A Project Report on

Impact of Climate Change on Temperature over Major Districts of Maharashtra State, India

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Vishwakarma Institute of Information Technology, Pune- 48

(An Autonomous Institute affiliated to Savitribai Phule Pune University)

(NBA and NAAC accredited, ISO 9001:2015 certified)

DEPARTMENT OF CIVIL ENGINEERING

ACADEMIC YEAR 2022-2023

REPORT ON

Impact of Climate Change on Temperature over Major Districts of Maharashtra State, India

UNDER THE GUIDANCE OF

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This is to certify that **Mr.Saurab Pawar, Miss.Aishwarya Mulay** has successfully completed the Project entitled **(Impact of Climate Change on Temperature over Major districts of Maharashtra State, India)** under my supervision, in the partial fulfillment of Bachelor of Technology degree in Civil Engineering the academic year 2022-2023

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We are thankful to The Director of VIIT Prof. Vivek Deshpande and Head of Civil Department Dr. Shrikant Shinde for giving us opportunity to work on this project.

Date: 26/05/2023

Place: **VIIT, Pune.**

UNDERTAKING BY STUDENTS

We, the students of B Tech Civil, hereby assure that we will follow all the rules and regulations of VIIT related to the project work for the academic year academic year **2022-23** semester **II**. The Project entitled '**Impact of Climate Change on Temperature over Major districts of Maharashtra State, India'** will be fully designed and developed by us and no part of the project/ full project will be designed and developed by any external entity or copied from some external resources. We are fully aware that copying or taking help of any external agency in the development of our project is totally unethical and illegal. The examiners have /University has full rights to initiate an action against us as per university norms if involved in unfair/ illegal/ unethical work.

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ABSTRACT

Climate change has a direct and indirect impact on many industries and aspects of daily life. According to previous research, temperature parameters change significantly around the world. A pilot study, therefore, attempted to understand temperature variation over Pune, Maharashtra state, India, during the periods 1985–2015 (historical) and 2015–2045 (future). Four general circulation models (GCMs) and two observed data sets, IMD and NASA POWER data (The Prediction of Worldwide Energy Resources), are used to study the variations in the maximum daily temperature. The Gumbel's distribution analysis was also done and compared the extreme temperature of four GCM (predicted data) with the extreme temperature of the observed value. For each GCM data set, 100 maximum temperature values are considered, and then extreme temperatures are calculated to compare the accuracy of the results and know which GCM (predicted values) is closest to the observed values. The extreme temperature of CMCC-ESM2 is most similar to both NASA and IMD (observed values).

Considering the earlier study, the present work aims to study the impact of climate change on temperature in the Maharashtra state of India. In this study, major districts in the state of Maharashtra were chosen for future temperature variation and crop patterns, considering temperature variation in each of the ten years. A similar methodology was used in the current study by expanding the study area.

This study estimates the possible effects of climatic change on temperature parameters over 14 districts of Maharashtra State, India. The mean temperature rise is more prominent in Chandrapur, Gadchiroli, and Nagpur (1.30 to 1.70 °C).

In the present study, Chandrapur, Gadchiroli, and Nagpur have experienced significant temperature increases, which will have a negative impact on crop productivity and may cause crop harvesting to be delayed. Temperature increases not only alter crop patterns but also increase water demand. Similarly, temperature variations are moderate in Amaravati, Aurangabad, and Nashik and mild in Jalgaon and Pune.

CHAPTER 1

1. INTRODUCTION

1.1 GENERAL: -

Global warming is a phenomenon where the earth's average temperature rises due to increased amounts of greenhouse gases. Greenhouse gases such as carbon dioxide, methane and ozone trap the incoming radiation from the sun [1]. One of the most immediate and obvious consequences of global warming is the increase in temperatures around the world. The **average global** temperature has increased by about 0.8 degrees Celsius over the past 100 years, according to the National Oceanic and Atmospheric Administration (NOAA) [1].

Global warming causes climate change, which poses a serious threat to life on Earth in the forms of widespread flooding and extreme weather. Climate is defined as long-term weather patterns that describe a region [2] . The global climate is the connected system of sun, earth and oceans, wind, rain and snow, forests, deserts and savannas, and everything people do, too [2]. The impacts of climate change on different sectors of society are interrelated. Drought can harm food production and human health. Flooding can lead to disease spread and damages to ecosystems and infrastructure. Human health issues can increase mortality, impact food availability, and limit worker productivity [2]. **Therefore, it is crucial to investigate how climate change will affect all hydrological parameters. Climate change impacts are seen throughout every aspect of the world we live in. However, climate change impacts are uneven across the country and the world, even within a single community, climate change impacts can differ between neighborhoods or individuals** [2]. Research on every parameter for every single small region in the world is required due to this unevenness that we see in climate change.

In the past 20 years, many engineers, ecologists, and climate scientists have worked on global warming and climate change. To understand the impact of global warming on various hydrological parameters, they studied data from the last 100 years. And, the stated that temperature has been rising in the every past decades. **According to a report by the US National Oceanic and Atmospheric Agency (NOAA), every decade since 1970 has been**

warmer than the preceding decade. Twelve of the 15 hottest years from 1901 to 2020 have been in the 21st century between 2006 and 2020 [3]. **On January 4, 2021, the India Meteorological Department (IMD) released a report titled 'The Statement on Climate of India During 2020', which states that 2020 is the eighth hottest year in India since 1901. The country's average temperature has risen by 0.62^{0}C [3].**

A developing country like India has a large geographical area. Agriculture plays an important role in economy as well as it is considered to be the backbone of economic system for developing countries. For decades, agriculture has been related with the production of vital food crops [4]. India is the second largest producer of wheat and rice. India is ranked under the world's five largest producers of over 80% of agricultural produce items, including many cash crops such as coffee and cotton, in 2010 [4]. **Any alteration in the climatic parameters such as temperature, rainfall etc. directly affects food productivity.**

Maharashtra in Western India is the third-largest state of India by size and the second-largest by population. It stretches from the west coast to the interior regions with a variable climate [5]. Maharashtra is divided into 6 revenue divisions, which are further divided into 36 districts. These 36 districts are further divided into 109 sub-divisions of the districts and 357 talukas [5]. **The climate of Maharashtra is tropical monsoons as it receives a heavy rainfall during the monsoon season with the summers being hot and winters being chilly [6].** In the past 20 years, Maharashtra has also observed a global warming effect.

In 2019, the Maharashtra government had to declare drought in 20,000 villages across 26 districts of the state. It is not only the rural areas that are experiencing the impact of climate change. Mumbai, the capital of Maharashtra, is also severely affected. In 2019, Mumbai received the maximum rainfall in its recorded history during the official monsoon season from June to September 2019 [7]. **The International Panel on Climate Change, an intergovernmental body set up by the United Nations in 1988 to study the impact of climate change, in its 2018 report, highlighted that an increase in global warming from 1.5 degree Celsius would make the coastal cities of the world, including Mumbai, more vulnerable to sea floods [8].**

Maharashtra contains India's most industrialized region, the Mumbai-Pune belt. Agriculturally, too, the state is one of India's more advanced and well-irrigated. Agriculture is the main occupation of the people. Almost 82% of the rural population depends on agriculture for livelihood. Both food crops and cash crops are grown in the state [9]. The main food crops of Maharashtra are mangoes, grapes, bananas, oranges, wheat, rice, jowar, bajra, and pulses. Cash crops include groundnut, cotton, sugarcane, turmeric, and tobacco [9]. **A slight increase or decrease in temperature will affect the cropping season (fertility season) and further it effects on the total yield of the crop.**

Consequently, these unseasonal rainfall, unwanted floods and droughts have caused a decline in not only in agricultural production but severely effects on the major and minor industries owing to change in the economic sector. Hence, now it is extremely important to study and understand impact of climate change on different hydro-meteorological parameters which directly influence the day to day life of individuals. To know or to study the impact of climate change on different hydro-meteorological parameters, one has to study long term observed data as well as should have pre-information of future events. The prior case can be done with the measured historical data which can be made available from different government and Non-government agencies which maintains the records of these parameters across the globe or for the specific regions as IMD, IITM (Indian Institute of Tropical Meteorology) but the crucial is the latter case, in which one should have a clear picture of the futuristic events –which is not possible without forecasting exercised or predictive analysis of these parameters. General circulation models (GCM) run by the IPPCC (Intergovernmental Panel on Climate Change) all around the world which solves Navier-Stoke’s equation to have causative forcing functions for futuristic time intervals provides various parameters for future time domains in different aspects. Many scientific communities had applied these GCM based parameters to forecast the hydro meteorological parameters for upcoming years (results / values available through different GCMs) and published fruitful results for the social help and set progressive a pathway for new researchers to work ahead in the allied field of interest. GCMs, RCMs and global climate models are used for weather forecasting, understanding the climate, and forecasting climate change.

Considering the above scenarios, the present study aims to study the impact of climate change on temperature of particular city / area/ location in the Maharashtra state of India.

1.2 PROBLEM STATEMENT: -

Today's globe faces a serious threat from climate change due to its effects on environment, agriculture, water availability, natural resources, ecosystems, biodiversity, economy and social well-being. In India, the average annual mean surface air temperature has shown a clear increasing trend. Any change in the environmental factors that control crop growth, such as temperature and humidity, will directly affect the amount of food productivity.

The annual average temperature over the Indian landmass has significantly increased in the north region. The number of warm days and warm nights has significantly increased over the last 35 years.

Climate models can be used to make projections about future climate and the knowledge gained can contribute to policy decisions regarding climate change. In order to predict temperature variation, this study concentrated on finding suitable of climatic models. Also, find out which downscaling method is most suitable. Purpose of downscaling method is to bring the GCM model data closer to the station-level data and reduce the resolution with the minimum loss of quality.

1.3 AIM AND OBJECTIVE

- To study temperature variation in next 30yrs of Pune city using two downscaling methods.
- Based on the first objective's results study the variation of temperature for 13 different district in Maharashtra.
- To relate change in temperature and crop productivity in divisions of Maharashtra.

CHAPTER 2

2. Literature review

To study the impact of climate change on temperature, one has to review the earlier literature on the basis of temperature variation, first in overall India and then in a specific region, i.e., Maharashtra state. As the present study focused on the impact of climate change on temperature variation, it was important to include the literature related to different GCMs and downscaling methods. In addition, also investigate seasonal crops in various Maharashtra districts and their effects on crops, taking temperature variations into account.

The Indian region experienced extreme weather events such as heat waves, cold waves, extremely heavy rain events, and many others. Since all these parameters directly and indirectly affect different sectors of India, researchers have been working on them for the last 20 years. [10] suggested that all-India surface air temperature during the dry part of the year (January-May) has been subjected to a relative cooling by as much as 0.3C during the last three decades (1968-1997). [11] have pointed out that, all-India annual maximum and minimum temperatures have significantly increased during the recent 3 decades (1971-2003) and accelerated warming is observed after 1990. [12] showed a significant increasing trend in minimum temperature and mean temperature during the monsoon and post monsoon seasons and it observed that in the recent period, minimum temperature increased faster than the maximum temperature.

Maharashtra, located in Western India, is the second-most populous and third-largest state in India. Since the previous 50 years, Maharashtra has also seen significant problems as a result of global climatic change. [13] studied impact of climatic changes on water availability and quality. According to this study, the main reasons of water crises in Maharashtra states are rising temperature and unpredictable rainfall. Since the Deccan basalts, a type of hard, non-porous rock, underlie nearly 90% of the state of Maharashtra, it is difficult to conserve water and recharge systems. Consequently, Maharashtra state experienced a water supply shortage and poor water quality. Additionally, it also discussed potential solutions and community response for preventing the water crisis in Maharashtra state. [14] Studied Sea Level Rise and Its Socio-economic Impacts in Mumbai city, India. This case study focused on the sea-level rise (SLR), its effects on coastal communities and its socio-economic impacts in India, with a special focus on the island city of Mumbai. The main causes of sea level rise are thermal expansion and the melting of land based ice. This paper showed sea Level Rise (SLR) is a by-product of climate change on a global scale. [15] also studied the temporal variation in temperature over Pune city, India, during the period 1901–2000. They found significant cooling trend in mean annual temperature.

One of the most significant economic sectors in the state of Maharashtra is the field of agriculture and related activities. Climate change will have negative affect economy since the agriculture sector is more affected by climatic variations. [16] studied impact of climate variability and change on crop production in Maharashtra, India. This study estimated the possible effects of change in climatic factors on the production of major crops in Maharashtra, India. [17] studied future climate change scenario over Maharashtra (near-term (up to 2050) and distant (up to 2100)). This study stated that although the monsoon rainfall over Maharashtra is expected to increase, future warming is very likely to reduce the agricultural yield. [18] also studied decadal changes in rainfall and temperature Extreme in Western Agro-Climatic zone of Punjab. In this study, a simple linear regression model was used to test the level of significance. It stated that the annual mean maximum temperature (Tmax) is decreasing significantly by 0.02 °C yearly and the annual mean minimum (Tmin) increasing. [19] studied Climate change and Indian agriculture and summarized the literature review on farmer's perception and adaptation in India. The study focused on several farmers upscale farming activities and improvement in their seeding techniques and irrigation. But lack of information, followed by household income, farm size and credit accessibility were the major influential factors in adopting adaptation measures.

Temperature is a primary factor affecting the rate of plant development. [20] studied Rainfall and Temperature Correlation with Crop Yield in the Case of Asunafo Forest, Ghana. The paper tested the null hypothesis that there is no statistically significant correlation between rainfall and crop yield as well as between temperature and crop yield using climate and crop statistics for 14 years (1995 – 2008). [21] observed that Temperature effects interact with the soil water status which would suggest that variation in precipitation coupled with warm temperatures would increase the negative effects on grain production. [22] suggested that temperature increase reduces global yields of major crops. CMIP5 is used along with RCP2.6, RCP4.5, RCP6.0, and RCP8.5 scenarios. The annual mean temperature over the global growing area of an individual crop was calculated by weighting each grid cell average (0.5° × 0.5° grids) according to the crop growing area within the grid cell [22].

General circulation models (GCMs) are mathematical models capable of representing physical processes of the atmosphere and ocean to simulate response of global climate to the increasing greenhouse gas emission. [23] Found the best AOGCM model in downscaling climatic parameters for Northern Karoon, Iran. They observed HadCM3 presented the best prediction of climate variability and change and they presented most of the climate change modelling by HadCM3 in different regions. [24] studied the effects of GHGs and (Anthropogenic Aerosols) AAs in the Indian Ocean warming and their mechanisms during 1870–2005. They used 17 CGCMs contributing to phase 5 of the Coupled Model Inter-comparison Project. The main conclusions were the Indian Ocean warming trend during 1870–2005 is mainly caused by GHGs while the emission of AAs slowed down the warming trend of the Indian Ocean in the twentieth century. [25] studied historical and projected surface temperature over India using Coupled Model Inter-comparison phase 5 (CMIP5). The surface temperature (ST) changes over India were studied by them using 109 simulations from global coupled climate models during 20th and future projections under different RCP emission scenarios in the 21st 9 centuries. The main conclusions were the Indian Ocean warming trend during 1870–2005 is mainly caused by GHGs while the emission of AAs slowed down the warming trend of the Indian Ocean in the twentieth century. [26] Evaluated the performances of 13 CMIP6 GCMs in simulating over Thailand for the 15- year period of 2000–2014. The evaluation of the 13 CMIP6 GCMs by five performance metrics indicated that GFDL-CM4 and CNRM group participating under the CMIP6 project were the best by performance.

Downscaling of climate change models is the procedure of using large-scale climate models to make climate predictions at finer temporal and spatial scales to fit the purpose of local level analysis and planning [27]. [28] studied the impact of climate change due to urbanization. This study provided two approaches of downscaling methods for 'exotic' variables like heat island or air quality indices, with a few examples of each approach. It suggested that statistical downscaling remains a valuable option for the rapid production of local-scale climate change information that cannot be obtained directly from GCMs or dynamical downscaling. [29] studied Distribution-based scaling to improve the usability of regional climate model projections for hydrological climate change. The distribution of precipitation intensities and Distribution of daily temperature were compared for all three study basins. It indicated DBS approach produced a more realistic representation of local hydrology than by using raw RCM output. This study showed that the second gamma distribution for rainfall events above the 95th percentile considerably improved the reproduction of the full range of the precipitation distribution. [30] studied the impact of climate change on rainfall over Mumbai using Distribution-based Scaling. He used the Distribution-based Scaling (DBS) Method to downscale and bias-correct the GCM data for both historical and future projections. Further, the evaluation was done by Climate statistics of observed data, and raw and bias-corrected GCM data by nine different GCM projections. The study provided a clearer picture of the future changes in rainfall in the Mumbai area. It indicated an increase in the number of precipitations in all future projections.

[31] presented the study of properties and applications of the gamma distribution to real-life situations such as fitting the gamma distribution into data. The study concluded that the Gamma distribution and its application is extremely important in risk analysis modelling, with a number of different uses like Hydrological Analysis, Poisson waiting time, etc. [32] Compared Rainfall amount for different return periods by Gumbel distribution and Gamma distribution. The study was carried out for Tiruchirappalli, which is situated in central south-eastern India. This paper indicated Gumbel and Gamma distribution fits well and rainfall amount for various return periods can be easily obtained using these two distributions. The comparison of these two methods showed that the Gumbel distribution provided a higher estimate than the Gamma distribution.

To study the impact of climatic change on temperature, one has to review the earlier literature on the basis of variation of temperature firstly in overall India then, specific area i.e Maharashtra. Additionally, also study seasonal crops in different districts in Maharashtra and effects on crops considering temperature variations.

Considering the above scenarios, the present study aims to study the impact of climate change on temperature in the Maharashtra state of India. In this study, major districts in the state of Maharashtra were chosen for future temperature variation and crop pattern considering temperature variation in each of the ten years.

CHAPTER 3

3. STUDY AREA AND DATA USED-

3.1 Study area-

The study is carried out for, every districts of State Maharashtra, India. The state has three crucial biogeographic zones, namely Western Ghats, Deccan Plateau, and the West coast. The Ghats nurture endemic species, Deccan Plateau provides for vast mountain ranges and grasslands while the coast is home to littoral and swamp forests [33]. Maharashtra is divided into 6 revenue divisions. The state's six divisions are further divided into 36 districts, 109 sub-divisions, and 358 talukas [33].

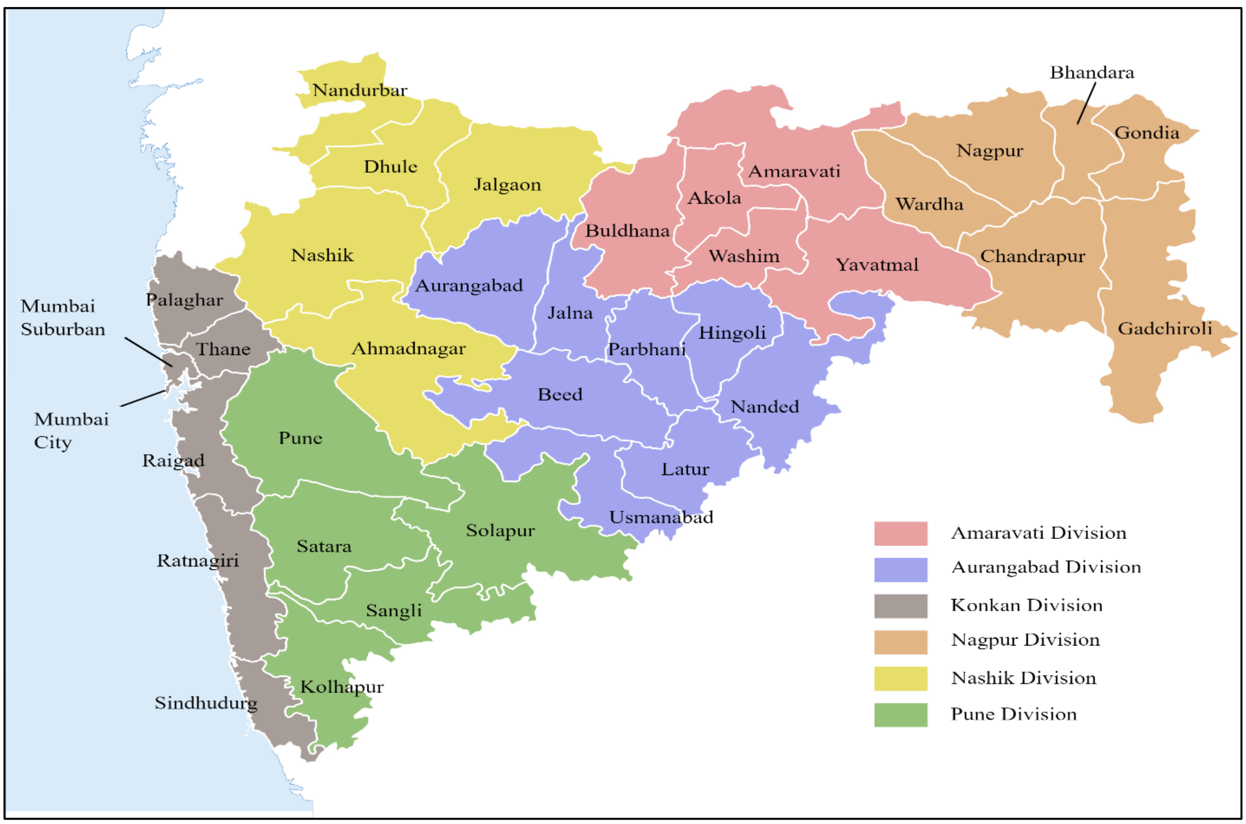


Fig-3.1. Districts of Maharashtra grouped by division [33]

- There are three natural regions-

a) Coastal areas known as Konkan and is characterized by rugged and hilly topography. Here heavy rainfall and steep slope cause severe soil erosion. A number of rivers and streams run through this area and join in the Arabian Sea [34].

b) Sahyadri hill ranges known as Western Ghats which is responsible for heavy rainfall in the coastal plains [34].

c) Deccan plateau is a land bounded by Sapura and Satmala ranges in the north, Sahyadri Ghats in the west. The valley area is flat and number of big rivers like Godavari and Krishna drain this area [34].

- Climate-

  The climate is tropical and its major portion is semi-arid with 3 distinct seasons, viz. Rainy (June to September), Winter (November to February) and Summer (March to May). The major portion of annual rainfall (50-100cm) is received in 60-70 days and is confined to southwest monsoon [34].

- Soils-

  There is a narrow strip of coastal alluvial soil in coastal districts, followed by laterite soils in Ratnagiri district, while in the remaining portion of Kolhapur and Thane districts, red loamy soils prevail. Black soils, mostly medium, occur in the rest of the state, with a few patches of deep black soils in south Nasik and Aurangabad districts and in Ahmednagar district extending to Parbhani and Nanded, Dhule and Jalgaon have significant patch of black cotton soil [34].

- Temperature-

  Normal maximum temperature varies from 24-32°C in January, 29-38°C in March going up to 43°C in May, the hottest month of the year. Maximum temperature is lowest in Mahabaleshwar and ranges between 19°C and 29°C. Minimum temperature is lowest in the month of December and January being 10-15°C. The minimum temperature in June is between 22-28°C. The annual mean temperature ranges from 20- 28°C [34].

- Rainfall-

  The annual rainfall varies from less than 50 cm in west Vidarbha to more than 200 cms in the coastal districts and adjoining areas. The districts lying between Vidarbha and Konkan receive rainfall between 50 to 200 cms. Rainfall is between 100-150 cm in the eastern Vidarbha region, 75 to 100 cm east of Aurangabad upto Nagpur [34].

3.2 Data for Temperature Study –

Observed daily maximum temperature data (Historical-1985 to 2014) for Maharashtra state, was obtained from the Prediction of Worldwide Energy Resources (POWER) project NASA.

Further, daily maximum data (Historical and Future) for the Maharashtra from three GCM (ACCESS-CM2, CMCC, CNRM) projections (Table 3.1), was extracted from the CMIP6 database, provided by the Copernicus site (https://cds.climate.copernicus.eu/). All GCMs were driven by the Shared Socioeconomic Pathways (SSPs) 4.5.

Time series in the period 1985-2045 from the GCMs grid cell covering India were extracted from each projection. The period 1985-2015 used as the historical time period and 2015-2045 as predicted time periods representing the future.

Table 3.1 - List of CMIP6 GCMs used in the present study

Model	Description	Country
ACCESS-CM2	The Australian Community Climate and Earth System Simulator (ACCESS) is an initiative aiming for a national approach to weather and climate modelling. Principal partners are the Bureau of Meteorology and CSIRO, through the Collaboration for Australian Weather and Climate Research (CAWCR).	Australia

CMCC-ESM2	Euro-Mediterranean Centre on Climate Change.CMCC-ESM2 contributes to the Climate Model Inter-comparison Project Phase 6.	Italy
CNRM-ESM2-1	Earth system (ES) model of second generation developed by CNRM-CERFACS for the sixth phase of the Coupled Model Inter-comparison Project (CMIP6). CNRM-ESM2-1 offers a higher model complexity than the Atmosphere-Ocean General Circulation Model CNRM-CM6-1 by adding interactive ES components such as carbon cycle, aerosols, and atmospheric chemistry	France

3.3 Data Downloading Procedure-

3.3.1 OBSERVED DATA-

In the current study, Observed data for the historical period (1985-2015) is required for comparison with predicted data. This will help to understand which GCM model is more effective for the Indian region. There are two websites for India: NASA (POWER Project) and IMD (Data Supply Portal). While IMD required permission to download and use data, NASA offered users a free service. Following are detailed instructions for downloading data.

1. **NASA (POWER PROJECT) DATA-**

   The POWER Data Access Viewer (DAV) Web Mapping Application contains geospatially enabled solar, meteorological, and cloud related parameters formulated for assessing and designing renewable energy systems. This site provides solar and meteorological data sets from NASA research for support of renewable energy, building energy efficiency and agricultural needs.

I. https://power.larc.nasa.gov/data-access-viewer/ is the official website for downloading NASA's observed data.

II. Open the official website and enter the following data for the location you've chosen.

Table 3.2 - Location and Co-ordinates in Maharashtra state

Sr.no	Location	Parameter	Time	Co-ordinates	
				Latitude	**Longitude**
1	**PUNE**	Daily Average Maximum Temperature at 2m from Surface of Ground	01/01/1984 to 01/01/2014	18.5044	73.8529
2	**AURANGABAD**			19.871	75.345
3	**AHMADNAGAR**			19.0924	74.7379
4	**SATARA**			17.6877	73.9913
5	**AMARAVATI**			20.9326	77.7507
6	**BEED**			18.9897	75.7559
7	**DHULE**			20.9026	74.7726
8	**BULDHANA**			20.589	76.4153
9	**GADCHIROLI**			20.1826	80.006
10	**KOLHAPUR**			16.7047	74.2416
11	**JALGAON**			21.0041	75.5667
12	**SOLAPUR**			17.658	75.9069
13	**SANGALI**			16.8568	74.5635
14	**NASHIK**			19.9965	73.7903

III. Save the CSV document.

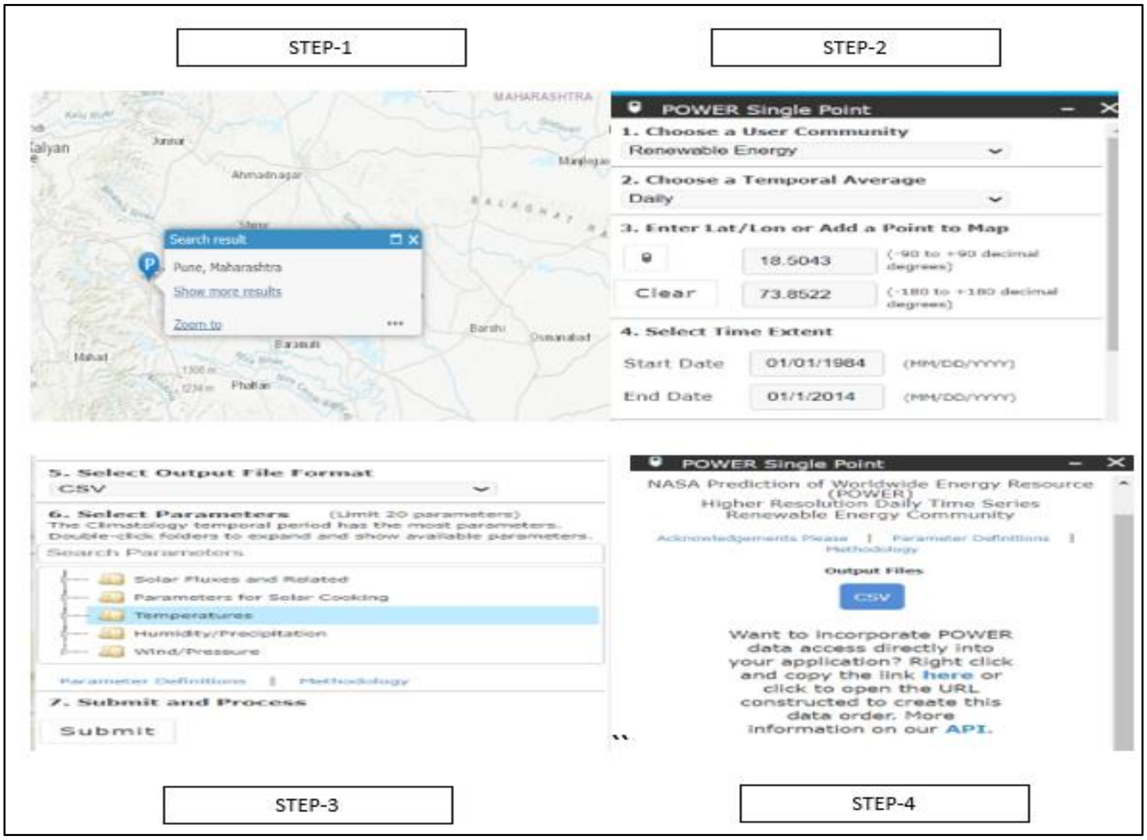


Fig. 3.2 – Steps of Downloading data for NASA

(Ref: Source https://power.larc.nasa.gov)

3.3.2 PREDICTED DATA-

Climatic models are effective in studying the impact of climatic change on different hydrological parameters for future prediction. GCM is a type of climatic model. It uses the Naiver-Stokes equations on a rotating sphere with thermodynamic terms for various energy sources (radiation, latent heat). These equations are the basis for computer programs used to simulate the Earth's atmosphere or oceans. There are two websites available that provide free service to users: Copernicus (Climate Change Service) and WCRF CMIP6 (World Climate Research Programme).

3.3.4 GENERAL CIRCULATION MODEL DATA-

- **Copernicus (Climate Change Service)-**

In the current study, The Copernicus website is used to download forecasted data (2015–2045). Copernicus Climate Change Service; ECMWF implements the Copernicus Climate Change Service (C3S) on behalf of the European Union. The Service provides comprehensive climate information covering a wide range of components of the Earth system (atmosphere, land, ocean, sea-ice and carbon) and timescales spanning decades to centuries (i.e. based on the instrumental record). It maximizes the use of past, current and future Earth observations (from in-situ and satellite observing systems) in conjunction with modelling, supercomputing and networking capabilities. This conjunction will produce a consistent, comprehensive and credible description of the past, current and future climate.

Below, the steps for downloading required data from Copernicus climate change services are given :-

I. Login/register on the site to access the database. The official website for downloading data is https://cds.climate.copernicus.eu/.

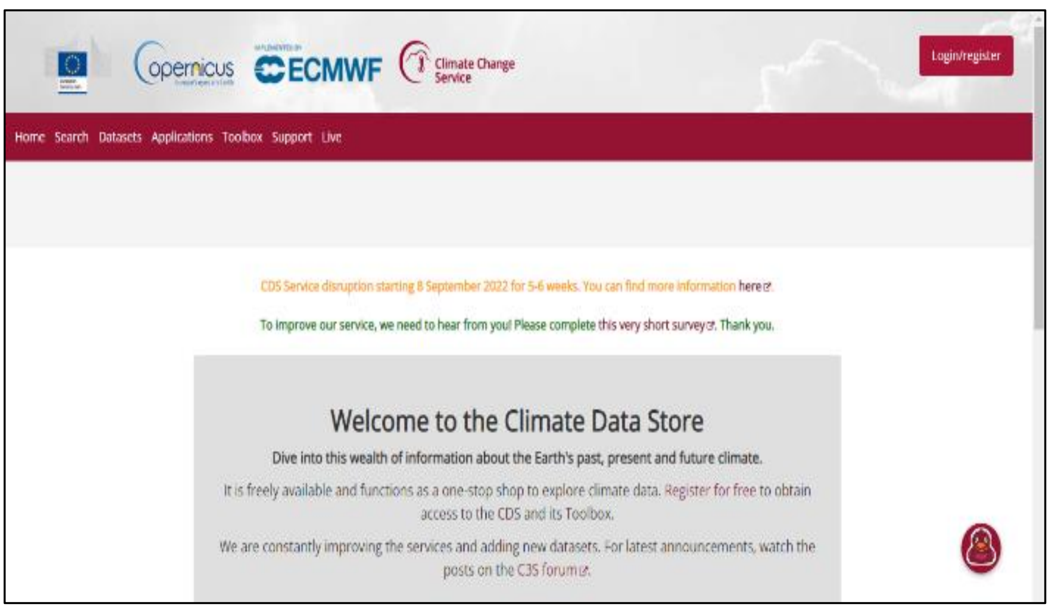


Fig.3.3 – Screenshot of Website

(Reff Source - https://cds.climate.copernicus.eu/)

II. Search CMIP 6 in the search bar option and Select the dataset – ‘’CMIP6 Climate Projections’’.

Many researchers have stated that the performance of cmip6 is better when compared to of cmip5. CMIP6 uses socioeconomic pathways, which is considered more realistic future scenarios. Also, CMIP6 GCMs’projections are less uncertain and therefore they are more reliable than CMIP5 GCMs’.

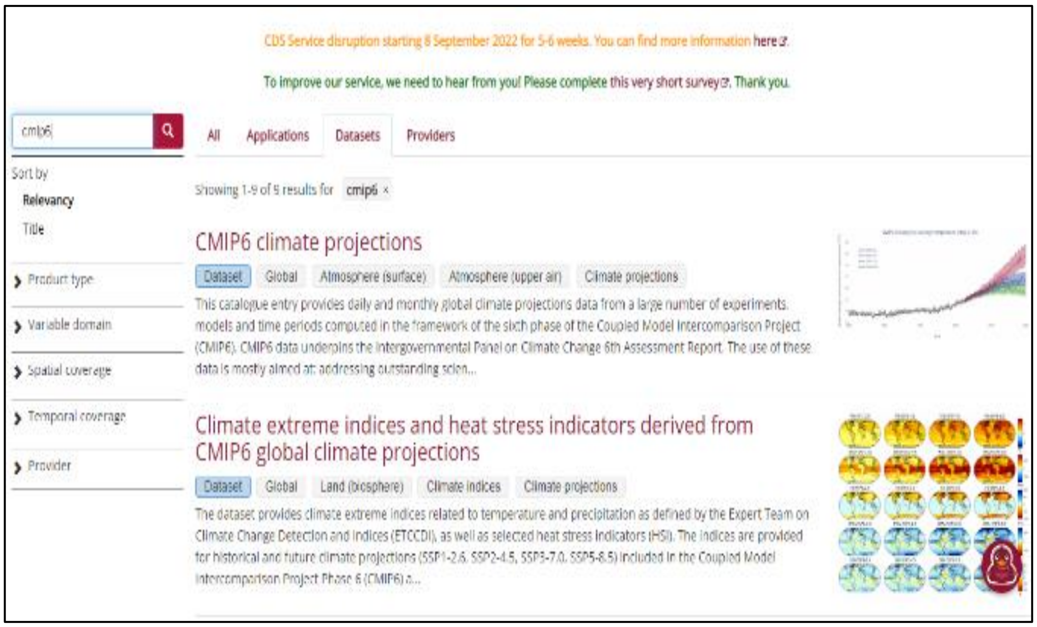


Fig.3.4 – Screenshot of Website

(Reff Source - https://cds.climate.copernicus.eu/)

III. After choosing the CMIP6 Climate projection, the application form for data collection must be filled out with the information mentioned below.

<u>Historical (1985-2015)-</u>

- Experiment – Historical
- Temporal resolution – Daily
- Variable - Daily maximum near-surface air temperature
- Model – ACCESS-CM2 (Australia), CNRM-ESM2-1 (France), CMCC-ESM2 (Italy).
- Region – Co-ordinates as per location mentioned in table no - 3.1

Future (2015-2045)-

- Experiment –SSP4.5
- Temporal resolution – Daily
- Region – Co-ordinates as per location mentioned in table no – 3.1
- Variable - Daily maximum near-surface air temperature
- Model – ACCESS-CM2 (Australia), CNRM-ESM2-1 (France), CMCC-ESM2 (Italy).

IV. The data is downloaded in the form of a zip file in NC format, which must be converted to excel format.

Table.no 3.3 – Data discription of GCM model

DATA DISCRIPTION	
Data type	Gridded
Projection	Regular latitude-longitude grid, ocean grid
Horizontal coverage	Global
Horizontal resolution	Varies between models
Vertical coverage	Single levels, pressure levels (1 - 1000 hPa)
Temporal coverage	1985-2045
Temporal resolution	Daily
File format	NetCDF4
Conventions	Climate and Forecast (CF) Metadata Convention v1.6
Versions	Latest version of the data is provided

V. The net CDF file is converted to a CSV file using code in MATLAB software.

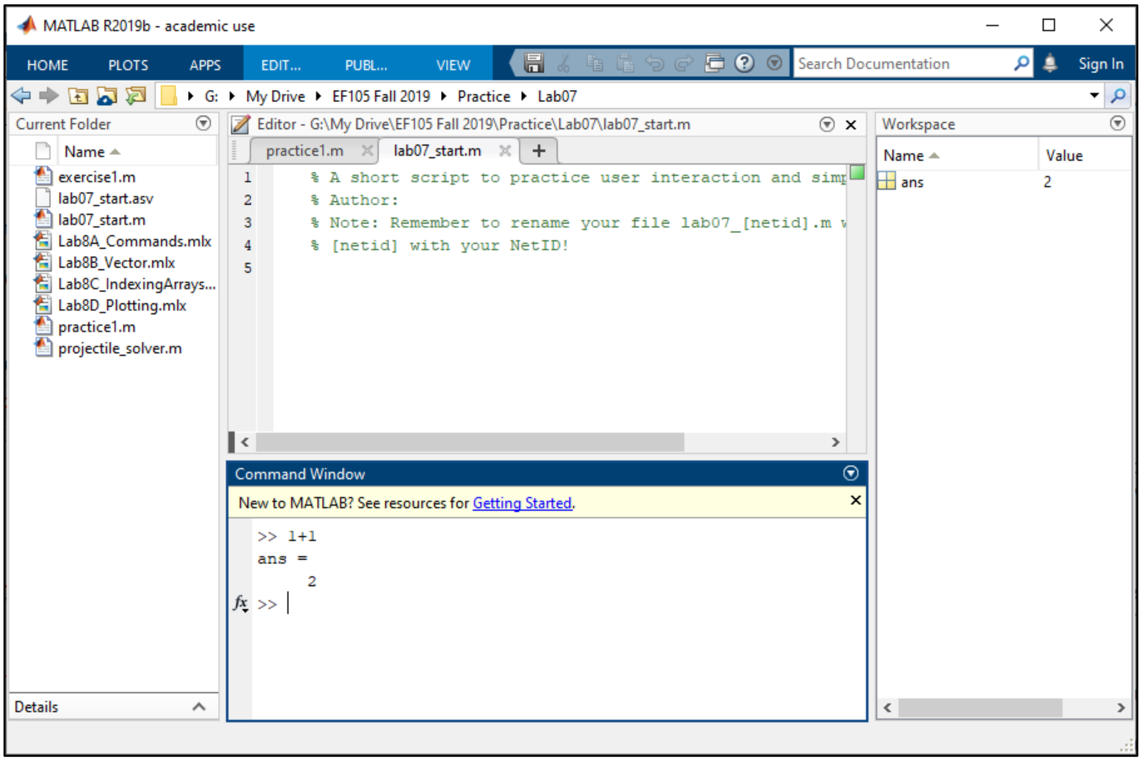


Fig.3.5 – Screenshot of MATLAB Software.

VI. The data obtained by the Copernicus website has four columns representing each corner point of grid. The approximate downscaling method is used to obtain data at a specific location.

VII. Bilinear interpolation (Approximate downscaling method) is used to approximate downscale data from corner grid points to specific co-ordinates.

3.4 Data for Crop pattern study

In the Maharashtra state, a variety of crops are grown, but the three main ones with the highest economic importance are rice, cotton, and sugarcane, which are all grown during the kharif season [35]. The Konkan and east Vidarbha region produces the most rice, whereas 0.9868 million hectares, including Madhya Maharashtra and Marath-wada, are used for sugarcane farming [35]. In some areas of Marath-wada and West Vidarbha, cotton is the primary crop. The average annual output of rice in Maharashtra is 3.6 million tonnes (mt), and the average annual production of sugarcane is 72.26 mt, or 20.52% of the production of all of India [35].

3.4.1 Cropping seasons

1. Rabi seasons

- The Arabic translation of Rabi is ‘Spring’. Rabi crops are sown during winter in India and Pakistan which is why they are also known as winter crops. The sowing season generally starts around November and the crops are harvested between March and April which is springtime in the region. Since monsoon is over by November in these countries, these crops are usually cultivated using irrigation or rainwater that has percolated into the ground [36].

- The seeds are sown at the start of autumn and the crop is harvested in the spring. Their seeds are planted at the start of the winter season, and the crop is harvested at the conclusion of the winter or early spring. Unseasonal showers in November and December are harmful to the growth of Rabi crops [36].

- Examples of Rabi crops:

  Some of the common examples of major rabi crops grown in India are wheat, mustard, barley, green peas, sunflower, coriander, cumin, etc.

➢ **Wheat**

- A large portion of agricultural income for India comes through the production of wheat. It is the second-largest producer of this crop in the world. As wheat requires low temperatures to grow, winter is the ideal season for farming this Rabi crop. The ideal temperature range should be around 140 to 180 C with a rainfall of 50 cms to 90cms. The crop is harvested in spring when the temperature is slightly warm [36].

- In India, Uttar Pradesh is the largest wheat-producing state and is closely followed by Punjab and Haryana [36].

- **Mustard**

- Mustard is another Rabi crop that is widely used in Indian households for cooking. It requires a dry and cool climate to grow (subtropical climate) and the ideal temperature range is in-between 100 to 250C. With 60% of total production in the country, Uttar Pradesh again is the largest mustard producing state in the country followed by Rajasthan and Madhya Pradesh [36].\

2. Kharif seasons

- The word Kharif is also Arabic and it means 'Autumn' and the Kharif crops are harvested in this season (September or October). These crops are also known as monsoon crops as they are cultivated in this season. They grow well in rain-fed areas with a hot and humid climate. Kharif crops are highly reliant on rainfall patterns. The quantity and timing of rains are the two most essential parameters that determine Kharif crop output. Their crops are harvested at the end of the monsoon season, and their seeds are planted at the start of the monsoon season [36].

- However, the Kharif season differs from state to state within India. The general period of sowing starts from June till November depending on the area. The sowing season varies depending on the arrival of monsoon in different parts of India; for example, in southern states like Kerala and Tamil Nadu, seeds are normally seeded towards the end of May, whereas in northern regions like Punjab and Haryana, seeds are sown around June [36].
- Some examples of Kharif crops are rice, bajra, groundnut, cotton, etc.

- **Rice**

- Rice is the most common example of a Kharif crop. India produces 20% of the world's rice production, second to China. It is one of the most important agricultural crops in the country and is a staple food pan India. Rice grows in regions with heavy rainfall and requires a minimum rainfall of 100cms and an average temperature of 250 C The crop is traditionally grown in waterlogged rice paddy fields. West Bengal is the largest rice-producing state in India [36].

➢ **Maize**

- Maize is another important cereal crop in India. It requires a minimum rainfall of 50 cms to 75 cms and temperatures in-between 210 to 270C. The largest maize-producing state in India is Karnataka [36] . Dent corn, flint corn, pod corn, popcorn, flour corn, and sweet corn are the six main varieties of maize. 55 Sweet corn varieties are grown for human consumption as kernels, whereas field corn varieties are used for animal feed, various corn-based human food uses (such as grinding into cornmeal or masa, pressing into corn oil, and fermentation and distillation into alcoholic beverages like bourbon whiskey), and chemical feed stocks. Ethanol and other biofuels are also made from maize [36].

3. **Zaid Season**

- It is a short season during the summer months which, comes between the rabi and the kharif seasons. So, the sowing time is March-June [36].
- Requires warm and dry weather for growth and longer day for flowering [36].
- Some of the crops produced during ‘Zaid’ are watermelon, muskmelon, cucumber, vegetables and fodder crops. These are mostly seasonal fruits and vegetables.

3.4.2 Primary crops in Maharashtra –

- **Sugarcane**

This is a tropical crop, and under warm and humid conditions continues its growth unless terminated due to flowering. A typical life cycle of sugarcane is around 15–18 months. Maximum temperature of 27°–38°C is essential during all phases of its growth. For germination, optimum temperature of 32°–38°C is required. Above 38°C, rate of photosynthesis decreases. A sufficient amount of water is also equally essential for development of the crop [35].

- **Cotton**

This is grown in a semi-arid climate and requires a mean temperature of 21°–27°C for proper vegetative growth. With adequate soil moisture, it can tolerate temperatures as high as 43°C, but below 21°C the growth slows down or ceases. Cotton requires 600–1000 mm of rainfall during its entire growth phase; however, heavy rainfall or moisture stress during bud development and boll shedding will substantially reduce the yield. Cotton is also called 'white gold' because of its economic value in the market [35].

- **Rice**

This crop needs a hot and humid climate. It is cultivated in the areas of high humidity, prolonged sunshine, an assured supply of water and requires 4–6 months for full growth. The average temperature required for rice crop development is 20°–40°C. The optimum temperature of 30°C during daytime and 20°C during night-time are favorable for growth and development of the crop. When the temperature is in the critical range, rainfall is the most crucial factor for cultivation of rice crops [35].

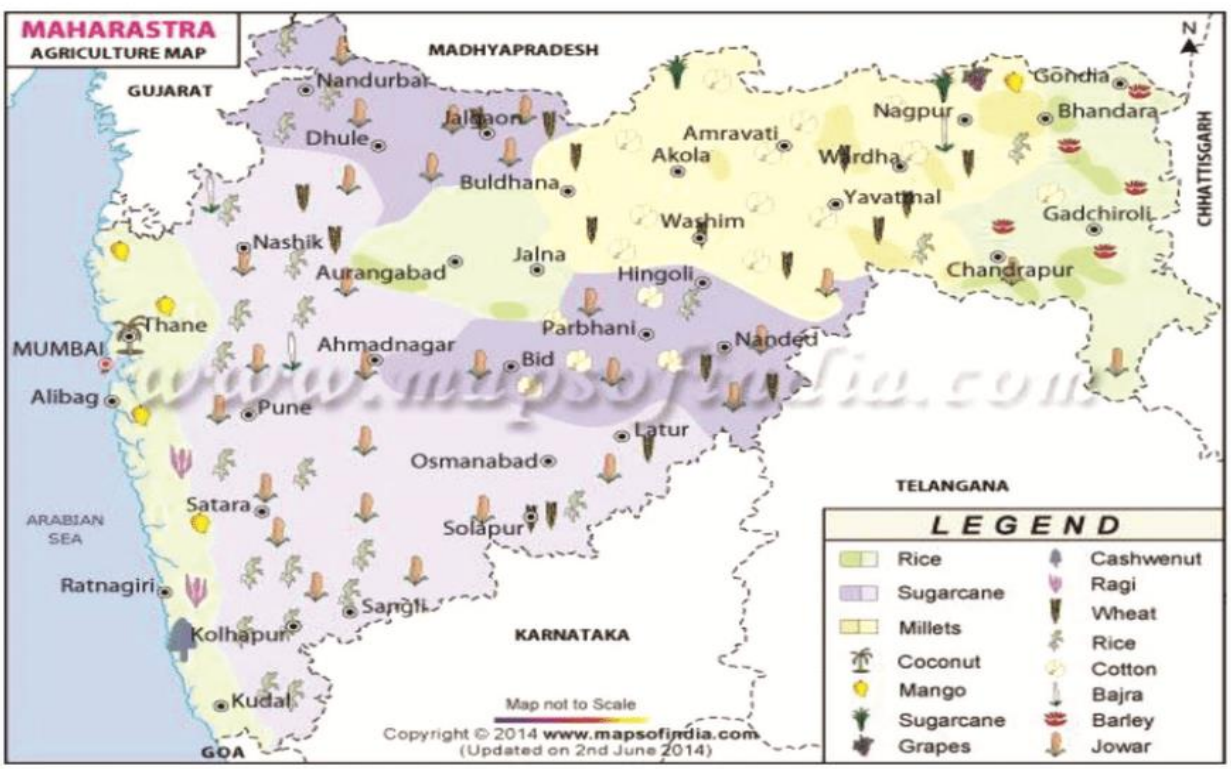


Fig.3.6 Major crops in Maharashtra state [35]

3.4.4 Districts and temperature ranges in different crop seasons-

1) AHMEDNAGAR –

Ahmednagar district is the largest district of Maharashtra state with a geographical area of 17 418 sq. km. The climate of the region is characterized by hot summers and general dry throughout the year except during the southwest monsoon season. The mean maximum temperature is 39.1°C and the mean minimum temperature is 12.3°C. The average annual rainfall in the district is 568.7 mm [37].

Table 3.4 Crop weather calendar for Ahmednagar.

DISTRICT	RABI CROP	SOWING TIME(NOV)		HARVESTING TIME(MAY)	
		MAX	MIN	MAX	MIN
Ahmednagar	**Jowar**	30	15	30	12
	Gram	30	20	30	20
	Safflower	40	15	40	15
	Wheat	30	15	30	12
	KHARIF CROP	**SOWING TIME(JUNE)**		**HARVESTING TIME(OCT)**	
		MAX	MIN	MAX	MIN
	Groundnuts	35	20	35	20
	Bajara	30	10	35	15
	Tur	35	10	35	10
	Sunflower	30	10	30	10

2) AMRAVATI –

The district in general has a tropical wet and dry climate. One can face extreme weather variation throughout the year over here, with very hot summers and very cold winters. July and August are the months during which the maximum rainfall occurs over here. Amravati district is considered to have the third highest rainfall in the entire Maharashtra state with approximately 1437mm of rainfall. Amarvati district is covered by three major rivers namely, Tapi, Purna and Wardha. Two main dams of the district helping in irrigation and water supply are the Shahanur dam on the Shahanur River and Chandrabhaga dam on River Chandrabhaga [38].

Table 3.5 Crop weather calendar for Amravati.

DISTRICTS	RABI CROP	SOWING TIME(NOV)		HARVESTING TIME(MAY)	
		MAX	MIN	MAX	MIN
Amravati	**Wheat**	30	15	32	15
	KHARIF CROP	**SOWING TIME(JUNE)**		**HARVESTING TIME(OCT)**	
		MAX	MIN	MAX	MIN
	Cotton	30	15	40	15
	Soyabean	35	20	38	20
	Groundnuts	35	20	30	25

3) AURANGABAD -

Aurangabad district is located in the north central part of Maharashtra between 19°15’ and 20°40’ N latitude and 74°37’ and 75°52’E Longitude. The mean maximum temperature 39.7 °C, the mean minimum temperature is 24.6 °C. The average annual rainfall is 619 mm. Major part of the district falls in Godavari basin with a small area in north eastern parts falling Tapi Basin. The major river in the district is the Godavari with its tributaries namely; Purna, Dudhna and Shivna rivers [39].

Table 3.6 Crop weather calendar for Aurangabad.

DISTRICTS	RABI CROP	SOWING TIME(NOV)		HARVESTING TIME(MAY)	
		MAX	MIN	MAX	MIN
Aurangabad	**Jowar**	30	10	35	15
	Safflower	30	20	35	20
	Wheat	30	15	30	12
	KHARIF CROP	**SOWING TIME(JUNE)**		**HARVESTING TIME(OCT)**	
		MAX	MIN	MAX	MIN
	Jowar	40	15	40	12
	Bajara	30	10	35	15
	Cotton	30	15	35	15
	Tur	30	10	40	15

4)CHANDRAPUR -

Chandpur district is one of the eleven districts of Vidarbha region of Maharashtra. The Climate of the district is characterized by a hot summer and general dryness throughout the year except during the south-west monsoon season, i.e., June to September. The temperature rises rapidly after February till May, which is the hottest month of the year. The mean daily maximum temperature during May is 42.8°C and the mean daily minimum temperature during December is 12.2°C The normal annual rainfall (1901-1992) varies from about 1200 to 1450 mm. It is minimum in the western part around Warora and gradually increases towards east and reaches maximum around Brahmapuri [40].

Table 3.7 Crop weather calendar for chandrapur.

DISTRICTS	**RABI CROP**	**SOWING TIME(NOV)**		**HARVESTING TIME(MAY)**	
		MAX	MIN	MAX	MIN
Chandrapur	**Wheat**	30	10	30	13
	KHARIF CROP	**SOWING TIME(JUNE)**		**HARVESTING TIME(OCT)**	
		MAX	MIN	MAX	MIN
	Paddy	41	20	40	20

5) GADCHIROLI -

The climate of the district is characterized by a hot summer, a well distributed rainfall during the southwest monsoon and general dryness except during rainy season. The winter is from December to February followed by summer from March to May. The mean minimum temperature is 14.6°C and mean maximum temperature is 42.1°C. The normal annual rainfall over the district varies from about 1300 mm to 1750 mm. There are three major rivers flowing in the district i.e., Wainganga, Indravati and Pranhita, all are tributaries of Godavari River [41].

Table 3.8 Crop weather calendar for Gadchiroli.

DISTRICTS	**RABI CROP**	**SOWING TIME(NOV)**		**HARVESTING TIME(MAY)**	
		MAX	MIN	MAX	MIN
Gadchiroli	**Gram**	30	10	35	16
	KHARIF CROP	**SOWING TIME(JUNE)**		**HARVESTING TIME(OCT)**	
		MAX	MIN	MAX	MIN
	Paddy	41	20	40	20

6) JALGAON -

Jalgaon district, an important district of Khandesh region is situated in north western part of Maharashtra. The district is well known for Banana cultivation. The climate of the district is characterized by a hot summer and general dryness throughout the year except during the south-west monsoon season, i.e., June to September. The mean minimum temperature is 10.8°C and means maximum temperature is 42.2°C. Jalgaon District received an average rainfall of about 521.61 mm during 2017. The major part of the district comes under Tapi basin. Tapi is the main river flowing through the district [42].

Table 3.9 Crop weather calendar for jalgaon.

DISTRICTS	**RABI CROP**	**SOWING TIME(NOV)**		**HARVESTING TIME(MAY)**	
		MAX	MIN	MAX	MIN
Jalgaon	**Jowar**	30	10	35	15
	KHARIF CROP	**SOWING TIME(JUNE)**		**HARVESTING TIME(OCT)**	
		MAX	MIN	MAX	MIN
	Jowar	40	15	40	12

7) NAGPUR -

Nagpur district is one of the nine districts of Vidarbha Region of Maharashtra State. The climate of the district is characterized by a hot summer and general dryness throughout the year except during the south-west monsoon season, i.e., June to September. The mean minimum temperature is 12°C and mean maximum temperature is more than 45°C. The normal annual rainfall (1901-1992) over the district ranges from about 1000 mm to 1200 mm [43].

Table 3.10 Crop weather calendar for Nagpur.

DISTRICTS	**RABI CROP**	**SOWING TIME(NOV)**		**HARVESTING TIME(MAY)**	
		MAX	**MIN**	**MAX**	**MIN**
Nagpur	**Wheat**	**30**	**15**	**32**	**15**
	Gram	**30**	**20**	**30**	**20**
	KHARIF CROP	**SOWING TIME(JUNE)**		**HARVESTING TIME(OCT)**	
		MAX	**MIN**	**MAX**	**MIN**
	Jowar	**35**	**15**	**40**	**15**
	Tur	**30**	**10**	**40**	**15**

8) NASHIK -

Nasik District is situated in north western part of Maharashtra. The climate of the district is on the whole is agreeable. The climate of Nashik district is characterized, by general dryness throughout the year except during the south-west monsoon season. The maximum temperature in summer is 42.5°C and minimum temperature in winter is less than 5.0°C. The average annual rainfall for the period 2002 to 2011 ranges from about 476.7 mm (Devali) to 3508.1 mm (Igatpuri). The normal annual rainfall in the district varies from about 500 mm to 3400 mm [44].

Table 3.11 Crop weather calendar for Nashik.

DISTRICTS	**RABI CROP**	**SOWING TIME(NOV)**		**HARVESTING TIME(MAY)**	
		MAX	MIN	MAX	MIN
Nashik	**Wheat**	30	15	30	20
	KHARIF CROP	**SOWING TIME(JUNE)**		**HARVESTING TIME(OCT)**	
		MAX	MIN	MAX	MIN
	Bajara	30	10	35	15

9) PUNE

Pune is the second largest district of Maharashtra State in respect of area. The climate of the district is on the whole is agreeable. The winter season is from December to about the middle of February followed by summer season which last up to May. June to September is the south-west monsoon season, whereas October and November constitute the post-monsoon season. The mean minimum temperature is about 12°C and mean maximum temperature is about 39°C. The normal annual rainfall over the district varies from about 468 mm to 4659 mm [45].

Table 3.12 Crop weather calendar for Pune.

<table>
<tr><th rowspan="2">DISTRICTS</th><th rowspan="2">RABI CROP</th><th colspan="2">SOWING TIME(NOV)</th><th colspan="2">HARVESTING TIME(MAY)</th></tr>
<tr><th>MAX</th><th>MIN</th><th>MAX</th><th>MIN</th></tr>
<tr><td rowspan="14">Pune</td><td>Wheat</td><td>30</td><td>15</td><td>30</td><td>20</td></tr>
<tr><td>Jowar</td><td>30</td><td>15</td><td>30</td><td>12</td></tr>
<tr><td>Wheat</td><td>30</td><td>15</td><td>30</td><td>20</td></tr>
<tr><td>Groundnuts</td><td>31</td><td>20</td><td>38</td><td>20</td></tr>
<tr><td>Gram</td><td>25</td><td>10</td><td>35</td><td>10</td></tr>
<tr><td>Safflower</td><td>40</td><td>15</td><td>40</td><td>15</td></tr>
<tr><th rowspan="2">KHARIF CROP</th><th colspan="2">SOWING TIME(JUNE)</th><th colspan="2">HARVESTING TIME(OCT)</th></tr>
<tr><th>MAX</th><th>MIN</th><th>MAX</th><th>MIN</th></tr>
<tr><td>Bajara</td><td>30</td><td>10</td><td>35</td><td>15</td></tr>
<tr><td>Jowar</td><td>30</td><td>20</td><td>30</td><td>20</td></tr>
<tr><td>Bajara</td><td>40</td><td>15</td><td>35</td><td>15</td></tr>
<tr><td>Sugarcane</td><td>35</td><td>12</td><td>35</td><td>20</td></tr>
<tr><td>Bajara</td><td>30</td><td>10</td><td>35</td><td>15</td></tr>
</table>

CHAPTER 4

4. METHODOLOGY

Climate change has an impact on many industries and aspects of daily life, both directly and indirectly. According to previous research, there is a significant variation in temperature parameters all over the world**.** Many researchers have been working on the future prediction of climate impact by using GCM models. Pilot study, therefore, attempted to understand temperature variation over Pune, Maharashtra state, India, during the periods 1985–2015 (historical) and 2015–2045 (future). Four General Circulation Models (GCMs) and two observed data IMD and NASA POWER data (The Prediction of Worldwide Energy Resources) are used to study the variations in the maximum daily temperature.

Considering the earlier study, the present–work aims to study the impact of climate change on temperature in the Maharashtra state of India. In this study, major districts in the state of Maharashtra were chosen for future temperature variation and crop pattern considering temperature variation in each of the ten years. Similar methodology was used in the current study by expanding the study area.

Most climate change projections are developed using global-scale models that generate average temperature changes that can be expected to occur over decades. These global models cannot capture minute atmospheric details such as cloud cover, airborne particles, and local pollution sources etc. Yet these smaller details can have a big impact on local climate. In this study, different downscaling techniques were also learned and compared in order to better account for regional climatic influences.

4.1 GENERAL: -

4.1.1 GCM-GENERAL CIRCULATION MODEL

It is a type of climate model. It employs a mathematical model of the general circulation of a planetary atmosphere or ocean. It uses the Naiver–Stokes equations on a rotating sphere with thermodynamic terms for various energy sources (radiation, latent heat) [46].

These equations are the basis for computer programs used to simulate the Earth's atmosphere or oceans. The two main types of General Circulation Models are Atmospheric and Ocean models. AGCM is used to provide a reinterpretation of the atmospheric response to the anomalous atmospheric forcing (from GHG and aerosols). Ocean general circulation models (OGCMs) are a particular kind of general circulation model to describe physical and thermos-dynamical processes in oceans. Separately they account for the changes within the atmosphere and the ocean respectively [46] .

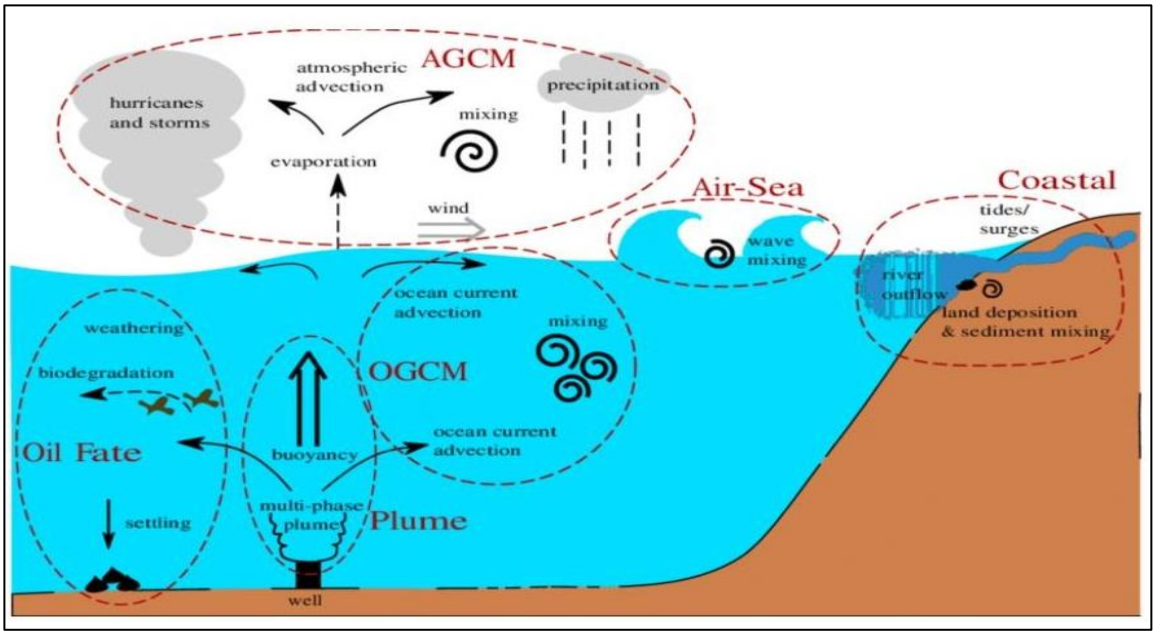


Fig. 4.1 Schematic depiction of processes and modeling components needed to address the transport problem in deep water oil blow-outs near coastal regions [47] .

4.1.2 The Intergovernmental Panel on Climate Change (IPCC)

It is an intergovernmental body of the United Nations responsible for advancing knowledge on human-induced climate change. These coordinated efforts are part of the Coupled Model Inter-comparison Projects (CMIP) [48] . The use of these data is mostly aimed at:

- Improving the understanding of the climate system.
- Providing estimates of future climate change and related uncertainties.
- Providing input data for the adaptation to the climate change.

- Examining climate predictability and exploring the ability of models to predict climate on decadal time scales.
- Evaluating how realistic the different models are in simulating the recent past.

CMIP5 provides daily climate projections on single levels from a large number of experiments, models, members and time periods computed in the framework of the fifth phase of the Coupled Model Inter-comparison Project (CMIP5) [49].

- Historical experiments show how the GCMs performs for the past climate and can be used as a reference period for comparison with scenario runs for the future. The period covered is typically **1850-2005.**
- The RCP scenarios provide different pathways of the future climate forcing. The period covered is typically, **2006-2100** some extended RCP experimental data is available from 2100-2300.

CMIP6 provides daily and monthly global climate projections data from a large number of experiments, models and time periods computed in the framework of the sixth phase of the Coupled Model Inter-comparison Project [49].

- Climate projection experiments following the combined pathways of Shared Socioeconomic Pathway (SSP) and Representative Concentration Pathway (RCP). The SSP scenarios provide different pathways of the future climate forcing. The period covered is typically 2006-2100.

4.1.3 Shared Socioeconomic Pathways (SSPs)

They are scenarios of projected socioeconomic global changes up to 2100. They are used to derive greenhouse gas emissions scenarios with different climate policies. They have been used to help to produce the **IPCC Sixth Assessment Report** on climate change. It shows socioeconomic factors may change over the next century. These include things such as population, economic growth, education, urbanization and the rate of technological development [50].

SSP	Scenario
SSP1-1.9	very low GHG emissions: CO_2 emissions cut to net zero around 2050
SSP1-2.6	low GHG emissions: CO_2 emissions cut to net zero around 2075
SSP2-4.5	intermediate GHG emissions: CO_2 emissions around current levels until 2050, then falling but not reaching net zero by 2100
SSP3-7.0	high GHG emissions: CO_2 emissions double by 2100
SSP5-8.5	very high GHG emissions: CO_2 emissions triple by 2075

Fig.4.2 Shared Socioeconomic Pathways and scenario [51]

4.1.4 Representative Concentration Pathway (RCP)

It is a greenhouse gas concentration (not emissions) trajectory adopted by the IPCC. Four pathways were used for climate modelling and research for the IPCC fifth Assessment Report (AR5) in 2014. The pathways describe different climate futures, all of which are considered possible depending on the volume of greenhouse gases (GHG) emitted in the years to come [52] .

Name of RCP's	Radiative Forcing	Time	Pathway shape	Concentration (ppm)	Emissions (Kyoto Protocol's greenhouse gases)
RCP 8.5	> 8.5 W/m2	in 2100	Rising	> ~1370 CO2-eq in 2100	Rising continues until 2100.
RCP 6.0	~6.0 W/m2	at stabilization after 2100	Stabilization without overshoot	~850 CO2-eq (at stabilization after 2100)	Decline in the last quarter of century
RCP 4.5	~4.5 W/m2	at stabilization after 2100	Stabilization without overshoot	~650 CO2-eq (at stabilization after 2100)	Decline from the mid-century
RCP3-PD*	~3.0 W/m2	peak at before 2100 and then decline	Peak and decline	peak at ~490 CO2-eq before 2100 and then decline	Decline in the first quarter of century
Based on IPCC, 2007					

Fig.4.3 Types of Representative Concentration Pathways [51]

- RCP 8.5 refers to the concentration of carbon that delivers global warming at an average of 8.5 watts per square meter across the planet.
- RCP 2.6 means the radiative forcing level reaches 3.1 W/m^2 by mid-century but returns to 2.6 W/m^2 by 2100.

4.1.5 DOWNSCALING METHODS-

Most climate change projections are developed using global-scale models that generate average temperature changes that can be expected to occur over decades. These global models cannot capture minute atmospheric details such as cloud cover, airborne particles, and local pollution sources etc. Yet these smaller details can have a big impact on local climate. In order to better account for regional climatic influences, coarse-resolution GCM outputs are translated into finer resolution climate information through the process of "downscaling" [53]. Downscaling, also called disaggregation, is a scale conversion process that increases the spatial resolution. Its purpose is to bring the GCM model data closer to the station-level data and reduce the resolution with the minimum loss of quality [53]. There are two main approaches to downscaling climate model outputs: Statistical and Dynamical downscaling. Bilinear interpolation is also used as Approximate downscaling method.

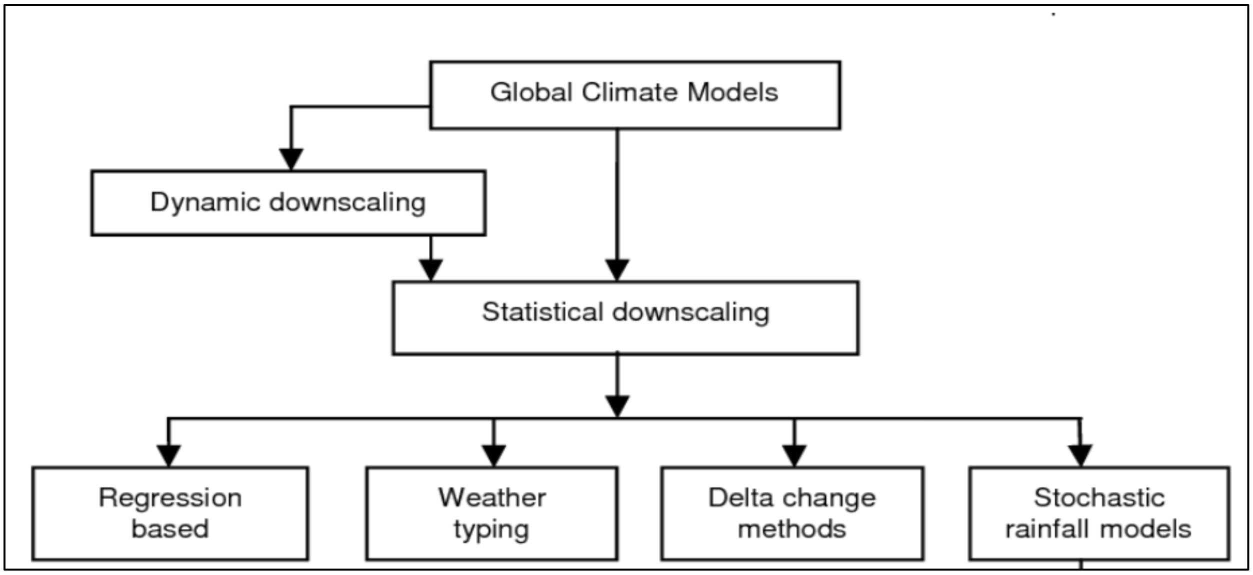


Fig.4.4 Overview of downscaling method [53]

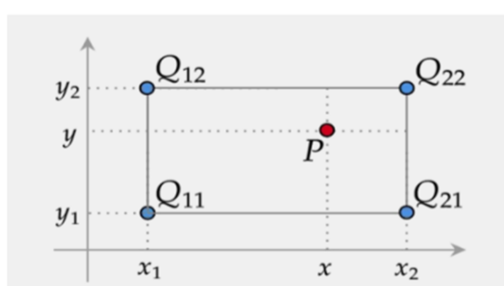
Approximate downscaling-

4.1.6 BILINEAR INTERPOLATION-

- The process of estimating unknown data values that lie between known values.
- Bilinear interpolation is a method for interpolating functions of two variables (e.g., x and y) using repeated linear interpolation.
- Bilinear interpolation is performed using linear interpolation first in one direction, and then again in the other direction. Although each step is linear in the sampled values and in the position, the interpolation as a whole is not linear but rather quadratic in the sample location [54].

P= P1+P2+P3+P4

- P1 = $\frac{(x_2 - x)(y_2 - y)}{(x_2 - x_1)(y_2 - y_1)} Q_{11}$
- P2= $\frac{(x - x_1)(y_2 - y)}{(x_2 - x_1)(y_2 - y_1)} Q_{21}$
- P3= $\frac{(x_2 - x)(y - y_1)}{(x_2 - x_1)(y_2 - y_1)} Q_{12}$
- P4= $\frac{(x - x_1)(y - y_1)}{(x_2 - x_1)(y_2 - y_1)} Q_{22}$



Here , X and Y are co-ordinates at each corner and Q is temperature.

- **Dynamical downscaling-** For Dynamical downscaling a higher resolution climate model is used. Dynamical downscaling adjusts coarse-grid simulations of GCMs to fine-grid results by using RCMs. In the dynamic downscaling approach, a Regional Climate Model (RCM) is nested into GCM. It can be further subdivided into one-way nesting and two-way nesting [55].

- **Statistical downscaling-** For Statistical downscaling, a statistical relationship is developed between the historic observed climate data and the output of the climate model for the same historical period. The relationship is used to develop the future climate data [56].

- **Statistical downscaling methods are generally classified into three groups-**

1.Linear methods: Establish linear relationships between (Large scale climatic variables) predictor(s) and (Regional and local variables) predictand.

1.Delta Method (Delta SD) – A simple method that is widely used and assumes that changes occur over larger, regional scales and that relationships between climate variables will remain the same in future scenarios. Same type of variable (e.g., both monthly temperature, both monthly precipitation) [57].

2.Simple and multiple linear regression, Canonical Correlation Analysis (CCA) and Singular Value Decomposition (SVD) - Variables can be of the same type or different (e.g., both monthly temperature or one monthly wind and the other monthly precipitation) [57].

Advantages of linear methods-

- Relatively straight-forward to apply.
- Employs full range of available predictor variables.

Dis-advantages of linear methods-

- Requires normality of data (e.g., monthly temperature, monthly precipitation, long-term average temperature).
- Cannot be applied to non-normal distributions (e.g., daily rainfall).
- Not suitable for extreme events.

2. Weather Classification-Weather classification/typing schemes, as the name suggests, classifies days into different weather groups, or in other words, it is the classification of local climate into different weather classes. Then, this weather classification is used to estimate climate change by evaluating the change in the frequency of these classes. (Fowler et al., 2007)
Variables can be of the same type or different (e.g., both monthly temperature, one large-scale atmospheric pressure field and the other daily rainfall) [57].

This method can be sub-divide into: -

I. Analog method
II. Cluster analysis
III. ANN (Artificial Neural Network)
IV. SOM (Self-Organizing Map)

Advantages of Weather classification-

- Versatile, i.e., can be applied to both normally and non-normally distributed data.

Dis-advantages of Weather classification-

- Requires large amount of data and some computational resources.
- Incapable of predicting new values that are outside the range of the historical data.

3. Weather Generator- Weather generators are stochastic (Random probability distribution) models, in which the statistical properties of a local climate variable are reproduced or replicated (Wilby et al., 2004). They use a two-state first-order Markov chain and a gamma distribution for modelling the occurrence and the amount of precipitation respectively [57].
This method can be subdivided into: -

I. LARS-WG (Long Ashton Research Station Weather Generator)
II. MarkSim GCM
III. NHMM (Nonhomogeneous Hidden Markov Model)

LARS-WG and MarkSim GCM- Same type of variable, different temporal scales (e.g., predictor is monthly precipitation and predictand is daily precipitation).

NHMM- Variables can be of the same type or different (e.g., both monthly temperature, one large-scale atmospheric pressure and the other daily rainfall).

Advantages of Weather Generator-

- Produces large number of series, which is valuable for uncertainty analysis.
- Production of novel scenarios.

Dis-advantages of Weather Generator-

- Sensitive to missing or erroneous data in the calibration set.
- Requires generation of multiple time-series and statistical post-processing of results.

4.2 Distribution Based Scaling and Bias-correction-

4.2.1 Introduction

Both Global and Regional Climate models (GCM, RCM) have systematic errors (biases) in their output. For example, climate models often have too many rainy days and tend to underestimate rainfall extremes. There can be errors in the timing of the monsoon or the amount of seasonal rainfall, or temperatures can be consistently too high or too low. To overcome the large biases in climate models, a range of bias correction methods have been developed.

- **DC approach**

The simplest approach is the Delta change method, which is often used in climate impact research. This approach uses the GCM or RCM response to climate change to modify observations. E.g. if the climate model predicts 3°C higher temperatures, 3°C is added to all historic observations to construct a new time series for the future climate [29].

In the DC approach, only the climate change signal between the control period and a future time period was derived from the time series of precipitation and temperature. For precipitation, the percent change was derived as DC factors for the mean precipitation in each month. The daily precipitation in the observations was then multiplied by the respective monthly DC factors to produce the adjusted time series [29].

- **DBS approach**

In this case, the DBS approach used two steps: In the first step, the wet fraction is adjusted to match the reference observations. In the second step of DBS, the remaining non-zero rainfall was transformed to match the observed cumulative probability distribution in the reference data by fitting gamma distributions to both observed and simulated daily rainfall [30].

4.2.2 Gamma distributions-

Gamma Distribution is a Continuous Probability Distribution that is widely used in different fields of science to model continuous variables that are always positive and have skewed distributions [31]. The Gamma distribution and its application are extremely important in risk analysis modelling, with a number of different uses like:

1. Poisson waiting time: The Gamma $(\alpha,\ \theta)$ distribution models the time required for α events to occur, given that the events occur randomly in a Poisson process with a mean time between events of θ. For example, if we know that major flooding occurs in a town on average every six years, Gamma (4, 6) models how many years it will take before the next four floods occur [31].
2. Hydrological Analysis: In hydrology, the gamma distribution has the advantage of having only positive values, since hydrological variables such as rainfall and runoff are always positive (greater than zero) or equal to zero as a lower limit value [31].

- A random variable X is said to have one parameter (standard) gamma distribution if its distribution is given by-

$$\boxed{f(x) = \frac{X^{\alpha-1}e^{-x}}{\Gamma(\alpha)}\ , \quad x > 0, \alpha > 0}$$

Where, the parameter α is called the shape parameter since it most influences the peak of the distribution [31].

- A random variable X is said to have the two-parameter (standard) gamma distribution if its distribution is given by-

$$\boxed{f(x) = \frac{1}{\Gamma(\alpha)\theta^{\alpha}} x^{\alpha-1} e^{\frac{-x}{\theta}}, \quad or \quad f(x) = \frac{\theta^{\alpha} X^{\alpha-1} e^{-\theta x}}{f(\alpha)}\ , \quad x > 0, \alpha > 0, \theta > 0}$$

Where, the parameter α is called the shape parameter, since it influences the peak of the distribution. The parameter θ is called the inverse scale parameter since most of its influence is on the spread of the distribution [31].

4.2.3 Procedure of DBS

In this study, Distribution-based Scaling (DBS) Method [30] is used to downscale and bias-correct the GCM data for both historical and future projections. Observed daily at 2m maximum temperature data for the 14 districts station in Maharashtra state, covering the period 1985 to 2015 used as reference period. It was obtained from the NASA Power Data. Further, Daily maximum near-surface air temperature data from three GCMs projections was extracted from the CMIP6 database by using MATLAB.

The DBS approach includes two steps-

In the first step, simulated (GCM data) and observed daily maximum temperature data (NASA data) were sorted in descending order. The cut-off value (mean temperature) was defined as the threshold that reduced the percentage of wet days in the GCM data to that of the observations. Days with Temperature amounts larger than the threshold value was considered as wet days and all other days as dry days.

In the second step of DBS, the remaining non-zero temperature was transformed to match the observed cumulative probability distribution in the reference data by fitting gamma distributions to both observed and simulated daily temperature. The density distribution of the two-parameter gamma distribution is expressed as:

$$\boxed{f(x) = \frac{(x/\beta)^{\alpha-1}\exp(-x/\beta))}{\beta\Gamma(x)} \quad x, \alpha, \beta > 0}$$

To capture the characteristics of normal temperature as well as extremes, in DBS the temperature distribution is divided into two partitions separated by the 95th percentile. Two sets of parameters α, β representing non-extreme values and α 95, β95 representing Extreme values were estimated from observations and the GCM output for the reference period 1985–2015.

4.2.3 Methodology adopted: flow chart

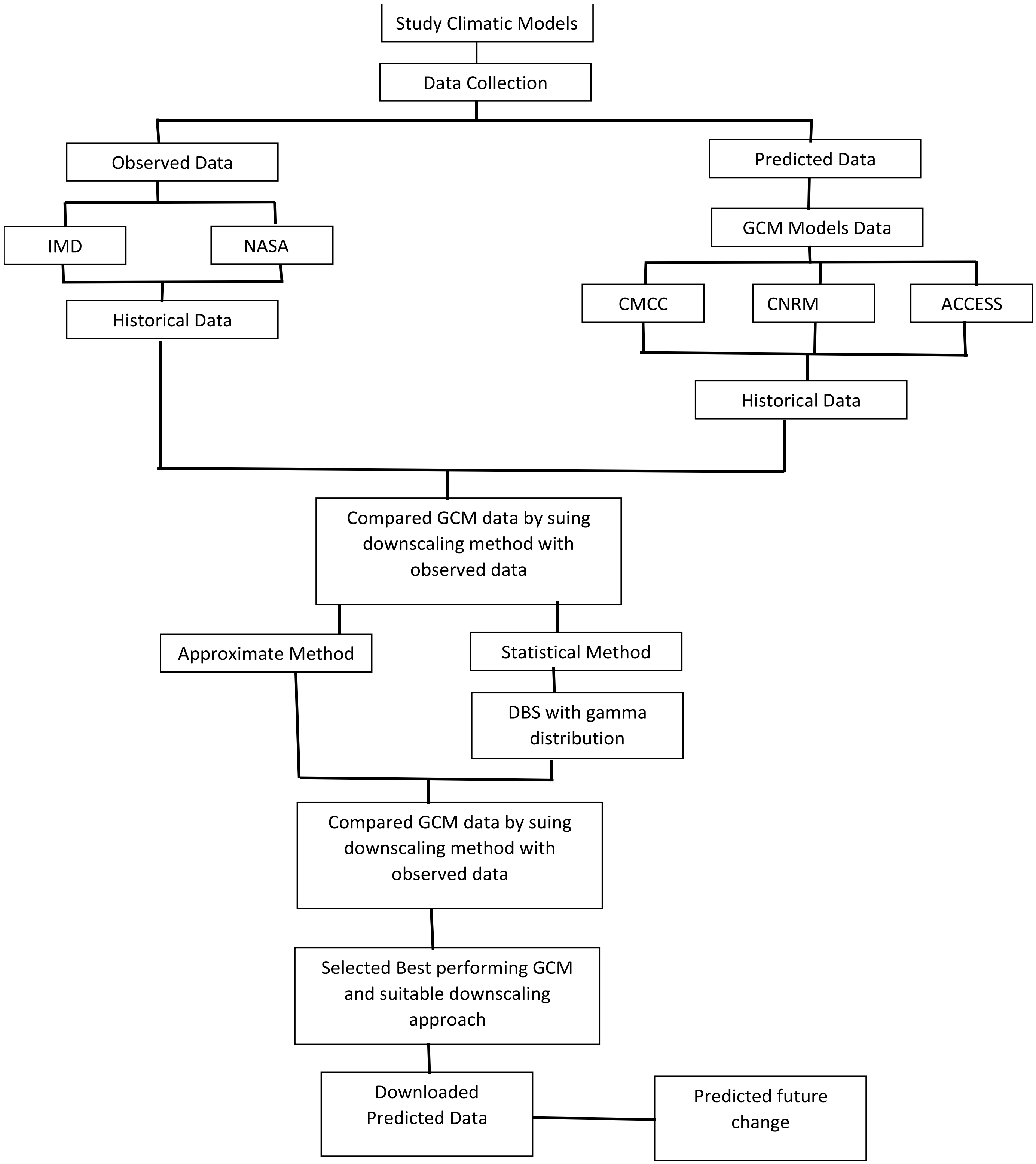


Fig.no 4.5 Methodology adopted: flow chart

4.3.2 PILOT STUDY: Pune region

As mentioned earlier, to set the methodology of the present work a pilot study is done for the Pune City of India. The details of it are presented below.

4.3.3 Study Area for pilot study

The study is carried out for Pune City (18.5204° N, 73.8567° E, formerly known as Poona), Maharashtra, India. Pune is in west-central Maharashtra state, western India, at the junction of the Mula and Mutha rivers. The city's total area is 15.642 km2. Pune has a tropical wet and dry climate, closely bordering upon a hot semi-arid climate with average temperatures ranging between 20 and 28 °C (68 and 82 °F). The highest temperature recorded was 43.3 °C (109.9 °F) on 30 April 1897. Fig 3.1 represents the location of Pune city, west-central Maharashtra state, India used in this study.

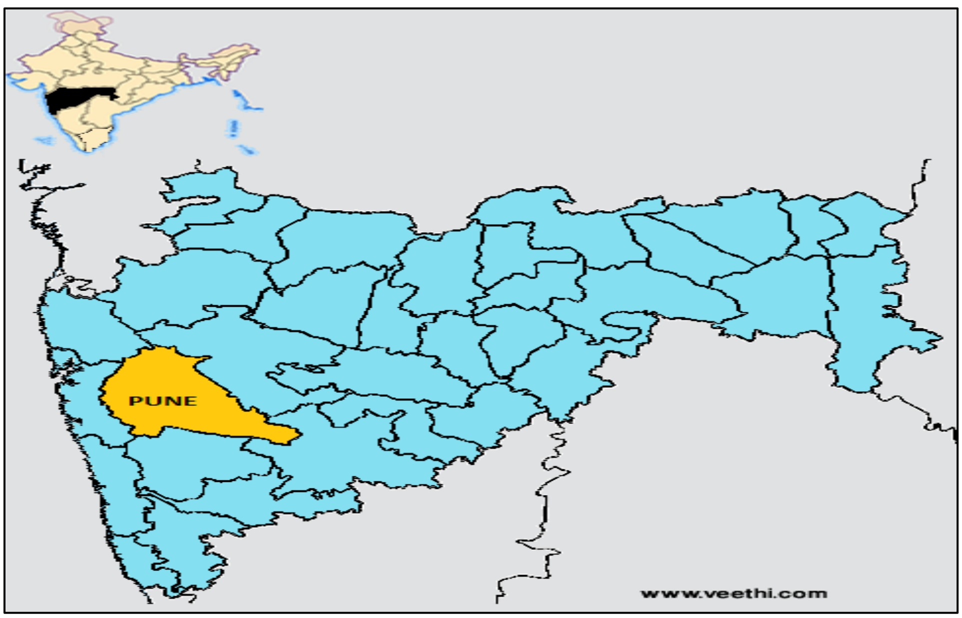


Fig 4.6 . The locations of Pune city, west-central Maharashtra state, India used in this study [58].

4.3.4 Data Used -

Observed daily maximum temperature data (Historical) for Pune (18.5204° N, 73.8567° E), covering the period 1984-2014, was obtained from the India Meteorological Department (IMD) and The Prediction of Worldwide Energy Resources (POWER) project. Further, daily maximum data (Historical and Future) for the Pune (N37.6, S8.4, W68.7, E97.25) from four GCM (ACCESS-CM2, MIROC6, CMCC , CNRM)projections , was extracted from the CMIP6 database, provided by the Copernicus site (https://cds.climate.copernicus.eu/). All GCMs were driven by the Shared Socioeconomic Pathways (SSPs) 4.5. Time series in the period 1984-2045 from the GCMs grid cell covering India were extracted from each projection. Pilot study used the period 1984-2014 as the historical time period and 2015- 2045 as predicted time periods representing the future.

4.3.5 Results of Pilot Study

PART A-

In the pilot study, data was statistically analysed from different GCMs and then compared to NASA's observed data (target data) to find a suitable GCM and gamma distribution method. The analysis section has been split into two sections. Section A contains data for five years, and Section B contains data for one year. For distribution-based scaling, daily maximum temperatures at 2 m were used for the PUNE station. For the purpose of analysis, the graphs are divided into three different seasons. In Maharashtra, there are mainly four seasons: summer (April, May, June), monsoon (Jul, Aug, Sep), winter (Oct, Nov, Dec), and spring (Jan, Feb, Mar).

Data - A pilot study used NASA power data as observed data in order to find out observed α, β and three GCM's (CMCC, CNRM, and MIROC6) for predicted α, β. The gamma distribution method is used (55) to study 2191-day s and 365 days of GCM data. In the DBS analysis, first consider observed $\alpha 2191$, $\beta 2191$ of 2191 days, then observed $\alpha 11323$, $\beta 11323$ of 11323 days using a double parameter and a single parameter, respectively, and the common cut-off value of 33.0 while analysing the data.

Section A – 2191 DAYS GCM DATA

The first section used and applied the gamma distribution method to three GCMs' (2190-day) data from 01/01/2015 to 31/12/2020 while taking one parameter and two parameters separately. Two sets of parameters α, β representing non-extreme values and $\alpha 95$, $\beta 95$ representing extreme values were estimated from observed data (NASA) for 2,191days and 11,323days. The table 4.1

shows that the correlation of a double parameter with a long time period (11323 days) predicts better results than a single parameter with a short time period.

Table 4.1 Correlation between Raw GCM and DBS data with NASA OBSERVED DATA (2191 DAYS GCM)-

	GCM	**2191-1**	**2191-2**	**11323-1**	**11323-2**
CMCC	0.760469	0.761428	0.757936	0.761815	0.784136
CNRM	0.746516	0.747092	0.744883	0.760853	0.772498
MIROC6	0.739869	0.739333	0.740197	0.739566	0.743422

1. CMCC-ESM2 (Italy)

In table 4.1 the 1 parameter (2191 days) and 2 parameters (11323 days) of DBS data have very close results to the target data. The statistics represented in Table 4.2 show that the mean standard deviation and kurtosis of the double parameters (11323 days) predict very similar results to the target value. It can also be observed in Table 5.3 DBS results, which show slightly higher root mean squared error and mean absolute error. From tables 4.2 and 4.3, it can be concluded that the double parameter of the gamma distribution method of the CMCC (11323 days) is suitable for the maximum temperature study.

Table 4.2 Climate statistics of (NASA)observed data, (CMCC) raw and bias-corrected GCM data.

	TARGET (NASA OBSERVED DATA)	PREDICTED (CMCC GCM DATA)	Single PARAMETER (2191DAYS) DBS	Double PARAMETER (2191DAYS) DBS	Single PARAMETER (11323DAYS) DBS	Double PARAMETER (11323DAYS) DBS
Mean	30.52027	30.9637	30.42819	30.35481	29.89275	30.64369
Standard Deviatio	4.786912	4.172961	4.434177	4.337369	4.49031	5.522471

n						
Kurtosis	-0.6343	-0.45159	-0.43874	-0.42015	-0.43341	-0.59101
Sum	66839.4	67810.51	66637.74	66477.04	65465.13	67109.68

Table 4.3 Root Mean Square Error and mean absolute error between target data(NASA) and predicted data.

	CMCC	2191-1	2191-2	11323-1	11323-2
RMSE	3.064	3.081	3.073	3.138	3.439
MAE	2.466	2.443	2.437	2.455	2.686

2. CNRM-ESM2-1 (France)

Table 5.1.4 shows that the DBS data for the double parameter (11323 days) is very close to the target data. The statistics represented in Table 5.1.4 show that the DBS approach increased the kurtosis results and predicted a much greater value than the target results. Similar to CMCC Table 5.1.3, we have also observed a slight increase in root mean squared error and mean absolute error in Table 5.1.4. We can conclude that the double parameters of the gamma distribution method of the CNRM (11323 days) is suitable for temperature analysis.

Table 4.4 Climate statistics of (NASA) observed data,(CNRM) raw and bias-corrected GCM data.

	TARGET(NASA OBSERVED DATA)	PREDICTED(CNRM GCM DATA)	1 PARAMETER (2191DAYS) DBS	2 PARAMETER (2191DAYS) DBS	1 PARAMETER (2191DAYS) DBS	2 PARAMETER (2191DAYS) DBS
Mean	30.52027	30.65211	30.28634	30.2409	29.76095	30.5917
Standar	4.786912	4.190501	4.327108	4.273769	4.379985	5.404867

d Deviation						
Kurtosis	-0.6343	-0.94148	-0.94051	-0.93134	-0.93975	-1.06997
Sum	66839.4	67128.11	66327.09	66227.56	65176.48	66995.82

Table 4.5 Root Mean Square Error and mean absolute error between target data (NASA) and predicted data

	CNRM	2191-1	2191-2	11323-1	11323-2
RMSE	3.112	3.139	3.138	3.215	3.451
MAE	2.489	2.515	2.519	2.582	2.668

3. MIROC6 (Japan)

Table 5.6 shows that single parameter (2191 days) DBS data have statistical results that are close to target data, but overall prediction has increased significantly. The statistics represented in Table 5.6 show that the raw GCM-predicted data is more suitable than any DBS results.

Table 4.6 Climate statistics of (NASA)observed data, (MIROC6) raw and bias-corrected GCM.

	TARGET (NASA OBSERVED DATA)	PREDICTED (MIROC6 GCM DATA)	1 PARAMETER (2191DAYS) DBS	2 PARAMETER (2191DAYS) DBS	1 PARAMETER (11323 DAYS) DBS	2 PARAMETER (11323 DAYS) DBS
Mean	30.52027	32.48286	35.52462	35.62	35.02847	36.21307
Standard Deviation	4.786912	4.811274	4.923451	4.786912	4.998727	6.322419
Kurtosis	-0.6343	-0.57246	-0.58225	-0.6166	-0.57805	-0.92422

Sum	66839.4	71137.47	77798.93	78007.8	76712.34	79306.63

Table 4.7 Root Mean Square Error and mean absolute error between target data (NASA) and predicted data

	MIROC6	2191-1	2191-2	11323-1	11323-2	MIROC6
RMSE	3.961	6.165	6.269	5.78	7.195	3.961
MAE	3.116	5.319	5.409	4.904	6.043	3.116

Section B – 365 DAYS GCM DATA

In Section B, the time period was shortened to 365 days of predicted data. From Section A, it can be seen that the double parameters (11323 days) α_{11323}, β_{11323} produced an overall better result. Therefore, the current part uses only the two-parameter gamma distribution method with the (11323 days) α_{11323}, β_{11323} parameter for further analysis. In table 5.8, DBS corrected data shows greater correlation than different raw GCMs with NASA target data. Tables 5.9 and 5.10 show that short-term GCM data predicts better results than DBS corrected data. As a result, it can be concluded that the DBS method increases not only correlation but also statistical values such as the root mean square error and the mean absolute error. Therefore, the DBS method is unsuitable for the correction of data that is too short.

Table 4.8 Climate statistics of (NASA)observed data, (CMCC) raw and bias-corrected GCM data.

	NASA	CMCC	DBS	MIROC6	DBS	CNRM	DBS
Mean	30.80027	30.02693	30.29989	31.7497	38.05305	30.1729	32.96674
Standard Deviation	3.904683	4.127768	8.201959	4.873565	10.03207	4.373	8.875025

Kurtosis	-0.19375	0.100616	-0.01271	-0.98516	-1.43646	-1.13595	-1.34184
Skewness	0.901519	0.618393	1.155615	0.333268	0.52862	0.131474	0.595158
Minimum	23.87	22.88	20.60013	23.51	25.62657	21.72	21.16729
Maximum	40.39	42.08	52.20801	42.59	57.06423	39.74	50.38319
Sum	11242.1	10959.83	11059.46	11588.64	13889.36	11013.11	12032.86

Table 4.9 Root Mean Square Error and mean absolute error between target data (NASA) and predicted data –

	CMCC	DBS	CNRM	DBS	MIROC6	DBS
RMSE	2.946	5.66	3.243	6.865	3.158	10.325
MAE	2.305	4.577	2.613	5.248	2.569	7.754

4.3.6 Final results of Distribution Based Scaling and Bias-correction (30 years historical data)-

In the final study, four GCM raw data sets (ACCESS-CM2 (Australia), CNRM-ESM2-1 (France), MIROC6 (Japan), and CMCC-ESM2 (Italy)) were used as predicted values and two observed data sets (NASA and IMD) as target values. In this future study, only the double gamma distribution method with the observed α_{11323} and β_{11323} used. Table 5.2.1 show that the correlation between each raw GCM, NASA corrected values and IMD corrected values with observed data obtained from NASA and IMD. CMCC IMD corrected data shows highest correlation of both observed NASA and IMD data. ACCESS shows poor correlation with both observed values less than 20%.

Table 4.10 The Correlation between GCM and DBS corrected data with NASA and IMD observed data.

	NASA	IMD
MIROC6	0.7204	0.6999
NASA DBS	0.7204	0.7
IMD DBS	0.7206	0.7003
CNRM	0.7487	0.7198
IMD DBS	0.7503	0.7211
CMCC	0.7704	0.7377
NASA DBS	0.7695	0.737
IMD DBS	0.7712	0.7383
ACCESS	0.1547	0.2462
NASA DBS	0.1759	0.2682
IMD DBS	0.1759	0.2684

Table 4.11 Climate statistics of (NASA)observed data,(MIROC6) raw and bias-corrected GCM MIROC6 (Japan)

	NASA	IMD	MIROC6	NASA DBS	IMD DBS
Mean	30.51989	31.72532	32.09714	34.40669	36.5227
Standard Deviation	4.595676	3.830355	4.839547	4.956224	4.318922
Kurtosis	-0.67755	-0.53092	-0.42636	-0.44739	-0.53464
Skewness	0.752407	0.424046	0.474489	0.466172	0.43623
Range	22.41	24.5	27.96837	28.54069	24.46857

Minimum	20.81	17.9	20.36541	22.35258	25.91912
Maximum	43.22	42.4	48.33377	50.89328	50.38769
Sum	345057.9	358686.5	362890.3	389002	412925.7

Table 4.12 Climate statistics of (NASA)observed data, raw and bias-corrected GCM CNRM-ESM2-1 (France)

	NASA	**IMD**	**CNRM**	**NASA DBS**	**IMD DBS**
Mean	30.51989	31.72532	30.23001	29.0382	31.42703
Standard Deviation	4.595676	3.830355	4.214351	4.286418	3.78887
Kurtosis	-0.67755	-0.53092	-0.91673	-0.90933	-0.93493
Skewness	0.752407	0.424046	0.157278	0.157871	0.160458
Range	22.41	24.5	23.53241	23.98607	21.01282
Minimum	20.81	17.9	18.90001	17.56705	21.15807
Maximum	43.22	42.4	42.43242	41.55312	42.17089
Sum	345057.9	358686.5	341780.5	328305.9	355314.1

Table 4.13 Climate statistics of (NASA)observed data, raw and bias-corrected GCM CMCC-ESM2 (Italy)

	NASA	IMD	CMCC	NASA DBS	IMD DBS
Mean	30.51989	31.72532	31.41403	30.31741	32.71619
Standard Deviation	4.595676	3.830355	4.097301	4.45412	3.926792
Kurtosis	-0.67755	-0.53092	-0.57741	-0.53886	-0.60307
Skewness	0.752407	0.424046	0.371058	0.382066	0.365617
Range	22.41	24.5	21.57164	23.64883	20.54595
Minimum	20.81	17.9	22.11268	20.25654	23.77901
Maximum	43.22	42.4	43.68432	43.90538	44.32497
Sum	345057.9	358686.5	355167	342768.7	369889.2

Table 4.14 Climate statistics of (NASA)observed data, raw and bias-corrected GCM ACCESS-CM2 (Australia)

	NASA	IMD	ACCESS	NASA DBS	IMD DBS
Mean	30.51989	31.72532	29.59322	34.40661	36.52262
Standard Deviation	4.595676	3.830355	1.563827	4.956218	4.318917
Kurtosis	-0.67755	-0.53092	1.159347	-0.44739	-0.53463
Skewness	0.752407	0.424046	-0.72196	0.466171	0.436228
Range	22.41	24.5	14.43611	28.54128	24.46908
Minimum	20.81	17.9	19.99528	22.35211	25.91868
Maximum	43.22	42.4	34.43139	50.89339	50.38776
Sum	345057.9	358686.5	334581	389001.1	412924.7

4.3.7 TEMPERATURE CHANGE PATTERN OVER PUNE CITY FOR EVERY 10 YEARS-

1. **1984-1993 -**

Table 4.15 Comparisons of different raw GCM data over time period 1984 to1993 **-**

	IMD	NASA	MIROC6	CNRM	CMCC	ACCESS
Minimum	21	22.47	20.36541	20.18696	22.22718	22.53101

Maximum	41.9	43.22	44.85155	41.23715	43.4648	34.43139
Mean	31.5935	30.6282	32.31357	30.1991	31.26725	29.38898

Table 4.16 Comparisons of different NASA-DBS corrected data over time period 1984 to1993-

	IMD	NASA	MIROC6	CNRM	CMCC	ACCESS
Minimum	21	22.47	22.353	18.859	20.384	22.60
Maximum	41.9	43.22	47.387	40.318	43.655	22.60
Mean	31.5935	30.6282	34.629	29.007	30.158	33.73

Table 4.17 Comparisons of different IMD-DBS corrected data over time period 1984 to1993-

	IMD	NASA	MIROC6	CNRM	CMCC	ACCESS
Minimum	21	22.47	25.919	22.355	23.895	26.144
Maximum	41.9	43.22	47.543	41.154	44.120	50.388
Mean	31.5935	30.6282	36.718	31.400	32.575	35.931

2. 1994-2004

Table 4.18 Comparisons of different raw GCM data over time period 1994 to 2004-

	IMD	NASA	MIROC6	CNRM	CMCC	ACCESS
Minimum	17.9	21.62	24.812	19.507	23.546	22.576
Maximum	42.2	43.13	45.313	40.519	41.703	33.118
Mean	31.59429	30.59081	32.901	29.053	30.746	29.280

Table 4.19 Comparisons of different NASA-DBS corrected data over time period 1994 to 2004-

	IMD	NASA	MIROC6	CNRM	CMCC	ACCESS
Minimum	17.9	21.62	26.941	18.177	21.792	22.719
Maximum	42.2	43.13	47.852	39.571	41.660	47.377
Mean	31.59429	30.59081	35.226	27.844	29.593	33.269

Table 4.20 Comparisons of different NASA-DBS corrected data over time period 1994 to 2004-

	IMD	NASA	MIROC6	CNRM	CMCC	ACCESS
Minimum	17.9	21.62	30.010	21.726	25.174	26.2504

Maximum	42.2	43.13	47.922	40.537	42.481	47.5347
Mean	31.59429	30.59081	37.220	30.363	32.076	35.5432

3. 2004-2014

Table 4.21 Comparisons of different raw GCM data over time period 2004 to 2014 -

	IMD	NASA	MIROC6	CNRM	CMCC	ACCESS
Minimum	21.1	20.81	20.459	18.900	22.709	22.325
Maximum	42.1	42.54	48.167	42.432	43.684	33.992
Mean	31.96518	30.35967	31.622	30.381	31.704	29.873

Table 4.22 Comparisons of different NASA-DBS corrected data over time period 2004 to 2014-

	IMD	NASA	MIROC6	CNRM	CMCC	ACCESS
Minimum	21.1	20.81	22.449	17.567	20.895	22.552
Maximum	42.1	42.54	50.725	41.553	43.905	50.725
Mean	31.96518	30.35967	33.992	29.191	30.632	35.332

Table 4.23 Comparisons of different IMD-DBS corrected data over time period 2004 to 2014-

	IMD	NASA	MIROC6	CNRM	CMCC	ACCESS
Minimum	21.1	20.81	26.007	21.158	24.361	26.100
Maximum	42.1	42.54	50.252	42.171	44.325	50.252
Mean	31.96518	30.35967	36.099	31.563	32.995	37.327

4.3.8 Final results of Distribution Based Scaling and Bias-correction (30 years future data)-

Table 4.24 Climate statistics of observed data, raw and bias-corrected GCM data for future prediction.

	CMCC	IMD DBS	NASA DBS	**MIROC6**	IMD DBS	NASA DBS
Mean	**31.41**	32.71	30.47492	**32.09**	36.48	34.40871
Standard Deviation	**4.10**	3.93	4.376882	**4.84**	4.30	4.958891

Kurtosis	**-0.58**	-0.60	-0.51056	**-0.43**	-0.50	-0.45012
Skewness	**0.37**	0.37	0.36499	**0.47**	0.46	0.466072
Range	**21.57**	20.55	23.48256	**27.97**	24.43	28.52367
Minimum	**22.11**	23.78	20.44934	**20.37**	25.93	22.37135
Maximum	**43.68**	44.33	43.9319	**48.33**	50.37	50.89502
Sum	**355424.33**	370106.50	344823.7	**363315.70**	413118.23	389609.8

	CNRM	IMD DBS	NASA DBS	**ACCESS**	IMD DBS	NASA DBS
Mean	**30.23**	34.88	29.02964	**29.59**	2.03	1.434782
Standard Deviation	**4.21**	3.80	4.290962	**1.56**	0.34	0.360952
Kurtosis	**-0.91**	-0.94	-0.90664	**1.16**	0.98	-0.07715
Skewness	**0.16**	0.17	0.160088	**-0.72**	-0.70	-0.07935
Range	**23.53**	20.98	24.01813	**14.44**	2.99	2.450258
Minimum	**18.90**	24.55	17.54987	**20.00**	0.40	0.159701
Maximum	**42.43**	45.53	41.56799	**34.43**	3.39	2.609959
Sum	**342286.74**	394956.66	328702.6	**335093.90**	22982.20	16246.04

4.4.1 Gumbel Extreme Distribution

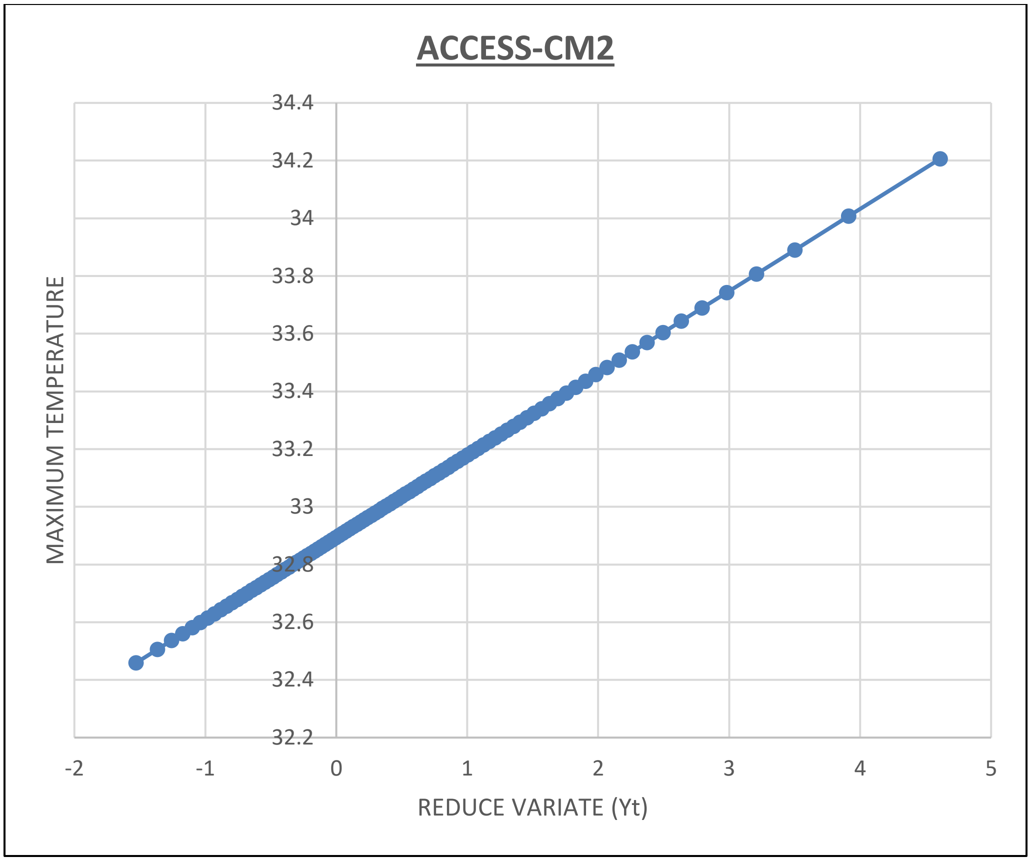
The Gumbel's distribution analysis was done following the above methodology (point no. 4.4.1).The following study compared the extreme temperature (Xt) of four GCM (Predicted data) with extreme temperature of the IMD and NASA which were Observed value. For each we GCM have taken 100 maximum temperature values from the data, then calculated extreme temperature to compare the accuracy of results to know which GCM (Predicted values) is closest to the Observed values. Calculated results for each GCM are shown below.

Table 4.25 – Sample Calculation of ACCESS-CM2 (AUSTRALIA)

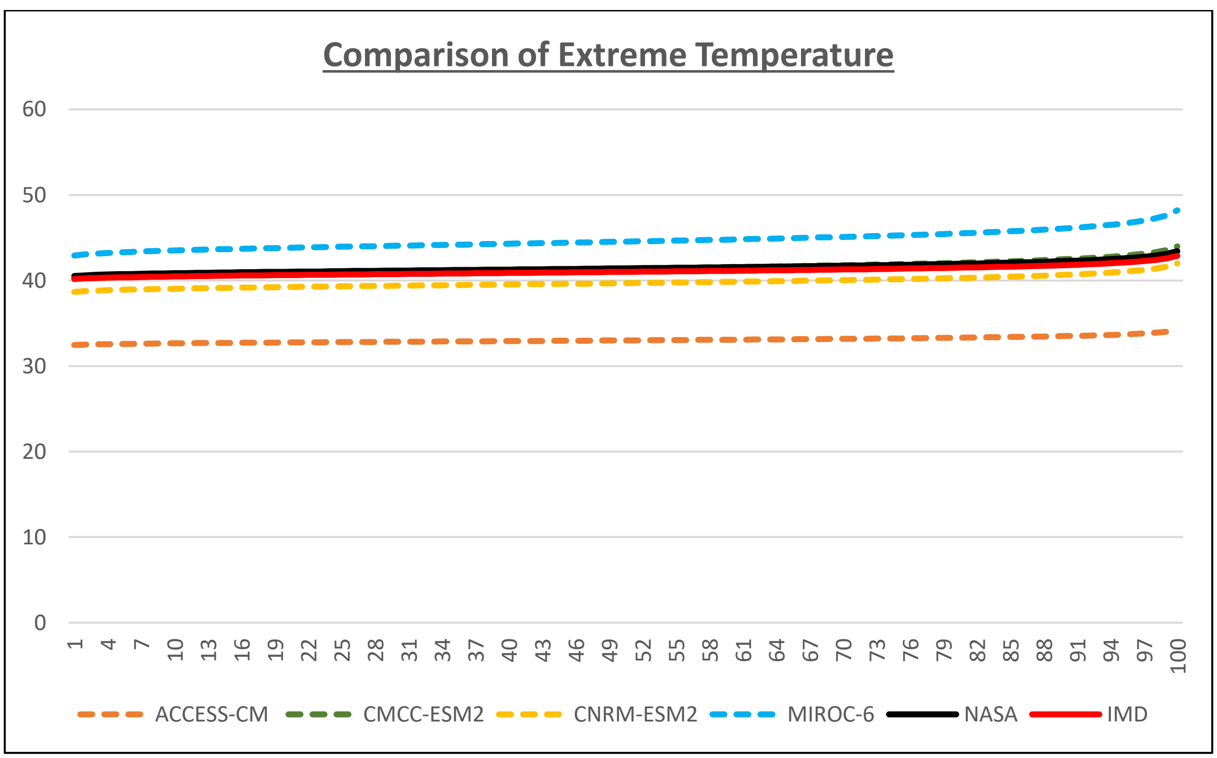
TMAX	M	n+1	T=(n+1/m)	T/T-1	yt=(ln*ln(T/T-1))	K=(Yt-Yn)/Sn	xt=x̄+K*σx
34.43139	1	101	101	1.01	4.610149477	3.356941133	34.20585
33.99214	2	101	50.5	1.02020202	3.911989671	2.778275732	34.00718
33.92597	3	101	33.66667	1.030612245	3.501469592	2.438018726	33.89036
33.92572	4	101	25.25	1.041237113	3.208689424	2.195349709	33.80704
33.89969	5	101	20.2	1.052083333	2.980403849	2.006136634	33.74208
33.86999	6	101	16.83333	1.063157895	2.792895513	1.850721519	33.68872
33.84418	7	101	14.42857	1.074468085	2.633512447	1.718617859	33.64336
33.7203	8	101	12.625	1.086021505	2.494702186	1.60356584	33.60386
33.60574	9	101	11.22222	1.097826087	2.371592895	1.501527472	33.56883
33.43846	10	101	10.1	1.10989011	2.260857809	1.409745387	33.53732
33.42738	11	101	9.181818	1.122222222	2.160123784	1.326252618	33.50865

yn=0.5600

sn=1.2065



Graph 4.1 - Extreme temperature Values of ACCESS-CM2 (AUSTRALIA)



Graph 4.2 – Comparison of Extreme Temperature of Predicted and Observed data

Maximum and Minimum Values of Extreme Temperature

As per the above comparison, it can be concluded that the extreme temperature of ACCESS-CM is least similar to the extreme temperature of the observed values. And the extreme temperature of MIROC6 is over predicted. For CNRM-ESM2, the extreme temperature is less than the observed values. The extreme temperature of CMCC-ESM2 is most similar to both NASA and IMD (observed values).

For further study, only CMCC-ESM2 GCM was considered as a predicted value, and for an observed value, NASA and GCM are considered. Now the extreme temperature for a return period of 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 years is predicted. And also determined the frequency of the occurrence of extreme temperatures at least once in a given year.

Table 4.26 – Maximum and Minimum Values of Extreme Temperature

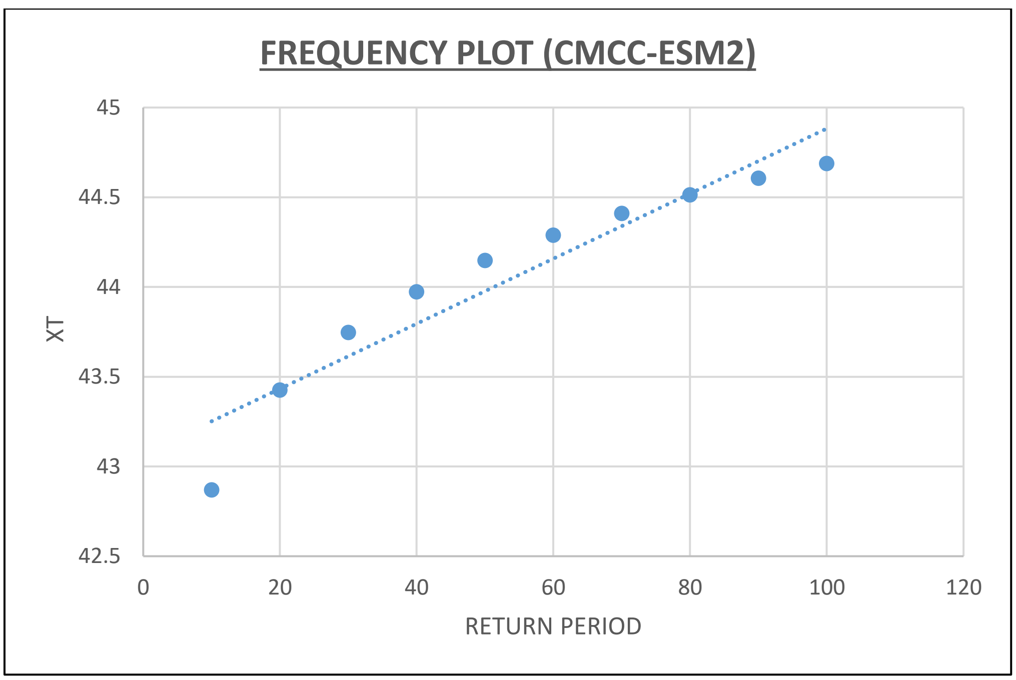
EXTREME TEMPERATURE		
SR NO	**MAXIMUM**	**MINIMUM**
PREDICTED DATA		
ACCESS-CM	34.2058516	32.45875287
CMCC-ESM2	43.97836641	40.24007945
CNRM-ESM2	41.99046068	38.66580035
MIROC6	48.1993334	42.91512518
OBSERVED DATA		
NASA	43.42457278	40.523548
IMD	42.87707104	40.17114097

Table 4.27 – Extreme temperature and Probability of occurrence for CMCC-ESM2

T	yt=-(ln(ln(T/T-1))	K=(Yt-Yn)/Sn	xt=x +(std.dev-1)	P=1/T	Probability of occurance	%
10	2.250367327	1.848322796	43.17285533	0.1	0.65132156	1.5353399
20	2.970195249	2.60635557	43.57594323	0.05	0.641514078	1.5588122
30	3.384294493	3.042433123	43.80782976	0.033333333	0.638338487	1.566567
40	3.676247258	3.349881274	43.97131692	0.025	0.63676756	1.5704318
50	3.901938658	3.58755124	44.09769917	0.02	0.63583032	1.5727466
60	4.085952773	3.781331901	44.20074306	0.016666667	0.635207689	1.5742882
70	4.2413095	3.944934183	44.28773943	0.014285714	0.634764023	1.5753886
80	4.375743836	4.086503619	44.36301972	0.0125	0.634431856	1.5762134
90	4.494228222	4.21127656	44.42936838	0.011111111	0.634173848	1.5768547
100	4.600149227	4.322819321	44.48868183	0.01	0.633967659	1.5773675

$\bar{x}$	42.19
std.dev	0.5317552

Yn	0.4952
Sn	0.9496



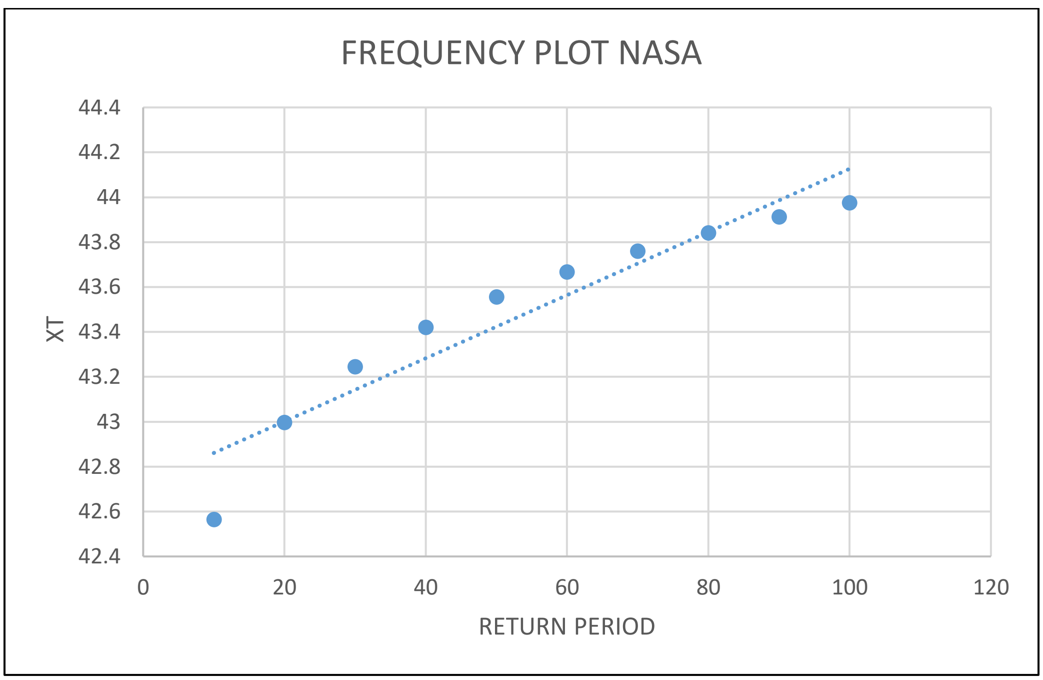
Graph 4.3 – Frequency of occurrence for CMCC-ESM2

Table 4.28 – Extreme temperature and Probability of occurrence for NASA

T	yt=-(ln(ln(T/T-1))	K=(Yt-Yn)/Sn	xt=x+(std.dev-1)	P=1/T	Probability of occurance	%
10	2.250367327	1.848322796	42.56451817	0.1	0.65132156	1.5353399
20	2.970195249	2.60635557	42.99666828	0.05	0.641514078	1.5588122
30	3.384294493	3.042433123	43.24527358	0.0333333	0.638338487	1.566567
40	3.676247258	3.349881274	43.420548	0.025	0.63676756	1.5704318
50	3.901938658	3.58755124	43.55604227	0.02	0.63583032	1.5727466
60	4.085952773	3.781331901	43.66651551	0.0166667	0.635207689	1.5742882
70	4.2413095	3.944934183	43.75978423	0.0142857	0.634764023	1.5753886
80	4.375743836	4.086503619	43.84049215	0.0125	0.634431856	1.5762134
90	4.494228222	4.21127656	43.91162448	0.0111111	0.634173848	1.5768547
100	4.600149227	4.322819321	43.97521436	0.01	0.633967659	1.5773675

x	41.5108
std.dev	0.570094

Yn	0.4952
Sn	0.9496



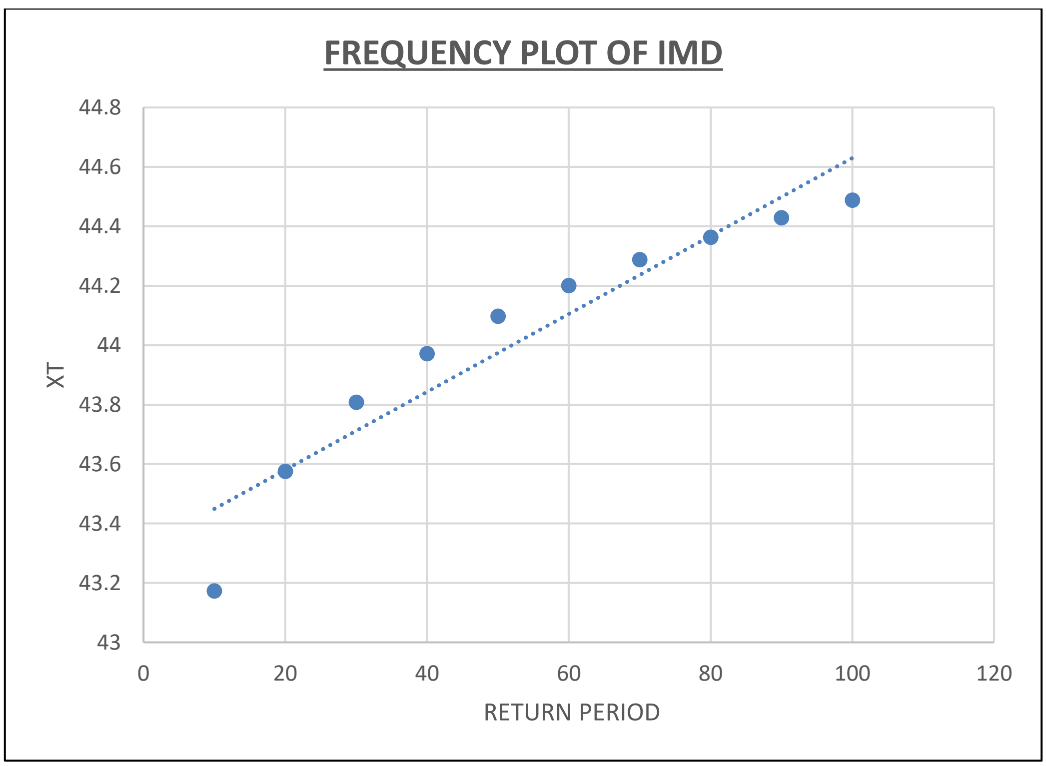
Graph 4.4 - Frequency of occurrence for NASA

Table 4.29 - Extreme temperature and Probability of occurrence for IMD

T	yt=-(ln(ln(T/T-1))	K=(Yt-Yn)/Sn	xt=x+(std.dev-1)	P=1/T	Probability of occurance	%
10	2.250367327	1.848322796	42.87009083	0.1	0.65132156	1.5353399
20	2.970195249	2.60635557	43.4269634	0.05	0.641514078	1.5588122
30	3.384294493	3.042433123	43.74731846	0.0333333	0.638338487	1.566567
40	3.676247258	3.349881274	43.97317867	0.025	0.63676756	1.5704318
50	3.901938658	3.58755124	44.14777783	0.02	0.63583032	1.5727466
60	4.085952773	3.781331901	44.29013465	0.0166667	0.635207689	1.5742882
70	4.2413095	3.944934183	44.41032157	0.0142857	0.634764023	1.5753886
80	4.375743836	4.086503619	44.51432253	0.0125	0.634431856	1.5762134
90	4.494228222	4.21127656	44.6059843	0.0111111	0.634173848	1.5768547
100	4.600149227	4.322819321	44.68792681	0.01	0.633967659	1.5773675

x	41.512261
std.dev	0.7346286

Yn	0.4952
Sn	0.9496



Graph 4.5 - Frequency of occurrence for NASA

CHAPTER 5

5.1 PRESENT STUDY INCLUDING RESULTS AND DISCUSSION-

As earlier in study impact of temperature on Pune city was conducted, considering the results obtained from previous study, statistically analyzed data from different GCMs and then compared it to NASA's observed data (Target Data) to find a suitable GCM and gamma distribution method, then predicted the extreme values for upcoming 10, 20, 30, 40, 50, 60, 70, 80, 90 100 years and compared it with GCM, in which CNRM-ESM2 performed better as compared to others.

The current study examines 14 districts in the state of Maharashtra. And three GCMs are used in this study: ACCESS-CM2, CMCC-ESM2, and CNRM-ESM2, because these GCMs performed better in previous attempts. The data from these GCMs is statistically analysed and then compared to NASA's observed data (target data) to find a suitable GCM for Maharashtra state. Two downscaling methods are used to investigate the temperature parameter: bilinear interpolation and distribution-based scaling using the gamma method.

RESULT DISCUSSION TABLES & GRAPHS

5.1.1 SECTION 1 - Temperature analysis

In this section, data is statistically analyzed for different GCMs and then compared with NASA's observed data (target data) to find a suitable GCM for Maharashtra state. The temperature parameter is studied using two downscaling methods: bilinear interpolation and distribution based scaling using the gamma method (wang et al.,2014).

1) PUNE DIVISION –

The Pune division's four districts (Pune, Satara, Sangali, Solapur, and Kolhapur) were chosen for this study. The investigation showed that both CMCC and DBS-CMCC give good results for the Pune division, except Sangali. CNRM showed the best results in case of the Sangali district. Kurtosis and maximum temperature, however, are far higher or smaller than the actual values in

CMCC-DBS. Therefore, the results of the CMCC obtained using the approximate downscaling method are better suited for temperature analysis.

1. PUNE –

Table 5.1 Climate statistics of (NASA)observed data and GCMs for Pune.

PUNE	**Mean**	**Standard Deviation**	**Kurtosis**	**Minimum**	**Maximum**	**Correlation**
NASA	30.53	4.57	-0.67	20.81	43.22	
ACCESS	29.70	1.59	1.13	19.95	34.61	0.17
CMCC	31.48	4.11	-0.60	22.21	43.77	0.77
DBS	31.47	5.60	-0.79	20.56	47.48	0.78
CNRM	29.95	4.40	-1.00	18.19	42.07	0.75
DBS	30.05	5.22	-1.02	41.28	44.00	0.76

2. SATARA –

Table 5.2 Climate statistics of (NASA)observed data and GCMs for Satara -

SATARA	**Mean**	**Standard Deviation**	**Kurtosis**	**Minimum**	**Maximum**	**CORR**
NASA	31.36222	4.833382	-0.9331	20.61	44.27	
ACCESS	32.13693	2.264692	0.202821	21.09918	38.80148	0.38788
DBS	10.63307	2.064789	-0.28277	2.834525	16.77334	0.397342
CMCC	31.45127	4.142832	-0.71163	22.7015	43.30812	0.779124
DBS	28.91684	4.487655	-0.72195	19.51719	41.96321	0.999939
CNRM	30.20084	3.336548	-0.66656	20.9336	41.0742	0.708047
DBS	21.91129	3.666832	-0.7259	12.259	34.07863	0.711219

3. KOLHAPUR –

Table 5.3 Climate statistics of (NASA)observed data and GCMs for Kolhapur.

KOLHAPUR	Mean	Standard Deviation	Kurtosis	Minimum	Maximum	CORR
NASA	31.61803	4.617716	-0.90977	21.55	43.07	
ACCESS	34.63208	3.252019	0.053285	22.52392	42.48056	0.485139
DBS	28.53142	4.102339	-0.12198	14.01324	38.53855	0.48272
CMCC	31.01087	3.504619	-0.74497	23.7014	40.85799	0.781005
DBS	24.72124	3.89693	-0.75011	16.85685	35.54756	0.782926
CNRM	29.56302	3.22598	-0.95759	21.08118	38.76229	0.749888
DBS	20.72092	3.378016	-0.93356	12.30326	30.27032	0.752008

4. SANGALI –

Table 5.4 Climate statistics of (NASA)observed data and GCMs for Sangali.

SANGALI	Mean	Standard Deviation	Kurtosis	Minimum	Maximum	Mean
NASA	31.77612	4.58055	-0.83162	20.02	43.42	
ACCESS	35.17545	3.485814	0.054801	22.1737	43.84136	0.500039
DBS	31.90211	4.362965	-0.02708	16.1463	42.99805	0.495944
CMCC	30.87947	3.68024	-0.78731	23.14675	41.10689	0.784339
DBS	25.86594	3.958448	-0.79537	17.75814	36.77168	0.786031
CNRM	30.89646	4.520782	-0.95189	19.41824	41.99835	0.759825
DBS	30.34582	4.344613	-0.94811	19.28539	41.02376	0.759693

5. SOLAPUR –

Table 5.5 Climate statistics of (NASA)observed data and GCMs for Solapur -

SOLAPUR	Mean	Standard Deviation	Kurtosis	Minimum	Maximum	Mean
NASA`	34.0297	4.057261	-0.48857	22.07	45.84	
ACCESS	35.02721	3.424982	-0.14737	23.123	43.83814	0.569985
DBS	31.65141	3.757581	-0.22286	18.93282	40.95883	0.572864
CMCC	31.45012	4.14181	-0.71036	22.7015	43.30812	0.707828
DBS	30.6147	3.680215	-0.71396	22.76938	41.22881	0.70677
CNRM	30.23193	4.850853	-1.03368	17.77582	43.17098	0.693109
DBS	31.80501	3.721726	-1.05049	21.79434	41.27809	0.68941

2) AURANGABAD DIVISION –

1. AURANGABAD –

The Aurangabad division's two districts (Aurangabad and Beed) were chosen for this study. The investigation showed that both CMCC and DBS-CMCC give good results for the Satara. In the case of the Sangali district, CNRM showed the best outcomes. In case of Beed district, three GCMs approximate downscaling and DBS showed lower results than actual values. However, CMCC correlation and other results are acceptable. Therefore, the results of the CMCC obtained using the approximate downscaling method, are better suited for temperature analysis.

Table 5.6 Climate statistics of (NASA)observed data and GCMs for A -

AURANGABAD	Mean	Standard Deviation	Kurtosis	Minimum	Maximum	CORR
NASA	32.907	4.547	-0.629	21.370	44.87	
ACCESS	35.083	3.568	0.020	17.775	44.82158	0.51
DBS	31.227	4.166	-0.074	12.233	43.2052	0.51
CMCC	31.666	4.757	-0.751	18.879	44.2741	0.73

DBS	31.751	4.404	-0.773	19.822	43.29068	0.73
CNRM	31.248	5.103	-0.934	19.826	44.92898	0.71
DBS	32.147	4.442	-0.966	17.307	43.74744	0.71

2. BEED –

Table 5.7 Climate statistics of (NASA)observed data and GCMs for Beed **-**

BEED	Mean	Standard Deviation	Kurtosis	Minimum	Maximum	CORR
NASA	33.18728	4.394737	-0.58743	22.34	44.92	
ACCESS	35.2175	3.557597	-0.08602	20.84217	44.60264	0.533512
DBS	31.78787	4.099594	-0.21164	15.98592	43.03292	0.540893
CMCC	31.4171	4.693156	-0.74626	18.92833	43.52904	0.741462
DBS	31.53866	4.230813	-0.78162	20.16973	42.29215	0.740786
CNRM	29.95523	4.989455	-1.00222	16.50156	43.4803	0.705776
DBS	30.19925	4.079429	-1.04894	18.97364	40.89367	0.706078

3) NASHIK DIVISION –

The Nashik division's four districts (Ahmednagar, Dhule, Jalgaon, and Nashik) were selected for this study. According to the investigation, CMCC provided good results for the Nashik district but slightly lower results for the Dhule and Jalgaon districts. CNRM showed the best results in the Ahmednagar district. Therefore, the results of the CMCC obtained using the approximate downscaling method are better suited for temperature analysis in Nashik Division.

1. AHMADNAGAR –

Table 5.8 Climate statistics of (NASA)observed data and GCMs for Ahmadnagar -

AHMADNAGAR	Mean	Standard Deviation	Kurtosis	Minimum	Maximum	CORR
NASA	32.13	4.30	-0.66	21.90	43.40	
ACCESS	35.29	3.62	-0.08	20.89	44.77	0.50
DBS	33.98	4.35	-0.21	17.52	45.70	0.51
CMCC	30.11	4.98	-1.00	16.38	43.65	0.73
DBS	31.37	4.20	-1.05	19.48	42.38	0.73
CNRM	31.20	4.37	-0.73	20.43	43.19	0.75
DBS	31.05	4.16	-0.74	20.74	42.40	0.75

2. DHULE –

Table 5.9 Climate statistics of (NASA)observed data and GCMs for Dhule **-**

DHULE	Mean	Standard Deviation	Kurtosis	Minimum	Maximum	CORR
NASA	34.58137	4.633731	-0.65503	22.53	47.57	0.485384
ACCESS	35.43626	4.287226	-0.16503	16.07017	45.78843	0.485998
DBS	35.47287	4.504428	-0.18668	15.36356	46.32066	0.709944
CMCC	32.13052	4.427856	-0.57954	18.68703	45.06305	0.70989
DBS	29.92375	4.105164	-0.57962	17.44961	41.91438	0.70989
CNRM	31.35512	5.181139	-0.85543	14.42206	46.10204	0.70733
DBS	31.23199	4.164543	-0.83803	16.93039	43.14442	0.704764

3. JALGAON –

Table 5.10 Climate statistics of (NASA)observed data and GCMs for Jalgaon -

JALGAON	Mean	Standard Deviation	Kurtosis	Minimum	Maximum	Mean
NASA	34.29641	4.791856	-0.64446	22.86	47.48	
ACCESS	35.3308	3.867658	0.012261	16.11245	45.40799	0.497996
DBS	32.18418	4.357119	-0.08117	11.64229	43.61516	0.497729
CMCC	32.24207	4.966226	-0.69532	16.59676	45.61813	0.719186
DBS	31.6645	4.440283	-0.67487	17.44579	43.59101	0.718528
CNRM	31.44168	5.224387	-0.85216	14.45383	46.21582	0.711352
DBS	31.09045	4.32029	-0.83645	16.4418	43.35042	0.709167

4. NASHIK –

Table 5.11 Climate statistics of (NASA)observed data and GCMs for Nashik -

NASHIK	Mean	Standard Deviation	Kurtosis	Minimum	Maximum	Mean
NASA	31.432	4.47991	0.557083	21.43	43.99	
ACCESS	31.40797	2.254843	-0.61982	18.25844	37.99296	0.256856
DBS	11.29294	2.022852	-0.27275	2.48481	17.66998	0.274825
CMCC	31.23883	4.338511	0.410614	18.17737	43.29739	0.689749
DBS	30.6786	4.368771	0.411723	17.58024	42.81859	0.689979
CNRM	30.81894	4.658831	0.234011	13.6487	44.26978	0.698061
DBS	31.26605	4.371835	0.227914	14.84259	43.87513	0.697353

4) AMARAVATI DIVISION –

The Amaravati division's two districts (Amaravati and Buldhana) were selected for this study. The investigation showed that both CMCC and DBS-CMCC give acceptable results for the Amaravati. In the case of the Buldhana district, three GCMs approximate downscaling and DBS showed lower results than actual values. However, CMCC correlation and other results are acceptable. Therefore, the results of the CMCC obtained using the approximate downscaling method, are better suited for temperature analysis.

1. AMARAVATI –

Table 5.12 Climate statistics of (NASA)observed data and GCMs for Amaravati -

AMARAVATI	Mean	Standard Deviation	Kurtosis	Minimum	Maximum	CORR
NASA	33.76665	5.268506	-0.61555	21.06	47.7	0.539894
ACCESS	35.59603	4.253047	-0.23263	18.61438	45.81737	0.545187
DBS	33.75365	5.00951	-0.35665	14.82183	46.1447	0.721
CMCC	32.43058	5.460244	-0.64984	17.54663	46.12272	0.719038
DBS	32.22218	4.99491	-0.65642	18.36785	44.62714	0.719038
CNRM	32.23921	5.652774	-0.87252	13.7793	45.92827	0.715184
DBS	32.44434	4.99	-0.8666	15.58908	44.32574	0.712103

2. BULDHANA –

Table 5.13 Climate statistics of (NASA)observed data and GCMs for Buldhana -

BULDHANA	Mean	Standard Deviation	Kurtosis	Minimum	Maximum	CORR
NASA	33.34031	4.808579	-0.65535	22.29	46.34	
ACCESS	36.02347	4.526515	-0.41178	19.93386	46.38526	0.535513
DBS	37.93773	5.057224	-0.43685	20.20718	49.58922	0.536552
CMCC	31.63954	4.697935	-0.70146	16.59284	44.62997	0.726797
DBS	30.32895	4.412874	-0.70105	16.12134	42.50368	0.726401
CNRM	29.72897	5.037664	-0.85589	12.28514	44.32585	0.715823
DBS	28.4942	4.185719	-0.84952	13.43883	40.35006	0.711995

5) NAGPUR DIVISION –

Gadchiroli in the Nagpur district was selected for this investigation. In the case of the Gadchiroli district, three GCMs approximate downscaling and DBS showed lower results than actual values. However, CMCC correlation and other results are acceptable. Therefore, the results of the CMCC obtained using the approximate downscaling method, are better suited for temperature analysis.

1. GADCHIROLI –

Table 5.14 Climate statistics of (NASA)observed data and GCMs for Gadchiroli -

GADCHIROLI	Mean	Standard Deviation	Kurtosis	Minimum	Maximum	CORR
NASA	34.29641	4.791856	-0.64446	22.86	47.48	
ACCESS	35.3308	3.867658	0.012261	16.11245	45.40799	0.493104
DBS	32.18418	4.357119	-0.08117	11.64229	43.61516	0.492858
CMCC	32.24207	4.966226	-0.69532	16.59676	45.61813	0.686007
DBS	31.6645	4.440283	-0.67487	17.44579	43.59101	0.686672
CNRM	31.44168	5.224387	-0.85216	14.45383	46.21582	0.706033
DBS	31.09045	4.32029	-0.83645	16.4418	43.35042	0.705459

5.1.2 SECTION 2 - Future prediction of temperature parameter-

According to the above tables of historical data analysis, the CMCC is a suitable GCM for the state of Maharashtra. The approximate downscaling approach using distribution-based scaling for temperature parameters gives the best results. Therefore, in future predictions, only the CMCC GCM will be used to analyze further variations in temperature. Table 5.2 shows the decadal mean variation from 1985 to 2045 and the overall temperature increase over the past 60 years, including historical and predicted future results.

Table 5.15 Districts and Predicted Decadal Mean Temperature of Maharashtra -

Sr.no	**Districts**	**Predicted Decadal Mean Temperature**					
		1985-2045	1995-2005	2005-2015	2015-2025	2025-2035	2035-2045
1	Amravati	32.5	31.9	32.7	32	32	33.5
2	Aurangabad	31.7	31.2	31.9	31.5	31.5	32.5
3	Chandrapur	33	32.5	33.1	33	33.5	34.5
4	Gadchiroli	32.3	31.7	32.5	33	33	34
5	Jargon	32.3	31.7	32.5	32	32	33
6	Nagpur	32.2	31.7	32.3	32	32	33.5
7	Nashik	31.2	30.8	31.5	31	31	32
8	Pune	31.3	31.2	31.7	31.5	31.5	32

The annual average temperature shows consistent warming over all districts of Maharashtra. Maximum increase in temperature observed in Chandpur, Nagpur and Gadchiroli Division. Minimum increase in temperature observed in Jalgaon and Pune division. It concludes that climate change has affected some parts of Maharashtra state severely and others only slightly, with an overall increase in Maharashtra.

Table 5.16 Districts and of Projected Increase in decadal Mean Temperature Maharashtra -

Sr.no	**Districts**	**Projected Increase in decadal Mean Temperature**					
		Total in Increase (1985-2045)	2005	2015	2025	2035	2045
1	Amravati	1	-0.6	0.8	- 0.7	0	1.5
2	Aurangabad	0.8	-0.5	0.3	-0.4	0	1
3	Chandrapur	1.5	-0.5	0.6	-0.1	0.5	1
4	Gadchiroli	1.7	-0.6	0.8	0.5	0	1
5	Jalgaon	0.7	-0.6	0.8	-0.5	0	1
6	Nagpur	1.3	-0.5	0.6	-0.5	0	1.5
7	Nashik	0.8	-0.4	0.7	-0.2	0	1
8	Pune	0.7	-0.1	0.5	-0.2	0	0.5

5.1.3 SECTION 2 - EFFECT OF TEMERATURE VARIATION ON CROPS OF VARIOUS DISTRICTS IN MAHARSHTRA STATE.

According to the table below, Chandrapur, Gadchiroli, and Nagpur have experienced significant temperature increases, which will have a negative impact on crop productivity and may cause crop harvesting to be delayed. Temperature increases not only alter crop patterns but also increase water demand. Similarly, temperature variations are moderate in Amaravati, Aurangabad, and Nashik, and mild in Jalgaon, Pune.

Table 5.16 Districts and of Projected Increase in decadal Mean Temperature Maharashtra and effect of temperature variation on crops -

Sr.no	Districts	EFFECT OF TEMERATURE VARIATION ON CROPS			
		RABI CROPS	KHARIF CROPS	TEMERATURE CHANGE (1985-2045)	EFFECT ON CROPS
1	Amravati	Wheat	Cotton, Soybean, Groundnut	1	Moderate
2	Aurangabad	Jowar, Safflower, Wheat	Jowar, Bajara, Cotton, Tur	0.8	Moderate
3	Chandrapur	Wheat	Paddy	1.5	Severe
4	Gadchiroli	Gram	Paddy	1.7	Severe
5	Jalgaon	Jowar	Jowar	0.7	Mild
6	Nagpur	Wheat, Gram	Jowar, Tur	1.3	Severe
7	Nashik	Wheat	Bajara	0.8	Moderate
8	Pune	Jowar, Safflower, Wheat, Gram	Jowar, Bajara, Sugarcane	0.7	Mild

CHAPTER 6

6.1 CONCLUSION

This study was conducted to investigate the effect of climatic change on temperature parameters using climatic models. Major districts in the state of Maharashtra were chosen for future temperature variation and to study crop patterns, considering temperature variation in each of the ten years. The various parts of Maharashtra experience different climatic conditions; some parts are heavy rainfall areas and some are drought-prone areas. Cash Crops like sugarcane, which consume more water, are grown in drought-prone regions. Hence, it is important to study average temperature increases to understand which areas require more water and whether it is necessary to study crop pattern changes further.

This study examines the impact of climate change on the next 30 years, initially with the Pune district and then using the same methodology for other major districts in Maharashtra state. Three general circulation models (CNRM, CMCC, and ACCESS) were compared, and it was determined that the CMCC GCM model produces the best results for the state of Maharashtra. In addition, distribution-based scaling (DBS) and approximate downscaling by bilinear interpolation were two general approaches used to adjust the GCM model's output for temperature parameters. It was discovered that distribution-based downscaling methods better than approximate downscaling methods in terms of future prediction, making approximate downscaling methods more reliable.

Minimum and maximum temperature projections for Maharashtra based on SSP 4.5 show increasing trends in mean temperature over the major districts from 1985 to 2045. The mean temperature rise is more prominent in Chandrapur, Gadchiroli, and Nagpur (1.30 to 1.70 ^{0}C), while other districts experience moderate to mild temperature variation. The Pune Division recorded the lowest temperature variation in 60 years (0.7 ^{0}C). The study's findings clearly show that average temperature will rise in the coming years, negatively impacting various sectors in Maharashtra. Because Maharashtra is an agricultural state, it might have an impact on crop production and crop patterns.

6.2 FUTURE SCOPE

- In this study, only three CMIP6 GCM models were compared and the best performing model was chosen. However, for further research, more GCM models can be compared to find the best working model that is accurately applicable for the state of Maharashtra.
- The current study area is limited to Maharashtra state, but it can be expanded to other Indian states.
- This investigation shows impact on crops only considering temperature parameters, but other hydrological and climatic parameters must be studied to predict accurate impact on crop productivity and possible changes in crop pattern calendar.
- The current study only compared approximate and only one statical downscaling method for adjusting output data, but other statistical downscaling methods and dynamic downscaling methods can be compared in future studies to predict more realistic future predictions.

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Appendix I

Gumbel Distribution Method –

The Extreme Value Distribution Type I: Gumbel Distribution (also called the Gumbel-Type). This is the most common EVD and has two forms: one for the minimum, and one for the maximum, although it is unbounded (not restricted to a range) and is defined on the entire range of real numbers. The probability density function has only one, unchanging shape which shifts according to the location parameter, μ. As μ increases, the distribution shifts to the left; As μ decreases, it shifts to the right. Let's say you had a list of minimum pollution levels for the last decade.

The general formula for the probability density function of the Gumbel (maximum) distribution is f(x)=1βe−x−μβe−e−x−μβ where μ is the location parameter and β is the scale parameter. The case where $\mu = 0$ and $\beta = 1$ is called the standard Gumbel distribution.

The equation for the standard Gumbel distribution (maximum) reduces to f(x)=e−xe−e−x Type 1, also called the Gumbel distribution, is a distribution of the maximum or minimum of a number of samples of normally distributed data. A Gumbel distribution function is defined as eq.3 eq.1 eq.2 71 where a and b are scale and location parameters, respectively.

The cumulative distribution function of a Gumbel distribution is given as Gumbel's Equation – $X_T = X + K.\sigma x$ eq. (5) Where, σx = Standard deviation of the Sample Size K = Frequency Factor, which is expressed as, eq. (6) Where, Yn and Sn are taken from table.I.I and table I.II