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Application of weather generator for environmental parameters estimation for upper indus basin

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Abstract

The major source of water for Indus basin is snowmelt runoff from the northern areas of Pakistan. The agricultural and hydropower is mainly dependent on the snowmelt runoff. The temperature is the major parameter responsible for the snowmelt and precipitation is source of snowfall and rainfall runoff. For better management and planning of water resources of the country, the prediction of environmental parameters is of great important. The stochastic model is used for generation of weather parameters. The LARS-WG model was applied in northern areas for prediction of minimum, maximum parameter and rainfall. The model was tested using different statistical tests such as F-test, T-test, Mann-Whitney test and Levene's test for climate parameters assessment on different time scales. This attempt was made first time in Pakistan, and it will help the researcher to use stochastic techniques effectively for planning and management of water resources in the country.

Key words: Weather Generator, LARS-WG, F-test, T-test, Climate parameters, stochastic model

Introduction

Stochastic weather generators are numerical models which produce long term time series synthetic daily data of climatic parameters i.e. rainfall, temperature and solar radiations (Richardson, 1981; Richardson and Wright, 1984; Racsko *et al.*, 1991). The climatic data generated by weather generator models is commonly used for hydrological applications, environmental management water quality, erosion and agricultural risk management. (Sultani and Hoogenboon, 2003; Yu, 2003, Zhang *et al.*, 2004; Yu, 2005; Zhang, 2005).

A number of studies have been completed in different parts of the world. Unfortunately no such work has been done in Pakistan so for. Different researchers like Chineke *et al.* (2000) conducted a study for 17 stations of Nigeria to check the dependence pattern of daily climatic parameter like rainfall and temperature; they found the coefficient of correlation for precipitation and temperature 0.833 and 0.802, respectively. This study encouraged the use of weather generators for other areas of the world for forecasting the climatic parameters.

The use of these models for forecasting has been stressed. Semenov and Brooks (1999) found that the stochastic weather generator LARS-WG was valid to Europe and it performed well for the simulation of different weather statistics including the climatic extremes which are related to agriculture. (Chineke *et al.,* 1999). The historic data for the meteorological parameters is required for stochastic models. Most of the observatories don’t have long term historical data. In the absence of such data it is very difficult for efficient planning and management of water and agriculture related projects. In such critical conditions, stochastic approaches (LARS-WG) are used for generation of long term climatic and hydrological data

According to Semenov *et al.* (1998) stochastic weather generator models are used in different studies for hydrological, agricultural and environmental management and quantitative assessment of risk of failure of the project. For such studies stochastic generators models can produce time series weather data of required time span.

Two commonly used weather generators LARS-WG and WGEN were compared in USA, Europe and Asia at 18 different sites. Different statistical tests were used for comparison. LARS-WG generated data matched more closely the observed data. The implications for use and development of weather generators were also discussed.

Barrow and Semenov (1995) and Zhang *et al.* (2004) used the WGEN weather generator to generate maximum and minimum temperature, solar radiation and precipitation. They applied this model for Six climate stations in Canadian region. To evaluate WGEN model, the observed data were compared with WGEN simulated daily data. The results showed that the comparisons between observed and WGEN generated data, in general, produced statistically

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significant correlations for maximum air temperature, solar radiation and precipitation.

Study area

The application of stochastic weather generators in water sector is of much importance because water has a vital role for sustaining quality of life on earth. This precious commodity plays a basic role in all sectors of economy. In Pakistan, its importance is more than ordinary because the economic life of the country depends on agriculture. Most of the fresh water originates from the northern part of Indus basin, which feeds to entire Indus Basin Irrigation System. The major source of water is snowmelt and rainfall that is mainly affected by climate variables such as temperature and precipitation. The climate parameters change both in temporal and spatial scales. The long time data are required for planning and management of water resources projects. Most of the time the long time data is not available. To overcome such constraints, weather generators are efficient tools which are helpful for generation of long term time series of weather parameters required for water resources management in Pakistan.

This study was conducted on the upper Indus catchment. The Indus catchment is divided in to number of sub catchments, the meteorological stations have been established for measurement of climate parameters such as temperature, wind velocity, precipitation etc. Nine sites were selected for the study with different elevation ranges. The elevations varied from 614 meter at Kotli to 2317 meter at Skardu. The meteorological stations are located at the lower elevations in the valley. The location of the study area are shown in Figure 1. The detail description regarding location and other parameters is given in Table 1.

Table1. Locations and elevations of the selected sites

Station	Latitude	Longitude	Elevation (meters)
Astor	35° 22'	74° 51'	2168
Bunji	35° 40'	74° 39'	1372
Chilas	35° 26'	74° 06'	1250
Chitral	35° 13'	74° 57'	1497
Gari Dopatta	34° 24'	73° 24'	813
Gilgit	35° 54'	74° 18'	1460
Kotli	33° 47'	73° 32'	0614
M.Abad	30° 08'	71° 21'	0838
Skardu	35° 18'	75° 41'	2317

(source: SWHP, 2002)

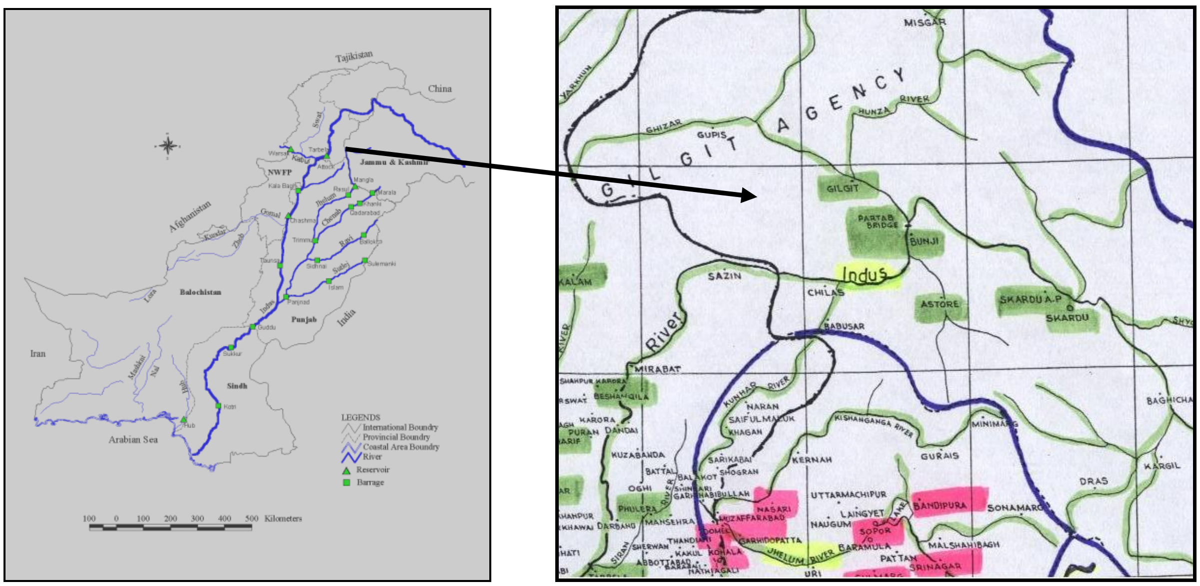

Figure 1: Location of the study area

Materials and Methods

The methodology adopted for this study included the selection of study area, collection of meteorological and hydrological data from different department. The Stochastic Weather Generator model LARS-WG was used. The detail about the model operation preparation of input file and output file are given in user manual. Some of the details can also be found from the web site: http://www.rothamsted.bbsrc.ac.uk/mas-models/larswg.php.

Data analysis

Climate data measurement (temperature, precipitation, humidity and wind velocity) is primarily the responsibility of the Pakistan Meteorological Department. Twenty five years daily data of precipitation, and maximum and minimum temperatures of nine sites in the northern areas of Pakistan was collected from the Pakistan Meteorological Department. The rainfall and temperature data of Astor site for 25 years from 1981 to 2005 was analyzed which represented that there was an increasing trend in maximum temperatures and minimum temperatures as shown in Figure 2. There is 0.73 ^{o}C increase in maximum temperature and 0.2 ^{o}C increase in minimum temperature in 25 years. The rainfall trend was also analyzed; Figure 3 shows that there was an increasing trend in rainfall from 1981 to 1995, then decreased from 1996 to 2005.

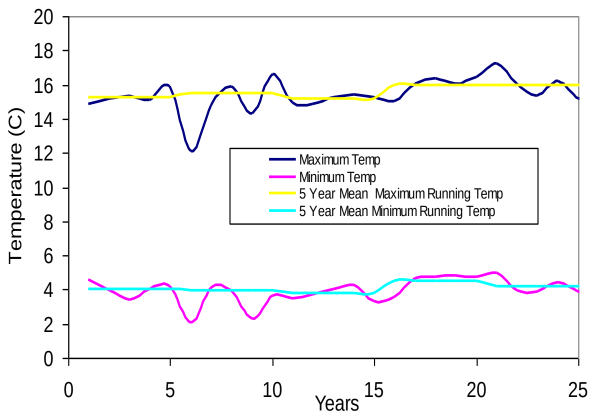

Figure 2: Annual and five year running mean temperature at Astor from 1981 to 2005

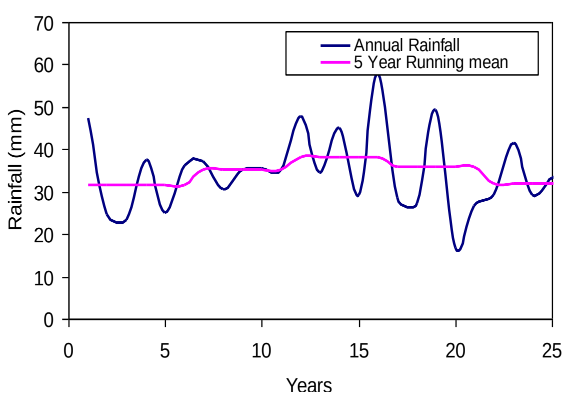

Figure 3: Annual and five year running mean rainfall at Astor from 1981 to 2005

Model application

As mentioned earlier, nine sites on upper Indus basin were selected for this study. Twenty five years (1981-2005) daily data was used as an input for LARS-WG. The generator can use its parameter file to generate a time series of synthetic data of any duration. For each of the nine sites, LARS-WG was used to generate the 250 years daily weather data. For testing the validity of the model results the statistical analysis was done. For longer series of the data statistical tests are powerful tools to produce significant levels of result when there is a difference between the simulated and observed data (Semenov *et al.*, 1998). To test the results, simulated data was divided into ten spans each with twenty five years in length. Each span data was compared with the observed data.

The occurrence of precipitation provides a basis for the other generated variables and therefore a critical component of the weather generator.

Statistical methods

Different statistical tests were used to compare a variety of characteristics of data. It is not only important for the simulated data to be similar to the observed data on average, but the distributions of observed and simulated data should also be similar across their whole range.

Kolmogorov smirnov test

The Kolmogorov Smirnov test (KS-test) was used for the comparison of the probability distributions for each month. KS-test is a non parametric and distribution free test which tries to determine if two data sets are extensively different and come from different distributions. It is an alternative to the Chi-square goodness of fit test. KS-test compares the two empirical distribution functions such as:

$$D = |E_1(i) - E_2(i)| \qquad (1)$$

Where E_1 and E_2 are the empirical distribution functions of the two distributions.

Mann-whitney U-test

On daily basis, non-parametric tests were used as the precipitation data was not normally distributed. Mann-Whitney U-test was used as a measure of central tendency. This is a substitute to the independent group t-test when the supposition of normality is not met. Unlike t-test it is nonparametric test and makes no supposition about distribution of data. Similar to many non-parametric tests, it uses ranks of the data rather than their raw values to calculate the statistic. This test does not make a distribution assumption; it is not as powerful as the t-test. The null hypothesis is described by the equation:

$$Z = \frac{U - \mu_u}{S_u} \qquad (2)$$

$$U = \text{Min}\,[U_1, U_2]$$

where

$$U_1 = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1$$

$$U_1 = n_1 n_2 + \frac{n_2(n_2+1)}{2} - R_2$$

Where R_1 is the sum of the ranks from the observed data and R_2 is the sum of the ranks from generated data. μ_u and S_u are mean and standard deviation of M test.

$$\mu_u = \frac{n_1 n_2}{2} \quad (3)$$

$$S_k = \sqrt{n_1 n_2 \frac{(n_1 + n_2 + 1)}{12}} \quad (4)$$

Levene's test

Levene's test was used as a measure of variability. It is a non parametric and distribution free test. The advantage of this test is that it is less sensitive to deviations from normality and is widely accepted as the most powerful homogeneity of variance test. The statistic test, which has F distribution with (N-k) and (k-1) degrees of freedom, is computed as follows;

$$F = \frac{(N-k)\sum_{i=1}^{k} N_i\left(\overline{Z_i} - \overline{Z}\right)^2}{(k-1)\sum_{i=1}^{k}\sum_{j=1}^{Ni}\left(Z_{ij} - \overline{Z_i}\right)^2} \quad (5)$$

where

$$Z_{ij} = \left| X_{ij} - \sum_{j=1}^{Ni} X_{ij} \right|, \quad \overline{Z_i} = \frac{\sum_{j=1}^{Ni} Z_{ij}}{N_i}, \quad \overline{Z} = \frac{\sum_{i=1}^{k} N_i \overline{Z_i}}{N}$$

Consistency test

Characteristics of the simulated and observed monthly and annual total precipitation data were compared by taking standard deviations, means, skewness and kurtosis for all months and for each span. Skewness may be defined as:

$$Skewness = \frac{\sum_{i=1}^{N}\left(Y_i - \overline{Y}\right)^3}{(N-1)s^3} \quad (6)$$

Where $\overline{Y}$ is the mean, s = standard deviation and N = number of data points.

Kurtosis is described as:

$$Kurtosis = \frac{\sum_{i=1}^{N}\left(Y_i - \overline{Y}\right)^4}{(N-1)s^4} \quad (7)$$

The variables are same as described in equation (6). Kurtosis for a standard normal distribution is equal to three. Kurtosis is defined by the following equation.

$$Kurtosis = \frac{\sum_{i=1}^{N}\left(Y_i - \overline{Y}\right)^4}{(N-1)s^4} - 3 \quad (8)$$

Means of the observed and simulated monthly total precipitation were compared using t-test. It is a parametric test with the assumption that the population from which the samples are drawn should be normally distributed. It tests the hypothesis that the samples came from the populations with equal means and has more power to produce significant results when difference exists. The test statistic is computed as follows;

$$T = \frac{\overline{X_1} - \overline{X_2}}{Sp\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \quad (9)$$

With $v = n_1 + n_2 - 2$, where $v =$ degrees of freedom (d.f).

Where $\overline{X_1}$ and $\overline{X_2}$ are the means of observed and generate data respectively, n_1 and n_2 are number of observations of observed and generated data and S_p is the collective estimate of the common variance δ^2.

$$S_p = \sqrt{\frac{(n_1-1){s_1}^2 + (n2-1){s_2}^2}{n_1 + n_2 - 2}} \quad (10)$$

Test is rejected if the t-statistic exceeds the critical value at a specified level of significance ("α"). And a t-test comparing means is used when variances are not equal i.e.

$$T' = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \quad (11)$$

With

$$v = \frac{\left[\left(s_1^2 / n_1\right) + \left(s_1^2 / n_2\right)\right]^2}{\frac{\left(s_1^2 / n_1\right)^2}{n_1 - 1} + \frac{\left(s_2^2 / n_2\right)^2}{n_2 - 1}} \quad (12)$$

That is why variances are compared first. F-test was applied on variances of all values for months across all the years. This measures the inter-annual variability. F-distribution does not depend upon the population variance but depends upon the two parameters v_1 and v_2 only. The procedure for F-test is as follows:

$$F = \frac{s_1^2}{s_2^2} \text{ (Assuming that } s_1^2 \text{ is larger than } s_2^2\text{)} \qquad (13)$$

Where $v_1 = n_1 - 1$ and $v_2 = n_2 - 1$

F-test and t-test are both based on the assumptions that the data (observed and simulated) is from the random samples in existing distribution and test the null hypothesis that the two distributions are similar. Both tests produce p-values measuring the probability that both data sets come from the same distribution (no distinction between observed and simulated data for that variable). A small p-value point out that the two data sets are not same (i.e. the model is not performing well). Similarly for annual total amount of precipitation the characteristics were also observed and both t-test and F-test values were also performed for each span for nine sites.

An additional test was performed only for annual total amount of precipitation to test the independence of data sets. Lag-one autocorrelation coefficients were computed.

Autocorrelation function (ACF) is the plot of autocorrelations and is very useful when examining stationary and when selecting from among various non-stationary models. Autocorrelation is one of the main tools in time series modeling.

By given measurements, Y_1, Y_2... Y_N at time X_1, X_2... X_N, the lag k autocorrelation function is defined as;

$$r_k = \frac{\sum_{i=1}^{N-k}\left(Y_i - \overline{Y}\right)\left(Y_{i+k} - \overline{Y}\right)}{\sum_{i=1}^{N}\left(Y_i - \overline{Y}\right)^2} \qquad (14)$$

Autocorrelation is a coefficient of correlation. However, as a substitute of correlation between two different variables, the correlation is between two values of the same variable at times X_i and X_{i+k}. When the autocorrelation is used to identify non-randomness, it is usually only the first (lag-1) autocorrelation that is useful.

We test the null hypothesis that autocorrelation coefficient is equal to zero. The data is generated through random process. For autocorrelations, we examine the t-statistic (T) for a particular lag to test whether or not the corresponding autocorrelation coefficient equals zero. One commonly used rule is that a t-statistic greater in absolute value than 2 indicates that the corresponding autocorrelation is not equal to zero.

Results and Discussions

In this study mainly two climate parameters temperature and precipitation were generated for future. The applicability and reliability of the generated data were test using model performance statistical parameter estimation. The details of the tests applied for temperature and precipitation are discussed as under.

Model performance on temperature data

The model was applied to different stations and climate data was generated for future. The model is based on stochastic approach for the data generation. The following statistical tests were performed to test the accuracy of the generated data.

Mann-whitney U-test

Mann-Whitney U Test was used to compare the medians of observed and LARS-WG produced data sets on daily basis. Each span was compared with observed data set. As there were 10 spans so number of successes out of 10 for each site on daily basis are shown in Table 2. LARS-WG showed moderate behavior but at some sites for some months there was not any single test in acceptance that medians of both data sets are same.

Levene's test

The Levene's test was used to test the variability among different climate variables. This test is efficient on the data which deviated from the normal distribution pattern. Similarly, Levene's test (Table 3) comparing variances of data sets showed good performance of LARS-WG except at Bunji. At Bunji there were six months where all tests were rejected.

Means of observed and LARS-WG generated maximum temperature on monthly and annual basis were compared using t-test as on monthly and annual basis maximum temperature was normally distributed. Each span was compared with observed data set. LARS-WG performed very well specially on annual basis data as compared to the monthly data, because not a single test was rejected on annual basis. But the variances were significantly different as shown in Table 4. All tests for all sites were rejected at 5% level of significance (except single test was not rejected at Astore and Chilas).

F test

F test was performed to test the central tendency variation. The model performed well on monthly basis, means and variances of observed and simulated data sets were not considerably different as shown in tables 5. At most of the sites only a few tests were rejected.

Medians of observed and LARS-WG generated daily minimum temperature were compared. A lot of tests were rejected at 5% level of significance as shown in table 6. It means LARS did not produced daily minimum temperature with the medians as in observed data. Same was the case with the Levene's test. Variations of values from their median were also significantly different at most of the sites as shown by Levene's test results in Table 7.

table 8. Every span was compared with observed data set. Means of observed and simulated annual minimum temperature were statistically in strong agreement as all the tests for all sites were accepted with 95% confidence level. Also, means of monthly minimum temperature were also in

Table 2: Number of successes for Mann-Whitney Test of daily Maximum Temperature out of 10 trials, each with 25 years in length

Site	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Astore	1	5	10	2	3	8	5	2	7	7	7	7
Bunji	0	6	4	0	3	2	1	2	3	2	4	6
Chilas	6	6	6	6	7	2	6	4	5	9	9	5
Chitral	3	4	9	2	7	4	5	7	1	8	7	7
Gari Dopata	1	6	9	5	7	0	3	5	0	9	7	6
Gilgit	2	5	9	3	4	6	5	8	8	10	7	6
Kotli	4	9	7	0	8	0	2	9	0	8	9	8
Muzafar Abad	5	6	9	2	10	0	8	5	0	10	7	10
Skardu	1	4	6	2	2	2	3	7	4	6	6	5

Table 3: Number of successes Levene's test of daily Maximum Temperature out of 10 trials, each with 25 years in length

Site	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Astore	10	10	8	6	6	10	5	9	10	10	10	10
Bunji	6	8	6	4	4	0	0	0	0	0	0	5
Chilas	10	9	10	7	5	7	10	7	10	8	6	1
Chitral	9	9	8	9	10	7	9	0	8	8	10	10
Gari Dopata	8	7	9	9	10	8	9	7	4	7	6	10
Gilgit	8	9	10	7	6	9	8	10	8	10	8	6
Kotli	8	9	9	9	8	6	10	0	6	10	4	7
Muzafar Abad	9	6	10	9	9	1	10	0	1	9	8	9
Skardu	3	9	9	8	7	1	3	10	10	9	8	7

Table 4: Number of successes for t-test of mean monthly Maximum Temperature out of 10 trials, each with 25 years in length

Site	Annual	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Astore	10	10	10	10	9	10	10	10	9	10	10	10	10
Bunji	10	9	10	10	10	10	10	10	10	10	10	10	10
Chilas	10	10	10	10	10	10	9	10	10	10	10	10	10
Chitral	10	10	10	10	5	10	7	10	10	10	10	10	10
Gari Dopata	10	10	10	10	10	10	2	8	10	9	10	10	10
Gilgit	10	9	10	10	8	10	10	10	10	10	10	7	10
Kotli	10	9	10	10	9	10	8	8	10	7	10	10	10
Muzafar Abad	10	9	10	10	9	10	3	10	9	7	10	10	10
Skardu	10	10	10	10	10	10	6	10	10	8	9	10	10

Means of observed and LARS-WG generated minimum temperature on monthly and annual basis were compared using t-test and successes numbers are shown in strong agreement as shown in table 9. Variability of observed and simulated data sets was statistically significant on annual basis as shown in table 10. LARS

Table 5: Number of successes for F-test of mean monthly Maximum Temperature out of 10 trials, each with 25 years in length

Site	Annual	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Astore	1	7	6	2	9	5	10	10	10	9	9	8	2
Bunji	0	9	8	8	8	5	5	1	2	3	6	6	9
Chilas	1	9	5	7	9	4	10	10	10	9	8	7	6
Chitral	0	6	6	5	10	5	10	10	10	9	6	7	5
Gari Dopata	0	9	6	6	7	5	10	10	10	10	7	10	6
Gilgit	0	3	7	6	10	3	10	9	10	10	9	7	3
Kotli	0	10	7	2	6	0	8	5	10	9	2	5	4
Muzafar Abad	0	10	10	5	9	3	9	0	10	10	3	6	2
Skardu	0	1	4	1	2	1	8	10	10	10	9	5	4

Table 6: Number of successes for M W Test of daily Minimum Temperature out of 10 trials, each with 25 years in length

Site	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Astore	5	9	2	2	3	8	4	0	9	5	7	9
Bunji	2	4	2	6	5	7	1	5	9	9	5	3
Chilas	4	2	5	5	7	3	4	4	8	6	4	2
Chitral	4	6	10	2	3	8	3	3	10	5	4	8
Gari Dopata	4	5	5	6	4	7	6	0	10	6	6	6
Gilgit	1	8	5	5	6	4	0	4	6	10	0	6
Kotli	2	1	6	5	2	1	6	3	5	0	10	2
Muzafar Abad	0	1	2	4	3	2	8	3	6	1	10	4
Skardu	0	2	5	3	5	6	6	8	6	4	0	7

Table 7: Number of successes Levene's test of daily Minimum Temperature out of 10 trials, each with 25 years in length

Site	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Astore	7	9	9	7	10	9	5	9	8	9	4	9
Bunji	5	6	9	8	5	1	2	5	6	7	8	10
Chilas	0	0	4	4	10	10	8	9	9	10	7	0
Chitral	9	8	6	8	6	6	9	6	8	8	7	10
Gari Dopata	1	0	8	7	8	9	4	9	0	0	0	0
Gilgit	10	8	6	8	10	8	7	9	10	9	3	3
Kotli	5	3	7	4	8	10	6	9	7	8	4	10
Muzafar Abad	4	10	8	9	9	9	6	7	9	9	6	5
Skardu	2	5	3	9	8	2	5	9	8	3	0	8

performed well on monthly basis as was less inter-annual variability. At most of the sites only a few F tests were rejected.

Model performance on precipitation data

Precipitation is a very important weather factor as all other weather factors depend upon it. The comparison results of observed and simulated daily precipitation data by using Levene's test and M.W test at for each month are shown in table 11 and 12. M.W test produced some significant values. Levene's test also produced some significant values for each month.

Means of observed and LARS-WG generated monthly and annual total amount of precipitation were compared using t-test and the number of successes are shown in table 12. Means of observed and simulated annual total precipitation were statistically in strong agreement as no test for any site was rejected at 5% level of significance.

Also means of monthly total amount of precipitation were also in strong agreement as shown in table and the minimum numbers of successes were at Gari Dopata for the month of June. Variability of observed and simulated data sets was statistically significant on annual basis while on monthly basis its performance was better than on annual basis as shown in table 13.

Trend of observed annual total precipitation for nine sites is shown in figs. There was no pattern in annual rainfall. Also autocorrelation results revealed that there was no momentous autocorrelation amongst the data points (At Skardu 1 span showed significant autocorrelation). The lag-

Table 8: Number of successes for t-test of mean monthly Minimum Temperature out of 10 trials, each with 25 years in length

Site	Annual	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Astore	10	10	10	10	9	9	10	10	7	10	8	10	10
Bunji	10	7	10	10	10	10	10	10	10	10	10	9	10
Chilas	10	10	9	10	10	10	8	10	10	10	10	10	10
Chitral	10	10	10	10	9	9	10	10	10	10	10	10	10
Gari Dopata	10	10	10	10	10	10	10	10	8	10	10	10	10
Gilgit	10	10	10	9	8	9	10	10	10	10	10	6	10
Kotli	10	10	10	9	10	10	10	10	10	9	9	10	10
Muzafar Abad	10	6	10	10	10	10	5	10	10	9	8	10	10
Skardu	10	10	10	10	10	10	10	9	10	7	8	4	10

Table 9: Number of successes for F-test of mean monthly Minimum Temperature out of 10 trials, each with 25 years in length

Site	Annual	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Astore	5	6	10	9	10	9	10	8	10	10	10	10	10
Bunji	0	9	10	8	5	1	3	1	2	1	8	10	10
Chilas	3	9	10	5	3	1	10	7	9	9	0	1	5
Chitral	0	10	10	8	5	8	9	4	3	6	8	10	10
Gari Dopata	2	10	7	10	7	1	10	10	10	3	7	9	10
Gilgit	0	1	8	6	9	10	10	4	3	0	10	10	0
Kotli	0	7	10	5	7	1	0	10	9	8	7	8	1
Muzafar Abad	1	10	10	7	8	7	9	10	10	9	6	10	7
Skardu	0	1	6	8	5	0	9	9	7	8	9	9	8

Table 10: Number of successes for M W Test of daily Amount of Rain out of 10 trials, each with 25 years in length

Site	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Astore	9	3	9	10	8	10	10	10	9	9	10	8
Bunji	0	7	5	9	8	10	9	9	9	10	1	0
Chilas	7	2	3	8	8	10	10	8	10	9	2	0
Chitral	9	3	10	10	9	8	7	10	10	9	9	7
Gari Dopata	9	2	9	10	9	7	10	7	10	10	7	0
Gilgit	7	1	7	10	6	9	10	9	9	10	5	1
Kotli	4	5	8	10	10	10	9	10	9	10	5	0
Muzafar Abad	9	6	8	8	9	10	8	10	10	10	9	3
Skardu	7	8	8	9	7	9	9	9	10	10	7	1

one autocorrelation results for Skardu and Kotli are given in Figure 4 and 5, respectively.

precipitation it was a common trend that the daily variability between simulated data was greater than the

Table 11: Number of successes Lenene's test of Daily Amount of Rain out of 10 trials, each with 25 years in length

Site	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Astore	9	8	9	10	10	9	10	10	10	10	9	10
Bunji	0	10	10	9	9	10	9	9	10	10	4	5
Chilas	9	9	7	9	9	10	10	10	10	9	7	2
Chitral	10	7	10	10	10	10	9	10	10	10	10	7
Gari Dopata	10	7	9	10	9	8	10	9	9	9	9	5
Gilgit	8	3	10	10	10	10	10	10	10	10	9	10
Kotli	9	9	8	10	10	10	9	10	9	9	9	1
Muzafar Abad	10	8	10	8	10	9	7	10	10	8	10	9
Skardu	10	10	10	9	9	10	9	10	10	10	9	6

Table 12: Number of successes for t-test of monthly Total Amount of Rain out of 10 trials, each with 25 years in length

Site	Annual	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Astore	10	10	9	10	10	10	10	10	10	10	10	10	10
Bunji	10	9	10	10	10	10	10	10	10	10	10	5	6
Chilas	10	10	9	8	10	10	10	10	10	10	9	10	4
Chitral	10	10	8	10	10	10	10	10	10	10	10	10	9
Gari Dopata	8	10	10	10	10	10	9	10	10	9	9	9	10
Gilgit	10	10	8	10	10	10	10	10	10	10	10	10	10
Kotli	10	10	9	10	10	10	10	10	10	10	9	9	8
Muzafar Abad	10	10	10	10	9	10	10	10	10	10	9	10	10
Skardu	10	10	10	10	10	10	10	10	10	10	10	10	9

Table 13: Number of successes for F-test of monthly Total Amount of Rain out of 10 trials, each with 25 years in length

Site	**Annual**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May.**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
Astore	10	9	10	10	10	7	10	10	9	5	5	8	8
Bunji	8	9	7	9	9	5	8	9	4	9	5	5	8
Chilas	7	9	9	6	10	3	10	6	8	3	4	8	10
Chitral	10	9	10	10	10	10	9	8	5	9	7	10	10
Gari Dopata	9	7	9	10	9	8	10	10	10	9	10	10	8
Gilgit	9	8	4	10	8	7	10	10	7	6	6	10	10
Kotli	8	3	10	7	10	10	10	8	10	7	8	9	9
Muzafar Abad	10	7	10	10	10	10	10	2	2	10	7	9	8
Skardu	8	8	10	8	10	8	9	9	5	6	2	8	9

Conclusion

LARS-WG regenerated good data in terms of mean values and variances of rainfall temperature on monthly basis but on daily basis its performance was not good. When comparing the daily observed and simulated

observed data sets and the Levene's test produced more significant results during winter season. Similarly, M W-test also produced more significant results during winter season. While talking about monthly total amount of precipitation there was high inter-annual variability as F-test produced several p-values less than 0.05 but the hypothesis about equality of means of observed and simulated data was not rejected more than twice a month for all the sites (except at Bunji where in Nov and Dec there were 5 and 4 rejection cases, respectively). All the F-tests showed significant variability in annual total amount of precipitation but none of the t-tests was significant at any site. LARS-WG is a random generator, its randomness was tested and only single significant result was found at Skardu.

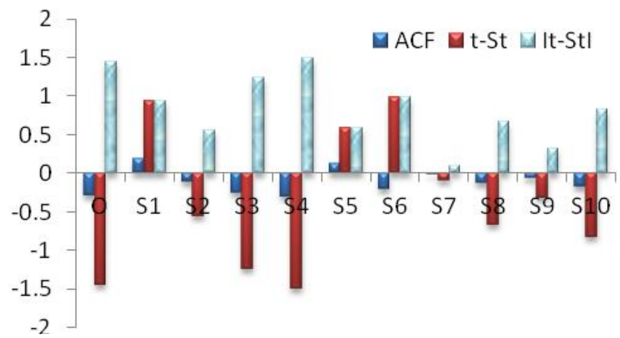

Figure 4: Autocorrelation test at Skardu

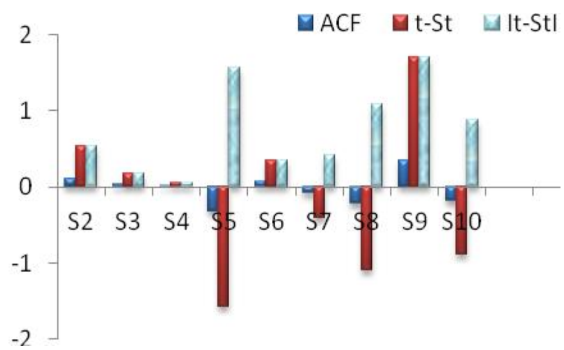

Figure 5: Autocorrelation test at Kotli

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