Assessment of Climate Change Impacts on Precipitation and Temperature Using SDSM Based on CanESM2 Predictors for Nanded, Maharashtra, India.

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Abstract: *Climate change directly impacts the hydrological cycle affecting the local climate of any area. Rapid changes in climate leads to change in weather pattern thus leads to extreme weather events. In this investigation, main objective was to understand the climate change impact on local climate of Nanded. The downscaling was done using Statistical Down Scaling Model (SDSM) version 4.2.9. The fourth generation coupled Global Climate Model CanESM2 was used in this study. Two meteorological parameters used in this study were precipitation and mean temperature. In this study, the observed rainfall and mean temperature pattern of past was used to predict future mean temperature and rainfall by using RCP (Representative Concentration Pathway) 4.5 and 8.5. SDSM downscaling for this study showed variation for both average temperature and precipitation with historical predictors. For future scenario generation rainfall showed variations for different time periods while temperature trend is mostly same in both rcp4.5 and rcp8. Downscaled predicted results show that there is a rise in temperature for both future scenarios. The RCP4.5 and RCP8.5 predicted maximum rainfall in August and increase in rainfall intensity. SDSM is surely a useful tool for studying impact of climate change on local weather pattern. SDSM performance efficiency depends on various factors like choice of GCM, accuracy of local meteorological data and chosen predictors etc.*

Keywords: CanESM2, SDSM, Downscaling, Temperature, Precipitation, RCP.

1.INTRODUCTION

The most emerging and appearing environmental issue of this century is definitely human-caused climate change. Climate change is actually a very natural phenomenon. There has always been changes observed in earth's climate since beginning but it was natural and self-occurring. What makes climate change a matter of concern is the speed at which we are experiencing climate change from last century. Urbanization and industrialization are two major factors contributing to the human caused climate change.

The effects of climate change are about to increase in many regions of India. Changes in precipitation pattern will affect system of water resources planning and its management. Indian economy depends on agriculture. Hence it relies mainly on monsoon for its crop production. Hence any change in climate will have tremendous impact on precipitation and temperature. That is why it is important to do assessment of the impact of climate changes and adopt proper measures for future scenarios.(Manish K.G. and Rao Y.S. 2018). For predicting future climate, we have to rely on simulation models.(Andrew G. and Richard B.R.2016).

A model basically represents a system, likewise a climate model will represent climate system. A climate system mainly contains basic parts of the earth system such as the atmosphere, ocean, ice and terrestrial system. A climate model consists set of equations that try to represent and reproduce each of the important pieces of the climate system, a climate model exists as a conceptual model coded into a computer. (Andrew G. and Richard B.R. 2016).

General circulation models (GCMs) or Global Climate Models are sophisticated three dimensional numerical tools. They simulate climate of earth with different climate variables, initial and boundary conditions, and structure.(Raju et al. 2018). GCMs try to represent earth atmosphere and oceans and when combined together with future emission scenarios they can forecast the climate pattern. Many GCMs can replicate the characteristics of current climate pretty well and most of these GCMs can imitate the observed climate change for recent past.
A Global climate model basically divide the earth surface by imaginary lines which are similar to latitude and longitude. The area enclosed between these lines is called as grid which defines resolution of a particular GCM. If the size of grid is large then it is called coarse resolution GCM and if the grid size is small then it is finer resolution GCM.

Efficiency of GCMs, which normally operate at coarser grid resolution of (3°×3°), decreases with increasingly temporal scales and finer spatial, making them unable to properly represent sub-grid scale features. GCMs are unable to precisely model sub-grid scale or local scale processes which are of main interest to hydrologists, policy makers and water resources planners.(Raju et al.2018). Considering above mentioned limitation of a GCM, need of downscaling arises. Downscaling is essential for studying climate change impacts on regional scale or sub-grid scale. The main purpose of downscaling is to bridge the gap between global climate and regional climate. In other words, downscaling is interpolation of climate models to acquire results for desired area. The assumptions based on which downscaling works are:

(1) The predictors are important variables which are modelled by the GCM.

(2) The transfer function is applicable even for altered climatic conditions.

(3) The predictors applied fully demonstrate the climate change signal.

Dynamical downscaling consists of the nesting of a higher resolution Regional Climate Model (RCM) within a coarser resolution GCM (Wilby & Dawson, 2007).Weather typing involve grouping of local, meteorological data in relation to existing patterns of an atmospheric circulation. Weather pattern downscaling is based on proper lining between large scale climate and local scale weather (Wilby & Dawson, 2007). Stochastic downscaling typically involves modifying and redefining the parameters of Conventional/traditional weather generators such as WGEN, LARS–WG or EARWIG (Wilby & Dawson, 2007).Transfer-function downscaling techniques relies mainly on empirical relationships between predictands and predictor(s) (Wilby & Dawson, 2007). Statistical downscaling has advantage of being computationally less challenging.

(Vidya R.S. and D.G. Regulwar, 2016) used Two Global Climate Models CGCM3 and HadCM3 to predict future maximum temperature (Tmax), minimum temperature (Tmin)
and precipitation for Upper Godavari River Basin, India. Their study concluded the rise in average temperature and increase in precipitation in all scenarios for both GCMs. (Mohammadreza Javaherian, et al., 2020) used CanESM2 model for projecting climatic parameter changes for Lar dam basin, Iran.

(Singay Dorji, et al., 2017) proposed a novel approach for improving and analysing climate predictions by joining SDSM and neural networks. Their study focuses on allowing user to combine SDSM with ANN for more skilled downscaling.

(Ayele E. G, et al., 2019) studied temperature change scenarios for Chamo sub basin in Ethiopia. They used CanESM2 model and SDSM for their study period of 1988-2003 and 2004-2016 and found the rise in average temperature for future.

The main purpose of this study is to study the local climate pattern of Nanded, India. Precipitation and average temperature are the parameters to be studied in this study. Statistical downscaling is applied in this study due to the fact that its computationally less demanding, economical for individual study and variables are readily transferable. CanESM2 of IPCC fifth assessment report is used as it gives data in SDSM compatible format and SDSM is used as downscaling tool. Past meteorological data of temperature and rainfall for Nanded for a period of 1981-2010 is obtained from http://www.soda-pro.com/web-services/meteo-data/merra. It is always desirable in climate change impact studies to study historical data of 20-30 years. In this study past meteorological data for 30 years is obtained. Future prediction for rainfall and mean temperature for the 2030's, 2050's and 2070's is projected.

2.DESCRIPTION OF STUDY AREA

The temperature and precipitation pattern are studied for the city of Nanded located in the Maharashtra state of India. Area of Nanded is 63.22 Kilometre Square.

Nanded is situated on the northern bank of Godavari River in the west-central region of India.

Latitude is 19.13° and Longitude is 77.32° . Nanded receives its maximum rainfall during period of June to September, Average highest temperature is 41°c and average lowest temperature is 12.8°c(IMD, Pune).

3.DATA COLLECTION

3.1. Global Climate Model/ General Circulation Model (GCM)

The GCM used for this study is CanESM2 predictors. The CanESM2 stands for (The Second Generation Canadian Earth System Model based on CMIP5 experiments which is the fourth generation coupled global climate model. CanESM2 is developed by the Canadian Centre for Climate Modelling and Analysis of Environment and Climate Change Canada. Predictors are extracted into single column text file per box or per grid cell based on standardized long term time series. Total 128×64 grid cells cover entire global domain on the basis of T42 Gaussian grid. This grid/box is uniform along the latitude with resolution of 2.8125° and nearly uniform along longitude with horizontal resolution of 2.8125°. The predictors for each grid cell are represented by corresponding folder named *BOX_iiiX_jjY*, where iii is longitudinal and jj is latitudinal index. The predictors organized this way are ready to be used as input in statistical downscaling models.(Source: https://climate-scenarios.canada.ca/?page=pred-canesm2.). For Nanded a zipped folder named BOX_028X_39Y is obtained based on latitude and longitude. The longitude and latitude coordinates correspond nearly to the centres of the grid boxes. That zipped folder when extracted contain historical predictors for period of 1961-2005, rcp26_2006-2100, rcp45_2006-2100, rcp85_2006-2100 and NCEP-NCAR_1961-2005. For this study historical data, reanalysis data and RCP scenarios (4.5 and 8.5) are used. Historical and reanalysis data gives predictor for period of 1961-2005 and we are applying them for the period of 1981-2010 for our local meteorological data. In CanESM2 NCEP reanalysis data is also provided for selected grid. Table 1 explains various NCEP predictors and their respective meaning.

3.2. Past daily meteorological data for Nanded(Average Temperature and Precipitation)

Past meteorological daily data for the period of 1981-2010 is obtained from webservice MERRA-2 (The Modern-Era Retrospective analysis for research and applications, version 2). Spatial resolution is approximately 50 km. The data availability is since January 1980 till now. MERRA-2 provides data for precipitation, temperature at 2m, relative humidity at 2m, wind speed and direction at 10m, snowfall, snow depth, and global horizontal irradiation. For this particular study only rainfall and temperature data are needed. Data can be obtained in .csv (comma separated value) format which makes it easier to convert into .DAT format for SDSM. Time steps range varies from 1 minute to 1 month, daily data is obtained for this study.

3.3. SDSM

This regression based model builds a statistical relation between a GCM and local climate data. SDSM assumes that the generated relation will be same in future.

Table 1:NCEP predictors and their definition.[Source: https://climate-scenarios.canada.ca/?page=pred-help] and [Vidya R.S. and D.G. Regulwar, 2016].

Predictor	Definition	Predictor	Definition
p_f	Surface airflow strength	r500	500 hPa relative humidity
p_u	Surface zonal velocity	p8_f	850 hPa airflow strength
p_v	Surface meridional velocity	p8_u	850 hPa zonal velocity
p_z	Surface vorticity	p8_v	850 hPa meridional velocity
p_th	Surface wind direction	p8_z	850 hPa vorticity
p_zh	Surface divergence	p8th	850 hPa wind direction
rhum	Surface relative humidity	p8zh	850 hPa divergence
p5_f	500 hPa airflow strength	r850	850 hPa relative humidity
p5_u	500 hPa zonal velocity	p500	500 hPa geopotential height
p5_v	500 hPa meridional velocity	p850	850 hPa geopotential height
p5_z	500 hPa vorticity	Temp	Mean temperature at 2 m height
p5th	500 hPa wind direction	shum	Surface-specific humidity
p5zh	500 hPa divergence	mslp	Mean sea level pressure

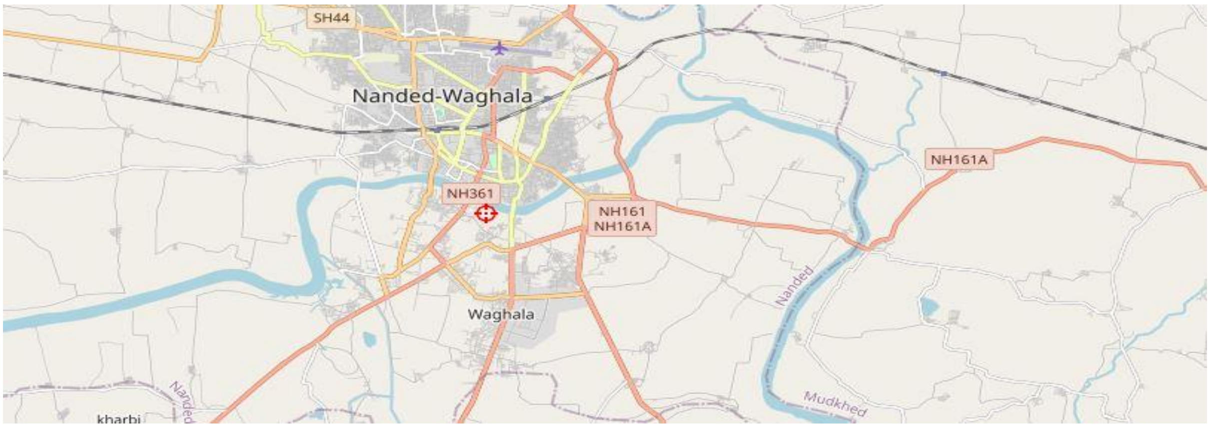

Figure 1: Location of study area on the map of MERRA-2 service

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4. METHEDOLOGY

The general methodology followed in downscaling through SDSM is illustrated in figure 2. These are the basic guidelines provided to downscale climate data for various climatic parameters. The SDSM software reduces the task of statistically downscaling daily weather series into seven discrete steps: 1) quality control and data transformation; 2) screening of predictor variables; 3) model calibration; 4) weather generation (using observed predictors); 5) statistical analyses; 6) graphing model output; 7) scenario generation (using climate model predictors)(Wilby & Dawson, 2007). However, for this study downscaling is done of climate data for temperature and precipitation in much simplified way. The steps involved in this study are mentioned in Table 2. For downscaling rainfall and temperature data the steps involved are 1)Quality control; 2)Screening of variables to set predictor-predictand relationship; 3)Model calibration; 4)Scenario generation; 5) Compare results; 6) Chart results.

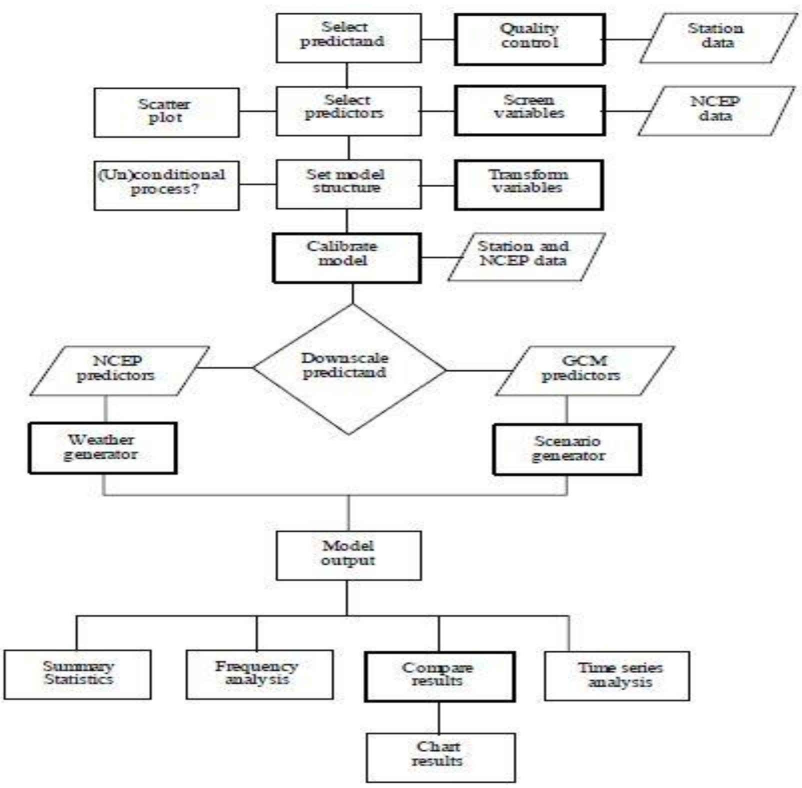

Figure 2: Standard steps to downscale and generating scenario using SDSM(SDSM Manual).

4.1. Quality Control

This is the first step in the process of downscaling. Data obtained for local climate might contain errors and is checked here to know if there is any missing value, difference in values, maximum and minimum values. SDSM provides a missing value code i.e., -999. Quality control does not affect further process of downscaling but it is recommended. For this study quality control is done for past Temperature and Rainfall data of Nanded.

4.2. Screening of Predictors

Screening of predictors is actually the longest step in the process of downscaling as it is meant to establish the relation between predictors and predictands. NCEP/NCAR reanalysis data obtained from CanESM2 goes through this process along with predictand i.e., local meteorological data of Nanded. Probable predictors are selected based on corelation analysis. Screening is necessary because the predictors obtained in this process is used in model calibration. Table 3 shows selected screen variables for temperature and rainfall.

4.3. Model Calibration

Predictors selected in the screening process are used along the predictand to perform calibration. Calibration of model generates output in .PAR format. This output file is further necessary in processes of scenario generation, weather generation.

4.4.Scenario Generation and Summary Statistics

Output of calibrated model is used to generate scenario. GCM data either historical or RCP scenarios are used along with output of calibration to generate scenarios. In this study rcp4.5 and rcp8.5 scenarios are used for future forecasting. Output of scenario generation comes in .OUT and .SIM format. For each RCP scenario separate output is obtained. In summary statistics .OUT file works as input file to summarise each scenario. Output file comes in .TXT format. Based on RCP 4.5 and 8.5 scenario temperature and rainfall of future is forecasted for the period of 2030's, 2050's, and 2070's.

4.5. Compare Results

In this step modelled and observed data from summary statistics to compare results. For future forecasting and for different RCP scenarios the result is compared for different time periods.

4.6. Chart Results

Results can be charted here in the form of bar charts, line charts. Obtained results can also be copied and tabulated.

Table 2:Breakdown of process to downscale and analyse GCM data.

Sr no.	Steps to downscale and scenario generation average temperature and rainfall using SDSM
1	Quality control
2	Screen variables
3	Calibration
4	Scenario generation
5	Compare results
6	Chart results

5. RESULTS

In this paper, climate change impact on rainfall and average temperature is the main objective of study. For which statistical downscaling approach is used for downscaling GCM predictors. Figure 3. Shows rainfall and temperature data both modelled and observed in comparison. Figure 4. Shows relative comparison between future climate scenarios for rcp4.5 and rcp8.5.

For temperature when historical predictors are applied it is showing either slight or in some cases higher variation. Maximum mean temperature is in the month of April and May in both observed and downscaled case. Minimum mean temperature is observed in the month of November and December.

For rainfall modelled data is showing approximately same value of rainfall in all twelve months of year which is unrealistic. This could be because errors in predictands. Observed rainfall is showing proper results and June to September is the period of receiving rainfall. Maximum rainfall is observed in the month of July.

Future scenarios rcp4.5 and rcp8.5 for 2030's, 2050's and 2070's is applied which shows gradual increase in precipitation for both scenarios. Precipitation is constantly rising for monsoon season. Maximum rainfall will be observed in the month of August which is shift from current month of July.

Temperature is also showing increasing trend in both scenarios and is almost equal for 30's, 50's and 70's. May month will witness highest temperature in all scenarios. December and January will witness lowest temperature. There will be approximately rise in one degree Celsius in temperature between the 2050's and 2070's. There is an obvious rise in temperature in future for both scenarios.

Table 3:Selected predictor variables during screening.

Sr No	Average Temperature	Precipitation
1	ncepp1thgl	ncepp8_ugl
2	ncepp500gl	2 nceppr cpgl
3	ncepp8thgl	3 nceps500gl
4	ncepp8_ugl	4 ncepshumgl
5	nceptempgl	5 ncepp5_zgl
6	ncepshumgl	6 ncepp1_vgl

6. CONCLUSIONS

Statistical downscaling is based on assumption that relation between predictor and predictand will also be valid in future, which is not always the case, still statistical downscaling is very suitable for local climate observers. SDSM does not necessarily require bias correction because it inherently corrects the biases. (Vidya R.S. and D.G. Regulwar, 2016) have applied bias correction to downscaled data. Their GCM was HadCM3 and CGCM3 but in this study CanESM2 GCM is used. For some reason CanESM2 is not responding well to bias correction and giving unexpected results after applying biases to downscaled data. Therefore, bias correction is not done for downscaled output in this study since SDSM is capable of applying bias correction. It is also observed that results of SDSM are dependent on many factors that are choice of GCM, scenarios applied, local climate data, time series of study, predictors choice, reanalysis data, etc. SDSM is considered to be reliable mode of downscaling among climate researchers, climate forecasters and water resource planners.

Impact studies of climate change on water resources, regional climate, energy conservation, etc is actually need of hour. There is definitely an increase in global warming which is leading to more hot summers. Rise in temperature impacts rainfall pattern of a region this results in droughts or unexpected floods. We are already witnessing the changes in weather in our surroundings. Extreme weather events are occurring all around the world. Increase in bush fire seasons, heat waves and repetitive floods are the most common impacts we all are witnessing globally. It is natural that change in global climate affects local climate. For a small city like Nanded climate change impacts on its local weather might be helpful for future planning and conservation of resources. There is more room for study on this region. ANN (Artificial Neural Networks can be used with statistical downscaling for better and improved downscaling(Singay Dorji, et al., 2017). SDSM is mostly used by individual researchers and some institutions for climate studied as it is user friendly, requires less computational power and economical. CanESM2 model also eases down the process of data extraction from GCM. It also provides reanalysis data for selected region in easiest readable format which makes obtaining NCEP/NCAR reanalysis data less hectic. Overall CanESM2 goes very well with SDSM. There are definitely chances of error and there is no way the future scenarios created are totally accurate. Each model and downscaling approach has its own uncertainties and limitations. SDSM is also no exception but still it is a very good approach in studying impacts of climate change on regional climate.

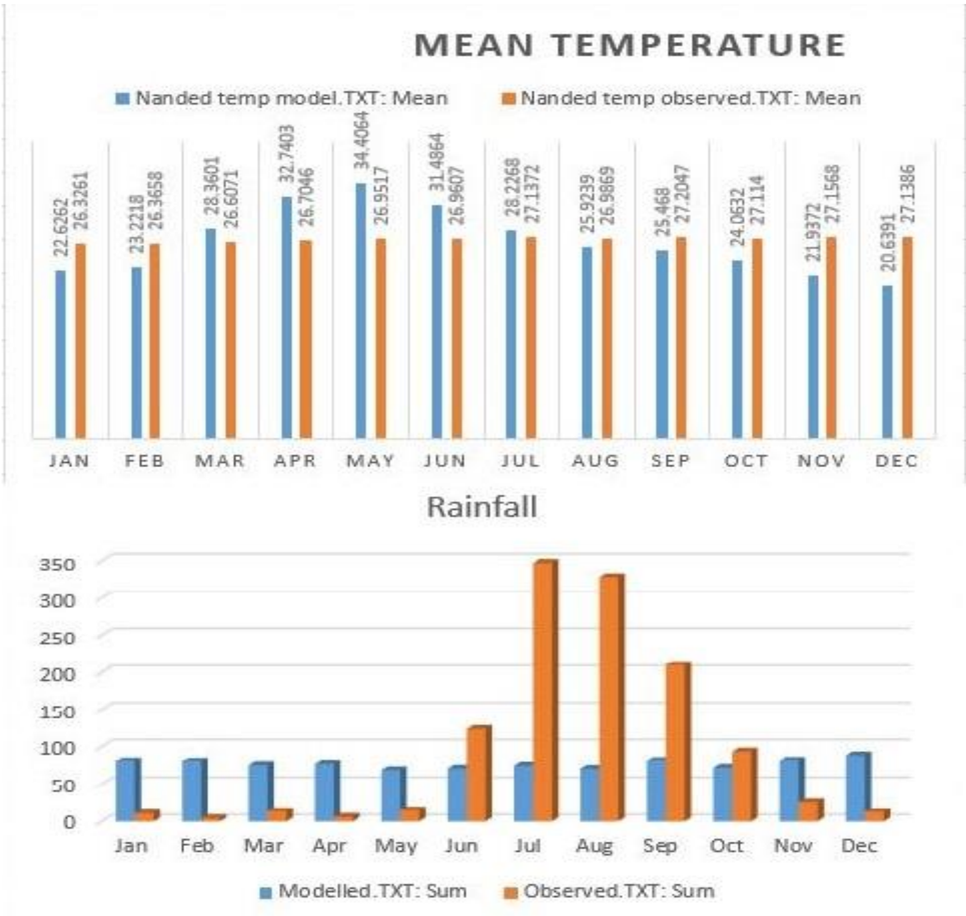

Figure 3: Observed versus modelled rainfall and temperature.

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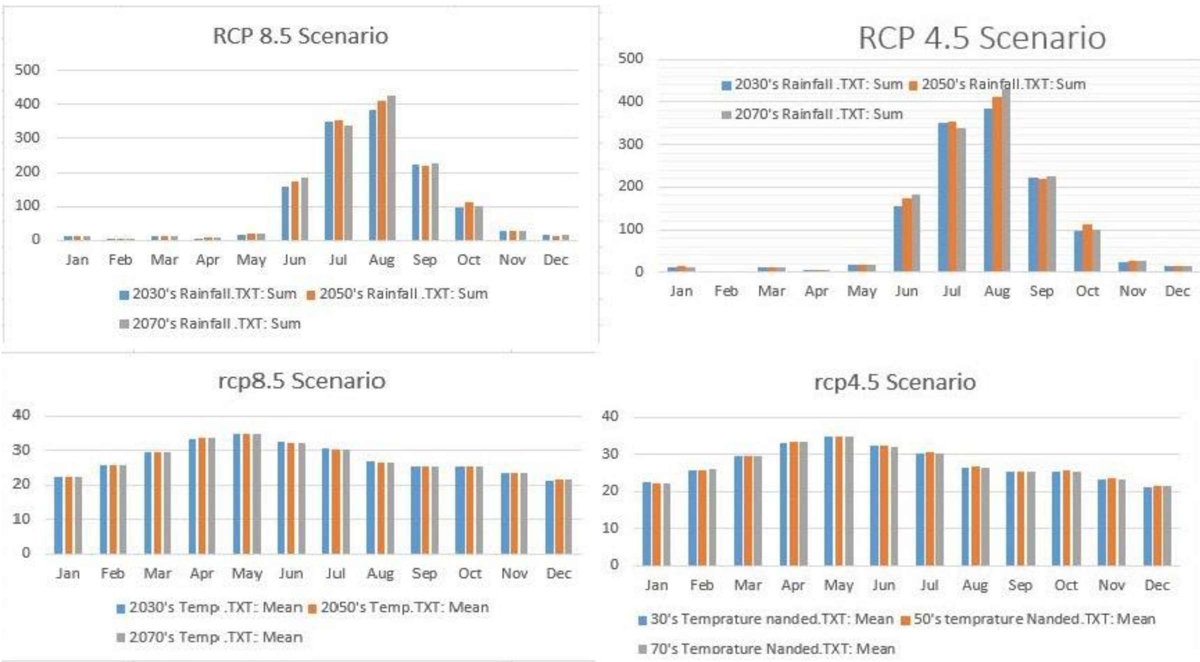

Figure 4: Future precipitation and temperature trend for RCP 4.5 and 8.5 scenarios.

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