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Future Climate Change Scenario at Hot Semi-arid Climate of Ahmedabad (23.04°N, 72.38°E), India Based on Statistical Downscaling by LARS-WG Model

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Abstract: General Circulation Models (GCMs) are widely used nowadays to simulate future climate scenarios. However, present GCMs have limited skills in simulating the complex and local climate features and to provide reliable information on precipitation and temperature data which are the principal inputs to hydrologic impact assessment models. Furthermore, the outputs provided by GCMs are too coarse to be used by such hydrologic models, as they require information at much finer scales. Downscaling of GCMs output is, therefore, a necessity. Keeping this in view, the present study aimed at verifying the skills of LARS-WG, a popular downscaling tool, in downscaling weather data in hot semi-arid climate of Ahmedabad and predict and analyze the future changes of temperature (daily maximum and minimum) and precipitation based on IPCC SRA2 scenario generated by seven GCMs' predictions for the near (2011-2030), medium (2046-2065) and far (2080-2099) future periods. For this purpose, daily rainfall, maximum and minimum temperature data for the study site Ahmedabad for 1969-2013 have been utilized.

LARS-WG showed excellent skill in downscaling maximum and minimum temperature and reasonably good skill in downscaling daily rainfall data at Ahmedabad. The downscaled precipitation from the predictions of seven GCMs indicated no coherent change trends among various GCMs' predictions of precipitation during near, medium and far future periods. Predicted rainfall in monsoon season (JJAS) based on the ensemble mean of seven GCMs showed a decrease in rainfall in near future i.e. 2011-2030 by about 2%; however, during medium future (2046–2065) it is predicted to increase and remain close to the baseline value; and during far future (2080–2099) period it is predicted to increase by about 5% compared to the baseline value. Summer maximum temperature is predicted to increase by 0.7, 2.0 and 4.0 deg. Celsius during 2011–2030, 2046–2065 and 2080–2099 respectively at the study site. Winter minimum temperature is predicted to increase by 1.0, 2.5 and 5.0 deg. Celsius during 2011–2030, 2046–2065 and 2080–2099 respectively at Ahmedabad.

Key words: Climate change, LARS-WG model, statistical downscaling, GCMs.

Introduction

A stochastic weather generator is a numerical model which produces synthetic daily time series of a suite of climate variables, such as precipitation, temperature and solar radiation, with certain statistical properties (Richardson, 1981; Richardson and Wright, 1984; Racsko et al., 1991). There are several reasons for the development of stochastic weather generators and most important of them in today's context is their application in future climate change studies. Climate change is considered as the greatest challenge faced by mankind in the twenty first century. Analyses and prediction of change in critical climatic variables like rainfall and

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temperature are, therefore, extremely important to develop strategies and make informed decisions about the future water allocation for different sectors and management of available water resources. The output from Global Climate Models (GCMs), which are the main tools for predicting the evolution of climate on Earth, cannot be used directly at a site because of their very coarse spatial resolution (even in a high resolution GCM, one grid box represents an area of greater than 50,000 km^2) (Semenov et al., 1998). Wilby and Wigley (1997) and Xu et al. (2005) also mentioned about the coarse spatial resolution problem of the GCMs.

To cope up with this challenge, it is of vital importance to transform the changes of large-scale atmospheric predictions of GCMs to the changes of regional-scale climate variables, such as precipitation and temperature (Chen et al., 2013). The methods used to convert GCM outputs into local meteorological variables are usually referred to "downscaling" techniques (Goyal and Ojha, 2012; Olsson et al., 2012; Segui et al., 2010). The basic assumption of downscaling is that the large scale atmospheric characteristics highly influence the local scale weather, but, in general, the reverse effects from local scales upon global scales are negligible and thus can be disregarded (Maraun et al., 2010). The downscaling methodologies developed to date can broadly be categorized as statistical and dynamical. Among the statistical downscaling methods, the use of stochastic weather generators is very popular. They are not computationally demanding, simple to apply and provide station scale climate change information (Dibike and Coulibaly, 2005; Kilsby and Jones, 2007). Wilks (1992) and Wilks (1999) also opined that when the climate change research community started looking for low cost, computationally less expensive and quick methods for impact assessment, the weather generator emerged as the most suitable solution.

Out of the different weather generators Long Ashton Research Station Weather Generator (LARS-WG), a stochastic weather generator, found to be better than some other generators (Semenov et al., 1998). It is specially designed for climate change impact studies (Semenov and Barrow, 1997) and has been tested successfully for diverse climates (Semenov et al., 1998; Reddy et al., 2014; Hashmi et al., 2012) of the world. LARS-WG can be used for the simulation of weather data at a single site (Racsko et al., 1991) under both current and future climate conditions. These data are in the form of daily time series for climate variables, namely, precipitation (mm), maximum and minimum temperature (°C) and solar radiation ($MJm^{-2}\cdot day^{-1}$). Another advantage of LARS-WG is that 15 GCMs' outputs with different scenarios have been incorporated into the model to better deal with the uncertainties of GCMs.

Keeping in mind the above fact, the present study has been conducted with the following objectives:

1. to verify the skills of LARS-WG in simulating weather data in hot semi-arid climate of Ahmedabad by using long period observed metrological data and
2. to predict future climate scenario at the study site by analyzing precipitation and temperature data downscaled by LARS-WG model which can further be used as reference results for developing future sustainable water resources and heat action plan for Ahmedabad.

Materials and Methods

Study Area and Data

For this study Ahmedabad (23.04°N, 72.38°E), India which is having hot semi-arid climate has been chosen. Save the monsoon season, the climate here is very dry. The weather is hot through the months of March to June. The average summer maximum and winter minimum temperature is 41°C and 15°C respectively. Sothwest monsoon (June–September) brings in humid climate from mid-June to mid-September. Sometimes heavy torrential rains cause local rivers to flood and drought is also not uncommon to this place when southwest monsoon is below par. Ahmedabad is having departmental meteorological observatory of India Meteorological Department (IMD) and having long period good quality meteorological data. The data series used in this study is daily rainfall, maximum and minimum temperature from 1969 to 2013 and obtained from IMD, Ahmedabad.

LARS-WG is having the advantage that output from 15 GCMs with different scenarios have been incorporated into the model to better deal with the uncertainties of GCMs. Among the 15 GCMs used in the IPCC AR4, seven GCMs (Table 1) had SRA2 emission scenario that stands among the worst case scenario, as it sees the future world as heterogeneous and more concerned for economic growth than environmental aspects (SRES, 2000). These seven GCMs with SRA2 scenario were used to predict the future change of local-scale precipitation and temperature in three periods: 2011-2030, 2046-2065 and 2080-2099.

Table 1: Selected seven global climate models from IPCC AR4 incorporated into the LARS-WG 5.0 in this study

No.	*GCM*	*Research centre*	*Grid*
1	CNCM3	Centre National de Recherches, France	1.9 × 1.9°
2	GFCM21	Geophysical Fluid Dynamics Lab, USA	2.0 × 2.5°
3	HADCM3	UK Meteorological Office, UK	2.5 × 3.75°
4	INCM3	Institute for Numerical Mathematics, Russia	4 × 5°
5	IPCM4	Institute Pierre Simon Laplace, France	2.5 × 3.75°
6	MPEH5	Max-Planck Institute for Meteorology, Germany	1.9 × 1.9°
7	NCCCS	National Centre for Atmospheric, USA	1.4 × 1.4°

Method

The LARS-WG uses semi-empirical distributions to simulate weather data based on the observed statistical characteristics of daily weather variables at a site both under current and future climatic conditions. There are two major stages in this method: the first is the site analysis (calibration) stage and the second is the scenario generation, which includes the down-scaling processes. The inputs to the weather generator are the series of daily observed data (precipitation, minimum and maximum temperature) of the base period (1969-2013) and site information (latitude, longitude and altitude). In the LARS-WG, the quality check is performed on fly (for example, some stations show Tmin is greater than Tmax) and corrected through site analysis module (Fiseha et al., 2012). After the input data preparation and quality control, the observed daily weather data at a given site were used to determine a set of parameters for probability distributions of weather variables. These parameters are used to generate a synthetic weather time series of arbitrary length by randomly selecting values from the appropriate distributions. The LARS-WG distinguishes wet days from dry days based on whether the precipitation is greater than zero. The occurrence of precipitation is modelled by alternating wet and dry series approximated by semi-empirical probability distributions. The detailed model setup and working principle are explained by Semenov and Barrow (1997) and Semenov (2007).

Calibration and Validation of LARS-WG

The calibration of the LARS-WG model is based on the derivation of statistical parameters using the observed historical data. The data on daily precipitation as well as minimum and maximum temperatures for the period of 1969-2013 at the selected station Ahmedabad were used to perform the site analysis. LARS-WG produces monthly means and standard deviations of precipitation, minimum and maximum temperature using semi-empirical distributions of dry and wet series. The statistical significance of the result is analysed by forcing the model to generate synthetic series of data for 500 years. The resulting synthetic values are then compared with the observed records considering the *t* test, *F*-test and K-S (Kolmogorov-Smirnov) tests.

Climate Scenarios

In this study, the local-scale climate scenarios based on the SRA2 scenario simulated by the selected seven GCMs are generated by using LARS-WG (5.0) for the time periods of 2011–2030, 2046–2065 and 2080–2099 to predict the future change of precipitation and temperature at Ahmedabad. Semenov and Stratonovitch (2010) introduced and used the procedure to generate the local-scale climate scenarios.

Results and Discussion

Results of Calibration and Validation of LARS-WG Model

LARS-WG model was calibrated and validated at Ahmedabad using daily weather data for 1969-2013. To assess the ability of LARS-WG, besides the graphic comparison, some statistical tests are also performed. The Kolmogorov–Smirnov (K–S) test is performed on testing equality of the seasonal distributions of wet and dry series (WDSeries), distributions of daily rainfall (RainD), and distributions of daily maximum (TmaxD) and minimum (TminD) calculated from observed data and downscaled data. The *t* test is performed on testing equality of monthly mean rainfall (RMM), monthly mean of daily maximum temperature (TmaxM), and monthly mean of daily minimum temperature (TminM). The *F*-test is performed on testing equality of monthly variances of precipitation (RMV) calculated from observed data and downscaled data. The test calculates a *p*-value, which is used to accept or reject the hypotheses that the two sets of data could have come from the same distribution (i.e., when there is no difference between the observed and simulated climate for that variable). A very low *p*-value, and a corresponding high K-S value means the simulated climate is unlikely to be the same as the observed climate; hence must be rejected. A *p*-value of 0.05 is the significance level used in this study.

The test results have been presented in Table 2, where the numbers show how many tests give significantly different results at the 5% significance level out of the total number of tests of 8 or 12. A large number indicates a poor performance of the LARS-WG model. The data therein reveal that for RMV, TminM and TmaxM the number of significant results are 2, 3 and 3 respectively; however, for WDSeries, RainD, RMM, TmaxD and TminD the number of significant results are either 0 or 1. This indicates that at Ahmedabad LARS-WG model is more capable of simulating seasonal distributions of wet and dry series (WDSeries), distributions of daily rainfall (RainD), and distributions of daily maximum (TmaxD) and minimum (TminD) temperature and monthly mean rainfall (RMM) compared to the monthly mean of daily maximum (TmaxM) and minimum temperature (TminM) and monthly variances of precipitation (RMV).

The comparisons of monthly mean and standard deviation of the simulated and observed rainfall at Ahmedabad (Figure 1) reveals that there are good matches between the monthly mean of the simulated and observed precipitation; however, for standard deviation the match is not as good as that of the mean, yet the results are reasonably good (Figure 1) considering the fact that it is difficult to simulate well the standard deviations in most statistical downscaling studies. Figure 2 shows that at Ahmedabad for all the months, LARS-WG simulated monthly mean daily Tmax and Tmin values match very well with the observed values as the lines representing the observed and simulated

Table 2: Results of the statistical tests comparing the observed data for Ahmedabad site with synthetic data generated through LARS-WG

Site	*WDSeries*	*RainD*	*RMM*	*RMV*	*TminD*	*TminM*	*TmaxD*	*TmaxM*
Ahmedabad	0	0	1	2	0	3	0	3
Total tests	8	12	12	12	12	12	12	12

Columns: The seasonal distributions of wet and dry series (WDSeries), distributions of daily rainfall (RainD), monthly mean rainfall (RMM) and its variances (RMV), and distributions of daily maximum (TmaxD) and minimum (TminD) temperature and their monthly means (TmaxM and TminM).

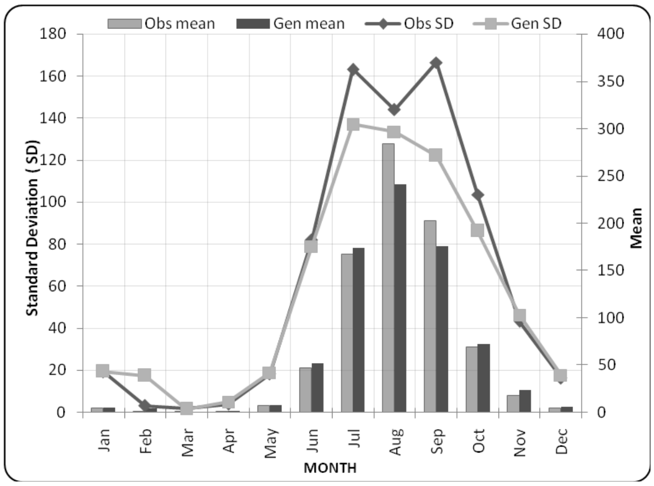

Figure 1: Comparison of the mean monthly observed and LARS-WG simulated rainfall (mm) and standard deviation at Ahmedabad in the period 1969-2013.

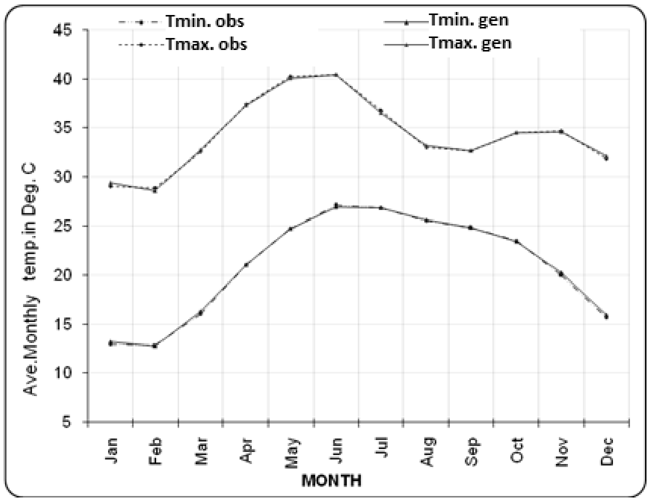

Figure 2: Comparison of the mean monthly observed and LARS-WG simulated minimum and maximum temperature at Ahmedabad in the period 1969-2013.

values are overlapping throughout which indicate that the new version of LARS-WG has great capacity in simulating temperature.

Generation of Future Climate Scenarios: Downscaling with LARS-WG

The above analysis confirms that LARS-WG has good skill in generating daily precipitation and daily Tmax and Tmin at Ahmedabad and then it was used to simulate daily precipitation and daily Tmax and Tmin for Ahmedabad for the periods of 2011–2030, 2046–2065 and 2080–2099 based on the SRA2 scenarios generated from seven GCMs. The results of the simulation of precipitation and temperature by using LARS-WG are presented in Figures 3(a)-(c) as box plots which are considered to be favourable methods of presenting data for analyses as they clearly display statistical information. The height of the box represents the inter-quartile range (distance between 25^{th} and 75^{th} percentiles), the horizontal line inside the box indicates the group median, and the vertical lines (called whiskers) issuing from the box extends to the group minimum and maximum values. In Figures 3(a)-(c) each box–whisker plot represents the prediction from one GCM. The plots in Figure 3(a) reveal that at the study site (Ahmedabad), out of the seven GCMs, rainfall prediction of five GCMs (CNCM3, GFCM3, INCM3, MPEH5, NCCCM) during 2011-2030 are less than the values of the baseline period; however, predictions from HADCM3 and IPCM4 are more than the baseline period values. During 2046-2065, rainfall prediction of four GCMs (CNCM3, GFCM3, HADCM3 and IPCM4) are less than the values of the baseline period and prediction from three GCMs (INCM3, MPEH5 and NCCCM) are more than the baseline values. During 2080-2099, except GFCM3 and MPEH5, rest five GCMs (CNCM3, INCM3, HADCM3, IPCM4 and NCCCM) have predicted more rainfall than the values of the baseline period. This clearly indicates that at the study site there are no coherent change trends among various GCMs' predictions of precipitation during 2011–2030, 2046–2065 and 2080–2099. This kind of uncertainty in rainfall predictions from different GCMs are not uncommon (Chen et al., 2013; Semenov and Stratonovitch, 2010). Contrary to rainfall predictions, simulations from the seven GCMs have coherent results for both the maximum and minimum temperatures for Ahmedabad. The box plots (Figures 3(a-b)) indicate that during near (2011-2030), medium (2046-2065) and far future (2080-2099) periods at the study site, in general, minimum temperature would increase by at least 0.4, 1.5 and 3.0 deg.C compared to the base line temperature and maximum temperatures would increase by at least 0.5, 2.0 and 3.5 deg.C compared to the values of base line temperature.

Considering the differences in prediction from the seven GCMs used in this study, an effort has been made to compute ensemble means of rainfall and temperature predictions from seven GCMs to further illustrate the future changes during near, medium and far future periods and the differences between the ensemble means and baseline values for the seasonal rainfall and minimum and maximum temperatures have been presented in Figures 4(a-c) for the periods of 2011–2030, 2046–2065 and 2080–2099. The data in Figure 4a reveal that at Ahmedabad monsoon rainfall (JJAS) in near future i.e. 2011-2030 is predicted to decrease by about 2%; however, during medium future (2046–2065) it is predicted to increase and remain close to the baseline value and during far future (2080–2099) period it is predicted to increase by about 5%. For maximum and minimum temperature for all the seasons and for all the three future periods consistent increase is observed. Summer maximum temperature is predicted to increase by 0.7, 2.0 and 4.0 deg. Celsius during 2011–2030, 2046–2065 and 2080–2099 respectively and winter minimum temperature is predicted to increase by 1.0, 2.5 and 5.0 deg. Celsius during 2011–2030, 2046–2065 and 2080–2099 respectively at Ahmedabad.

Despite uncertainties in future rainfall scenario in Ahmedabad, an unmistakable trend of increase in monsoon rainfall is predicted during 2046–2065 and 2080–2099; however no uncertainty is observed for both the summer maximum and winter minimum temperature with regards to their rising trend, a possible fall out of global warming.

Conclusions

The performance of statistical downscaling model LARS-WG was tested in generating daily rainfall, maximum and minimum temperature at Ahmedabad, India. After successful performance the model has been used to downscale future changes of precipitation, Tmin, and Tmax for the study site from the seven GCM outputs of SRA2 scenario for the three-time windows i.e. near (2011–2030) medium (2046–2065) and far (2080–2099) future periods. Following conclusions are drawn from the study:

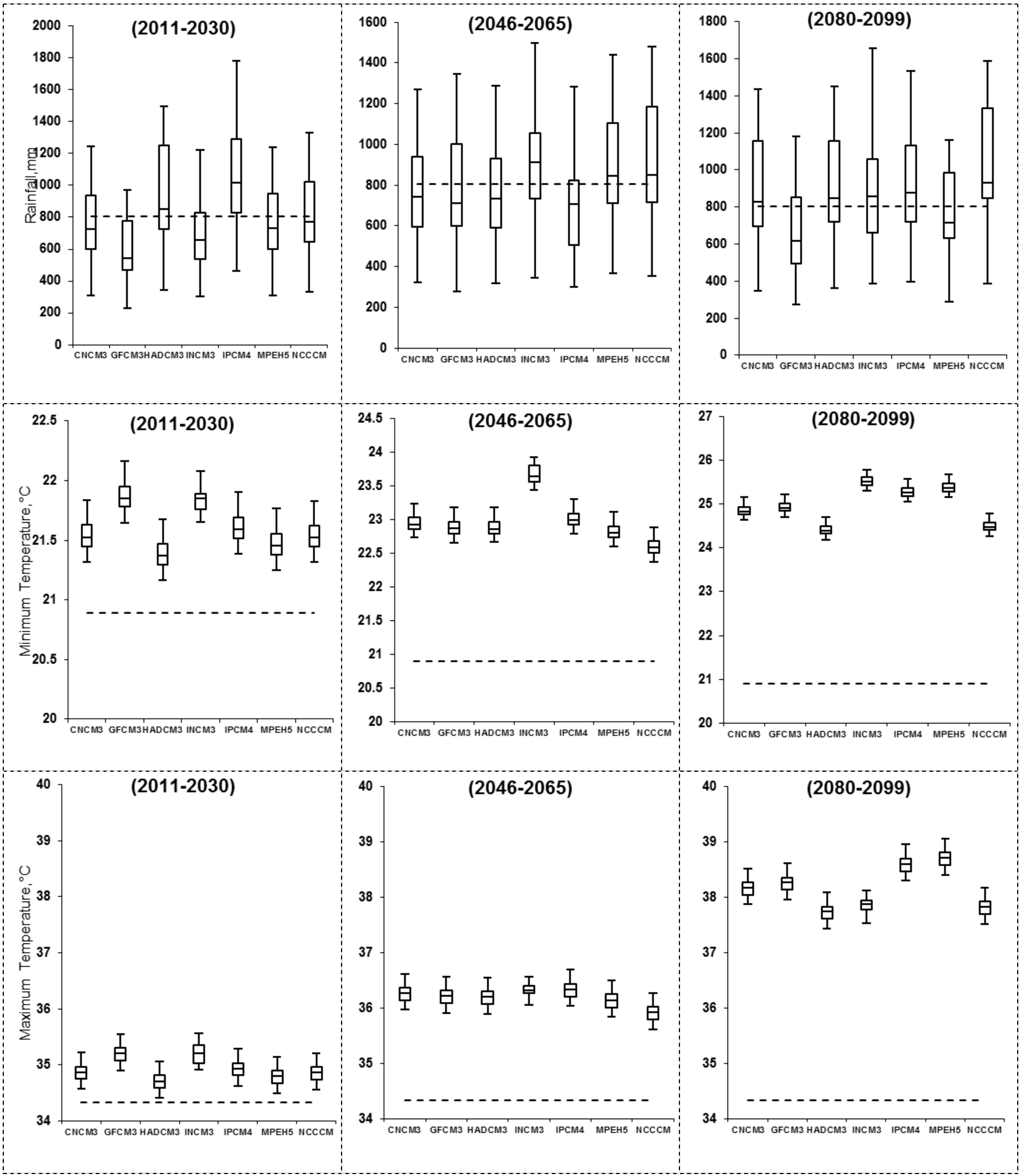

Figure 3: Box-whisker plots to show the distribution of maximum temperature for Ahmedabad downscaled from seven GCMs for the future [near (2011-2030), medium (2046-2065) and far (2080-2099)] periods compared to the current period (1969-2013). Dashed line is the value of observation in the baseline period.

(i) LARS-WG has been found to generate satisfactorily daily rainfall, maximum and minimum temperature at Ahmedabad, India.

(ii) No coherent change trends have been observed among various GCMs' predictions of precipitation during 2011–2030, 2046–2065 and 2080–2099.

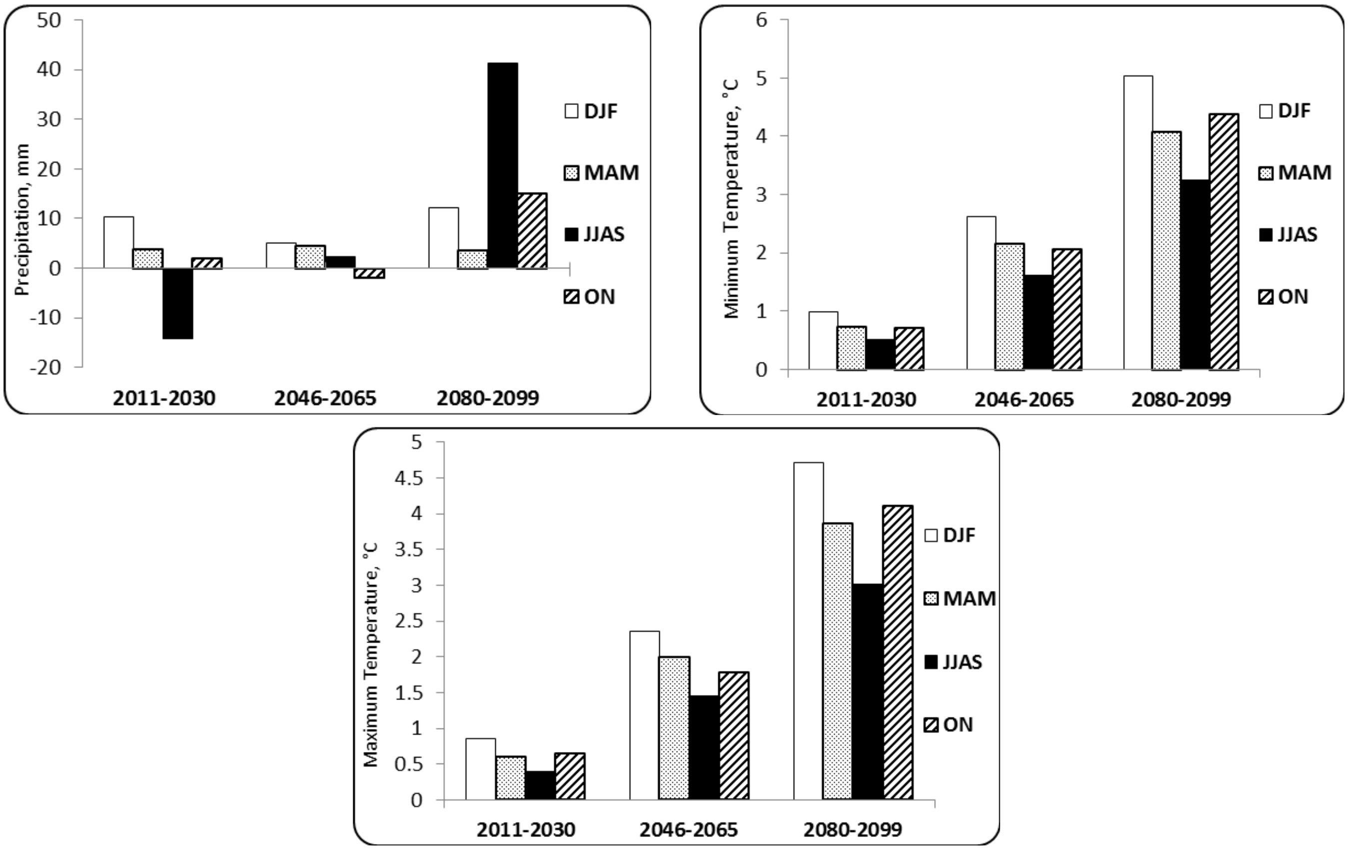

Figure 4: The differences of rainfall, minimum temperature and maximum temperature between the future [near (2011-2030), medium (2046-2065) and far (2080-2099)] periods and the current period (1969-2013) at Ahmedabad through calculating the mean ensemble of seven GCMs.

This indicates that there are great uncertainties in the prediction of future rainfall using a single GCM and hence more GCMs should be considered in the study of climate change to reduce the uncertainty of GCMs.

(iii) LARS-WG showed more skill in downscaling temperature data as the downscaled Tmax and Tmin from the predictions of seven GCMs showed consistent results (increasing trend).

(iv) Predicted rainfall in monsoon season (JJAS) based on the ensemble mean of seven GCMs showed a decrease in rainfall in near future i.e. 2011-2030 by about 2%; however, during medium future (2046–2065) it is predicted to increase and remain close to the baseline value and during far future (2080–2099) period it is predicted to increase by about 5% compared to the baseline value.

(v) Summer maximum temperature is predicted to increase by 0.7, 2.0 and 4.0 deg. Celsius during 2011–2030, 2046–2065 and 2080–2099 respectively at the study site.

(vi) Winter minimum temperature is predicted to increase by 1.0, 2.5 and 5.0 deg. Celsius during 2011–2030, 2046–2065 and 2080–2099 respectively at Ahmedabad.

(vii) This study will provide valuable reference results for developing future sustainable water resources and heat action plan for Ahmedabad.

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