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# A Multi-Sites Daily Precipitation Forecasting Model for Sulaimania Governorate in Iraq

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**Abstract**
A new model for daily precipitation forecasting was developed. The model is a modification of Wilks (1999) method that adopts a two state modeling process, one for the precipitation occurrences and the other for the nonzero precipitation series values. However, a different method of precipitation occurrence representation was adopted, that is to create codes values for this occurrence in a form of a series. This series of occurrence is then fitted by a suitable frequency distribution. The non-zero values are also fitted by a suitable frequency distribution. The best distributions are selected according to the Chi-square and Kolmogorov-Smirnov tests. Another modification was also done by obtaining the minimum and maximum number of dry periods (runs) and their minimum and maximum lengths on monthly basis from the historical records. The generation of future precipitation values was performed by generating the occurrence series using the best fitted distribution and modifying them according to the minimum and maximum numbers and lengths of the dry runs in each month. The final generated series are obtained by generating non-zero values of precipitation according to the best fitted distribution and combine them with the generated and modified series of occurrence. The model was applied for the case study of three metrological stations at Sulaimania governorate located north of Iraq. These stations are Sulaimania, dokan, and Derbendikhan. The data series used for obtaining the model parameters are the precipitation of eight months (Oct to May) for years (2000-2008). The best fitted frequency distribution found for the occurrence is the Gamma distribution, while for the non-zero precipitation were exponential for sulaimania, and Gamma for Dokan and Derbendikhan stations. The verification of the model was obtained by comparing the statistical properties of the generated with that of the observed precipitation series, for the three years (2009-2011). The results indicate the capability of the model to preserve these statistical properties.
**Key words**: Precipitation, data generation, frequency distribution, Multi-sites data generation models, Occurrence of wet and dry days state,  Chi-square test, Kolmogorov-Smirnov test.

## I. Introduction

Recent researches in hydrologic modeling tried to have a more global approach to understand the behavior of hydrologic systems to make better long term predictions and to face the major challenges in water resources management. These long term forecasting are needed to provide future view of hydrologic variables such as precipitation and evaporation which are important for water resource management. Weather generation models have been used successfully for a wide array of applications. They became increasingly used in various research topics, including more recently, climate change studies. They can generate series of climatic data with the same statistical properties as the observed ones. Furthermore, weather generators are able to produce series for any length of time, which allows developing various applications linked to extreme events, such as flood analyses, and draught analysis, hence putting proper long term water resources management to face the expected draught or flood events.

Most of the existing weather generators are used at a single site independently of the others, thus ignoring the spatial dependence exhibited by the observed data. Tobler, (1970) had mentioned in the first law of geography that "everything is related to everything else, but near things are more related than distant things." Time series of daily precipitation are required increasingly, not only for hydrological purposes but also to provide inputs for  models  of crop  sensitive projects, Srikanthan and McMahon, (2001). Wilks (1998) developed a multi-site version of the Richardson (1984) weather generator based on serially independent but spatially correlated random numbers. The chain-dependent-process stochastic model of daily precipitation, consisting of a two-state, first-order Markov chain for occurrences and a mixed exponential distribution for nonzero amounts, was extended to simultaneous simulation at multiple sites by driving a collection of individual models with serially independent but spatially correlated random numbers. The procedure was illustrated for a

network of 25 sites in New York State, with inter station separations ranging approximately from 10 to 500 km.

Wilks (1999) described stochastic generation of daily precipitation, maximum temperature, minimum temperature and solar radiation, simultaneously at a collection of stations in a way that preserves realistic spatial correlations. The procedure is a generalization of the familiar Richardson (1984) weather generator (WGEN) approach using the same basic model structure and local parameter sets. Beersma and Buishand (2003) used nearest-neighbor re-sampling to generate multi-site sequences of daily precipitation and temperature; through re-sampling, the spatial correlations of the daily precipitation and temperature data that were automatically preserved in the simulated series. Fowler et al (2003) examined the impacts of climatic change and variability on water resource reliability, resilience, and vulnerability using eleven hydrometric stations within the Yorkshire water resource zone, UK .The work was carried out by modeling changes to weather type frequency, mean rainfall statistics, and potential evapo-transpiration. Mehrotra and Sharma (2005) described and illustrated a semi-parametric stochastic model for the generation of daily precipitation amounts, simultaneously at a collection of stations in a way that preserves realistic spatial correlations, accommodates seasonality, and reproduces a number of key aspects of the distributional and dependence properties of observed rainfall. Khalili et al (2007) proposed a multisite generation approach of daily precipitation data based on the concept of spatial autocorrelation. The theory referred to spatial dependence between observations with respect to their geographical adjacency. Ilich and Despotovic(2008) presented an algorithm for generating stationary stochastic hydrologic time series at multiple sites. The algorithm relied on the recent advances in statistical science for simulating random variables with arbitrary marginal distributions and a given covariance structure. Bardossy and Pegram(2009) introduced two new ideas concerning multisite stochastic daily rainfall modeling. The first is the use of asymmetrical copulas to model the spatial interdependence structure of the rainfall amounts together with the rainfall occurrences in one relationship. The second, is the evaluation of congregating behavior of the higher values of simulated rainfall. Khalili and Brissette(2009) successfully used the concept of spatial autocorrelation (a correlation between the values of a single variable, considering their geographical sites) for multi-site generation of daily precipitation data. The study aimed to obtain an accurate reproduction of the spatial intermittence property in synthetic precipitation amounts, and to extend the multi-site approach to the generation of daily maximum temperature, minimum temperature

and solar radiation data. Makhnin and Mcallister (2009) proposed a new precipitation generator based on truncated and power transformed normal distribution, with the spatial-temporal dependence represented by multivariate auto-regression.

Some of the most common and important probability distributions used in hydrology are the normal, log-normal, gamma, Gumbel and Weibull. The normal and log-normal distribution generally fits to the annual flows of rivers. In hydrology the gamma distribution has the advantages of having only positive values, since hydrological variables are usually greater than zero, the Gumbel and Weibull distributions are used for extreme values of hydrological variables. AKSOY, (2000) had found in at least some cases that distribution of daily nonzero rainfall amounts are better represented by the mixed exponential distribution. However using the mixed exponential distribution is sometimes more complicated Wilks, (1999). The exponential one parameters, a skewed normal three parameters, and the Kappa distribution two parameters are also frequency distributions used in daily rainfall amount simulating, Chapman, (1994).

The problem of daily precipitation modeling is the existence of so many zero values (dry days), a problem that smoothened out in monthly precipitation modeling. Hence, the modeling of these daily precipitation series could not be done using the applied models for monthly series. In most available models the generation of daily precipitation involves two components, Apipattanavis,(2007);

1. The occurrence process (i.e. the sequence of "dry" or "wet" days),and
2. The intensity process (i.e. the sequence of precipitation amounts on wet days).
   For multisite modeling, the time series of rainfall amounts at location (s) can be generally represented as given by, Wilks, (1999), as:

$$Y_{t_s} = Occ_s X_{t_s} \dots\dots\dots\dots\dots\dots\dots 1)$$

Where

$Y_{t_s}$ : represents the rainfall amount series at site (s),

$Occ_s$ : represents the multisite occurrence series for site (s), and

$X_{t_s}$: represents the nonzero rainfall amounts at site (s). Clearly, $(Y_s)$ is equal zero when $(Occ_s=0)$ at day (t) , and equals$(X_{t_s})$ when $(Occ_s=1)$ at day (t) for site (s).

The previous literature review revealed that there are many relatively recent trails to model spatial-temporal variations. However the models are rather difficult to apply, and/or had some limitations. A new

approach for daily precipitation modeling at multiple sites was developed herein, based on the observed nonzero daily rainfall amounts and wet-dry day occurrences. The development made herein is in concern with the simulation of the occurrence of the daily precipitation in the multiple sites by a series of codes obtained from the historical data and by preserving the number of dry day runs and their lengths on monthly basis.

## II.    The developed model:

The new developed model is a modification of Wilks (1999) method that adopt a two state modeling process, one for the precipitation occurrences and the other for the nonzero precipitation series frequency distributions as in equation (1). The model developed herein depends on two basic concepts for simulation. The first concept is the simulation of the inter-relation that exists between the occurrence of the precipitation in three selected sites (Sulaimani, Dokan, and Darbandikhan) in Sulaimania governorate, north Iraq . The occurrence of the precipitation in any day and any site as ("wet,1" and "dry,0") is designated as the state of occurrence . Using these notations occurrence codes can be developed using a certain time step. A one day time step was selected for the present model. For three sites for example and one time step, each code can be represented by a matrix of three rows and two columns. Each site is represented by a row and each occurrence day is represented by a column. Hence for the historical series of daily rainfall at the three sites an observed occurrence series of codes could be obtained. This occurrence series is then fitted by different frequency distributions and a test of fit will give the best frequency distribution that fits the series of occurrence. Secondly the non zero precipitation series are fitted to obtain the best frequency distribution that fits this non zero series for each site. The idea of this developed new multisite daily precipitation model is presented in two stages as follows:

### Stage1: Analysis and Model Parameter Estimation

**Step1:** occurrence codes for the day at time (t) and the preceding day time t-1, for the ns-sites (ns=3 for the case study) are estimated from the historical series and converted to a series of observed occurrence herein as follows:

$$Occ_{(code=0)} = \begin{pmatrix} 0 \text{................} 0 \\ 0 \text{................} 0 \\ 0_{t-1} \text{..........} 0_t \end{pmatrix} \begin{matrix} \text{................} site\,1 \\ \text{................} site\,2 \\ \text{................} site\,3 \end{matrix} \qquad (2)$$

where this code (code =0) indicates that there is no precipitation at all the sites and at both time (t) and (t-1) i.e., the present day and the preceding day, while:

$$Occ_{(code=1)} = \begin{pmatrix} 0 \text{................} 1 \\ 0 \text{................} 0 \\ 0_{t-1} \text{..........} 0_t \end{pmatrix} \begin{matrix} \text{................} site\,1 \\ \text{................} site\,2 \\ \text{................} site\,3 \end{matrix} \qquad (3)$$

This code indicates that precipitation occurs at day (t) at site (1) only, while all other sites and times are in dry day condition. Hence, so many codes can be found to simulate the states of wet and dry days at all sites and at both time steps. In general the number of codes types, are given by the following equation:

Number of codes= number of state(dry and wet)$^{(\text{number of lag}(t,t-1)*\text{number of site}(ns))}$

$$(4)$$

for example for three sites, number of codes types=$2^{2*3} = 64$ types of codes.

**Step2:** Is to find a series of codes of occurrence for each day and for all the sites using the observed daily series of precipitation at all sites. Then the series of observed occurrence is found with the number of observations equal the number of years used for analysis multiplied by the number of days per year. This observed occurrence series is then fitted by a frequency distribution to find which one is the best that fits the occurrence series such as: (Normal, Lognormal, Gamma, Exponential, and Chi-square Distribution).

**Step3:** In this step further analysis is done on the observed dry days number of sequences (ns) and length of dry run of each sequence (Lr), for each month, and all the years. Hence the range of (ns) and length of run of each (Lr) is found for each month as an observed parameters of the model, as follows:

$$ns_{min}(m) \le ns(m) \le ns_{max}(m) \qquad (5)$$

$$Lr_{min}(m) \le Lr(m,j) \le Lr_{max}(m) \qquad (6)$$

Where

*(m)* is the month, $m = 1,2 ,…..nm$ , $j = 1,2,…..ns(m)$

*nm* is the number of non-dry months per year(Oct to May), nm=8, for the case study.

**Step4:** The observed nonzero values of the precipitation data in each site is tested for the most fitted frequency distribution, i.e. (Normal, Lognormal, Gamma, Exponential, Chi-square) using Chi-square test and Kolmogorov-Smirnov test, Corder and Foreman ,( 2009) and the best one is adopted for the generation purpose.

### Stage2: *Daily Precipitation Generation and Verification*

**Step1:** Generation of nonzero daily precipitation values using the parameters of the best fitted frequency distribution found in step 4 stage1.These values represent ($X_t$s for the sites s= 1,2...ns, and for all the time steps t=1,2…(nd * nyg), where (nd) is number of days per year for the (nm) months and (nyg) is the number of the years for the daily

precipitation to be generated, then the total generated values are (nd * nyg)

**Step2:** Generating the occurrence series using the best fitted distribution with its observed parameters at step2, satge1, with a number of values of (nd * nyg)

**Step3:**The generated occurrence series in step2 above is modified according to the observed values of $[ns_{min}(m), ns_{max}(m), Lr_{min}(m), Lr_{max}(m)]$ found in step 3 stages 1. The modification is done by using a randomly generated ns (m) value that is located within the ranges observed and shown in equation(5), then an $Lr(m,j)$ value is also randomly generated $Lr(m,j)$ ,j=1,2,.. ns (m)), each of the value for $Lr(m,j)$ should be in the range of $Lr_{min\ i}, Lr_{max\ i}$,i.e. according to equation(6),with other condition of $\sum_{j=1}^{ns(m)} Lr(m,j) \leq no.of\ days\ per\ month\ (ndi)$.

After that an ns*(m)* position values of the start day of the $Lr(m,j)$ values were generated randomly

with (1 to $ndi$). Zero values of occurrence are then placed in the position generated with the lengths $Lr(m,j)$ generated to replace those values of occurrence generated in step2. Any $Lr(m,j)$ value that exceeds the length of month (m) is ignored

**Step 4:** for the estimation of the final generated precipitation values equation (1) is to be applied using the nonzero generated series in step1 as($Xt_s$),with the modified occurrence series generated in step 2.

**The Case Study** I

In order to apply the new developed daily precipitation model described above, Sulaimania governorate is selected as a case study. This governorate is located north of Iraq as shown in figure (1) with a total area of (17,023 km²) and a population of 1,350,000 according to(2009) records. The city of Sulaimania is located (198) km from Kurdistan Regional capital (Erbil) and (385) km from the federal Iraqi capital (Baghdad).

**Figure (1) Sulaimania governorate location in Iraq and satellite image shows the locations of the selected three meteorological stations. (Google Earth)**

Sulaimania city is surrounded by the Azmar Range, Goizja Range and the Qaiwan Range in the north east, Baranan Mountain in the south and the Tasluje Hills in the west. The area has a semi-arid climate with very hot and dry summers and very cold winters. Data are taken from three meteorological stations (sites) inside and around Sulaimania city, which are (Sulimania, Dokan dam, and Darbandikhan dam meteorological stations). Dokan dam

metrological station is located (61 km) north east, and Darbandikhan dam meteorological station is located (55 km) south east of Sulaimania city respectively. Dokan dam meteorological station is located (114 km) north east of Darbandikhan dam metrological station .These sites coordinates are shown in table (1), Barzinji,(2003). The Satellite image of the locations of the three stations is shown in figure (1)

**Table (1) The selected meteorological stations coordinates, Sulaimnia governorate.**

| Site | Coordinate | |
|---|---|---|
| | N | E |
| Sulaimani metrological station | $35^0$ 33' 18" | $45^0$ 27' 06" |
| Dokan dam metrological station | $35^0$ 57' 15" | $44^0$ 57' 10" |
| Darbandikhan dam metrological station | $35^0$ 06' 46" | $45^0$ 42' 23" |

**The application of the Developed Model to the case study**

The developed multisite daily precipitation model given above was applied to the daily precipitation series for the case study mentioned before (Sulaimani, Dokan, and Darbandikhan daily precipitation) data. The model parameters estimation and its verification was done using the daily precipitation records for the three metrological stations for the period (2000-2011).The first (9) years (2000-2008) were used for estimating the model parameters, while the other (3) years (2009-2011) were left for model validation. The model was applied for the daily precipitation of eight months per year, October to May. The developed model

application was carried out by the stages, and steps explained above:

*Stage1: Analysis and Model Parameter Estimation*
**Step1:** The descriptive statistics of the daily precipitation series from (2000-2008) are shown in the table (2). The observed multisite occurrence codes series was estimated from the precipitation data of the nine years (2000-2008) for each day. The range of the code values types is (0,63).
**Step2:** The observed occurrence series was fitted by some frequency distributions to find which one is the best that fits the data. These frequency distributions are Normal, Lognormal, Gamma, Exponential, and Chi-Square distribution. The results of these fittings are shown in table (3).

**Table (2) Descriptive statistics for the daily precipitation series (2000-2008)**

| Descriptive statistics | Variable | | |
|---|---|---|---|
| | Observed Sulaimania Precipitation(mm) | Observed Dokan Precipitation (mm) | Observed Darbandikhan Precipitation(mm) |
| Mean | 2.6 | 2.5 | 2.3 |
| Minimum | 0.0 | 0.0 | 0.0 |
| Maximum | 130.4 | 107.0 | 107.8 |
| Variance | 59.0 | 58.6 | 59.9 |
| Standard deviation | 7.7 | 7.7 | 7.7 |
| Skewness | 5.6 | 4.9 | 5.7 |
| Kurtosis | 53.3 | 33.2 | 44.7 |

**Table (3) Results of occurrence series fitting to different distributions(2000-2008)**

| Distribution | Chi-Square test | Kolmogorov-Smirnov test |
|---|---|---|
| Normal | 4906 | 0.223 |
| Gamma | 281 | 0.102 |
| Exponential | 696 | 0.192 |
| Lognormal | 402 | 0.082 |
| Chi-Square | 14011 | 0.489 |
| Critical Chi-Square value = 2306 for $\alpha = 95\%$ | | |

As the results above show, the Gamma distribution (2-parameters) is the most fitted distribution for the occurrence series.

**Step3:** In order to simulate the observed dry days sequences, the number of sequences (ns) and lengths of run of each sequence (Lr), for each month, and all the years is found as observed parameters of the model. As explained in step 3, above. The results are given in table (4).

**Table(4) Observed lengths of run and number of sequences of dry days, for the case study,(2000-2008).**

| Parameter | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May |
|---|---|---|---|---|---|---|---|---|
| Maximum Length of Dry run ( Lr max) | 24 | 26 | 29 | 12 | 8 | 18 | 12 | 25 |
| Minimum Length of Dry run ( Lr min) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Maximum number of Dry sequences (ns max) | 4 | | | | | | | |
| Minimum number of Dry sequences (ns min) | 1 | | | | | | | |

**Step4:** In this step, tests for the most fitted frequency distribution(Normal, Lognormal, Gamma, Exponential, and Chi-square) was carried out for the observed nonzero values of the precipitation data in each site. The series of nonzero daily precipitation amount descriptive statistics are shown in table (5).

**Table(5) Descriptive statistics for nonzero Sulaimani, Dokan, and Darbandikhan sites precipitation (2000-2008).**

| Variable | Nonzero Sulaimania Precipitation(mm) | Nonzero Dokan Precipitation(mm) | Nonzero Darbandikhan Precipitation(mm) |
|---|---|---|---|
| Values No. | 589 | 567 | 518 |
| Mean | 9.8 | 9.7 | 9.9 |
| Minimum | 0.1 | 0.1 | 0.1 |
| Maximum | 130.4 | 107.0 | 107.8 |
| Variance | 149.6 | 157.1 | 179.4 |

| Standard deviation | 12.2 | 12.5 | 13.4 |
|---|---|---|---|
| Skewness | 3.3 | 2.4 | 2.8 |
| Kurtosis | 23.0 | 11.9 | 14.3 |

Results of frequency distributions fitting for the nonzero series are shown in tables (6) to (8)

**Table(6) Results of nonzero Sulaimania precipitation fitting to different distributions,(2000-2008).**

| Distribution | Chi-Square test | Kolmogorov-Smirnov test |
|---|---|---|
| Normal | 378 | 0.21 |
| Gamma | 9 | 0.03 |
| Exponential | 6.1 | 0.01 |
| Lognormal | 80 | 0.083 |
| Chi-Square | 267 | 0.102 |
| Critical Chi-Square value = 515 for α = 95% | | |

**Table (7) Results of nonzero Dokan precipitation fitting to different distributions,(2000-2008).**

| Distribution | Chi-Square test | Kolmogorov-Smirnov test |
|---|---|---|
| Normal | 482 | 0.22 |
| Gamma | 12.8 | 0.02 |
| Exponential | 41 | 0.044 |
| Lognormal | 38 | 0.04 |
| Chi-Square | 447 | 0.12 |
| Critical Chi-Square value = 468 for α = 95% | | |

**Table (8) Results of nonzero Darbandikhan precipitation fitting to different distributions(2000-2008).**

| Distribution | Chi-Square test | Kolmogorov-Smirnov test |
|---|---|---|
| Normal | 533 | 0.23 |
| Gamma | 6.7 | 0.027 |
| Exponential | 32 | 0.051 |
| Lognormal | 23 | 0.038 |
| Chi-Square | 348 | 0.118 |
| Critical Chi-Square value = 540 for α = 95% | | |

It is clear that the most suitable frequency distributions for nonzero precipitation for Sulaimania is the exponential distribution, while for both Dokan and Darbandikhan the Gamma distribution is the most suitable. Equations (7) and (8) are the Gamma (2-parameters) and Exponential distribution functions respectively (Johnson et al, 1994).

$$f\left(x_t; \alpha, \beta\right) = \frac{1}{\beta^\alpha \Gamma(\alpha)} X^{\alpha-1} e^{-\frac{X}{B}} \qquad for \ x > 0 \ and \ \alpha, \beta \ > 0 \dots\dots. (7)$$

$$\begin{cases} f\left(x, \lambda\right) = \ \lambda e^{-\lambda x} & x \geq o \\ 0, & x < 0 \end{cases} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (8)$$

where :
$x_t$ : Time series
Γ : Gamma function
β **:** Scale parameter
α **:** Shape parameter
λ **:** Rate parameter

The estimated parameter λ of the exponentially distributed nonzero Sulaimania precipitation series and the maximum likelihood estimates (MLEs) for the parameters of the gamma distribution (α and β) for the nonzero Dokan and Darbandikhan, precipitation are given in the table (9).

**Table(9) Distributions parameters for the nonzero series of precipitation at the three stations.**

| Parameter | Variable | | | |
|---|---|---|---|---|
| | Occurrence series | Nonzero Sulaimani Precipitation | Nonzero Dokan Precipitation | Nonzero Darbandikhan Precipitation |
| λ | - | 9.7084 | - | - |
| α | 0.6262 | - | 0.5983 | 0.5423 |
| β | 17.56 | - | 16.1943 | 18.1724 |

**Stage2:** A (MATLAB) code was written to perform the steps of this stage.

**Step1:** Nonzero daily precipitation values were generated using the distributions and parameters calculated in step 4 stage1 for Sulaimani, Dokan, and Darbandikhan sites (generated nonzero Sulaimania precipitation, generated nonzero Dokan precipitation, and generated nonzero Darbandikhan precipitation).The generation was performed for three years ahead in order that the generated series can be compared with the three years daily precipitation data(2009-2011) that were left for validation. For each site three sets of generated daily precipitation was done.

**Step2:** The occurrence series was generated using the Gamma distribution with its observed parameters at step2, satge1, for three years (i.e. series length=732).

**Step3:** The generated occurrence series in step 2 above is modified according to the procedure explained above for the length of runs of zero precipitation in each month according to equations (5) and (6).

**Step 4:** Using the nonzero precipitation series generated for each site, with the occurrence series and equation (1), three daily precipitation series for each site were generated.

**5-3-2 Model Validation:**

For the three generated series, descriptive statistics were calculated and compared with those of observed series. The generated series means and standard deviations were also tested by the (t-test and F-test). The descriptive statistics and tests' results are shown in tables (10) to (13) for the daily and the total monthly precipitation series respectively.

**Table (10) Descriptive statistics of observed and three generated series daily precipitation series (mm), for each station,(2009-2011).**

| Site | Series | Mean | Min | Max | Sd | Cs | Ck |
|---|---|---|---|---|---|---|---|
| Sulaimania Site | Observed | 2.5 | 0.0 | 72.5 | 7.4 | 4.8 | 32.8 |
| | Generated 1 | 2.4 | 0.0 | 68.2 | 6.3 | 4.3 | 29.1 |
| | Generated 2 | 2.2 | 0.0 | 65.7 | 6.5 | 4.6 | 32.2 |
| | Generated 3 | 1.8 | 0.0 | 63.6 | 5.9 | 4.7 | 31.0 |
| Dokan Site | Observed | 1.9 | 0.0 | 57.0 | 5.8 | 5.0 | 34.6 |
| | Generated 1 | 2.0 | 0.0 | 55.6 | 6.2 | 4.8 | 30.6 |
| | Generated 2 | 2.2 | 0.0 | 58.5 | 6.5 | 4.6 | 30.9 |
| | Generated 3 | 2.1 | 0.0 | 52.5 | 6.3 | 4.4 | 35.7 |
| Darbandikhan Site | Observed | 2.4 | 0.0 | 91.6 | 8.4 | 6.2 | 50.9 |
| | Generated 1 | 2.5 | 0.0 | 111.6 | 7.1 | 8.1 | 54.0 |
| | Generated 2 | 2.2 | 0.0 | 95.9 | 6.6 | 4.1 | 53.4 |
| | Generated 3 | 2.1 | 0.0 | 70.9 | 7.0 | 5.0 | 53.0 |

**Table (11) Results of t-test and F-test for daily precipitation series(2009-2011)**

| Site | Series Generated | t -value | F-value |
|---|---|---|---|
| Sulaimania  site | Generated 1 | 0.4 | 1.38 |
| | Generated 2 | 0.8 | 1.30 |
| | Generated 3 | 2.2 | 1.57 |
| Dokan  site | Generated 1 | -0.2 | 1.14 |
| | Generated 2 | -1.0 | 1.26 |
| | Generated 3 | -0.6 | 1.18 |
| Darbandikhan site | Generated 1 | 0.4- | 1.40 |
| | Generated 2 | 0.5 | 1.62 |
| | Generated 3 | 0.8 | 1.44 |
| Critical t-value   tc=2.41     for α=0.025 | | | |
| Critical F-value Fc= 2.07 for α=0.025 | | | |

**Table (12) Results of t-test and F-test  for the total monthly precipitation series (2009-2011).**

| Site | Variable | t -value | F-value |
|---|---|---|---|
| Sulaimania  site | Generated 1 | -0.70 | 1.37 |
| | Generated 2 | 0.30 | 1.67 |
| | Generated 3 | 0.70 | 1.05 |
| Dokan site | Generated 1 | -1.40 | 1.16 |
| | Generated 2 | -1.10 | 2.00 |
| | Generated 3 | -0.95 | 1.30 |
| Darbandikhan site | Generated 1 | -0.30 | 1.70 |
| | Generated 2 | 1.10 | 1.40 |
| | Generated 3 | 0.00 | 1.77 |
| Critical t-valuetc=2.41 for α=0.025 | | | |
| Critical F-value Fc= 2.07 for α=0.025 | | | |

**Table (13) Descriptive statistics of observed and three generated series**
**(total monthly precipitation series)(mm)**

| Site | Variable | Mean | Min | Max | Sd | Cs | Ck |
|---|---|---|---|---|---|---|---|
| Sulaimania Site | Observed | 74.1 | 0.6 | 214.8 | 53.2 | 0.8 | 3.8 |
| | Generated 1 | 83.8 | 1.1 | 207.9 | 45.5 | 0.8 | 3.9 |
| | Generated 2 | 70.1 | 1.7 | 198.5 | 41.1 | 0.5 | 3.2 |
| | Generated 3 | 65.4 | 2.6 | 224.6 | 54.6 | 0.6 | 2.2 |
| Dokan Site | Observed | 58.4 | 1.2 | 165.8 | 44.2 | 0.7 | 3.2 |
| | Generated 1 | 70.4 | 1.2 | 157.0 | 41.1 | 0.9 | 2.3 |
| | Generated 2 | 69.5 | 2.5 | 137.7 | 31.3 | 0.5 | 2 |
| | Generated 3 | 66.0 | 4.2 | 163.4 | 38.7 | 0.6 | 2.1 |
| Darbandikhan Site | Observed | 73.5 | 3.6 | 224.6 | 56.2 | 1.1 | 4.5 |
| | Generated 1 | 77.4 | 4.2 | 214.7 | 43.2 | 0.9 | 6.7 |
| | Generated 2 | 81.0 | 3.0 | 208.7 | 47.2 | 0.4 | 3.4 |
| | Generated 3 | 73.5 | 4.4 | 223.0 | 42.2 | 0.8 | 2.8 |

These tables illustrate that the developed multisite daily precipitation model is successful in resembling the observed statistical properties of the observed series with a high degree of accuracy. The t-test values for preserving the daily precipitation means and those of  the total monthly precipitation are all less than the critical t-values which indicates that there are no significant differences in mean values of the observed and generated series. Similar observation was obtained for the F-test.

## Conclusions:

1. The derived multisite daily precipitation model was found capable of resembling the precipitation data and it's occurrence in the selected three sites of the cases study , Sulaimani , Dokan , and Darbandikhan .

2. The number of occurrence codes found were (64) calculated for the observed series of the three sites and is found to follow Gamma frequency distribution as the best among the checked frequency distributions ,Normal, Exponential, Gamma, Lognormal, and Chi-square distributions. This was decided according to the Chi-square test and Kolmogorov-Smirnov test. The gamma distribution gave the minimum tests values of (281.11, 0.102) respectively.

3. The best fit frequency distribution of the non-zero precipitation values for Sulaimani daily Precipitation was the exponential frequency distribution with the minimum Chi-square and Kolmogorov-Smirnov tests values of (6.12, 0.01) respectively. The best fit frequency distribution for Dokan and Darbandikhan non-zero daily precipitation is the Gamma distribution, with the minimum Chi-square and Kolmogorov-Smirnov tests values of (12.85, 0.02), and (6.7 ,0.027) respectively.

4. The t-test for means and the F-test for variances shows that the developed model can forecast daily data that had no significant differences in their means and variances than the those of the observed series. The two test results indicate 100% succeed for a three sets of generated daily precipitation for each site.

5. The t-test for means and F-test for variances for the total monthly precipitation series generated using the developed model indicate the model capability to preserve the observed total precipitation monthly means and variances with 100% succeed.

## References:

[1] AKSOY H., 2000,”*Use of Gamma Distribution in Hydrological Analysis”*, Turk J Engin Environ Sci, 24: 419-428.

[2] Apipattanavis S., Podesta G. and Rajagoplalan B., 2007, "*A Semiparametric Multivariate and Multisite Weather Generator*", Water Resource Research, Vol. 43, W11401 doi 10. 1029.

[3] Bardossy A., andPegram G.G.S., 2009, “*Copula Based Multisite Model for Daily Precipitation Simulation*”, J Hdrol.EarthSyst.Sci., V13, 2299-2314.

[4] Barzinji K. T., 2003,"*Hydrogic Studies for GoizhaDabashan and Other Watersheds in Sulimani Governorate* ", M.Sc. thesis submitted to the college of Agriculture, University of Sulaimani.

[5] Beersma J.J. and Buishand T. A., 2003, "*Multi-Site Simulation of Daily Precipitation and Temperature Conditional on the Atmosphere Circulation*", climate research, Vol. 25:121-132.

[6] Chapman T.G., 1994,”*Stochastic Models for Daily Rainfall*”, Surface Hydrology and Water Resources Papers; Preprints of Papers. Barton, ACT: Institution of Engineers, Australia, 7-12.

[7] Corder G.W.,and Foreman D. I.,2009,”*Nonparametric Statistics for Non-Statisticians: A Step-by-Step Approach* “,John Wiley and Sons.Inc.,Hoboken, New Jersey

[8] Fowler H.J. , Kilsby C.G., and O’connel P.E. , 2003, “*Modeling the Impacts of Climatic Change and Variability on the Reliability ,Resilience ,and Vulnerability of a Water Resource System*", J Water Resource Research, Vol. 399 no. 8, 1222

[9] Illich N. and Despotivic J., 2008,"*A Simple Method for Affective Multi-Site Generation of Stochastic Time Series*”,Stoch.Enviro Risk Asses, 22:265-279

[10] JohnsonN. L., and Kotz S., 1994, and BalakrishnanN.*,” Continuous Univariate Distributions*”, Vol. 1, Wiley Series in Probability and Statistics.

[11] Khalili M, Leconte R. and Brissette F., 2007, "*Stochastic Multisite Generation of Daily Precipitation Data Using Spatial Autocorrelation*", J Hydrometeorology, Vol.8, P 396-412

[12] Khalili M. and Brissette F., 2009, " *Stochastic Multi-Site Generation of Daily Weather Data*”, Stoch Environ. Risk Asses, 23, 837-849.

[13] Makhnin O.V. and Mcallister D. L., 2009, "*Stochastic precipitation Generation Based on a Multivariate Autoregression Model*", J hydrometeor, 10, 1397-1413

[14] Mehrotra, R. And Sharma A., 2005, "*A Semi-Parametric Stochastic Model for Simultaneous Stochastic Simulation of Daily Precipitation Amount at Multiple Sites*”, Journal of Hydrology,V-335,Issues 1-2,P180-193

[15] Richardson C. W. and Wright D. A., 1984, "*WGEN: A Model for Generating Daily Weather Variables*", United States Department of Agriculture, Agriculture Research Service ARS-8

[16] Srikanthan R. and McMahon T. A., 2001, “*Stochastic Generation of Annual, Monthly and Daily Climate Data: A Review*:,Hydrology and Earth System Sciences, 5(4), 653–670.

[17] Tobler W., (1970) "*A computer Movie Simulating Urban Growth in the Detroit*

*Region*". Economic Geography, 46(2): 234-240.

[18] Wilks D.S., 1998, "*Multisite Generalization of Daily Stochastic Precipitation Generation Model*", journal of Hydrology 210, 178-191

[19] Wilks D. S., 1999, "*Simultaneous Stochastic Simulation of Daily Precipitation, Temperature and Solar Radiation at Multiple Sites in Complex Terrain*", Elsevier, agricultural and forest meteorology 96:85-101.