Climate change analysis in southern Telangana region, Andhra Pradesh using LARS-WG model

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Weather-generating models are widely used for studying the climate change over longer periods. LARS-WG model was evaluated for southern Telangana region (Hayathnagar, Yacharam and Rajendranagar). A 30-year base weather data (1980–2010) was used to generate the long-term weather series from 2011 to 2060. The results of *t* and *F* tests at probability of 5% for comparing means and standard deviations of monthly rainfall and air temperatures indicated that the observed and predicted series for the base period are within acceptable limits. The statistics of model efficiency indicates that mean monthly rainfall and daily air temperature are close to the predicted series over the base period. The model efficiency was highest in the case of Rajendranagar (98.75%). The root mean square error and sum of square error varied from 0.4 to 1.3 mm and 615 to 1745 mm respectively. The model predicted the maximum increase in average annual rainfall of 5.16% in 2030 and 9.5% in 2060 for Yacharam compared to Hayathnagar and Rajendranagar over the normal annual rainfall of the base period (1980–2010). However, the model predicted increase in average seasonal rainfall for Hayathnagar (6.2% in 2030 and 8.8% in 2060). In case of air temperature, the model predicted increase in maximum temperature in the range 1–1.53% and 2.5% for 2030 and 2060 respectively, for these locations whereas minimum temperature decreased in the range 3.7–10.2% and 6.3–11.7% respectively, for 2030 and 2060. The performance of LARS-WG model was ranked high with maximum model efficiency in all selected mandals of Ranga Reddy district in southern Telangana. This model can be replicated in other mandals of southern Telangana as climate characteristics of the present mandals are similar to other districts in the region.

Keywords: Climate change, rainfall, temperature, weather-generating models.

THE southern Telangana region is mainly dependent on rainfall for crop production. Alfisols and black soils are predominant in the area. The region is affected by the vagaries of rainfall variability (30–60%) and change in maximum and minimum temperatures. Climate change in terms of rainfall variability is considered to be the greatest challenge. Both climate variability and change can lead to severe impacts on rainfed farming reducing yields and profitability. It is desirable to analyse and predict the change in critical climatic variables, such as temperature and rainfall, which will provide valuable reference for future water resources planning and management in the region[1]. The analysis of future air temperature is important as it influences crop evapotranspiration (ET), yield and quality. It is reported that increasing the temperature increases the ET of wheat, maize and cotton by 10.83%, 7.9% and 8.4% respectively, compared to ET under current climate conditions reducing the crop yield[2]. Long-term climate data analysis, particularly rainfall and temperature, is required to develop future strategies for efficient water and crop planning in rainfed areas[3]. Such information can be directly used by the hydrologic impact models[4] for long-term productivity analysis. There are several weather generators for simulation of long-term weather data, out of which ClimGen and LARS-WG (Long Ashton Research Station Weather Generator) are well suited for semiarid regions[3].

LARS-WG is a stochastic weather generator specially designed for climate change impact studies[5]. It is useful to simulate the extreme rainfall events and can be adopted as an effective tool for incorporating climate change impacts into sustainable development[4]. LARS-WG generates daily weather data series as well as rainfall, minimum and maximum temperatures and radiation. Applicability of such weather generators has been studied successfully in different climates of the world[5]. A low-cost weather generator has been tested for 18 sites in USA, Europe and Asia to represent a range of climates and it was able to reproduce most of the characteristics of the observed data well at each site[5,6]. It was reported that LARS-WG adequately predicted precipitation and temperature in Phu Luong watershed in northern Viet Nam[7]. Mahat and Anderson[8] 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

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Alberta. The model projected less than a 10% increase in precipitation in winter and a similar amount of precipitation decrease in summer. In India, LARS-WG was used in Bihar to assess the climate change and tested for its validity in the region[9]. Kumar *et al.*[10] reported that LARS-WG has reasonable skill to downscale the point rainfall data and the results obtained are useful to analyse the impact of climate change on the hydrology of the basin. The present article deals with the application of LARS-WG weather generator model to assess long-term variability in rainfall and temperature in three mandal headquarters of Ranga Reddy (RR) district in southern Telangana region of Andhra Pradesh.

Materials and methods

Study area

Three mandals, namely Yacharam, Hayathnagar and Rajendranagar of RR district in southern Telangana region were selected for the study (Figure 1). The region is characterized as semiarid. The average annual rainfall of the base period (1980–2010) at Yacharam, Hayathnagar and Rajendranagar was 710, 760 and 797 mm respectively. The mean temperature of the base period was 25.5°C, 25.4°C and 24.7°C for Yacharam, Hayathnagar and Rajendranagar respectively. The latitute and longitude of Yacharam, Hayathnagar and Rajendranagar are 17.08°N and 78.66°E; 17.20°N and 78.35°E, and 17.31°N and 78.39°E respectively. The average minimum and maximum temperatures of the three study mandals are presented in Table 1.

A historical base weather data from 1980 to 2010 (30 years) was used to generate long-term (2011–2060) synthetic weather data of rainfall and air temperature using a LARS-WG model for the selected mandals. The model gives the generated statistical output for the base period of 1980–2010 for comparison of the model performance and synthetic data series from 2011 to 2060 for climate change analysis.

LARS-WG stochastic weather generator

LARS-WG is a stochastic weather generator used to generate long-term weather data series to study the assessment of climate change. The model produces synthetic daily time series of maximum and minimum temperatures, rainfall and solar radiation. The weather generator uses observed daily weather for a given site to determine parameters specifying probability distribution for weather variables as well as correlations between the variables. The generation procedure to produce synthetic weather data is then based on selecting values from the appropriate distributions using a pseudo-random number generator. The model was downloaded from Department of Computational and Systems Biology, Rothamsted Research, UK website (www.rothamsted.ac.uk).

The weather generator distinguishes dry and wet days depending on rainfall values. Rainfall is modelled using semi-empirical probability distributions for each month for the lengths of series of wet and dry days and for the amount of rainfall on a wet day. A semi-empirical distribution Emp = $\{e_0, e_i, h_i, i = 1,\ldots, 10\}$ is a histogram with 10 intervals, (e_{i-1}, e_i), where $e_{i-1} < e_i$ and h_i denotes the number of events from the observed data in the ith interval.

The histogram has the effect of slightly smoothing the exact distribution of the empirical values. Minimum temperature, maximum temperature and radiation are related to the amount of cloud cover band. LARS-WG uses separate wet and dry day distributions for each of these variables. The normal distribution is used for the temperature variables with the mean and standard deviation taking into account the daily variation estimated by finite Fourier series of order 3. Time auto-correlations used for minimum and maximum temperature are constant throughout the year for the particular site. The cross-correlation of the standardized residuals from the daily mean is pre-set for all sites in the model. Semi-empirical distributions with equal interval size are used for estimating solar radiation for a given set of parameters[5]. LARS-WG produces synthetic data on a daily time step by first determining the rainfall status of the day. The detailed procedure can be found in LARS-WG user manual in version 3 (ref. 11).

Model evaluation

The simple statistical parameters such as mean and coefficient of variation are used to evaluate LARS-WG model for three selected mandals using historical base data from 1980 to 2010. The average monthly rainfall data were used to compare observed and generated weather data series using mean and coefficient of variation as the model gives statistical analysis only for monthly and annual series. The adequacy of LARS-WG model to simulate the rainfall and temperature was tested by P-value of F and t tests. The percentage difference in

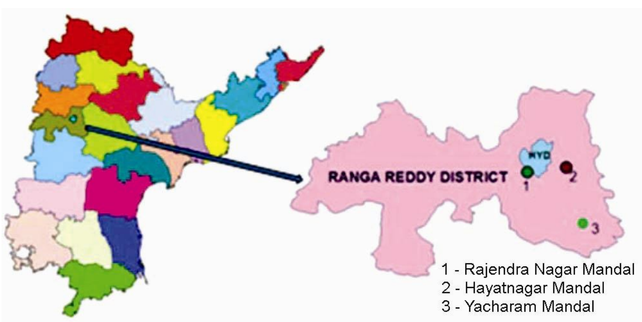

Figure 1. Location map of study mandals in Ranga Reddy district of southern Telangana.

Table 1. Geo reference, average annual rainfall (mm), average minimum and maximum temperatures of the three study sites in Ranga Reddy district

Location	Latitude (°N)	Longitude (°E)	Elevation (m)	Average annual rainfall (mm)	Average minimum temperature (°C)	Average maximum temperature (°C)
Yacharam	17.08	78.66	632	710	8.94	42.06
Hayathnagar	17.20	78.35	515	760	8.97	41.83
Rajendranagar	17.31	78.39	564	797	7.38	41.96

mean monthly rainfall between observed and generated series was calculated using the following formula

$$\%\text{Difference} = \frac{(\text{Gen} - \text{Obs})}{\text{Obs}} * 100, \quad (1)$$

where Gen is the generated value and Obs is the observed value.

The daily maximum and minimum temperatures from their respective years were selected to compare observed and generated series of temperatures in order to evaluate the LARS-WG model for climate change analysis. The statistical parameters like sum of squared error (SSE), model efficiency (EF), and root mean square error (RMSE) were considered for evaluation of the model for selected mandals according to the procedures suggested by Qunying *et al.*[12]. The ranks are given to the model based on the values of the above statistical parameters to compare the performance of the model in different mandals.

Trend analysis

The daily precipitation, maximum and minimum temperatures were simulated to generate a long-term weather data series (2011–2060) for trend analysis from base line observed data (1980–2010) by LARS-WG model.

Results and discussion

The statistical properties of the synthetic time series were compared to those of the observed data in order to evaluate the ability of LARS-WG in reproducing the observed rainfall statistics. The rainfall and air temperatures were tested by comparing the monthly means using the *t*-test and the monthly standard deviation using the *F*-test.

Yacharam

Rainfall: The statistical comparison for Yacharam mandal is summarized in Figure 2 *a* and Table 2, which show that the coefficient of variation (CV) of monthly rainfall is in close agreement with the generated data by LARS-WG, except for the summer months (March and April) where they are overestimated, while for November and December, they are underestimated. LARS-WG gave better results for monthly means, except for the months of July, August and September. The model performed better in non-monsoon months because these months experiences less number of rainy days and total rainfall, and thus the statistical variations are less compared to monsoon months. The percentage difference in monthly mean ranged between –3.63 (November) and 88.61 (January).

Results indicated that the accuracy of predicted rainfall is within an acceptable range and that the simulation results can be used for any hydrological modelling in the region. The *t*-test (5% level of significance) indicated that there is no significant difference between observed and generated values which shows the agreement between observed and generated rainfall (Table 2). The statistical parameters of SSE, EF and RMSE are 1745.4 mm, 94.33% and 1.34 mm respectively, in Yacharam (Table 3). The model ranked third in performance while comparing the model efficiency for prediction of monthly rainfall.

Temperature: The monthly minimum and maximum temperatures for Yacharam mandal are presented in Figures 3 *a* and 4 *a* respectively. The minimum temperature is overestimated for summer months (January–April) and underestimated for rest of the months. The model underestimated the values of maximum temperature for all the months, except April and May. Though the model underestimated the values, the deviations were minimum (Table 3). There is no significant difference between observed and generated air temperatures. Therefore, the model performance was good in Yacharam mandal. The statistical parameters estimated for maximum temperature were 0.32°C, 0.15°C and 99.76% and for minimum air temperature, 0.45°C, 0.80°C and 89.3% of SSE, RMSE and EF respectively (Table 3). The model ranked first in the prediction of minimum temperature in the Yacharam, while it ranked third in the prediction of maximum temperature (Table 3).

Hayathnagar

Rainfall: The means of observed and generated monthly rainfall for base period are presented in Figure 2 *b*. It was observed that there is close agreement between the observed and generated values of rainfall. However, the model underestimated the mean monthly rainfall during the first six months (January–June) and overestimated for the next six months of the year (July–December). The variability in the monthly rainfall observed was within reasonable limits in most of the months of the year (Table 2), as

Table 2. Comparison between rainfall (mm) and air temperature at Yacharam, Hayathnagar and Rajendranagar mandals

Yacharam												
Rainfall (mm)												
Obs mean	6.15	6.36	15.15	26.17	43.65	100.89	131.71	131.95	127.36	103.54	38.77	7.37
Gen mean	11.6	6.06	13.62	18.94	50.65	92.1	139.46	107.68	107.52	125.67	37.36	6.79
Obs SD	13.97	15.76	21.51	25.02	36.76	65.26	77.14	79.26	88.04	88.34	57.91	14.53
Gen SD	21.32	16.33	23.48	30.18	42.18	57.86	69.78	54.42	78.73	89.00	43.17	13.71
% Difference	88.61	–4.71	–10.09	–27.62	16.03	–8.71	5.88	–18.39	–15.57	21.37	–3.63	–7.87
P values for *t*-test	0.19	0.93	0.76	0.25	0.43	0.51	0.63	0.10	0.28	0.26	0.89	0.85
P values for *f*-test	0.01	0.84	0.59	0.25	0.40	0.43	0.51	0.01	0.46	0.97	0.06	0.70
Minimum temperature (°C)												
Obs mean	14.2	16.51	19.78	23.04	25.38	23.65	22.22	21.52	21.3	19.47	16.29	13.26
Gen mean	14.5	16.62	19.9	23.14	25.24	23.69	22.41	21.57	21.17	19.56	16.67	13.58
Obs SD	1.78	1.65	1.58	1.64	1.57	1.41	1.39	1.22	1.41	1.38	2.06	1.98
Gen SD	0.55	0.60	0.37	0.42	0.45	0.36	0.32	0.33	0.37	0.46	0.62	0.52
% Difference	2.11	0.67	0.61	0.43	–0.55	0.17	0.86	0.23	–0.61	0.46	2.33	2.41
P values for *t*-test	0.27	0.68	0.60	0.68	0.55	0.85	0.36	0.80	0.54	0.64	0.22	0.27
Maximum temperature (°C)												
Obs mean	28.34	31.35	34.87	37.29	38.42	34.22	30.85	29.55	30.46	30.45	28.92	27.83
Gen mean	28.67	31.06	34.92	37.36	38.33	34.07	30.96	29.49	30.39	30.46	29.06	28.05
Obs SD	0.88	1.0	0.97	1.06	1.52	1.57	1.07	0.67	0.82	1.19	0.84	0.81
Gen SD	0.36	0.49	0.39	0.42	0.43	0.57	0.45	0.35	0.33	0.43	0.32	0.32
% Difference	1.16	–0.93	0.14	0.19	–0.23	–0.44	0.36	–0.20	–0.23	0.03	0.48	0.79
P values for *t*-test	0.01	0.08	0.70	0.69	0.67	0.53	0.50	0.55	0.63	0.96	0.30	0.10
Hayathnagar												
Rainfall (mm)												
Obs mean	4.7	7.25	17.64	22.03	33.85	98.79	122.42	152.31	110.33	81.58	28.01	6.09
Gen mean	3.78	11.37	14.21	19.2	38.98	81.95	148.87	145.3	114.81	99.71	33.74	7.79
Obs SD	9.52	15.20	37.76	20.61	34.31	51.03	85.27	92.33	70.58	87.83	41.15	12.46
Gen SD	7.29	28.46	26.19	26.09	28.86	51.48	71.27	78.66	79.08	75.14	49.22	14.49
% Difference	–19.57	56.83	–19.44	-12.85	15.16	–17.05	21.61	–4.60	4.06	22.22	20.46	27.91
P values for *t*-test	0.62	0.44	0.62	0.59	0.46	0.14	0.12	0.71	0.79	0.31	0.57	0.58
P values for *f*-test	0.09	0.00	0.02	0.15	0.26	0.97	0.25	0.30	0.49	0.31	0.27	0.36
Minimum temperature (°C)												
Obs mean	14.2	16.51	19.78	23.04	25.38	23.65	22.22	21.52	21.3	19.47	16.29	13.26
Gen mean	14.46	16.46	20.08	23.06	25.26	23.62	22.34	21.68	21.24	19.61	16.75	13.44
Obs SD	1.78	1.65	1.58	1.64	1.57	1.40	1.39	1.21	1.41	1.38	2.06	1.98
Gen SD	0.54	0.45	0.47	0.39	0.48	0.37	0.32	0.28	0.31	0.45	0.70	0.46
% Difference	1.83	–0.30	1.52	0.09	–0.47	–0.13	0.54	0.74	–0.28	0.72	2.82	1.36
P values for *t*-test	0.33	0.82	0.21	0.93	0.61	0.87	0.53	0.37	0.77	0.49	0.14	0.54
Maximum temperature (°C)												
Obs mean	28.34	31.35	34.87	37.29	38.42	34.22	30.85	29.55	30.46	30.45	28.92	27.83
Gen mean	28.74	31.05	34.95	37.34	38.38	34.28	31.07	29.65	30.4	30.42	29	27.95
Obs SD	0.89	1.0	0.97	1.06	1.52	1.57	1.07	0.67	0.82	1.19	0.84	0.81
Gen SD	0.36	0.43	0.36	0.43	0.51	0.60	0.33	0.40	0.35	0.40	0.40	0.26
% Difference	1.41	–0.96	0.23	0.13	–0.10	0.18	0.71	0.34	–0.20	–0.10	0.28	0.43
P values for *t*-test	0.01	0.06	0.59	0.76	0.85	0.79	0.18	0.39	0.64	0.87	0.61	0.35
Rajendranagar												
Rainfall (mm)												
Obs mean	4.62	7.32	25.03	22.52	36.87	110.25	149.92	174.02	138.13	92.99	29.23	5.47
Gen mean	3.63	12.65	28.47	16.92	44.2	96.79	151.38	163.13	143.61	87.62	39.12	11.02
Obs SD	10.06	18.79	38.14	22.26	34.95	61.15	90.06	91.80	80.09	75.31	52.22	10.75
Gen SD	5.94	26.60	37.71	18.82	39.77	54.90	82.39	77.53	71.13	73.01	62.83	19.03
% Difference	–21.43	72.81	13.74	–24.87	19.88	–12.21	0.97	–6.26	3.97	–5.77	33.84	101.46
P values for *t*-test	0.60	0.33	0.70	0.24	0.40	0.32	0.94	0.58	0.75	0.76	0.47	0.13
P values for *f*-test	0.00	0.04	0.94	0.31	0.45	0.51	0.59	0.31	0.47	0.85	0.28	0.00
Minimum temperature (°C)												
Obs mean	13.6	16.04	19.43	22.99	25.56	24.14	22.93	22.38	22.2	19.8	16	12.84
Gen mean	13.8	16.28	19.77	22.96	25.52	24.09	23.03	22.46	22.07	19.63	16.38	12.78
Obs SD	1.31	1.64	1.34	1.25	0.94	0.99	0.85	0.82	0.55	0.99	1.97	1.68
Gen SD	0.57	0.50	0.47	0.42	0.46	0.36	0.25	0.20	0.21	0.53	0.74	0.63
% Difference	1.47	1.50	1.75	–0.13	–0.16	–0.21	0.44	0.36	–0.59	–0.86	2.37	–0.47
P values for *t*-test	0.36	0.37	0.14	0.89	0.82	0.78	0.47	0.55	0.18	0.36	0.26	0.82
Maximum temperature (°C)												
Obs mean	29.19	32.27	35.62	38.01	39.19	34.51	31.16	29.97	30.69	30.76	29.36	28.43
Gen mean	29.46	32.12	35.73	37.99	39.01	34.28	31.44	30.2	30.72	30.87	29.5	28.45
Obs SD	0.86	1.00	1.16	1.15	1.53	1.56	1.02	0.69	0.94	1.01	0.82	0.80
Gen SD	0.47	0.44	0.43	0.48	0.63	0.47	0.46	0.39	0.38	0.53	0.37	0.33
% Difference	0.92	–0.46	0.31	–0.05	–0.46	–0.67	0.90	0.77	0.10	0.36	0.48	0.07
P values for *t*-test	0.09	0.41	0.56	0.90	0.50	0.38	0.12	0.07	0.87	0.55	0.34	0.88

Obs, Observed; Gen, Generated. A probability of 0.05 or less indicates a departure from the observed values significant at 5% level.

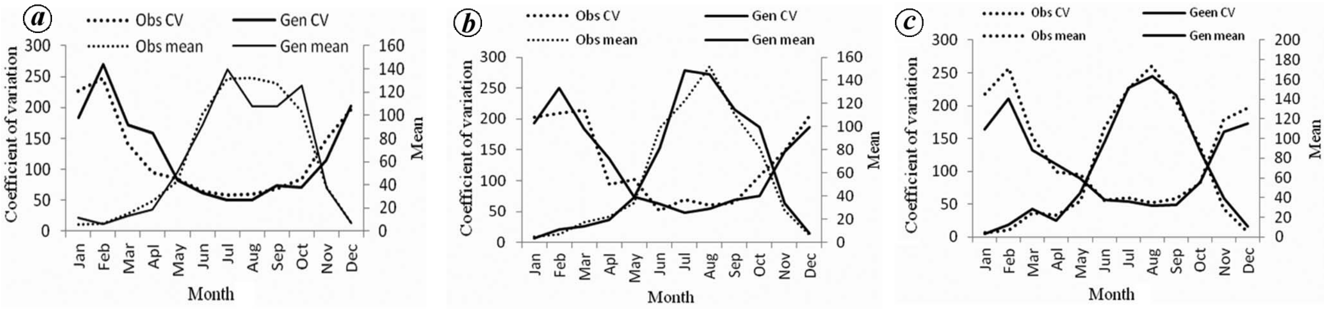

Figure 2. Comparison of observed and generated mean and coefficient of variation of monthly rainfall: ***a***, Yacharam; ***b***, Hayathnagar; ***c***, Rajendranagar (1980–2010).

Table 3. Statistical parameters for observed and generated monthly mean data series for (1980–2010)

Mandal	Parameter	Obs mean	Gen mean	SSE	EF	RMSE
Yacharam	Rainfall (mm)	61.58	59.78	1745.4	94.33	1.34
	Model rank			3	3	2
	T_{max} (°C)	31.87	31.90	0.45	89.30	0.80
	Model rank			3	3	3
	T_{max} (°C)	19.71	19.06	0.32	99.76	0.15
	Model rank			1	1	1
Hayathnagar	Rainfall (mm)	57.08	59.97	1480.73	95.14	1.7
	Model rank			2	2	3
	T_{max} (°C)	31.86	31.93	0.48	99.70	0.34
	Model rank			2	2	2
	T_{max} (°C)	19.71	19.83	0.35	99.69	0.23
	Model rank			2	2	3
Rajendranagar	Rainfall (mm)	66.36	66.58	615.69	98.57	0.42
	Model rank			1	1	1
	T_{max} (°C)	32.43	32.50	0.42	99.78	0.26
	Model rank			1	1	1
	T_{max} (°C)	19.82	19.89	0.37	99.74	0.22
	Model rank			3	1	2

*Model efficiency in percentage.

the standard deviation of generated monthly rainfall was close to the observed rainfall. There was no significant difference between observed and generated rainfall for the base period of 1980–2010. For the prediction of the monthly rainfall of Hayathnagar, the model performance ranked 2.

Temperature: As seen from Table 2, the observed and generated monthly means of maximum and minimum temperatures are close to each other. The percentage difference between observed and generated means of monthly minimum temperature varied from 0.09 to 2.82. Both positive and negative differences were less than 5%. The percentage difference of 0.10–1.41 was observed in the case of monthly mean maximum temperatures of observed and generated series. The difference was within 2% indicating the best predictability of LARS-WG. The model behaviour is good at Hayathnagar in the case of temperature as the model has both under and over estimation of the values, maintaining less deviation between observed and generated means (Figures 3 *b* and 4 *b*).

The statistical parameters such as EF, SSE and RMSE were 99.7%, 0.34°C and 0.47°C respectively, for mean monthly maximum temperature and 99.69%, 0.35°C and 0.34˚C for mean monthly minimum temperature (Table 3). The model performance ranked 2 based on the model efficiency over the other mandals. Similar results were obtained by other researchers[6,7].

Rajendranagar

Rainfall: The mean monthly rainfall showed good agreement between observed and predicted values for Rajendranagar. The results presented in Figure 2 *c* indicate that CV and means of observed series are in close agreement with predicted values of monthly rainfall. The probabilities of the monthly rainfall indicated by *t*-test showed that there was no significant difference between observed and predicted means of monthly rainfall of Rajendranagar for all the 12 months in the year (Table 2). Also, the probabilities obtained for variance by *F*-test indicated no significant difference for 10 months, except January and February. The LARS-WG model is the best suited for Rajendranagar with rank for generating monthly rainfall with maximum model efficiency of

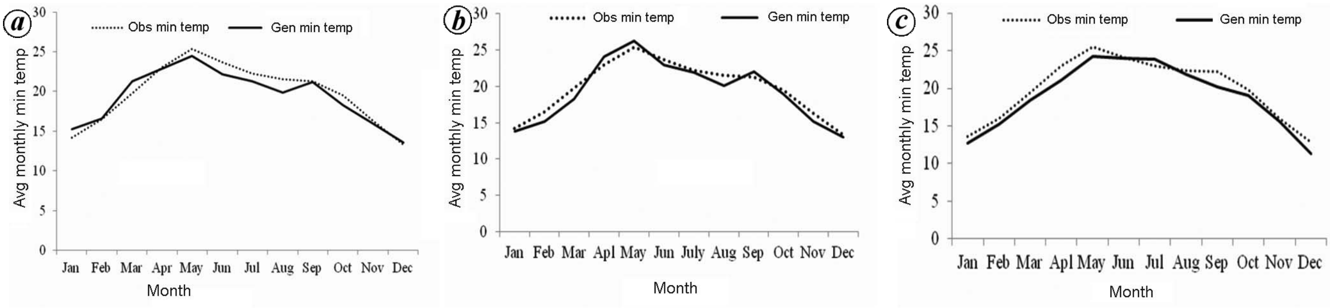

Figure 3. Comparison of monthly observed minimum temperature and generated minimum temperature: ***a***, Yacharam; ***b***, Hayathnagar; ***c***, Rajendranagar (1980–2010).

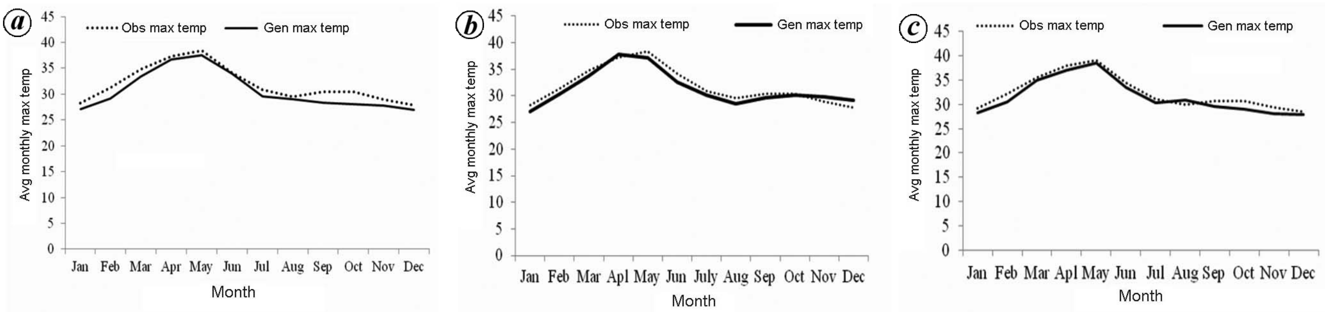

Figure 4. Comparison of monthly observed maximum temperature and generated maximum temperature: ***a***, Yacharam; ***b***, Hayathnagar; ***c***, Rajendranagar (1980–2010).

98.57% compared to other mandals (Table 3). The other statistical parameters of SSE and RMSE obtained are 615.69 and 0.42 mm respectively.

Temperature: For Rajendranagar mandal, the model underestimated the minimum temperature for 10 months of the year, but means were insignificant at probability level of 5% (Figure 3 *c* and Table 2). The maximum temperature was well predicted by the model for Rajendranagar as the mean monthly values were in close agreement with the generated series (Figure 4 *c*). There was no significant difference between observed and generated maximum temperatures as the probabilities of *t*-test were more than 5% level (Table 2). Moreover, the model predictions were rated higher with model efficiency of 99.7% for both maximum and minimum temperatures (Table 3). The SSE and RMSE for maximum and minimum temperatures were 0.42°C and 0.26°C, 0.37°C and 0.22°C respectively which were lower with first rank in Rajendranagar followed by Hayathnagar and Yacharam in rainfall. Model predictions were good in the case of maximum and minimum temperatures in all the three mandals.

Trend analysis of rainfall and temperature

The past historical data from 1980 to 2010 were used to generate 50 years (2011–2060) rainfall and air temperature. The trend analysis was done for all three selected mandals. The air temperature is a major factor for climate variability among other weather parameters. It was observed that there was an increasing trend in average temperature from 1980 to 2010.

Yacharam

Rainfall: It was observed that annual rainfall would increase in 2030 and 2060 by 5.16% (36.63 mm) and 9.50% (67 mm) respectively, against 710 mm of base period normal rainfall (Figure 5 *a*). The analysis of seasonal rainfall indicated that there would be a decrease in 2030 by 4.80% (23.07 mm) and in 2060 by 10.33% (51.18 mm) against average seasonal rainfall of 495.52 mm for the base period Figure 5 *b*. From the trend analysis, it was observed that the average annual rainfall exhibited increasing trend, while seasonal rainfall had decreasing trend. It was observed that there would be a shift in weekly rainfall, as seasonal weeks are getting less rainfall compared to other weeks at Yacharam mandal (Figure 5 *c*).

Temperature: The average temperature in Yacharam mandal is 25.50°C and there is an increase of 0.5°C against normal temperature in the base period. The minimum temperature would decrease by 0.92°C (10.2%) in 2030 and 0.71°C (7.94%) in 2060 respectively, against average minimum temperature (Figure 5 *d*). The maximum temperature would increase by 0.44°C (1%) in 2030 and 1.05°C (2.5%) in 2060. The trend analysis showed that there would be decreasing trend in minimum temperature, whereas maximum temperature would exhibit

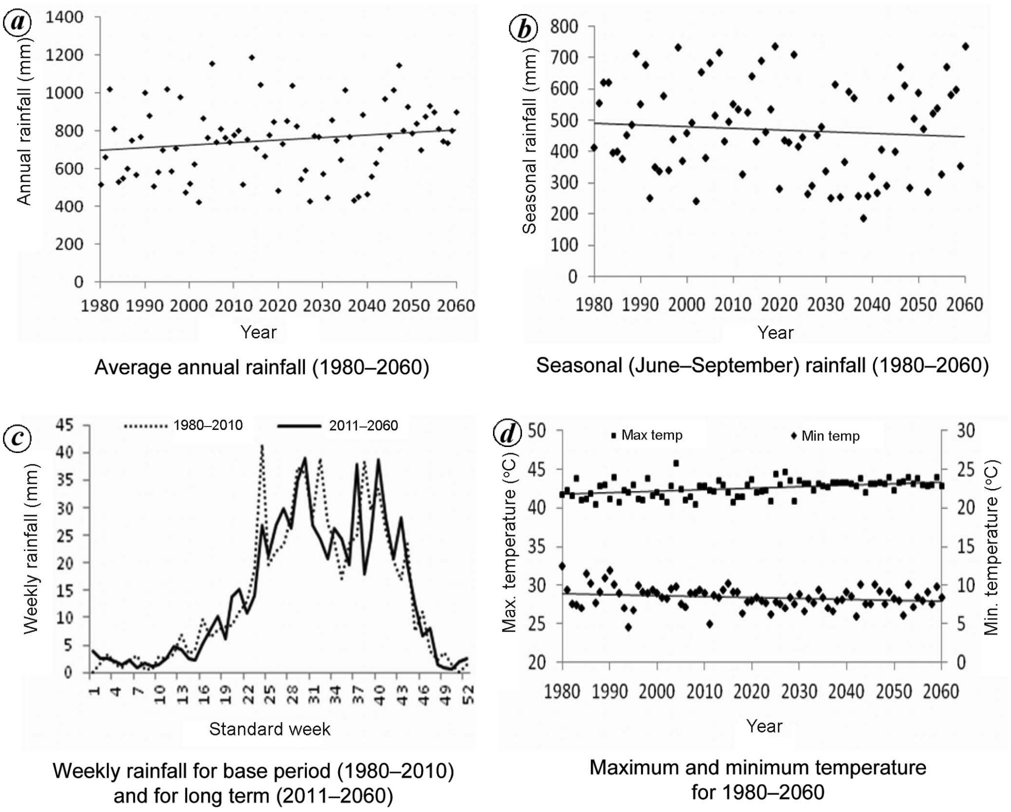

Figure 5. Trend analysis of (***a***) average annual rainfall, (***b***) seasonal rainfall, (***c***) weekly rainfall and (***d***) air temperature for Yacharam mandal.

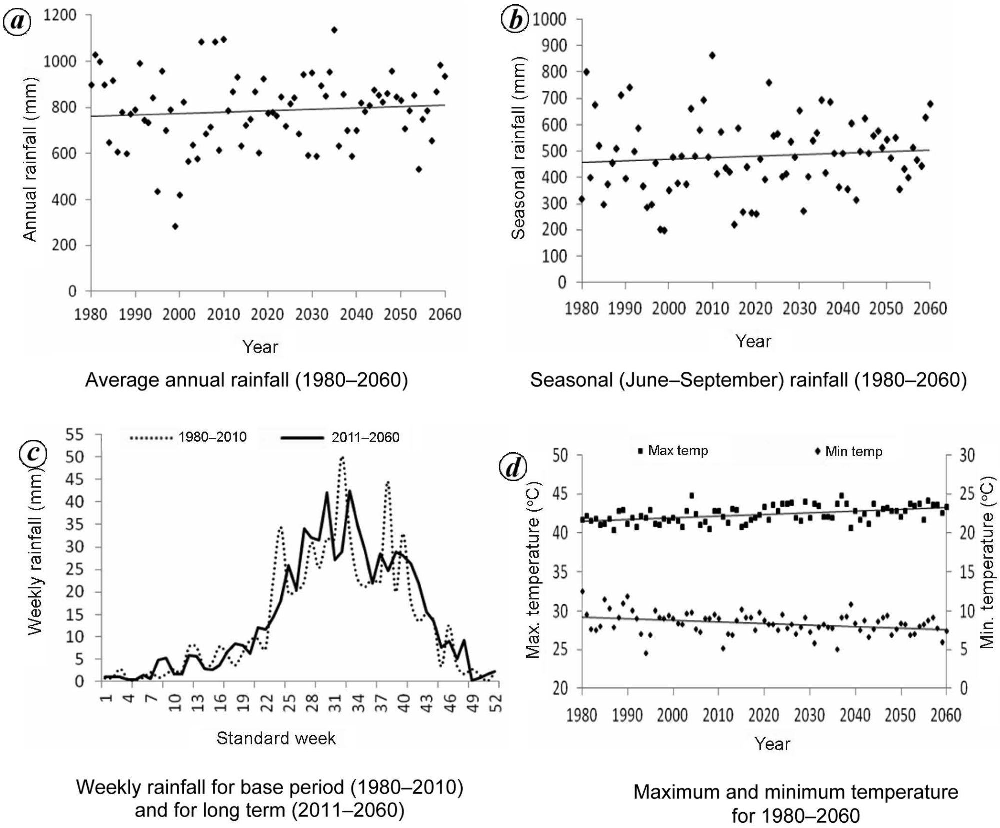

Figure 6. Trend analysis of (***a***) average annual rainfall, (***b***) seasonal rainfall, (***c***) weekly rainfall and (***d***) air temperature for Hayathnagar mandal.

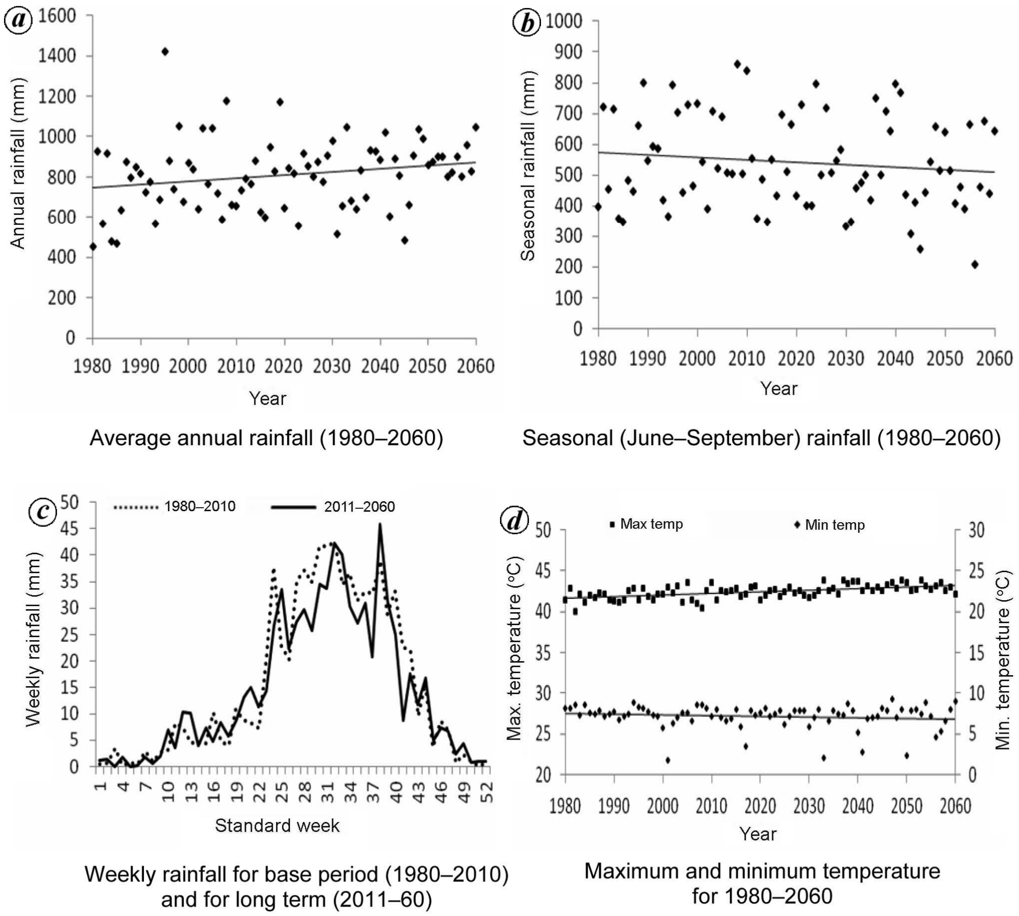

Figure 7. Trend analysis of (***a***) average annual rainfall, (***b***) seasonal rainfall, (***c***) weekly rainfall and (***d***) air temperature for Rajendranagar mandal.

increasing trend resulting in more diurnal temperatures, which may affect crop production in the crop-growing periods by increasing the crop evapotranspiration. The same trend is observed by ClimGen model for the same region[3].

Hayathnagar

Rainfall: The average annual rainfall of Hayathnagar mandal is 760 mm for a period of 30 years (1980–2010). From the trend analysis, it was observed that average annual rainfall would increase by 3.8% (28.91 mm) and 6.17% (46.9 mm) in 2030 and 2060 respectively (Figure 6 *a*) compared to normal rainfall of the mandal. The normal seasonal rainfall (485.54 mm) is expected to increase by 6.2% (30 mm) in 2030, but in 2060 it would further increase by 8.8% (42.5 mm) (Figure 6 *b*). The seasonal weekly rainfall showed increasing trend and no changes were observed in the summer months (Figure 6 *c*).

Temperature: The normal temperature during 2011–2060 would increase by 0.5°C (1.96%) compared to base period (1980–2010) of 25.40°C. The trend analysis of maximum and minimum temperatures of Hayathnagar is presented in Figure 6 *d*. The minimum temperature would decrease by 0.81°C (9%) in 2030 and 1.05°C (11.7%) in 2060 compared to base period temperatures. The maximum temperature is observed to be increasing by 0.64°C (1.53%) in 2030 and 1.08°C (2.5%) by 2060. The increase or decrease in air temperature above a certain threshold may affect the crop yields[13].

Rajendranagar

Rainfall: In Rajendranagar mandal, the normal rainfall (797 mm) is going to be increased by 2.33% (18.6 mm) in 2030 and 4.13% (32.96 mm) in 2060. For seasonal rainfall, it is observed that the rainfall will have a decreasing trend of 9.3% (54.03 mm) and 11.40% (66.33 mm) by 2030 and 2060 respectively, against normal seasonal rainfall of 581.37 mm (Figure 7 *a* and *b*). As seen from Figure 7 *c*, the standard weekly rainfall decreases during the season for the period 2011–2060 compared to the base period of 1980–2010. However, the weekly rainfall predicted by the model is found to increase in all the standard weeks except seasonal weeks, indicating off-season rainfall availability for crop activity in the mandal.

Temperature: The normal temperature in the mandal would increase by 0.63°C over the base period of 1980–2010. The minimum temperature would decrease by 0.3°C (3.7%) and 0.46°C (6.3%) and maximum temperature would increase by 0.4°C (1%) and 1.5°C (2.5%) by 2030 and 2060 respectively. In three mandals, there is similar trend in air temperature (Figure 7 *d*). The increase in diurnal variation in maximum and minimum temperatures suggested increased potential evapotranspiration. Thus, the crop water requirement is likely to increase in these mandals. The result indicates the enhanced irrigation water requirement in future in the southern Telangana region and may increase the groundwater exploitation. Thus for sustainability point of view, surface water harvesting may be implemented in the region.

Conclusion

Weather generators have been extensively used for generating long-term weather data for climate change assessment in different regions of the country. LARS-WG model was applied for climate change assessment in the southern Telangana region with base data of daily rainfall and temperature for 30 years (1980–2010). The model performance was evaluated for its validity in three mandals of Yacharam, Hayathnagar and Rajendranagar in RR district. The statistics obtained from the model over the base data indicated that the model-predicted monthly rainfall means and standard deviations are in agreement with the observed series as evidenced by the t and F tests at 5% probability. Similar is the case with maximum and minimum air temperatures in the region. The model predictability of rainfall and temperature was good as indicated by the EF of more than 90%. In future, the model predictions indicate that the average annual rainfall (AAR) is expected to increase in all the mandals with decreased average seasonal and weekly rainfall in Yacharam and Rajendranagar, except Hayathnagar. The maximum increase in AAR (5.16% in 2030 and 9.5% in 2060) was observed in Yacharam compared to the other mandals. The model predicted the maximum and minimum air temperatures with EF more than 95% in all mandals, indicating good performance in the southern Telangana region. The maximum temperatures are likely to increase and minimum temperatures are likely to decrease with diurnal variation affecting the crop growth with increased evapotranspiration. Overall, the model predictions of rainfall and temperature are rated very high and found suitable for climate change assessment in the southern Telangana region.

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ACKNOWLEDGEMENTS. We thank the Indian Council of Agricultural Research, New Delhi and the Government of India for funding the studies under National Initiative on Climate Resilient Agriculture project. We also thank the Director, Central Research Institute for Dryland Agriculture and Principal Investigator, NICRA for encouragement and support and Dr D. Raji Reddy, Head (Agrometeorology), Agricultural Research Institute, Acharya N.G. Ranga Agricultural University, Hyderabad for providing the climate data of Rajendranagar for the present study.

Received 28 September 2013; revised accepted 25 April 2014