Impact of climate change on rainfall over Chennai

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Abstract. Global warming and climate change are currently topics of importance in environmental studies. Climate change is predominantly contributed by human activities and it presents a serious threat to nature and people. Greenhouse gasses such as carbon dioxide trap heat in the atmosphere and regulate climate. In addition, rapid urbanization and industrialization add more greenhouse gases to atmosphere and increase overall global temperature and further change the weather patterns. The unexpected weather conditions in Chennai has gained wide attention, especially after 2015 flood, Vardah and Ocki cyclones. In this study, the possible impact of climate change on rainfall over Chennai city is analysed under various Representative Concentration Pathway (RCP) scenarios. Simulations of a Coordinated Regional Climate Downscaling Experiment (CORDEX) Regional Climate Model (RCM) is downscaled using change factor method. The study results show that the intensity and frequency of extreme rainfall over Chennai is likely to increase.

1. Introduction
Climate change is considered as a global challenge and it has been affecting every country on every continent; thus, it requires coordinated effort by all the countries. Climate change is the variation in different atmospheric components over a longer time period and it has a major impact on human activities. The change in climate is becoming a menace to environment and global development. The risks result from unabated climate change having cumulative nature and which further leads to more violent weather episodes such as, drought, fires, extinctions of various plant and animal species, flooding from lakes and rivers, rise in sea level, destruction of economic resources and food systems and many more. The climate system varies over time due to natural reasons such as changes in solar energy, greenhouse gas emissions and volcanic eruptions etc. However, latest researches show that anthropogenic activities have been the supreme reason behind global warming and climate change[1]. Human activities have contributed an increased greenhouse gas emission and intensification of rainfall events. Current climate change scenarios and related local weather variability across the world makes it a place unfavourable for living[2]. For countries like India, the rainfall variability has been affecting their national economy as it is primarily depending on agriculture. The changes in climate produce heavy rainfall in some areas while less in some other areas. This uncertainty negatively affect agricultural patterns and crop yield [3]. Heavy rain events caused by climate change in the recent past have resulted floods and landslides, causing severe loss of human life and economy of the south Asian countries. The living environment and society are highly sensitive to the duration of extreme events.
The agriculture sectors, food, and energy security of India are closely associated with the severity of weather events. Therefore, a proper understanding and advance prediction of the climate change characteristics are important to respond the adoption policies. Prediction of future rainfall or any other climate parameters have become very important to make efficient abatement measure.

The climate condition is becoming more and more uncertain and devastated and this will be more severe in the future. This current climate scenario has forced many countries to do more investigations and studies in the climate field and also to establish strict control policies. The basic step to attain the result is to assess the impacts on various atmospheric components from climate change and project the changes to the future. Prediction has got much attention in this era as it would give a rough idea about the possible future changes that might happen to the atmosphere and make public aware about the seriousness. Global circulation models (GCMs) and regional climate models (RCMs) are used to predicting hydrological parameters and meteorological parameters. They make use of high-level mathematical representations of atmospheric, continental, and oceanic processes. These models can predict future climate patterns for likely future emission scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) [4]. The spatial resolution of GCMs is generally quite coarse, with a grid size of about 100–500 kilometers. GCM grid cells are assumed to be uniform for the entire dataset. Coarse GCM output is found to be acceptable when the variation within a grid is quite low or in case of global assessment. GCMs are very important predictive tools however they cannot account for small scale heterogeneity [5]. To overcome the issue and incorporate the variations in climate parameters within a grid cell it is required to downscale the parameters to regional level. Basically, downscaling is a method to obtain high-resolution climate or climate change information from relatively coarse-resolution GCMs. Dynamical downscaling or regional climate modeling (RCM) also relies on output from GCM simulations.

The amount of possible greenhouse gas emissions in future is a key variable to be considered in the study. And, data related to population, various technologies, land use patterns, energy productions and uses, economic circumstances are needed to be considered. So that research between different sectors is complementary and comparable, a standard set of scenarios are used to ensure that starting conditions, historical data and projections are employed consistently across the various branches of climate science. The IPCC has presented four different scenarios of representative concentration pathways (RCP) for climate change predictions [6]. RCP scenarios were proposed by converting the emitted greenhouse gases into solar radiative forcing, such as in the cases of RCP2.6, RCP4.5, RCP6.0, and RCP8.5. The scenarios were labelled by considering the possible radiative force values that can occur by the year 2100 [3]. The present study aims to determine the change in rainfall pattern over Chennai under RCP4.5 and RCP8.5 scenarios. It is assumed that greenhouse gas (GHG) emission of RCP4.5 attains peak value in the year 2040 and for RCP8.5 the peak emission continues to rise throughout the 21st century.

2. Material and methods

2.1. Study area

Chennai the capital city of Tamilnadu is located at 13°N and 80.2°E on the south east coast of India, is the fourth largest metropolitan city with a density of over 26000 people per kilometre square area. It is the biggest cultural, economic and educational centre of south India. Chennai is the sixth-most populous city and fourth-most populous urban agglomeration in India according to the 2011 Indian census report. The city together with the adjoining regions constitute the Chennai Metropolitan Area, which is the 36th-largest urban area by population in the world. The major issue that the state is facing now is water scarcity and large variation in the climate. The weather patterns have been changed drastically over the years and the city witnessed a drought, a flood, heavy rains and winds in the last five years. The typical rains that occur in summer have become rare, and recently the city has seen 200 dry days at a stretch. Change in rainfall, wind patterns and sea level increase and many more climate issues those happened in the state created a societal stress. This situation has forced the government to take necessary abatement measures and mitigation strategies. Studies predicts that the climate of Chennai will become more and more uncertain in the coming years. The unpredictability in rainfall...
pattern is analysed under various representative concentration pathway scenarios. Rainfall data for different time periods are collected for Chennai city.

2.2. Data
There are three types of data used in this study namely, observed rainfall, historic GCM rainfall data and GCM simulated rainfall data for the future. The observed daily rainfall data is from 1st January 1901 to 31st December 2013 and it is from Indian Meteorological Department (IMD). Rainfall data for both future and historical for RCP 4.5 and RCP 8.5 scenario were collected from CORDEX. Historical data and future rainfall data were divided into two time period. The time period considered for historical rainfall data was 1971-2005 and for the future the time period was 2021-2095. The future projections for two time periods are defined as early period T1 (2021-2055) and late period T2 (2061-2095).

2.3. Methodology
The aim of the study is to assess the impact of climate change on rainfall over Chennai. The Rainfall data for the historical time period and future data were downloaded from CORDEX. When the simulation is required at the smaller or regional scale, rainfall data from GCM cannot be directly used [7]. Downscaling of data is employed here to get high resolution data from a low resolution GCM data. Many downscaling methods are available, each with their own negatives and positives. Dynamical and statistical are two major downscaling techniques, in which dynamical downscaling technique make use of regional climate models to predict at smaller scales with high resolution. Whereas statistical downscaling has empirical model to simulate in coarse scale [4].

Change factor methodology (CFM) also known as delta change method and it is one of the commonly used statistical downscaling technique, which is appropriate for the estimation of climate variables at future time periods and also for the assessment of local climate change [8]. The main advantage of this methodology is the speed and easiness of application. In this study CFM is used to downscale the future rainfall of Chennai. Future rainfall at local scale is estimated through constant scaling, in which a constant factor (change factor) is determined for all the RCP scenarios and multiplied with the observed rainfall data [9]. For this, average monthly rainfall is calculated and change factor is determined for all the months. The equation used to calculate change factor is given in Eq. (1) [8]. The change factor calculated is single multiplicative type.

\[
\text{CF} = \frac{GCM R_{fut}}{GCM R_{hist}}
\]  

where GCM \( R_{fut} \) is the GCM simulated rainfall for future and GCM \( R_{hist} \) is the GCM simulated rainfall for historical period.

Further, to understand the changes in extreme events, the changes in extreme rainfall return periods is analysed. The frequency of extreme rainfall events is calculated by fitting the generalized extreme value distribution to the annual maximum series. Return level (rainfall intensity \( Z_T \)) for the given return period \( T \) is calculated using Eq. (2).

\[
Z_T = \mu + \frac{\sigma}{k} \left[ -\ln \left( 1 - \frac{1}{T} \right) \right] - 1
\]

here \( k, \sigma, \mu \) are the shape, scale, and location parameters of generalized extreme value distribution respectively.
3. Results and discussion

3.1. Results of downscaling

The ratio of GCM $R_{\text{fut}}$ and GCM $R_{\text{hist}}$ yields the change factor. The change factor values obtained for two time periods of RCP4.5 and RCP8.5 are summarized in the Tables 1. It is seen that change factor obtained for the month May has the highest value for all the time periods.

| Month   | $CF_{\text{RCP4.5 T1}}$ | $CF_{\text{RCP4.5 T2}}$ | $CF_{\text{RCP8.5 T1}}$ | $CF_{\text{RCP8.5 T2}}$ |
|---------|-------------------------|-------------------------|-------------------------|-------------------------|
| January | 1.552                   | 1.551                   | 0.854                   | 1.458                   |
| February| 1.124                   | 0.872                   | 0.386                   | 1.099                   |
| March   | 0.852                   | 0.538                   | 0.717                   | 0.644                   |
| April   | 0.500                   | 1.175                   | 0.805                   | 1.283                   |
| May     | 1.664                   | 1.152                   | 4.606                   | 0.799                   |
| June    | 0.821                   | 0.743                   | 0.491                   | 0.918                   |
| July    | 0.929                   | 0.973                   | 1.029                   | 0.824                   |
| August  | 1.328                   | 1.243                   | 1.051                   | 1.118                   |
| September | 1.254                 | 1.024                   | 0.899                   | 1.293                   |
| October | 0.985                   | 1.133                   | 1.043                   | 0.736                   |
| November| 1.598                   | 1.981                   | 1.877                   | 2.194                   |
| December| 0.652                   | 0.824                   | 0.805                   | 0.946                   |

The change factor determined for RCP4.5 and RCP8.5 are multiplied with the observed rainfall value. The resulted rainfall is represented using box plots to evaluate the distribution characteristics. The statistical parameters of downscaled rainfall of different RCP scenarios and time scales are given in Table 2 and Table 3.

| Parameters   | Observed | $RCP4.5_{\text{T1}}$ | $RCP4.5_{\text{T2}}$ | $RCP8.5_{\text{T1}}$ | $RCP8.5_{\text{T2}}$ |
|--------------|----------|----------------------|----------------------|----------------------|----------------------|
| Maximum      | 2404.6   | 2932.11              | 3323.82              | 3059.15              | 3597.11              |
| Minimum      | 878.6    | 1034.47              | 1056.72              | 1067.24              | 1036.73              |
| Median       | 1332.9   | 1616.16              | 1726.46              | 1780.04              | 1696.03              |
| Average      | 1360.2   | 1617.56              | 1764.61              | 1805.78              | 1781.94              |

| Parameters   | Observed | $RCP4.5_{\text{T1}}$ | $RCP4.5_{\text{T2}}$ | $RCP8.5_{\text{T1}}$ | $RCP8.5_{\text{T2}}$ |
|--------------|----------|----------------------|----------------------|----------------------|----------------------|
| Maximum      | 368.114  | 588.849              | 730.443              | 692.904              | 809.774              |
| Minimum      | 3.551    | 3.007                | 1.843                | 2.611                | 2.345                |
| Median       | 88.105   | 88.217               | 77.543               | 118.956              | 81.0981              |
| Average      | 113.354  | 134.796              | 147.0513             | 150.482              | 148.495              |
Figures 1 and 2 show the box plots for yearly and monthly rainfall data. The box plots for yearly and monthly rainfall data follow different pattern of distribution. In the yearly rainfall data, the median of observed rainfall data is lower than RCP scenarios, and all the data are symmetric and follows a normal distribution except for RCP8.5 T1. However, the median is almost lying in the similar range with different distributions for monthly rainfall data.

![Box plot for yearly rainfall](image1)

**Figure 1.** Box plot for yearly rainfall.

![Box plot for monthly rainfall](image2)

**Figure 2.** Box plot for monthly rainfall

3.2. Analysis of Extreme value distribution

The distribution parameters estimated for time periods are given in Table 4.

| Rainfall data | Κ   | Σ    | μ      |
|---------------|-----|------|--------|
| Observed      | 0.2254 | 45.2250 | 112.4355 |
| RCP4.5_T1     | 0.2431 | 63.8789 | 137.3119 |
| RCP4.5_T2     | 0.2819 | 77.5994 | 152.0310 |
| RCP8.5_T1     | 0.3446 | 84.7612 | 160.0039 |
| RCP8.5_T2     | 0.3579 | 99.0891 | 161.5291 |
Return levels are determined for the 2, 5, 10, 25, 50 and 100 year return periods using the parameters. Graphs for return levels are plotted for observed, RCP4.5 and RCP8.5 scenarios in Figures 3 and 4. From the return level calculations, it is seen that both RCP4.5 and RCP8.5 are having higher values of return level than observed rainfall data.

![Figure 3](image1.png)  
**Figure 3.** Return level plot for observed and RCP4.5 scenario.

![Figure 4](image2.png)  
**Figure 4.** Return level plot for observed and RCP8.5 scenario.

### 4. Summary and conclusions
Climate change today has become one of the complex and biggest concern for all the countries. The objective of this study is to evaluate the changes in the climate trends and extreme events and constructs the rainfall scenarios for Chennai. Simulations of a CORDEX RCM is downscaled using sophisticated change factor methodology. The downscaled rainfall value is exhibiting high variations from observed data. The study results show that the intensity and frequency of extreme rainfall over Chennai is likely to increase under RCP 4.5 and RCP 8.5 scenarios.

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