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Climate Change Scenario in the Gujarat Region—Analyses based on LARS-WG (Long Ashton Research Station-Weather Generator) Model

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Abstract: LARS-WG (Long Ashton Research Station-Weather Generator) model was used to predict future climate change scenario over the Gujarat region. For this purpose, three locations of the region namely Ahmedabad, Deesa and Vadodara for which long period daily weather data (1969 – 2013) are available were chosen.

The results indicated that LARS-WG model adequately predicted monthly rainfall means and standard deviations and they were in agreement with the observed series as reflected in the *t* and *f*-tests at 5% probability. The agreement was even better for maximum and minimum air temperatures at all the three locations of the Gujarat region. LARS-WG-predicted climate change scenario indicated an increasing trend in annual and seasonal rainfall at Ahmedabad and it would increase by 6.7% i.e. 54.3 mm (in 2020) to 18.2% i.e. 147.4 mm (in 2060) against the base period normal rainfall of 807.5 mm. Seasonal rainfall (monsoon) also has shown an increasing trend and it would increase by 5% (38.0 mm) in 2020 to 14.5% (110.8 mm) in 2060 against the average seasonal rainfall of 766.4 mm for the base period. At Deesa and Vadodara no trend has been observed in the annual and seasonal rainfall scenario. Standard weekly rainfall during the monsoon season has been found to increase at the start as well as in the middle of the season during 2014 to 2063 compared to the base period (1969-2013) at Deesa and Vadodara; however, no such changes have been observed for Ahmedabad. For all the three locations no trend has been observed in the annual average minimum and maximum temperature as well as in the summer maximum and winter minimum temperature.

Key words: Climate change, LARS-WG model, weather data generation, Gujarat region.

Introduction

Climate change is considered to be the biggest challenge facing mankind in the twenty first century. The change in the climate means state within a certain time period is referred to as climate variability which can be more detrimental than the climate change. Both climate variability and change can lead to severe impacts on different major sectors of the world such as water resources, agriculture, energy and tourism (Osman et al., 2014). Long-term climate data analysis, particularly rainfall and temperature, is required to develop future strategies for efficient water and crop planning (Reddy et al., 2012). Such information can directly be used by the hydrologic impact models (Hashmi et al., 2012) for long-term productivity analysis. When the climate change research community started looking for low cost, computationally less expensive and quick methods for impact assessment, the weather generators emerged as the most suitable solution (Wilks, 1992; Wilks and Wilby, 1999). There are several weather generators for simulation of long-term weather data, out of which LARS-WG (Long Ashton Research Station Weather Generator) has been found to be a robust model capable

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of generating synthetic weather data for a wide range of climates (Binh, 2012). LARS-WG is a stochastic weather generator specially designed for climate change impact studies (Semenov and Barrow, 1997). It has been tested for diverse climates and found better than some other generators (Semenov et al., 1998).

A recent study by Semenov (2008) has tested LARS-WG for different sites across the world and has shown its ability to model rainfall extremes with reasonable skill. LARS-WG has been found to adequately predict precipitation and temperature in Phu Luong watershed in northern Vietnam (Binh, 2012). Mahat and Anderson (2013) used LARS-WG model to evaluate the impacts of climate and forest changes on streamflow in the upper parts of the Oldman River in Southern Alberta. In India, Abdul Haris et al. (2010) used LARS-WG in Bihar to assess the climate change and tested for its validity in the region. Kumar et al. (2013) also found that LARS-WG has reasonable skill to downscale to the point rainfall data and the results obtained are useful to analyse the impact of climate change on the hydrology of the basin. The objective of this study is to evaluate the applicability of LARS-WG model in generating long-period weather data to assess long-term variability in rainfall and maximum and minimum temperatures at the three locations of the Gujarat region.

Data and Methodology

Study Area

Gujarat state comprises two meteorological sub-divisions namely Gujarat Region and Saurashtra-Kutch. The present study has been conducted for the Gujarat region taking two stations from the north and one from the south Gujarat region i.e. total three stations for which long-period data (1969-2013) are available. Locations of weather stations have been depicted in Figure 1.

A historical base daily weather data for a period of 45 years (1969-2013) was used to generate long-term (2014-2063) synthetic meteorological data of rainfall and maximum and minimum temperatures for the selected stations using LARS-WG model. The model gave the generated statistical output for the base period of 1969-2013 for comparison of the model performance and synthetic data series for the period from 2014 to 2063 for analyses of climatic change.

LARS-WG Model Description

LARS-WG is based on the series weather generator described by Racsko et al. (1991). It utilizes semi-empirical distributions for the lengths of wet and dry day series, daily precipitation and daily solar radiation. The simulation of precipitation occurrence is modelled as alternate wet and dry series, where a wet day is defined to be a day with precipitation > 0.0 mm. The length of each series is chosen randomly from the wet or dry semi-empirical distribution for the month in which series starts. In determining the distributions, observed series are also allocated to the month in which they start. Daily minimum or maximum temperatures are considered as stochastic processes with daily mean and daily standard deviations conditioned on the wet or dry status of the day. The technique used to simulate the process is very similar to that presented in Racsko et al. (1991). The seasonal cycles of means and standard deviations are modelled by finite Fourier series of order 3 and the residuals are approximated by a normal distribution. The Fourier series for the mean is fitted to the observed mean values for each month.

The observed standard deviations for each month are adjusted to give an estimated average daily standard deviation by removing the estimated effect of the changes in the mean within the month. The adjustment is calculated using the fitted Fourier series already obtained for the mean. The observed residuals, obtained by removing the fitted mean value from the observed data, are used to analyse a time autocorrelation for minimum and maximum temperatures. The analysis of daily solar radiation over many locations showed that normal distribution for daily solar radiation, commonly used in other weather generators, is unsuitable for certain climates (Chia and Hutchinson, 1991). The distribution of solar radiation also varies significantly on wet and dry days. Therefore, separate semi-empirical distributions were used to describe solar radiation on wet and dry days. An autocorrelation coefficient was also calculated for solar radiation and assumed to be constant throughout the year. Solar radiation is modelled independently of temperature. LARS-WG accepts sunshine hours as an alternative to solar radiation data. If solar radiation data are unavailable, sunshine hours may be used; these are automatically converted to solar radiation using the approach described by Robert and John (1998). The process of generating synthetic weather data can be divided into three distinct steps:

1. Model Calibration-SITE ANALYSIS: Observed weather data are analysed to determine their statistical characteristics. This information is stored in two parameter files;
2. Model Validation-QTEST: The statistical characteristics of the observed and synthetic weather

data are analysed to determine if there are any statistically-significant difference and

3. Generation of Synthetic Weather Data-GENERATOR: The parameter files derived from observed weather data during the model calibration process are used to generate synthetic weather data having the same statistical characteristics as the original observed data, but differing on a day-to-day basis. Synthetic data corresponding to a particular climate change scenario may also be generated by applying global climate model-derived changes in precipitation, temperature and solar radiation to the LARS-WG parameter files.

Preparation of the LARS-WG Model Inputs

In order to prepare data for LARS-WG model, a set of climate variables (period from 1969 to 2013), namely, daily precipitation (mm) and maximum and minimum temperatures (^{o}C) were gathered from three local weather stations (Figure 1) within the Gujarat region.

Evaluation of Model Performance

Model performances were evaluated in two ways by comparing the means using the *t*-test and the standard deviations using the *f*-test. The percentage difference in mean monthly rainfall between observed and generated series was calculated by the following formula:

$$\% \text{ Difference} = \frac{\text{Gen} - \text{Obs}}{\text{Obs}} \times 100$$

where Gen and Obs are the generated and observed values respectively.

Results and Discussion

Ahmedabad

Rainfall: Statistical properties of the synthetic time series were compared with those of the observed time series to examine the ability of the LARS-WG model in reproducing the observed rainfall statistics and presented in Table 1a and Figure 2(a). Data reveal that the cv of monthly rainfall was reasonably in good agreement with that of the LARS-WG generated data during the crucial monsoon months of June to September; however, they were underestimated during January-March and October-December. Comparison of monthly means of observed and generated data further revealed much better performance of the LARS-WG model for Ahmedabad except for July and August which are the two most rainy months at Ahmedabad. July and August, being most rainy months, have more rainy days and total rainfall and thus statistical variations were more compared to non-monsoon months. Similar results have been obtained by Reddy et al. (2014) for the Telangana region. The percentage difference in monthly mean rainfall varies from –40.35 in April to 134.13 in May.

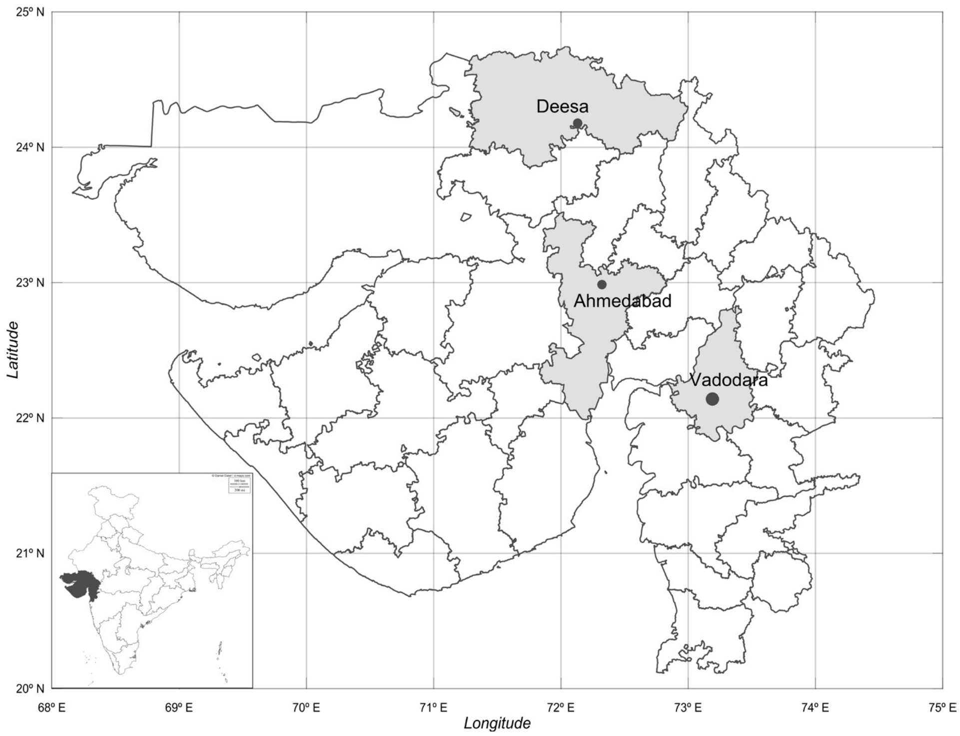

Figure 1: Location of selected weather stations in the Gujarat region.

Table 1: Comparison between observed and generated precipitation (mm) and minimum and maximum temperature (°C) at (a) Ahmedabad, (b) Deesa and (c) Vadodara

Rainfall (mm)	*(a) Ahmedabad*											
Obs mean	1.40	1.10	0.38	2.28	9.67	117.07	275.82	268.55	104.97	16.42	7.30	2.62
Gen mean	2.23	1.03	0.54	1.36	22.64	119.74	299.51	238.58	96.85	29.67	4.53	3.86
Obs SD	3.41	2.76	1.47	5.23	21.38	126.78	150.34	153.43	120.61	42.07	20.99	7.43
Gen SD	5.19	1.71	1.82	4.98	37.80	133.94	145.98	135.05	107.17	45.14	11.67	9.28
% Difference	59.29	-6.36	42.11	-40.35	134.13	2.28	8.59	-11.16	-7.74	80.69	-37.95	47.33
p value for *t*-test	0.36	0.87	0.65	0.39	0.05	0.92	0.44	0.31	0.73	0.14	0.42	0.48
p value for *f*-test	0.01	0.00	0.15	0.74	0.00	0.71	0.84	0.38	0.42	0.64	0.00	0.14
Minimum temperature (°C)												
Obs mean	12.15	14.23	19.23	23.88	26.70	27.40	25.85	24.97	24.55	21.43	16.87	13.36
Gen mean	12.13	14.02	19.28	23.73	26.63	27.46	25.85	25.01	24.40	21.53	17.18	13.57
Obs SD	1.31	1.65	1.12	0.93	0.74	0.74	0.65	0.69	0.86	1.18	2.05	1.45
Gen SD	0.44	0.61	0.55	0.32	0.29	0.45	0.26	0.21	0.22	0.52	0.53	0.60
% Difference	-0.16	-1.48	0.26	-0.63	-0.26	0.22	0.00	0.16	-0.61	0.47	1.84	1.57
p value for *t*-test	0.90	0.41	0.79	0.27	0.57	0.62	0.97	0.71	0.22	0.60	0.30	0.35
Maximum temperature (°C)												
Obs mean	28.07	30.68	35.82	39.76	41.56	38.62	33.53	31.97	33.69	35.73	32.99	29.58
Gen mean	28.17	30.41	35.82	39.43	41.42	38.55	33.71	31.99	33.69	35.56	33.10	29.87
Obs SD	0.91	1.24	1.34	1.19	0.94	1.57	1.26	1.28	1.43	1.40	1.09	0.88
Gen SD	0.37	0.55	0.55	0.46	0.46	0.70	0.53	0.46	0.60	0.55	0.44	0.38
% Difference	0.36	-0.88	0.00	-0.83	-0.34	-0.18	0.54	0.06	0.00	-0.48	0.33	0.98
p value for *t*-test	0.48	0.17	0.97	0.07	0.34	0.76	0.36	0.92	0.99	0.43	0.53	0.03

Rainfall (mm)	*(b) Deesa*											
Obs mean	2.36	3.16	0.48	3.53	5.13	66.35	225.52	196.84	85.74	19.39	10.94	1.71
Gen mean	3.07	0.99	0.80	6.37	6.25	67.90	274.86	171.25	89.86	21.58	15.12	1.04
Obs SD	5.86	12.13	1.26	12.00	11.39	80.81	171.70	158.75	100.26	43.46	27.89	5.30
Gen SD	5.44	2.42	1.57	22.23	12.90	77.72	156.10	129.35	93.41	40.62	46.70	3.94
% Difference	30.08	-68.67	66.67	80.45	21.83	2.34	21.88	-13.00	4.81	11.29	38.21	-39.18
p value for *t*-test	0.54	0.22	0.29	0.45	0.66	0.93	0.15	0.39	0.84	0.80	0.61	0.48
p value for *f*-test	0.61	0.00	0.15	0.00	0.41	0.79	0.52	0.17	0.63	0.64	0.00	0.05
Minimum temperature (°C)												
Obs mean	9.86	12.05	17.33	22.03	25.14	26.65	25.46	24.49	23.83	20.46	15.66	11.58
Gen mean	9.96	11.85	17.55	22.11	25.17	26.75	25.45	24.65	23.71	20.32	16.11	11.61
Obs SD	1.30	1.74	1.27	1.23	1.16	1.26	1.16	1.36	1.17	1.49	1.97	1.33
Gen SD	0.48	0.74	0.47	0.40	0.35	0.50	0.36	0.36	0.31	0.50	0.67	0.44
% Difference	1.01	-1.66	1.27	0.36	0.12	0.38	-0.04	0.65	-0.50	-0.68	2.87	0.26
p value for *t*-test	0.63	0.46	0.26	0.68	0.88	0.63	0.95	0.43	0.47	0.52	0.13	0.87
Maximum temperature (°C)												
Obs mean	26.99	29.54	35.01	38.97	40.52	38.61	33.91	32.18	34.36	36.37	33.07	29.00
Gen mean	27.10	29.17	34.96	38.72	40.56	38.65	33.89	32.19	34.00	36.17	33.16	29.39
Obs SD	0.96	1.51	1.52	1.27	1.08	1.25	1.43	1.46	1.71	1.35	1.25	1.11
Gen SD	0.44	0.69	0.63	0.43	0.39	0.59	0.55	0.73	0.80	0.40	0.54	0.41
% Difference	0.41	-1.25	-0.14	-0.64	0.10	0.10	-0.06	0.03	-1.05	-0.55	0.27	1.34
p value for *t*-test	0.49	0.12	0.83	0.18	0.84	0.83	0.94	0.96	0.19	0.31	0.66	0.02

(*Contd.*)

Rainfall (mm)						*(c) Vadodara*						
Obs mean	1.60	1.53	0.03	1.73	5.71	127.59	283.77	292.53	139.22	25.89	12.54	2.01
Gen mean	2.30	2.01	0.09	2.54	17.83	127.97	307.96	268.28	131.36	29.85	17.53	5.15
Obs SD	6.02	7.66	0.14	5.16	16.31	125.10	154.20	197.29	134.30	45.69	35.24	6.42
Gen SD	6.25	9.59	0.20	7.79	31.87	128.72	128.51	148.63	102.90	57.88	32.70	13.25
% Difference	43.75	31.37	200.00	46.82	212.26	0.30	8.52	-8.29	-5.65	15.30	39.79	156.22
p value for *t*-test	0.58	0.79	0.13	0.56	0.02	0.99	0.41	0.50	0.75	0.72	0.48	0.15
p value for *f*-test	0.81	0.13	0.01	0.01	0.00	0.85	0.22	0.06	0.07	0.12	0.61	0.00
Minimum temperature (°C)												
Obs mean	12.80	14.56	18.92	23.55	26.90	27.27	25.91	25.18	24.81	22.06	17.52	13.97
Gen mean	12.87	14.50	19.05	23.38	26.79	27.28	25.90	25.28	24.56	21.87	17.93	14.13
Obs SD	1.28	1.54	1.13	1.00	0.73	0.66	0.42	0.50	0.69	1.06	1.93	1.37
Gen SD	0.53	0.53	0.41	0.43	0.26	0.47	0.30	0.18	0.20	0.47	0.72	0.53
% Difference	0.55	-0.41	0.69	-0.72	-0.41	0.04	-0.04	0.40	-1.01	-0.86	2.34	1.15
p value for *t*-test	0.73	0.79	0.44	0.29	0.34	0.89	0.90	0.21	0.02	0.24	0.16	0.44
Maximum temperature (°C)												
Obs mean	29.54	31.78	36.33	39.23	39.95	36.93	32.62	31.43	33.20	35.73	33.66	30.75
Gen mean	29.56	31.45	36.20	39.01	39.83	36.89	32.77	31.65	33.10	35.59	33.73	31.04
Obs SD	1.05	1.40	1.28	1.22	0.89	1.23	0.91	1.00	1.39	1.40	1.19	0.97
Gen SD	0.45	0.66	0.48	0.37	0.36	0.55	0.47	0.47	0.56	0.54	0.45	0.39
% Difference	0.07	-1.04	-0.36	-0.56	-0.30	-0.11	0.46	0.70	-0.30	-0.39	0.21	0.94
p value for *t*-test	0.89	0.14	0.50	0.22	0.38	0.85	0.32	0.17	0.63	0.52	0.68	0.06

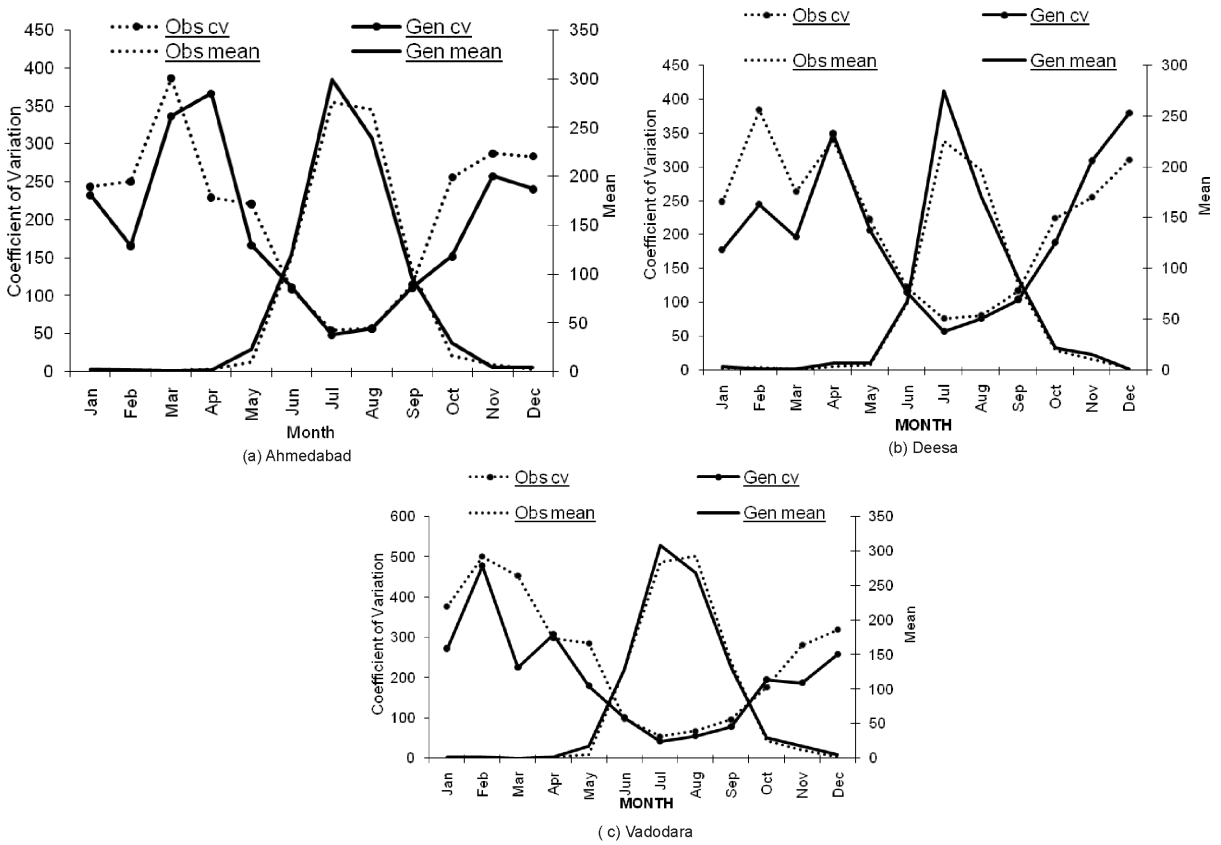

Figure 2: Comparison of the observed and generated mean (mm) and coefficient of variation (cv) of monthly precipitation.

Table 2: Statistical parameters for observed and generated monthly mean data series for 1969-2013

(a) Ahmedabad	*Parameter*	*Obs mean*	*Gen Mean*	*SSE*	*RMSE*
	Rainfall (mm)	67.30	68.38	1887.04	0.978141932
	Tmin (°C)	20.89	20.90	0.25	0.993659834
	Tmax(°C)	34.33	34.31	0.37	0.974987568
(b) Deesa					
	Tmin (°C)	19.55	19.60	0.38	0.998057318
	Tmax(°C)	34.04	34.00	0.55	0.986572353
(c) Vadodara					
	Rainfall (mm)	74.51	76.07	1433.86	0.98216095
	Tmin (°C)	21.12	21.13	0.37	0.984546346
	Tmax(°C)	34.26	34.24	0.38	0.972038343

The *t*-test at 5% level of significance (Table 1a) revealed that there was no significant difference between the observed and the LARS-WG model generated values which suggested good agreement between the observed and the generated rainfall. The SSE and RMSE were 1887.04 and 0.98 mm respectively (Table 2a).

Temperature: Monthly maximum and minimum temperatures for Ahmedabad (Figure 3a) indicated an excellent agreement between the observed and model generated temperatures as the lines representing the observed and simulated values are overlapping throughout. The statistical parameters estimated for maximum temperature were 0.37°C and 0.97°C for SSE and RMSE respectively. The same for the minimum temperature were 0.25°C and 0.99°C for SSE and RMSE respectively (Table 2a).

Deesa

Rainfall: The mean values of observed and LARS-WG model generated rainfall for the base period of 1969-2013 have been presented in Figure 2(b). Both the means have been found to be in close agreement. However, there was an overestimation/underestimation of model generated mean monthly rainfall for the months of July/August. The *p* value of *t*-test at 5% level of significance (Table 1b) revealed that there was no significant difference between the observed and the LARS-WG model generated values which indicated good agreement between the observed and the generated rainfall. The observed and generated cvs were found to be in close agreement in most of the months as reflected in the *p* value of *f*-test at 5% level of significance. The percentage difference in monthly mean rainfall varies from –68.67 in February to 80.45 in April. The SSE and RMSE were 3146.01 and 1.07 mm respectively (Table 2b).

Temperature: Monthly maximum and minimum temperatures for Deesa have been presented in Figure 3(b) which indicated an excellent agreement between the observed and model generated temperatures. The statistical parameters estimated for maximum temperature were 0.55°C and 0.99°C for SSE and RMSE respectively. The same for the minimum temperature were 0.38°C and 0.98°C for SSE and RMSE respectively (Table 2b).

Vadodara

Rainfall: In the case of Vadodara, the observed and generated monthly mean values of rainfall matched very well (Figure 2c) except for the month of May when the *p* value for *t*-test indicated statistically significant difference. The percentage difference in monthly mean rainfall ranged between –8.29 in August and 212.26 in May. The SSE and RMSE were 1433.86 and 0.98 mm respectively (Table 2c). The cv values of monthly rainfall showed a very close agreement between the observed and generated values during the months of the monsoon season; however they were underestimated during rest of the months of the year (Figure 2c).

Temperature: Monthly minimum and maximum temperatures matched quite well with that of the generated ones (Table 1c) as has been reflected in the *p* values of *t*-test. The percentage difference for the monthly minimum temperature found to range from –1.01 in September to 2.34 in November. The same for the monthly maximum temperature were –1.04 in

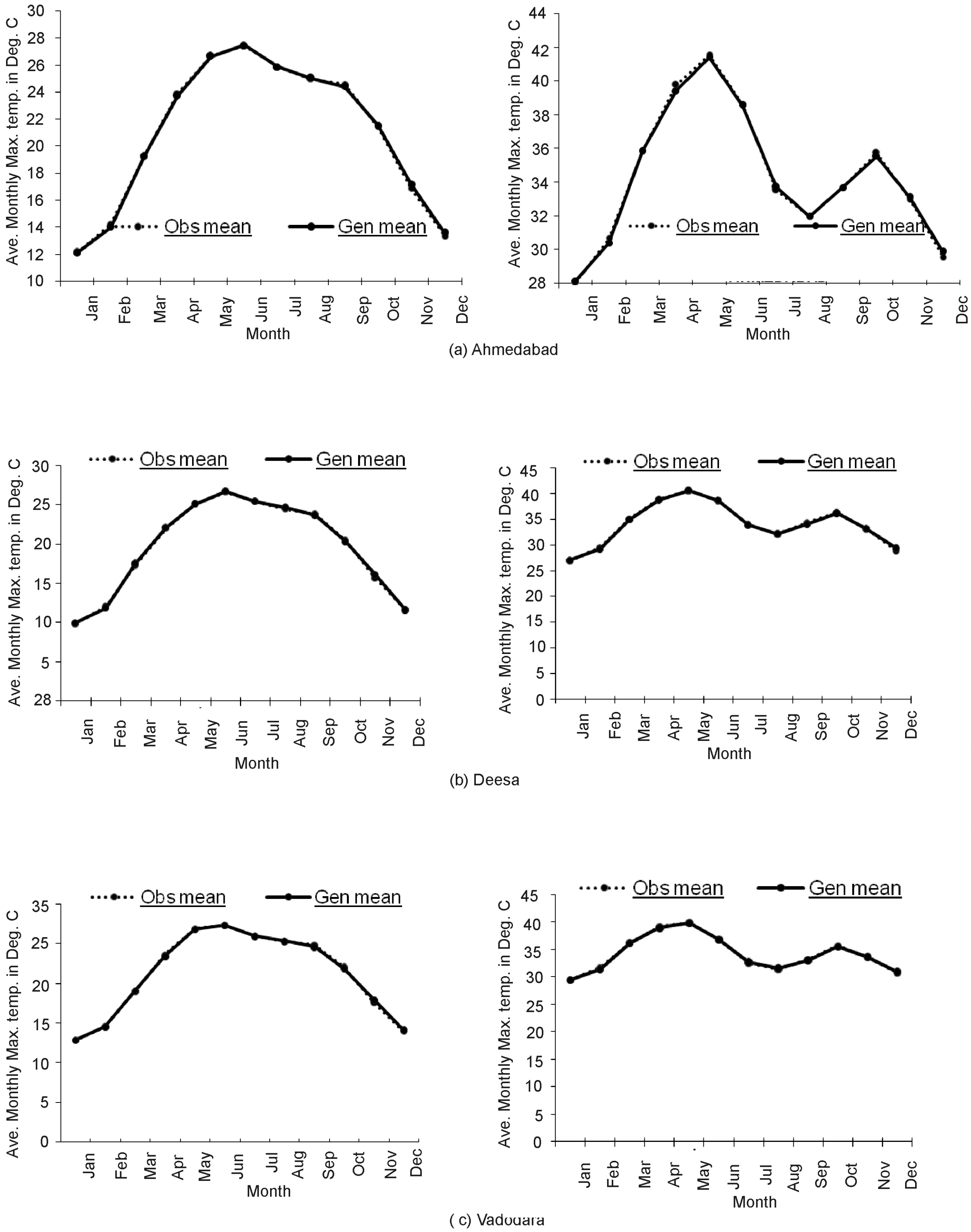

Figure 3: Comparison of monthly observed and generated minimum and maximum temperature (a) Ahmedabad, (b) Deesa and (c) Vadodara.

February to 0.94 in December. The statistical parameters estimated for maximum temperature were 0.37°C and 0.98°C for SSE and RMSE respectively. The same for the minimum temperature were 0.38°C and 0.97°C for SSE and RMSE respectively (Table 2c).

Analyses of Trend in Rainfall and Temperature

Trend analyses of rainfall and temperature were done for all the three selected locations of the Gujarat region. For this purpose 45 years of observed weather data (1969-2013) were used to generate long-term (50 years) weather series from 2014 to 2063.

Annual rainfall at Ahmedabad has shown (Figure 4a) an increasing trend and it would increase by 6.7% i.e. 54.3 mm (in 2020) to 18.2% i.e. 147.4 mm (in 2060) against the base period normal rainfall of 807.5 mm. Seasonal rainfall (monsoon) also has shown (Figure 4b) an increasing trend and it would increase by 5% (38.0 mm) in 2020 to 14.5% (110.8 mm) in 2060 against the average seasonal rainfall of 766.4 mm for the base period. Standard weekly rainfall during the monsoon season for the base period (1969-2013) and the generated period (2014-2063) has not shown any

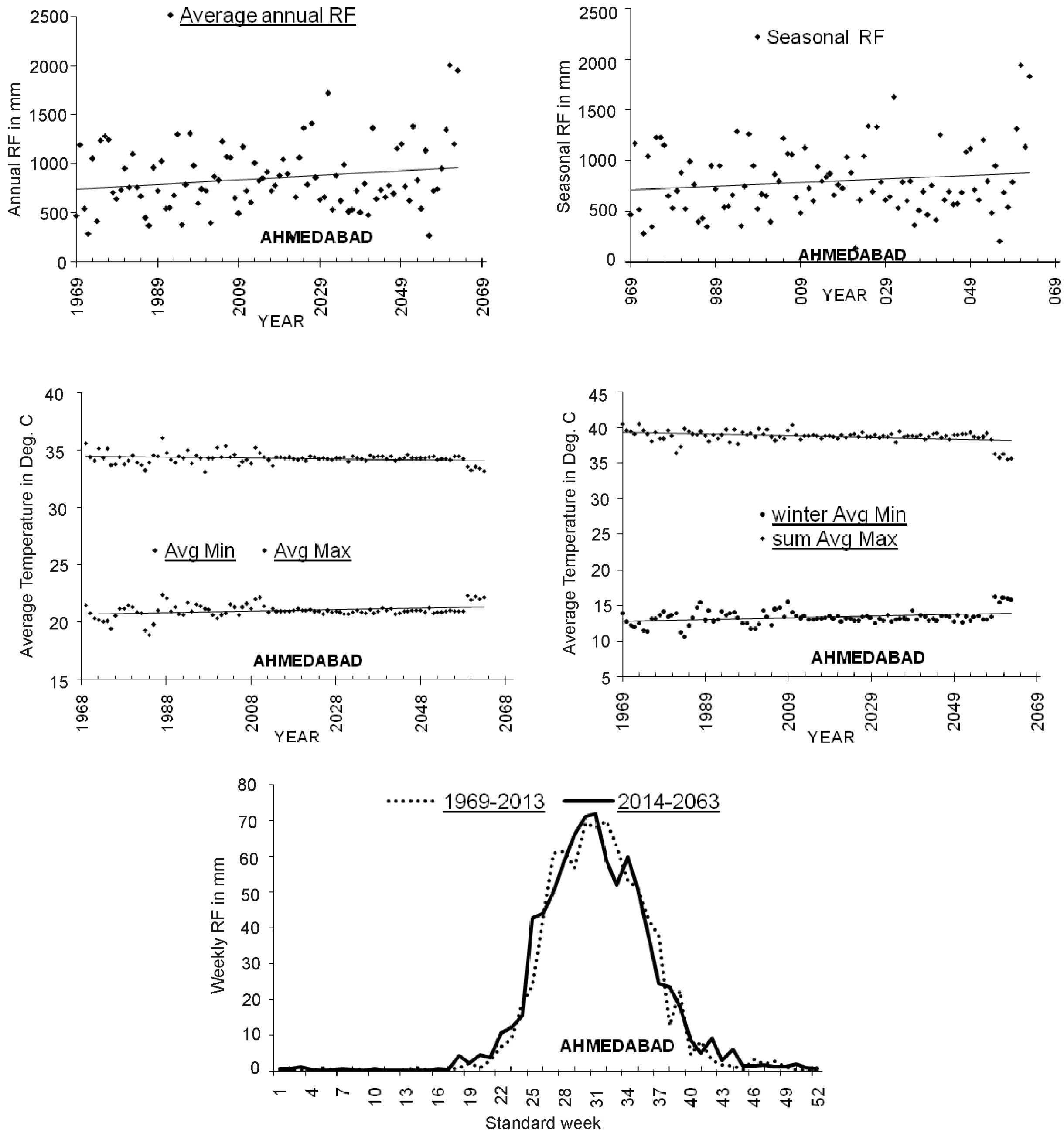

Figure 4: Trend analyses of (a) average annual rainfall, (b) seasonal rainfall, (c) average minimum and maximum temperatures, (d) average winter minimum and summer maximum temperatures and (d) weekly rainfall at Ahmedabad.

significant shift. No trend has been observed in the annual average minimum and maximum temperature as well as in the summer maximum and winter minimum temperatures.

At Deesa (Figure 5) and Vadodara (Figure 6) no trend has been observed in the annual and seasonal rainfall scenario. However, at these two stations standard weekly rainfall during the monsoon season has been found to increase at the start as well as in the middle of the season during 2014 to 2063 compared to the base period (1969-2013). No trend has also been observed in the annual average minimum and maximum temperatures as well as in the summer maximum and winter minimum temperatures.

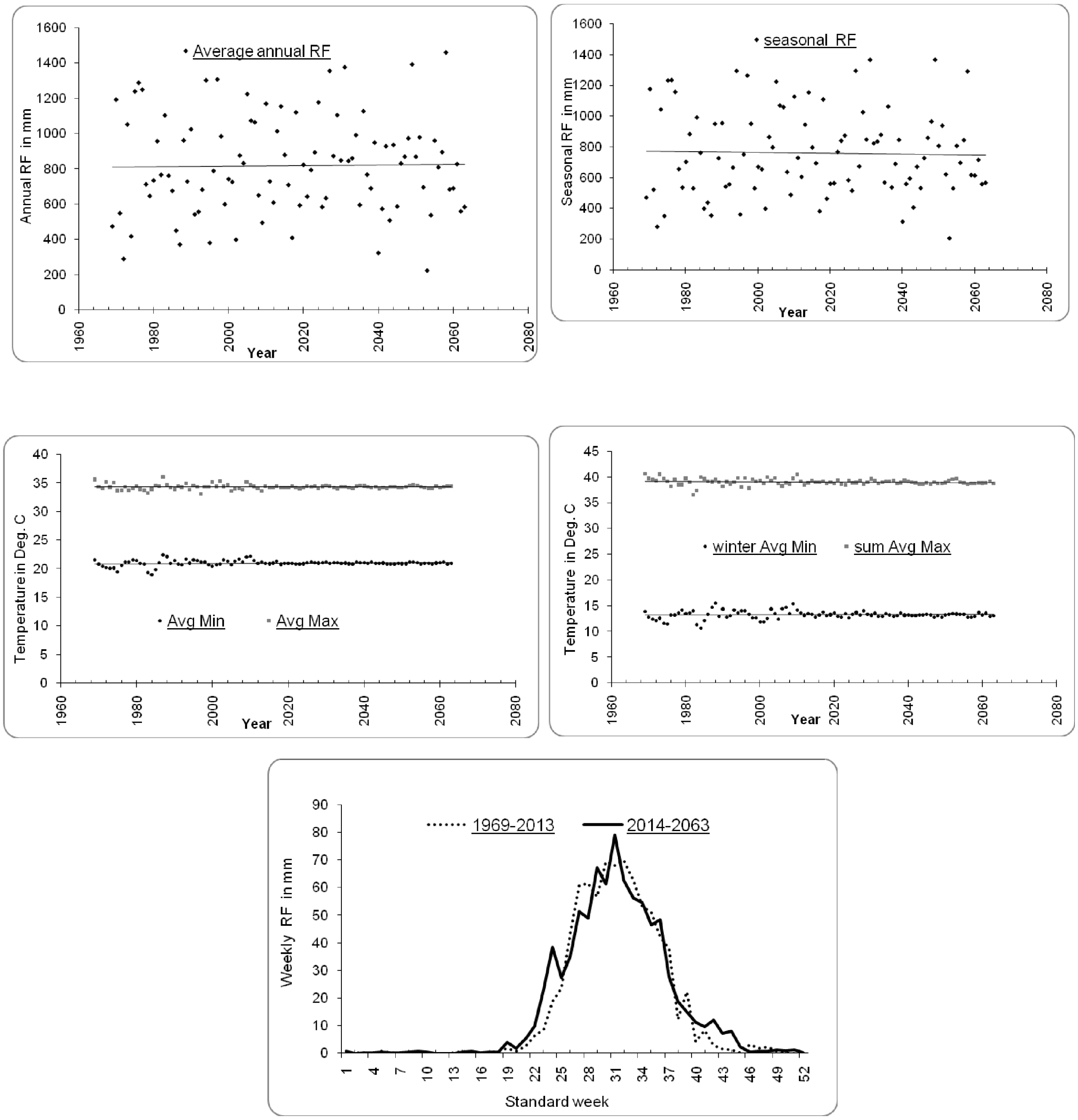

Figure 5: Trend analyses of (a) average annual rainfall, (b) seasonal rainfall, (c) average minimum and maximum temperatures, (d) average winter minimum and summer maximum temperatures and (d) weekly rainfall at Deesa.

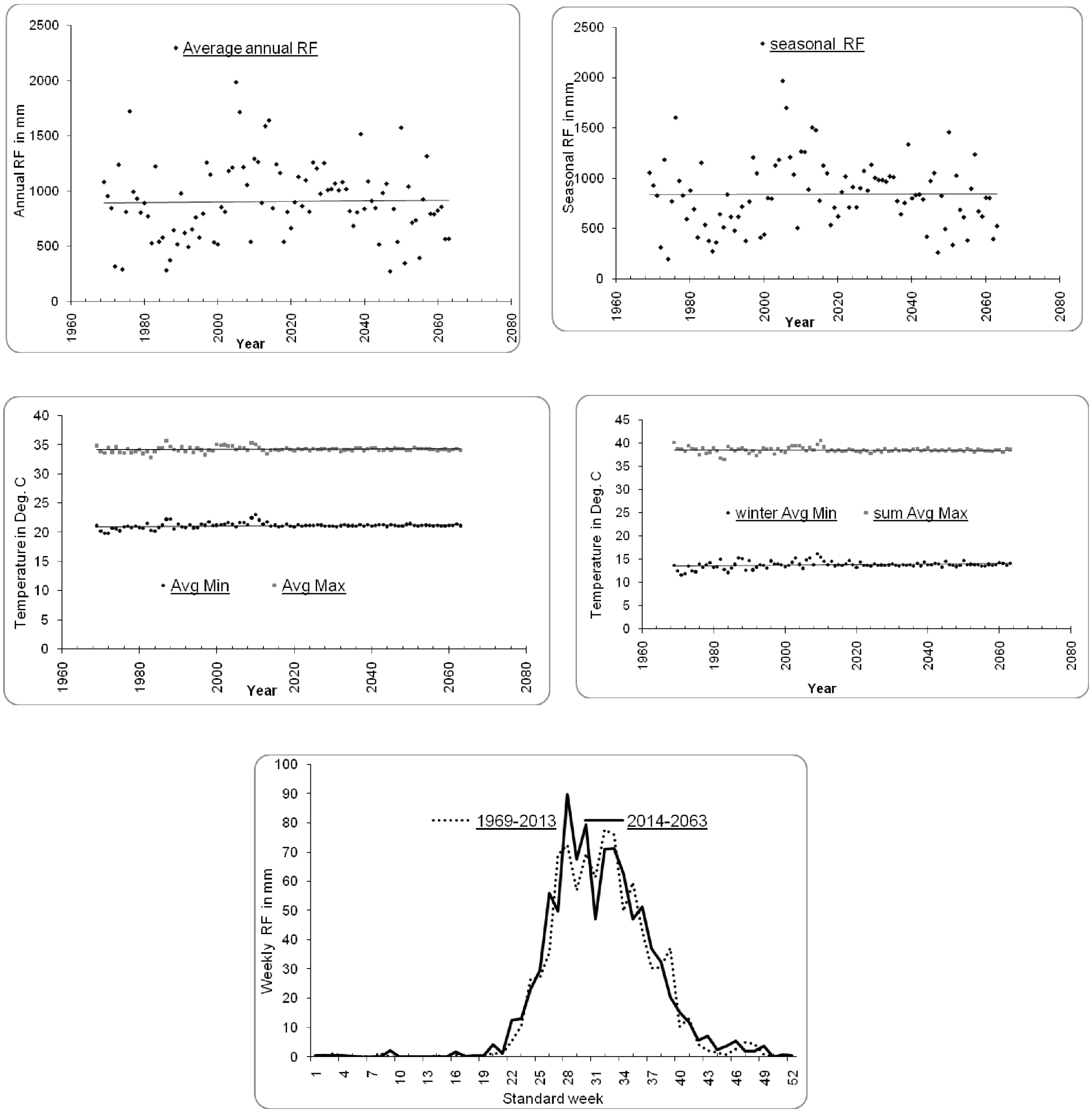

Figure 6: Trend analyses of (a) average annual rainfall, (b) seasonal rainfall, (c) average minimum and maximum temperatures, (d) average winter minimum and summer maximum temperatures and (d) weekly rainfall at Vadodara.

Conclusion

LARS-WG weather generator has been used to generate long-term weather data (rainfall, maximum and minimum temperatures) for assessing climate change scenario over the Gujarat region. Three locations of the region, Ahmedabad, Deesa and Vadodara for which long-period data (1969-2013) were available, were chosen. Performance of the LARS-WG model was evaluated for simulating weather data at these three locations by analysing statistical characteristics of the observed and generated weather data to determine if there are any statistically significant differences. The results indicated that LARS-WG adequately predicted monthly rainfall means and standard deviations and they were in agreement with the observed series as reflected in the *t* and *f*-tests at 5% probability. The agreement was even better for maximum and minimum air temperatures at all the three locations of the Gujarat region.

LARS-WG predicted climate change scenario indicated an increasing trend in annual and seasonal rainfall at Ahmedabad and it would increase by 6.7% i.e. 54.3 mm (in 2020) to 18.2% i.e. 147.4 mm (in 2060) against the base period normal rainfall of 807.5 mm. Seasonal rainfall (monsoon) also has shown an increasing trend and it would increase by 5% (38.0 mm) in 2020 to 14.5% (110.8 mm) in 2060 against the average seasonal rainfall of 766.4 mm for the base period. At Deesa and Vadodara no trend has been observed in the annual and seasonal rainfall scenario. Standard weekly rainfall during the monsoon season has been found to increase at the start as well as in the middle of the season during 2014 to 2063 compared to the base period (1969-2013) at Deesa and Vadodara; however, no such changes have been observed for Ahmedabad. For all the three locations no trend has been observed in the annual average minimum and maximum temperatures as well as in the summer maximum and winter minimum temperatures.

The study showed that LARS-WG model can be used suitably for predicting future climate change scenario for the Gujarat region.

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