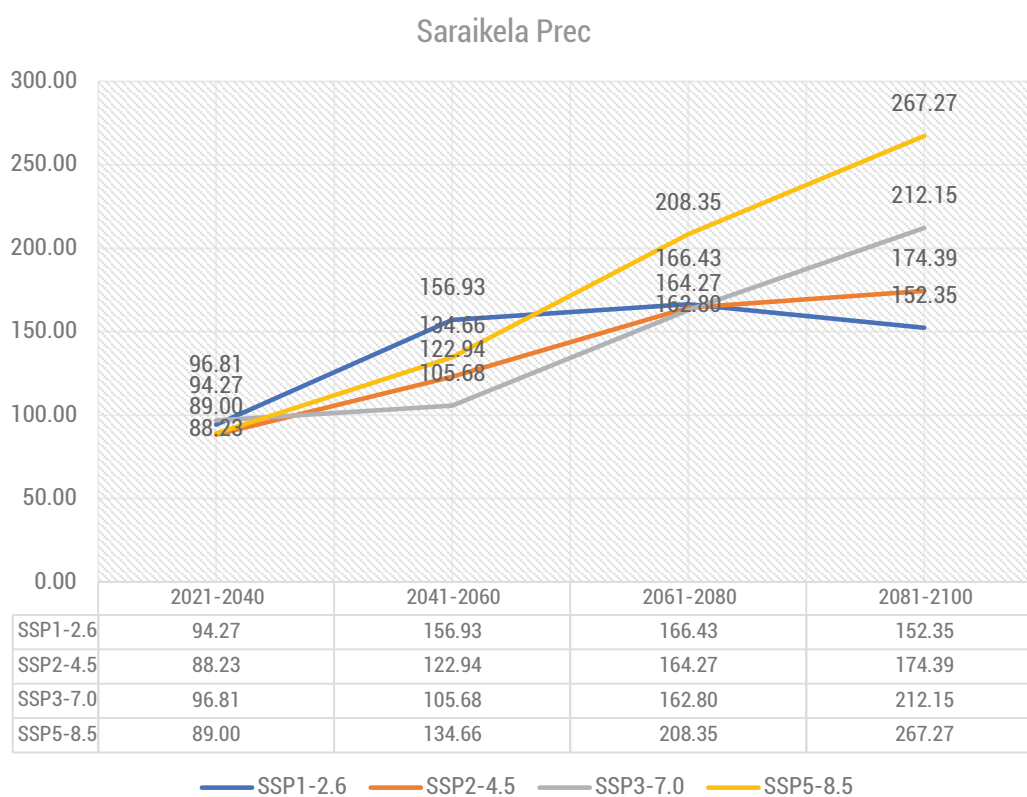
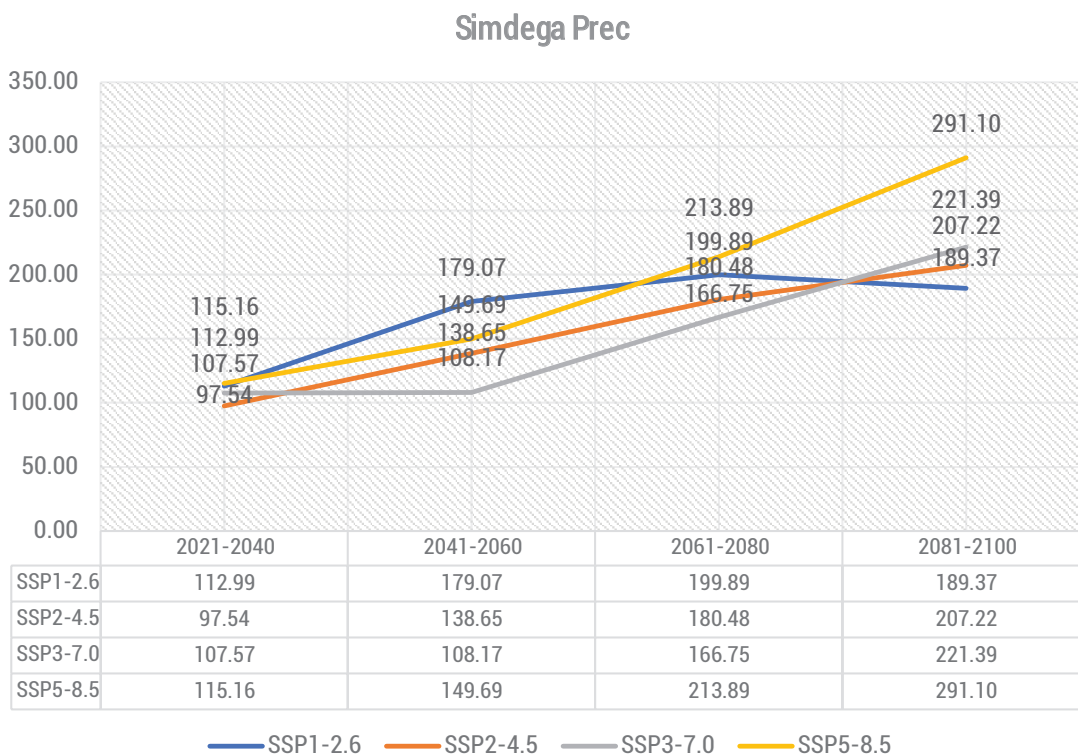


Figure 68 : Expected variation in Rainfall -Simdega district



7 Conclusion

Although climate projections are generally more reliable at the global scale than at regional and local scales, with the advent of data science, regional climatic models, and downscaling methodology, projection can be done at finer spatial resolution (even at the grid scale or 1 km) with a good approximation.

Undeniably, localized projections of climate variables have become the need of the hour and even more important for sub-national level climate policy formulation, designing climate mitigation actions, and preparing adaptation plans. This study has projected the main climatic variables i.e. temperature and precipitation using CMIP6- ensemble multiple models and multiple scenarios for the state of Jharkhand. The statistical downscaling method has been used for arriving the district and block-level results for Jharkhand.

Below are the major conclusions based on the results of the projection.

1. The CMIP6-based model ensemble predict increase in the means warming ranges from 1.54 °C (SSP1-2.6) to 5.06°C (SSP5-8.5) in the various part of the state (from 2021s to 2100s), for outlining the wide range of future climate change possibilities.
2. State's mean precipitation is projected to increase by 143 mm to 388 mm under the scenarios SSP1-2.6, SSP1-8.5 respectively, by 2100s relative to the 1970–2020 base, while much larger variability is seen in the spatial and seasonal distribution of precipitation.
3. While the increase in temperature is expected to be in the north- western part of the state, maximum increase in the mean rainfall is expected to be in the north-western regions.

The projection data shows that out of the four scenarios considered in this study, only **SSP1-2.6** is consistent with the global goal of limiting warming to **2°C** by the end of this century. These findings show that even after the adoption of the best GHG mitigation strategies, it is improbable that the temperature increase will be contained within 2°C above pre-industrial levels.

The projection data indicate that various parts of the state may face devastating climate change effects, including killer heat waves and dry spells in the next 80 years. The result is very alarming for the state of Jharkhand which is already India's most climate-vulnerable state, and whose economy is primarily based on coal and farming, with very fragmented and marginal land holdings, high tribal population, less irrigation coverage, and low per capita income.

Seeing the threat of expected temperature rise, uneven precipitation patterns, and extreme events, Jharkhand needs a comprehensive climate adaptation policy, departmental and district-level climate budget allocation for developing climate-resilient adaptation measures in various sectors like agriculture, water resources, forest, rural development, urban development energy, and health.

References

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- <https://www.ipcc.ch/report/sixth-assessment-report-cycle/>
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- <https://www.wcrp-climate.org/wgcm-cmip>
- <https://www.iamconsortium.org/about-us/>



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Government of Jharkhand**