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Evaluation of *climgen* model to generate weather parameters under different climatic situations in Punjab

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ABSTRACT

In the present study, *ClimGen* (weather generator) generated data was compared to the observed weather data of Ballowal, Ludhiana and Bathinda weather stations representing different type of climatic situations in Punjab. Several years of daily data of solar radiation, maximum and minimum temperature, morning and evening relative humidity, rainfall and wind speed were used as input and five years data were used for validation purpose. Evaluation was done on the basis of coefficient of determination (R^2), Residual Mean Square Error (RMSE), General Standard Deviation (GSD) and Wilmott's index (d) of agreement between generated and observed data. The *ClimGen* generated data for maximum and minimum temperature showed good performance (GSD d" 0.10 and d e" 0.95) and the data generated for morning relative humidity was acceptable (GSD > 0.10 but d" 0.20 and d < 0.95 but e" 0.90) while evening relative humidity and wind speed were poor except for Ludhiana station. However, the generated rainfall data was poor for all the stations and hence, cannot be accepted. Overall, results indicated *ClimGen* a good performer as a weather generator for certain parameters.

Key words: *ClimGen*, weather generation, solar radiation, temperature Punjab.

Long-term series of daily weather data are often required for the analysis of weather-impacted crop production and management systems (e.g., cropping systems, hydrologic studies, environmental studies etc.). Weather generators are computer programs that use existing weather records and generate long series of synthetic daily climatic data assuming statistical properties of the generated data similar to those of the observed data. In crop growth and water balance models, different weather variables like precipitation, maximum and minimum temperature, rainfall, solar radiation, wind speed and some measurement of air water vapor are required (Acock and Acock, 1991). In some cases observed records of such variables may be not available, incomplete, insufficient in length, or only summarized in monthly archives. To overcome the problem of missing or incomplete weather data, weather generators (WG) are practical tools (Johnson *et al*., 1996). Several computer programs like WGEN (Richardson and Wright, 1984), WXGEN (Sharpley and Williams, 1990), CLIGEN (Arnold and Elliot, 1996), USCLIMATE (Johnson *et al*., 1996) and *ClimGen* (Stöckle *et al*., 1999) have been developed that are capable of producing stochastically generated weather data from existing daily data.

In the present study, *ClimGen* model was evaluated to generate solar radiation, temperature (maximum and minimum), rainfall, relative humidity (maximum and minimum) and wind speed under varied climatic zones of Punjab. Ballowal Saunkhri represents the sub-mountain, Ludhiana represents the central plain and Bathinda represents the semi arid dry regions of Punjab. Similar work was carried out by Gargi Das and Ray, 2005 to compare the efficiency of two weather generators in generating temperature and rainfall for one station.

MATERIALS AND METHODS

The study area

The study sites Ballowal Saunkhri (31^{0} $31^{/}$N and 75^{0} $54^{/}$ E), Ludhiana (30^{0} $54^{/}$N and 75^{0} $48^{/}$ E) and Bathinda (30^{0} $10^{/}$N and 74^{0} $34^{/}$ E) represent different climatic scenarios of the Punjab state. In Ballowal, the major types of crop grown during kharif and rabi seasons are rice, maize, wheat and sugarcane. Rice and wheat are the major crops grown in Ludhiana, which has a sub-tropical semi-arid and monsoon type of climate with extreme winters, where as cotton, rice and wheat are the major crops for Bathinda, which experiences comparatively drier climate as compared

Table 1: Periods of weather data used as input in the model for different stations

Name of the station	Data used as input in the model		Data used as input in the model
	RF, T, RH, WS	R	RF, T, RH, WS, R
Ballowal Saunkhri	1984-2000	1990-1999	2001-2005
Ludhiana	1971-1990	1981-1990	1991-1995
Bathinda	1975-2000	1990-1999	2001-2005

RF, Rainfall; T, Temperature; RH, Relative Humidity; WS, Wind Speed; R, Solar radiation

Table 2: Mean monthly average values and standard deviation (parentheses) of observed and generated weather parameters using *climgen* model

Parameters	Monthly average					
	Observed value			Generated value		
	Ballowal	Ludhiana	Bathinda	Ballowal	Ludhiana	Bathinda
Solar radiation ($MJ\ m^{-2}\ day^{-1}$)	19.4 (3.5)	16.0 (3.8)	15.8 (5.1)	18.2 (4.3)	16.7 (4.2)	15.7 (4.5)
Max. temperature (^0C)	30.3 (2.8)	29.5 (2.6)	31.2 (2.9)	29.6 (3.2)	29.5 (3.3)	31.3 (3.1)
Min. temperature (^0C)	16.3 (2.6)	16.8 (2.6)	17.5 (2.4)	16.2 (3.1)	15.8 (2.9)	17.0 (3.1)
Rainfall (mm)	76.7 (6.1)	65.8 (5.7)	46.0 (3.5)	95.1 (7.5)	50.7 (4.7)	35.0 (4.9)
R.H. morning (%)	76.0 (9.0)	83.0 (8.0)	77.0 (9.0)	71 (5)	79.0 (6.0)	80.0 (8.0)
R. H afternoon (%)	48.0 (13.0)	46.0 (12.0)	42.7 (12.0)	43 (10)	40.0 (11.0)	39.0 (10.0)
Wind speed ($m\ sec^{-1}$)	0.97 (0.35)	1.21 (0.52)	1.41 (0.67)	1.17 (0.61)	1.39 (0.64)	1.91 (1.24)

to other two stations.

Model description

In the Richardson type weather generator (eg. *ClimGen*), precipitation occurrence is modeled using a first order two state Markov procedure which describes two precipitation classes i.e. wet or dry and takes into account precipitation occurrence on the previous day only. The Markov process gives information on transition probabilities e.g. on the probability of a wet day following a dry day or on the probability of a wet day following a wet day calculated from the observed station data. If precipitation occurs, then the amount of precipitation falling on the wet days is determined usually by using a pre defined frequency distribution i.e. Weibull distribution. The remaining climatic variables *i.e.* temperature, solar radiation, relative humidity and wind speed are then calculated based on their correlation with each other and on the wet or dry status of each day. The Climgen software is based on the assumption that temperature is a weekly stationary process (Matalas, 1967). It considers maximum and minimum temperature to be continuous, multivariate and stochastic process with daily means and standard deviations conditioned by the precipitation status (wet and dry period of the day (Richardson, 1981). The time series of each variable (maximum and minimum temperature) is reduced to a time series of residual elements through the removal of the periodic means and scaling by standard deviations.

Data used

In the present study, observed daily meteorological data (rainfall, maximum and minimum temperature, morning and evening relative humidity, wind speed and solar radiation) were collected from meteorological

Table 3: Coefficient of determination (R^2) and RMSE values for observed and generated weather parameters using *climgen* model.

stations at respective locations (Table 1).

Statistical evaluation of the generated data

In the first step, the five years generated data for Ludhiana (1991-1995) and Ballowal and Bathinda (2001-2005) as well as the observed data for the same period was averaged to compute monthly mean and standard deviation. To evaluate the agreement between observed and generated data, the indices used were Residual Mean Square Error (RMSE), General Standard Deviation (GSD) and Wilmott (1982) index of agreement (d).

$$RMSE = SQRT\,[\{(^1/_n) * {}^n\Sigma_{i=1} (P_i - O_i)^2\}]$$

$$d = 1.0 - \Sigma (O_i - P_i)^2 / \Sigma [\,|P_i - O_{bar}| + |O_i - O_{bar}|\,]^2$$

$$GSD = RMSE / O_{bar}$$

Where, O_i = observed data; P_i = generated data; O_{bar} = mean of the observed data.

The performance of the model was evaluated from GSD and Wilmot indicators. If GSD is ≤ 0.10 and d is ≥ 0.95, then the performance is good and if GSD is > 0.10 but ≤ 0.20 and d is < 0.95 but ≥ 0.90, then the performance was considered acceptable. Other values indicated poor performance. Willmott index (d) is considered an improved model evaluation tool over R^2 because it takes into account differences in observed and model means (biases) and variances, as well as correlation.

RESULTS AND DISCUSSION

The comparison of monthly means of weather parameters generated with the model and observed values showed a good agreement for most of the parameters (Figs. 1a-1g). Different statistical indices used in order to evaluate the performance of *ClimGen* model in generating weather parameters have been discussed individually under following sub sections.

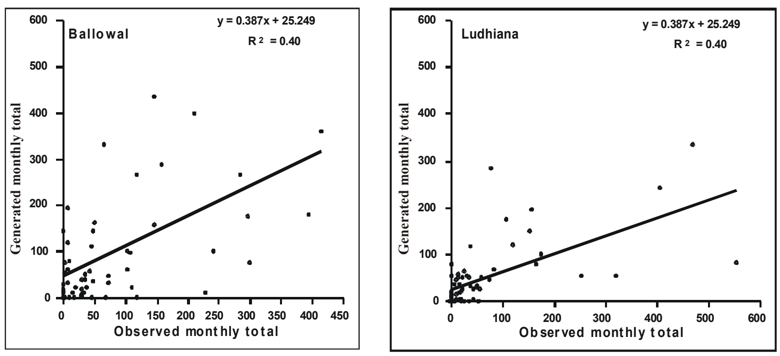
Regression analysis

The coefficient of determination (R^2) between the observed and generated values ranged from 0.40 to 0.97 for Ballowal and Ludhiana and 0.22-0.97 for Bathinda, respectively (Table 3). For most of the parameters *i.e.* maximum temperature, minimum temperature for all the stations and solar radiation except at Ludhiana, R^2 value was more than 0.85 while for other parameters it varied from 0.22 to 0.84 being lowest for rainfall at all the stations.

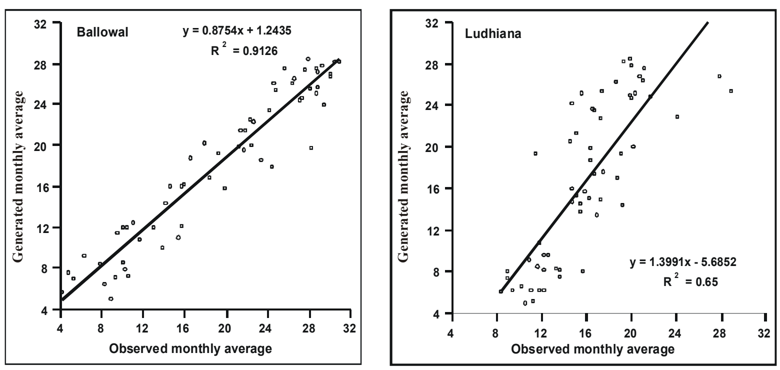
The regression line for maximum and minimum temperature matched well with 1:1 line being closest for minimum temperature (Figs. 1c-1d). The regression line for solar radiation also matched closely with 1:1 line except for Ludhiana station where due to lower R^2

Parameters	Observed value			• M
	Ballowal	Ludhiana	Bathinda	
Solar radiation (MJ m^{-2} day^{-1})	19.4 (3.5)	16.0 (3.8)	15.8 (5.1)	
Max. temp. (^{0}C)	30.3 (2.8)	29.5 (2.6)	31.2 (2.9)	
Min. temp. (^{0}C)	16.3 (2.6)	16.8 (2.6)	17.5 (2.4)	
Rainfall (mm)	76.7 (6.1)	65.8 (5.7)	46.0 (3.5)	
R.H. morning (%)	76.0 (9.0)	83.0 (8.0)	77.0 (9.0)	
R. H. afternoon (%)	48.0 (13.0)	46.0 (12.0)	42.7 (12.0)	
Wind speed (m sec^{-1})	0.97 (0.35)	1.21 (0.52)	1.41 (0.67)	

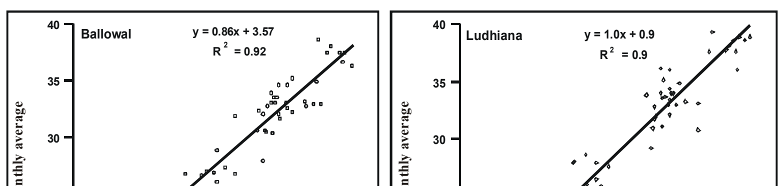
1. (a) Rainfall



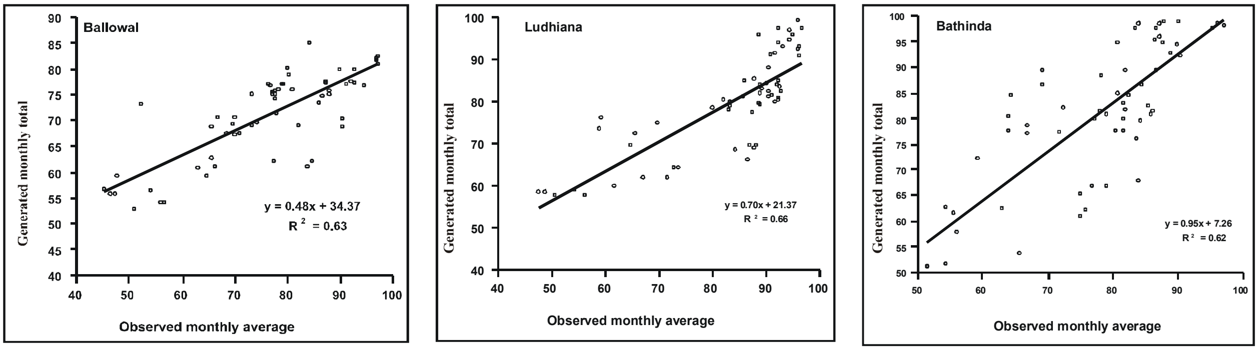
1. (b) Solar radiation



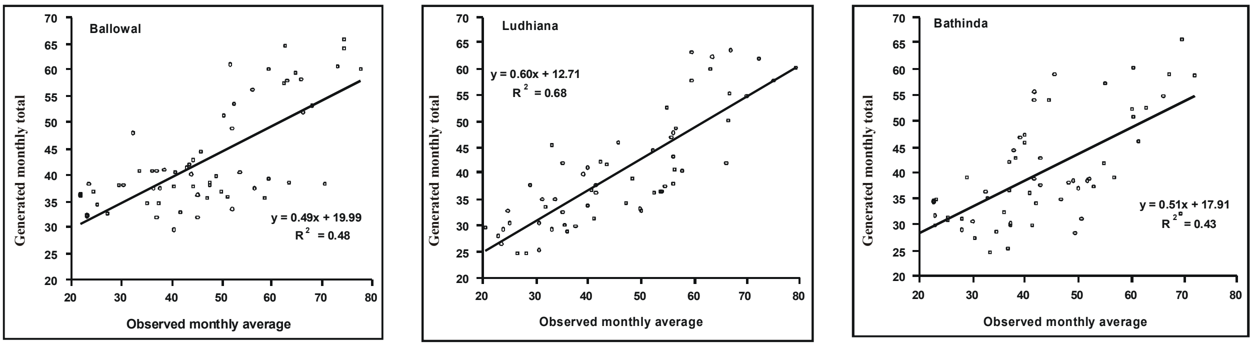
1. (c) Maximum temperature



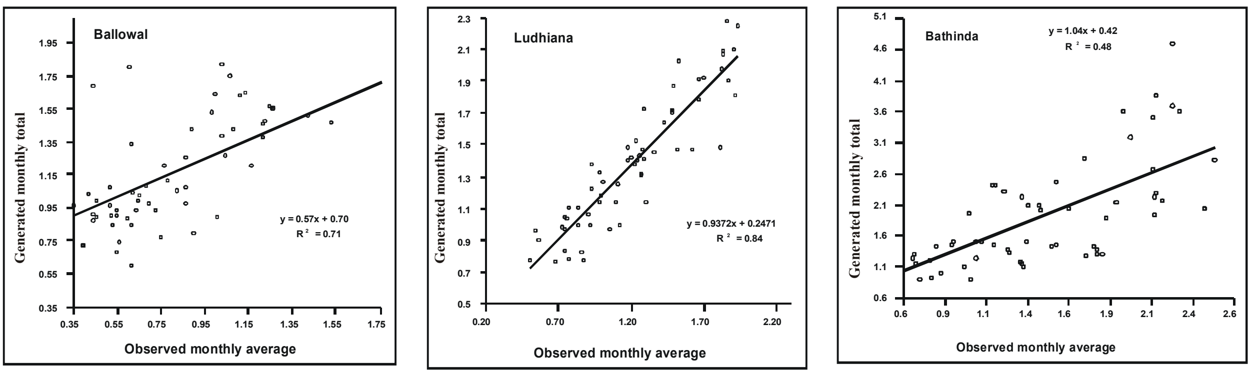
1. (e) Morning RH



1. (f) Afternoon RH



1. (g) Wind speed



Figs.1a-g: Co-efficient of determination and 1:1 line between the observed and generated values of different weather parameters.

(0.65) value, there was a wide gap between these two lines. The low coefficient of determination for Ludhiana station seems to be the results of integrating effects of industrial / Vehicular pollution (Sehra, 2007) which may have influenced in measuring/recording the accurate amount of observed incidental radiation corresponding to the generated value. Since model is insensitive to pollution factor, it overlooked while generating the solar radiation for the corresponding periods (1991-1995). Thus, the generated value seems to be in poor agreement with observed value. For moring and afternoon relative humidity, the regression line between the generated and observed values showed a moderate closeness with 1:1 line having R^2 value confined to the range of 0.60 – 0.70. However, irrespective of the study area, rainfall generated through *Climgen* reflected the poorest association with that of the observed value. The R^2 value for rainfall remained

Table 4: Evaluation of performance of the climgen model in generating different weather parameters for all the stations.

Parameter	GSD			Wilmott's index (d)			Performance of model		
	Ballowal	Ludhiana	Bathinda	Ballowal	Ludhiana	Bathinda	Ballowal	Ludhiana	Bathinda
Solar radiation (MJ m^{-2} day^{-1})	0.14	0.26	0.14	0.97	0.82	0.98	Acceptable	Poor	Acceptable
Max. Temp. (^0C)	0.06	0.06	0.08	0.97	0.98	0.97	Good	Good	Good
Min. Temp. (^0C)	0.07	0.09	0.18	0.99	0.99	0.99	Good	Good	Acceptable
Rainfall (mm)	1.59	1.36	1.31	0.65	0.71	0.67	Poor	Poor	Poor
R.H. morning (%)	0.14	0.10	0.12	0.79	0.88	0.87	Acceptable	Acceptable	Acceptable
R. H. afternoon (%)	0.23	0.22	0.30	0.85	0.85	0.67	Poor	Acceptable	Poor
Wind speed (m sec^{-1})	0.72	0.18	0.57	0.44	0.99	0.68	Poor	Acceptable	Poor

less than 0.45 at all the stations since the number of dry days was more and the model could not predict accurately the exact number of rainfall days using the probability concept.

Residual mean square analysis (RMSE)

RMSE value for maximum and minimum temperature varied from 0.8 to 3.2, with Ludhiana having the lowest for both these parameters as compared to other two stations (Table 3). Ludhiana is in the central plain with a relatively narrow range of both maximum and minimum temperature variations as compared to the other two stations falling in the extreme climatic conditions. However departures were observed in some cases but all generated values seemed plausible. The RMSE values for solar radiation was comparatively higher for Ludhiana (4.1) as compared to the other two stations probably due to poor agreement shown by the model as a result of cumulative effects of pollution. For rainfall a wide variation among the study areas were observed with a value ranging from 38.1 for Ludhiana to 122.3 for Ballowal. The geographical location of Ludhiana, which lies in the central plain, seems to be the sole reason for this relatively lower RMSE value compared to other two stations. Since Ballowal receives higher rainfall (total as well as on a single day) owing to its location in sub mountainous region, the range of variation between maximum and minimum with in the rainfall is much higher as compared to other two stations. Next to Ballowal, Bathinda has 85%, higher RMSE than the Ludhiana. Higher number of dry days owing to aridic climate in Bathinda seems to be reason to have higher RMSE. Similar to rainfall, the RMSE value for Ludhiana station was relatively lower for other parameters compared to the two stations owing to their respective geographical locations. However, for relative humidity no remarkable variations in RMSE values were observed among the stations.

GSD & Wilmott index (d) goodness of fit criteria

The test of goodness of fit between observed and generated data using GSD and Wilmott's index indicated that performance of *ClimGen* generated data for maximum and minimum temperature was good at all the stations (Table 4). The data generated for morning relative humidity was also acceptable as per the goodness of fit criteria between GSD & Wilmott's index. However, for evening relative humidity and wind speed the generated data for Ludhiana station was only acceptable where as for other two stations the model gave a poor performance. On the contrary, the generated data for solar radiation showed a complete reverse trend being acceptable for Bathinda and Ballowal and poor at Ludhiana station. However, irrespective of geographic location of the study areas, the data generation for rainfall showed a poor performance reflected by GSD / Wilmott's index (d) goodness of fit criteria when compared with the corresponding observed values. With the increase in deviation of values between the generated and observed parameters, RMSE values also increase. As a result, GSD increases while Wilmott's index decreases correspondingly (Table 4). In a nutshell, the integrated effects of low R^2 and Wilmott's index, higher RMSE and GSD owing to inherent wide variability in the observed data resulted a relatively less reliable generated data for these parameters.

In majority of the weather parameters for the study areas, good agreement between observed and generated weather data was found for monthly period parameters. Disagreement between the observed and generated values can be attributed to several reasons. As noticed by Harmel *et al* (2002) most of the weather parameters are not generally evenly distributed in each month but are often skewed which contradicts the assumption of normality used by Climgen. Especially for rainfall it registered the maximum RMSE and least regression coefficient than the others may be due to high proportion of dry as well as rainless days in daily rainfall data due to skewed distribution of rainfall besides the higher inter-annual variability of rainfall compared to the parameters (Richardson, 1981). Overall, results indicated a mixed performance of good and acceptable generated parameters by Climgen weather generator.

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