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Assessment of Spatio-Temporal Variability and Probabilistic Prediction of Annual Rainfalls in a River Catchment of Udaipur, Rajasthan

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ABSTRACT

In the present study, the spatial and temporal variability of annual rainfall is assessed and predicted at selected return periods by using probabilistic approach for the Wakal River catchment of Udaipur, Rajasthan, India. Annual rainfall data for five raingauge stations (i.e. Dewas, Jhadol, Ogna, Kotra and Gogunda) of the study area for a period of 15 years (1992-2006) were analysed by box plots and normal probability plots. Normality was tested by applying four normality tests. Spatial and temporal variability of the rainfall was evaluated by using Levene's analysis of variance (ANOVA) and Mann-Kendall tests. Furthermore, nine probability distributions were fitted to the annual rainfall series. The best-fit distribution was selected based on Chi-square and Kolmogorov-Smirnov tests. Box plots revealed few outliers in the rainfall series of Dewas, Jhadol and Ogna stations. Due to outliers, the annual rainfall of these three stations was found to be non-normal by normal probability plots, which was further confirmed by the normality tests. After removing outliers, the annual rainfalls were found to be normal. Moreover, the annual rainfall does not have significant spatial and temporal variability. The results of the goodness-of-fit tests indicated that log Pearson type-III is the best-fit distribution and rainfalls are predicted at selected return periods.

Keywords: Annual rainfall, Normal probability plot, Probability distribution, Spatial and temporal variability

INTRODUCTION

Rainfall is one of the important components of water cycle. Accurate measurement, prediction and forecasting of rainfall are essential for estimating watershed/catchment responses. Generally, large catchments are less likely to experience high-intensity storms over the entire catchment area than small catchments (Siriwardena and Weinmann, 1996). This necessitates estimation of mean areal rainfall

based on several point rainfall values measured with a network of raingauges in the catchment. Areal rainfall cannot be directly measured, and estimation of areal rainfall has been the focus of many studies in the past (Omolayo, 1993; Srikathan, 1995; Siriwardena and Weinmann, 1996; Sivapalan and Blöschl, 1998; Asquith and Famiglietti, 2000; De Michele *et al.*, 2001; Durrans *et al.*, 2002). The necessity for converting point rainfall to areal rainfall arises for large catchment areas, where rainfall may vary widely over space and time.

A probabilistic approach to planning the development of water resources is widely dealt with frequency analysis. The usual approach is to fit probability distribution functions to the observed data and use goodness-of-fit tests to determine the best-fit distribution (Machiwal *et al.*, 2004, 2006; Singh *et al.*, 2011). The search for a proper probability distribution function for floods (i.e. an extreme process) has been the subject of several studies (Castillo, 1988; Önöz and Bayazit, 1995). However, relatively less number of studies is reported wherein probability distribution function has been selected for non-extreme rainfall or other meteorological processes. Lowing (1987) suggested a procedure for selecting a probability function for non-extreme hydrologic data.

The Wakal River catchment of Udaipur, Rajasthan, produces small runoff streams that are ephemeral in nature during the monsoon season of the year. There are a total of five raingauge stations in the catchment to measure point rainfall values. The present study was carried out to determine presence/absence of spatial and temporal variability of the annual rainfall. Furthermore, annual rainfalls of five raingauge stations are estimated at selected return periods by using the best-fit probabilistic models.

STUDY AREA AND DATA

The Wakal River originates from the hills in the northwest region of Udaipur district of southern Rajasthan, India (Figure 1). The river flows in the southern direction through the Udaipur district and then enters the Gujarat state of India. The catchment of the Wakal River is surrounded by hills with latitudes of 24°0' and 24°52' N and longitudes of 73°4' and 73°36' E. The catchment area of the Wakal River is about 1688.82 km^2. The total length of the basin is 71.77 km, whereas the maximum width is 44.67 km. The Wakal River catchment is one of the most water-stressed regions of India. Rivers or streams in this region are ephemeral, and therefore, groundwater acts as the main source of water supply for various purposes.

In this study, the annual rainfall data for five raingauge stations (i.e. Dewas, Jhadol, Ogna, Kotra and Gogunda) of the Wakal River catchment, Udaipur, are analysed. The location of raingauge stations is shown in Figure 1. Daily rainfall data for a period of 15 years (1992-2006) for the five raingauge stations were collected from the Irrigation Department, Udaipur, Rajasthan.

METHODOLOGY

The collected daily rainfall data were checked for the presence of anomalies and were found to be free from them. There were no missing data in the dataset. Preliminary analysis of the collected data was performed with the help of box plots (which represent a five-number summary consisting of the median, the two

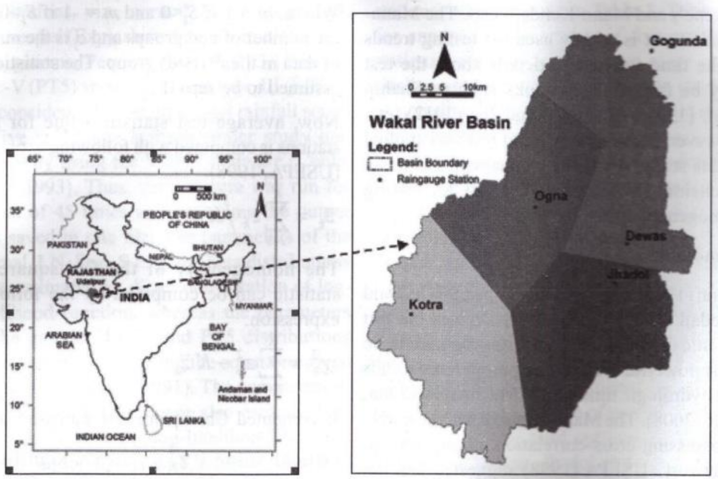

Figure 1: Location map of study area showing location of raingauge stations.

quartiles and the two extremes) and normal probability plots in order to identify the outliers and their effects on the data as well as to check the normality of the data. In addition to normal probability plots, four most widely used statistical tests, i.e. Geary's test (Walpole and Myers, 1989), Kolmogorov-Smirnov test (NIST/SEMATECH, 2007), D'Agostino-Pearson omnibus test (D'Agostino, 1986) and Shapiro-Wilk test (USEPA, 1998) were applied to examine the normality of the annual rainfall series for five raingauge stations under study. Among the four applied normality tests, the D'Agostino-Pearson omnibus test is reported to be a powerful normality test (e.g. DeCarlo, 1997; Öztuna *et al*., 2006). Details about box plots, normal probability plots and normality tests can be found in USEPA (1998) and Machiwal and Jha (2012).

It is a good practice to correlate annual rainfall of one raingauge station with annual rainfall of other stations by single and multiple linear regression models. If the relationship between rainfall of one station and the rainfall of other stations is found to be significant, then some mathematical relationship can be developed to estimate the missing annual rainfall of any station based on the annual rainfalls of other stations for a particular year. In this study, single and multiple linear regression analyses were performed with the help of MS-Excel and SYSTAT 8.0 software to find out the relationship amongst the rainfall of different stations.

Furthermore, the spatial and temporal variability of annual rainfalls among five raingauge stations was evaluated by applying

Levene's and Mann-Kendall tests. The Mann-Kendall test is widely used for testing trends in the time series, and details about the test may be found in textbooks such as Shahin *et al*. (1993), Machiwal and Jha (2012), etc. However, homogeneity trend test was applied in this study, which may be considered as an extension of Mann-Kendall test for testing homogeneity of the trends.

Trend Test

Mann (1945) originally developed this test and Kendall (1975) subsequently derived the test statistic distribution. This test is reported to be most powerful for detecting monotonic trends in a hydrologic time series (Machiwal and Jha, 2006, 2008). The Mann-Kendall test is capable of assessing cross-correlation among sites in a network. USEPA (1998) suggested that the Mann-Kendall test can be used for evaluating spatial homogeneity. Let $t = 1, 2, ..., n$ represent time, $k = 1, 2, ..., K$ represent sampling locations and x_{tk} represent the measurement at time t for location k. Considering the time series x_{tk} ($t = 1, 2, \ldots, n_k$) for each station k, each value x_{tk} is compared with all subsequent values x_{tk+1} and a new series y_k is generated as shown below (Salas, 1993):

$$\begin{aligned} y_k &= 1 \quad & f\ x_t > x_{t'} \\ y_k &= 0 \quad & f\ x_t = x_{t'} \\ y_k &= -1 \quad & f\ x_t < x_{t'} \end{aligned} \qquad (1)$$

The test statistic (z_k) for n_k>10 may be written as follows (USEPA, 1998):

$$z_k = \frac{\sum_{t'=1}^{n_k-1}\sum_{t=t'+1}^{n_k} y_k + m}{\sqrt{\frac{1}{18}\left[n_k(n_k-1)(2n_k+5) - \sum_{i=1}^{g} e_i(e_i-1)(2e_i+5)\right]}} \qquad (2)$$

Where, $m = 1$ if S_k<0 and $m = -1$ if S_k>0, g is the number of tied groups and e_i is the number of data in the i^{th} (tied) group. The statistic z_k is assumed to be zero if $S_k = 0$.

Now, average test statistic value for all K stations is computed with following expression (USEPA, 1998):

$$\bar{z}_k = \sum_{z=1}^{K} z_k \Big/ K \qquad (3)$$

The homogeneity of the Chi-square test statistic can be computed by the following expression:

$$\chi_h^2 = \sum_{k=1}^{K} z_k^2 - K\,\bar{z}_k \qquad (4)$$

If computed Chi-square test statistic (χ_h^2) < critical value (χ_{K-1}^2) at 5% significance level for K-1 degrees of freedom, then there are comparable dynamics across raingauge stations and the annual rainfalls are considered to be homogeneous, i.e. non-significant spatial variability. Now, χ^2 with one degree of freedom (i.e. χ_1^2) is compared with the expression $K\bar{z}^2$. If $K\bar{z}^2 \le \chi_1^2$, then there is no significant evidence of a monotonic trend across all stations and the raingauge stations are considered stable over time. This indicates absence of significant temporal variability in annual rainfall.

It is customary to check and compare the suitability of several types of distributions and to make a choice among them. In these comparisons, the descriptive and predictive abilities of distributions are not always taken into account (Cunnane, 1987). In this study, nine continuous and homogeneous probability distributions, viz., normal, log-normal (LN), exponential (Exp), shifted exponential (S Exp), beta, gamma, Pearson type-III (PT3), Pearson type-V (PT5) and log-Pearson type-III (LPT3), are considered for fitting annual rainfall series of five raingauge stations under study one by one by using the VTFIT software (Cooke *et al.*, 1993). Thus, the software was run for a total of 45 times and each time the output was saved in one file. The parameters of the normal, LN, Exp, S Exp and beta distributions were estimated by direct optimisation of log-likelihood function, whereas the parameters of the gamma, LPT3 and PT5 distributions were estimated by solving the equations given by Law and Kelton (1991). The parameters of the PT3 distribution were also estimated by direct optimisation of log-likelihood function, but the initial estimate of location parameter was obtained by the method suggested by Kline and Bender (1990). VTFIT, which is used for fitting probability distributions, also provides the observed test statistic values for six different goodness-of-fit tests along with degrees of freedom. A brief description of these distributions is given in Machiwal *et al.* (2006).

Moreover, the Chi-square and Kolmogorov-Smirnov tests were used to select best-fit distributions for annual rainfall series. Finally, the median test (Kanji, 2001) was performed to test the fitness of single probability distribution for describing each individual annual rainfall series of five raingauge stations.

RESULTS AND DISCUSSION

Statistical Characteristics of Annual Rainfall Series

Basic statistical characteristics of all the five annual rainfall series (i.e. for five raingauge stations) are presented in Table 1. Time plots for annual rainfall series of five raingauge stations (not shown here) have more or less similar pattern over time. However, the Kotra region always experiences high annual rainfall compared with regions where other raingauge stations are situated. Box plots were drawn for annual rainfalls of five raingauge stations and are shown in Figure 2. Plots indicate that the upper half range of annual rainfall data for the Dewas and Jhadol stations is heavily weighted or more data lie in the upper half range. On the contrary, the lower half range of annual rainfall data for Ogna, Kotra and Gogunda stations is heavily weighted compared with the upper half range. The most significant finding of the box plots is the presence of one severe outlier and two and one mild outliers in the annual rainfall for Dewas, Jhadol and Ogna stations,

Table 1: Basic statistical characteristics of annual rainfall of the Wakal River catchment, Udaipur

Description	Annual rainfall series				
	Dewas	Jhadol	Ogna	Kotra	Gogunda
Mean (mm)	565.4	625.5	530.0	836.8	572.2
Standard deviation (mm)	285.2	278.1	213.7	351.4	188.7
Coefficient of variation (%)	50.45	44.45	40.33	41.99	32.98
Skewness	2.05	1.73	1.78	0.86	0.57
Kurtosis	6.31	3.20	3.79	-0.11	-0.01
Minimum (mm)	175.0	319.0	319.0	388.0	319.0
Maximum (mm)	1436	1377	1131	1564	982.0

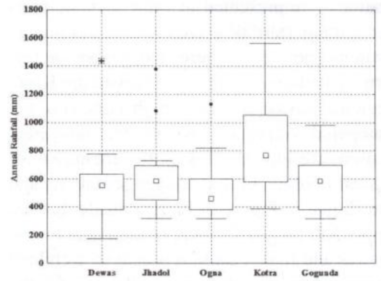

Figure 2: Box plots of the annual rainfalls for five raingauge stations of the study area.

respectively.

Normal probability plots for annual rainfall series of five raingauge stations were plotted and are shown in Figure 3i and 3ii for Ogna and Kotra stations, respectively. It is seen that the normal probability plots of Kotra (Figure 3ii) and Gogunda lie on straight line and, hence, the annual rainfall data for these two stations are considered to be normally distributed. However, annual rainfalls of three raingauge stations, i.e. Dewas, Jhadol and Ogna (Figure 3i), deviate very much from the straight line, which indicates non-normality of the rainfall data. Furthermore, normality probability plots for these three stations are found lying on a straight line after removing one severe outlier, and two and one mild outliers from the annual rainfalls of Dewas, Jhadol and Ogna (Figure 4) stations, respectively. Therefore, it is inferred that all five annual rainfall series can be considered normal after removing outliers.

Normality of Annual Rainfall

Results of four tests are presented in Table 2. For a normally distributed time series, the value of Geary's test statistic approaches one (Walpole and Myers, 1989). Given this criterion, the annual rainfall series of two stations (i.e. Kotra and Gogunda) can be considered normal based on the Geary's test (Table 2). However, value of Geary's test statistic is different from the one for annual rainfalls of other three stations. The results of the Kolmogorov-Smirnov, the D'Agostino-Pearson omnibus and Shapiro-Wilk tests can be interpreted by comparing the observed *P*-values with 0.05. If the *P*-value is more than 0.05, then null hypothesis of normality cannot be rejected. It can be seen from Table 2 that the observed *P*-values for the annual

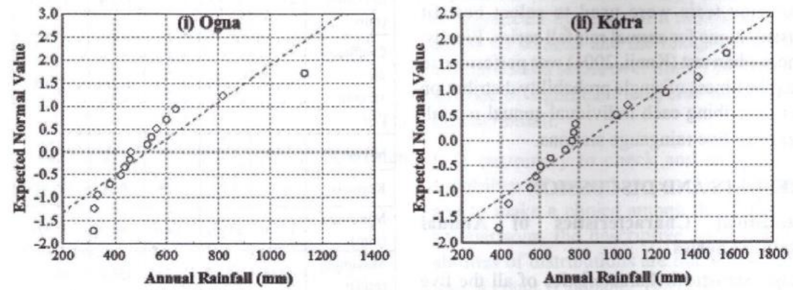

Figure 3: Normal probability plots of the annual rainfalls for two raingauge stations.

Table 2: Observed test statistics and results of four normality tests

Test statistic	Dewas	Jhadol	Ogna	Kotra	Gogunda
(a) Geary's test					
Geary's test statistic	0.80	0.88	0.90	1.03	1.03
Normality	No	No	No	Yes	Yes
(b) Geary's test after removing outliers					
Number of removed outliers	1	2	1	–	–
Geary's test statistic	0.95	1.02	1.02	–	–
Normality	Yes	Yes	Yes	–	–
(c) Kolmogorov-Smirnov test					
KS test statistic	0.2635	0.2215	0.1782	0.2253	0.1141
P-value	0.0062	0.0460	>0.10	0.0392	>0.10
Normality	No	No	Yes	No	Yes
(d) Kolmogorov-Smirnov test after removing outliers					
KS test statistic	0.1533	0.1486	0.1427	–	–
P-value	> 0.10	> 0.10	> 0.10	–	–
Normality	Yes	Yes	Yes	–	–
(e) D'Agostino-Pearson omnibus test					
K^2 test statistic	18.86	12.09	13.34	2.268	1.072
P-value	< 0.0001	0.0024	0.0013	0.3218	0.5851
Normality	No	No	No	Yes	Yes
(f) D'Agostino-Pearson omnibus test after removing outliers					
K^2 test statistic	0.6449	1.316	3.330	–	–
P-value	0.7244	0.5179	0.1892	–	–
Normality	Yes	Yes	Yes	–	–
(g) Shapiro-Wilk test					
W test statistic	0.8056	0.8264	0.8318	0.9178	0.9515
P-value	0.0043	0.0082	0.0097	0.1783	0.5479
Normality	No	No	No	Yes	Yes
(h) Shapiro-Wilk Test after removing outliers					
W test statistic	0.9669	0.9607	0.9321	–	–
P-value	0.8323	0.7647	0.3264	–	–
Normality	Yes	Yes	Yes	–	–

Note: Test statistic values are at 5% level of significance.

rainfalls of Ogna and Gogunda are greater than 0.05 for the Kolomogorov-Smirnov test. Similarly, the observed *P*-values are greater than 0.05 for the annual rainfalls of Kotra and Gogunda for the D'Agostino-Pearson omnibus and Shapiro-Wilk tests. Thus, it is observed that three annual rainfall series (i.e. Dewas, Jhadol and Ogna) are found to be significantly different from normality. After removing these mild and severe outliers and then applying all the four tests, it was found that observed *P*-values are not significant (Table 2). Thus, all the five rainfall series under the study could be considered normal.

Regression Analysis of Annual Rainfall

In this study, linear relations among annual rainfalls of five raingauge stations were found out by applying simple and multiple regression models. Scatter diagrams between annual rainfalls of the raingauge stations were drawn and a linear model was fitted. The equation and coefficient of determination (R^2) of the simple linear regression model is given in Table 3. It is seen from Table 3 that R^2 values are more than 0.70 for annual rainfalls of four raingauge stations (i.e. Dewas, Jhadol, Ogna and Gogunda). However, R^2 values are found to be less than 0.70 for all simple linear regression models of Kotra. Correlation coefficients among annual rainfalls of five raingauge stations were computed. Results of significance test for correlation coefficients revealed that simple linear relations among all the annual rainfalls are highly significant at 5% level of significance.

The values of the coefficients for the fitted multiple linear regression models are presented in Table 4. It is observed from Table 4 that R^2 values are higher than 0.75 for all the five multiple linear regression models and the F ratios are within critical limits. Thus, all the simple and multiple linear relationships among the annual rainfalls are found to be significant and the developed regression models can be used to find out the missing annual rainfall.

Table 3: Single linear regression models for the annual rainfall series of the Wakal River catchment, Udaipur

Raingauge station	Dewas	Jhadol	Ogna	Kotra	Gogunda
Dewas	–	0.9209 *R* - 10.599 (0.81)	1.2262 *R* - 84.466 (0.84)	0.613 *R* + 52.427 (**0.57**)	1.2736 *R* - 163.33 (0.71)
Jhadol	0.8752 *R* + 130.66 (0.81)	–	1.2053 *R* - 13.283 (0.86)	0.5484 *R* + 166.62 (**0.48**)	1.3093 *R* - 123.7 (0.79)
Ogna	0.6885 *R* + 140.68 (0.84)	0.7121 *R* + 84.567 (0.86)	–	0.5054 *R* + 107.06 (**0.69**)	1.0011 *R* - 42.86 (0.78)
Kotra	0.9304 *R* + 310.73 (**0.57**)	0.8757 *R* + 289.02 (**0.48**)	1.3661 *R* + 112.79 (**0.69**)	–	1.4073 *R* + 31.542 (**0.57**)
Gogunda	0.5574 *R* + 257.03 (0.71)	0.603 *R* + 195.04 (0.79)	0.7804 *R* + 158.62 (0.78)	0.4058 *R* + 232.6 (**0.57**)	–

Note: *R* = annual rainfall; bracketed figures indicate coefficient of determination (R^2) values; boldface figures indicate small R^2 values.

Table 4: Multiple linear relations among annual rainfalls of five stations

Raingauge station	Multiple linear relation	Multiple R^2	Std. error of estimate	F ratio
Dewas	0.358 J + 0.704 O + 0.047 K + 0.034 G – 90.396	0.861	125.961	15.445
Jhadol	0.218 D + 0.863 O - 0.209 K + 0.461 G – 44.541	0.911	98.298	25.506
Ogna	0.180 D + 0.362 J + 0.176 K + 0.050 G + 25.678	0.937	63.637	36.977
Kotra	0.128 D - 0.924 J + 1.864 O + 0.588 G + 18.001	0.752	206.86	7.599
Gogunda	0.018 D + 0.408 J + 0.106 O + 0.117 K + 152.325	0.829	92.427	12.088

Note: D, J, O, K and G indicate annual rainfalls of Dewas, Jhadol, Ogna, Kotra and Gogunda raingauge stations, respectively.

Spatial and Temporal Variability of Annual Rainfalls

In the present study, spatial variability among the annual rainfalls within the study area was tested by two tests (i.e. Levene's analysis of variance (ANOVA) and Mann-Kendall tests). Mann-Kendall test also tested temporal variability across all the raingauge stations by other test statistics. Results of both the tests are summarised in Table 5. It is apparent from Table 5 that computed test statistic of Levene's test is less than the critical value at 5% level of significance. Thus, the annual rainfall within the study area does not have significant spatial variability. Furthermore, the computed test statistic value of Mann-Kendall test (χ_h^2) is compared with its critical value (Table 5). It is clear that the computed χ_h^2 is less than its critical value at 5% level of significance. Therefore, the null hypothesis of presence of homogeneity among the annual rainfalls of five raingauge stations cannot be rejected. Thus, Mann-Kendall test also suggested the presence of homogeneity or absence of significant spatial variability among the annual rainfalls within the study area. Moreover, another test statistic (i.e. $K\bar{z}^2$) is compared with its critical value (Table 5). It is seen that $K\bar{z}^2$ is less than its critical value at 5% level of significance and therefore, there is no temporal variability in the annual rainfall across all the raingauge stations. Based on Levene's and Mann-Kendall tests, it is concluded that the annual rainfall within the study area is uniform over the space and time.

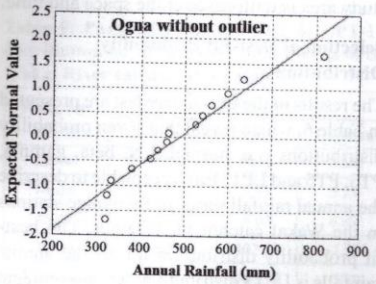

Figure 4: Normal probability plots of the annual rainfall for Ogna raingauge station after removing outliers.

Table 5: Observed and critical test statistics of Levene's, Mann-Kendall and Median tests for the annual rainfalls of the Wakal River catchment, Udaipur

Levene's test		Mann-Kendall test				Median test	
f	$f_{critical}$	χ_h^2	$\chi_{critical}^2$	$K\bar{z}^2$	χ_1^2	$\chi_{computed}^2$	$\chi_{critical}^2$
0.043	2.517	0.498	9.49	3.29	3.84	8.571	9.49

Selection of Best-Fit Probability Distribution

The results of the Chi-square test are presented in Table 6, which reveal that seven probability distributions (i.e. normal, LN, beta, gamma, PT3, PT5 and LPT3) are acceptable to describe the annual rainfall series of raingauge stations in the Wakal catchment, Udaipur. The best-fit probability distribution for all the annual rainfalls is LPT3 distribution. It is also evident that more than one probability distribution has similar minimum test statistic values for the consecutive 4-, 5- and 6-day maximum rainfall series.

The results of the Kolmogorov-Smirnov test are presented in Table 7, which reveal that seven probability distributions (i.e. normal, LN, beta, gamma, PT3, LPT3 and PT5) are acceptable. In this case, S Exp distribution is also acceptable for the annual rainfall series of four stations, except Ogna raingauge station. The best-fit probability distribution for the annual rainfall of Dewas is beta, whereas for the annual rainfall series of Jhadol, it is LPT3 distribution (Table 7). Similarly, normal is the best-fit distribution for the annual rainfall of Ogna and PT5 is the best-fit distribution for the annual rainfall of Kotra stations. Gamma is the best-fit distribution for the annual rainfall of Gogunda raingauge station.

LPT3 probability distribution could be chosen as most appropriate and common for describing all the annual rainfall series of the Wakal River catchment, Udaipur. The selection of the single PT3 distribution as overall best-fit is justified by the minimum Chi-square test statistic values for all the annual rainfall series and the minimum Kolmogorov-Smirnov test statistic values for the annual rainfall series of Jhadol and Kotra raingauge stations. Results

Table 6: Summary of the Chi-square test statistic values for the nine probability distributions fitted to the annual rainfall series of five stations of Udaipur

Raingauge station	Values of the Chi-square test statistic for the probability distributions								
	Normal	LN	Exp	S Exp	Beta	Gamma	PT3	LPT3	PT5
Dewas	3.6	0.4	8.4*	10*	0.4	3.6	2.8	**0**	1.2
Jhadol	2.8	**0.4**	12.4*	24.4*	**0.4**	1.2	1.6	**0.4**	**0.4**
Ogna	**0**	0.4	5.2	8.4*	0.4	0.4	0.4	**0**	1.6
Kotra	0.4	**0**	10*	19.6*	0.4	**0**	3.6	**0**	**0**
Gogunda	**0.4**	**0.4**	8.4*	30*	1.6	**0.4**	1.2	**0.4**	**0.4**

Note: * As $\chi_{\text{observed}}^2 > \chi_{\text{critical}}^2$ (5.991), the probability distribution cannot be accepted; boldface figures indicate the best-fit probability distribution.

Table 7: Values of the Kolmogorov-Smirnov test statistic for the nine probability distributions fitted to the annual rainfall series of five stations of Udaipur

Raingauge station	Values of the Kolmogorov-Smirnov test statistic for the probability distributions								
	Normal	LN	Exp	S Exp	Beta	Gamma	PT3	LPT3	PT5
Dewas	0.260	0.175	0.365*	0.247	**0.157**	0.204	0.183	0.166	0.194
Jhadol	0.217	0.136	0.400*	0.150	0.143	0.172	0.167	**0.113**	0.151
Ogna	**0.119**	0.186	0.432*	0.379*	0.164	0.192	0.184	0.145	0.242
Kotra	0.227	0.152	0.371*	0.168	0.180	0.165	0.204	**0.145**	**0.142**
Gogunda	0.122	0.127	0.427*	0.189	0.153	**0.105**	0.209	0.130	0.122

Note: * As $d_{observed} > d_{critical}$ (0.338), the probability distribution cannot be accepted; boldface figures indicate the best-fit probability distribution.

of the median test are presented in Table 5. It can be seen from the table that computed χ^2 test statistic is less than its critical value at 5% level of significance. Hence, the null hypothesis that five annual rainfall series have the same probability distribution cannot be rejected. Thus, selection of single best-fit probability distribution for all individual rainfall series is statistically justified.

Prediction of Annual Rainfall

The values of the parameters of the overall best-fit distribution for the six maximum rainfall series are shown in Table 8. The annual rainfalls of the five raingauge stations in this study are predicted for the return periods of 1.33, 2, 3, 4, 5, 10, 15, 20 and 30 years (Table 9). It should be noted that these predicted values are based on the corresponding best-fit probability distribution for the five annual rainfall series. These rainfall predictions are useful for planning and designing of soil and water conservation structures in the catchment of the study area.

Table 8: Parameters of the best-fit LPT-III distribution for the annual rainfall series of the Wakal River catchment, Udaipur

Raingauge station	Parameters		
	Scale	Shape	Location
Dewas	0.074	34.86	3.64
Jhadol	0.122	9.33	5.23
Ogna	-0.207	4.03	6.89
Kotra	0.020	402.07	-1.27
Gogunda	0.008	1419.53	-5.70

Table 9: Annual rainfalls for five raingauge stations at the selected return periods

Return period (Year)	Annual rainfall (mm)				
	Dewas	Jhadol	Ogna	Kotra	Gogunda
1.33	375	444	339	590	438
2	498	557	458	768	542
3	604	656	536	911	622
4	676	725	580	1005	672
5	732	779	610	1075	710
10	909	951	684	1287	819
15	1016	1057	719	1409	879
20	1094	1135	741	1496	922
30	1209	1251	768	1620	981

CONCLUSIONS

The present study deals with evaluating spatial-temporal variability and forecasting of annual rainfall at selected return periods. Box plots indicated presence of normality in the rainfall series of Kotra and Gogunda raingauge stations and non-normality in the annual rainfall of Dewas, Jhadol and Ogna raingauge stations due to single or two mild outliers. The absence of non-normality in annual rainfall series of above three raingauge stations was further confirmed from the normal probability plots. After removing the mild outliers, all four applied normality tests indicated presence of normality in annual rainfall series for five raingauge stations under study.

Two best-fit criteria, i.e. coefficient of determination and correlation coefficient, showed that both simple and multiple linear regression models developed in the study could be selected for computation of the annual rainfall in a particular year for any of the raingauge stations based on the annual rainfall of other stations in that year. Moreover, multiple linear relationships were developed for the computation/prediction of annual rainfall of any station in the Wakal River catchment from annual rainfalls of other stations.

Results of Levene's ANOVA and Mann-Kendall tests revealed that the annual rainfall over the study area is stable and uniform over the space and time. Furthermore, Chi-square goodness-of-fit test accepted normal, LN, beta, gamma, PT3, PT5 and LPT3 probability distributions for describing the annual rainfalls of five raingauge stations. The similar seven probability distributions were accepted for describing the annual rainfall series based on the Kolmogorov-Smirnov goodness-of-fit test. Overall, the best-fit distribution for the study area was selected as LPT3 probability distribution. Finally, annual rainfall was predicted by using the best-fit probability distribution for the return periods of 1.33, 2, 3, 4, 5, 10, 15, 20 and 30 years.

REFERENCES

Asquith, W.H. and Famiglietti, J.S. (2000). Precipitation areal-reduction factor estimation using an annual-maxima centered approach. J Hydrol. 230(1-2), 55-69.

Castillo, E. (1988). *Extreme Value Theory in Engineering.* Academic Press, Inc., San Diego, CA.

Cooke, R.A., Mostaghimi, S. and Woeste, F.E. (1993). VTFIT: A microcomputer-based routine for fitting probability distribution functions to data. *Appl. Eng. Agric. ASAE.* 9(4), 401-408.

Cunnane, C. (1987). Review of statistical models for flood frequency estimation. In Singh, V.P. (ed.), *Hydrologic Frequency Modeling*, D. Reidel, Dordrecht, pp. 49-95.

D'Agostino, R.B. (1986). Tests for the normal distribution. In D'Agostino, R.B. and Stephens, M.A. (eds.), *Goodness of Fit Techniques*, Chapter 9, Marcel Decker, New York.

De Michele, C., Kottegoda, N.T. and Rosso, R. (2001). The derivation of areal reduction factor of storm rainfall from its scaling properties. *Water Res. Res.* 37(12), 3247-3252.

Decarlo, L.T. (1997). On the meaning and use of kurtosis. Psychological methods. *Am. Psychol. Assoc.* 2(3), 292-307.

Durrans S.R, Julian, L.T. and Yekta, M. (2002). Estimation of depth-area relationships using radar-rainfall data. *J. Hydrol. Eng.* 7(5), 356-367.

Kanji, G.K. (2001). *100 Statistical Tests.* Sage Publication, New Delhi, pp. 111.

Kendall, M.G. (1975). *Rank Correlation Methods.* Charles Griffin, London, UK.

Kline, D.E. and Bender, D.A. (1990). Maximum likelihood estimation for shifted Weibull and lognormal distributions. *Trans. ASAE.* **33**(1), 330-335.

Law, A.M. and Kelton, W.D. (1991). *Simulation Modeling and Analysis.* McGraw-Hill, Inc., New York.

Lowing, M.J. (ed.) (1987). *Casebook of Methods for Computing Hydrological Parameters for Water Projects.* UNESCO, Paris.

Machiwal, D. and Jha, M.K. (2006). Time series analysis of hydrologic data for water resources planning and management: A review. *J. Hydrol. Hydromech.* **54**(3), 237-257.

Machiwal, D. and Jha, M.K. (2008). Comparative evaluation of statistical tests for time series analysis: application to hydrological time series. *Hydrol. Sci. J.* **53**(2), 353-366.

Machiwal, D. and Jha, M.K. (2012). *Hydrologic Time Series Analysis: Theory and Practice.* Springer, Germany and Capital Publishing Company, New Delhi, India, pp. 303.

Machiwal, D., Jha, M.K. and Mal, B.C. (2006). Forecasting of salient consecutive days' maximum rainfalls of Kharagpur, India using probabilistic approach. *Int. Agric. Eng. J.* **15**(2 and 3), 65-77.

Machiwal, D., Jha, M.K., Sharma, A. and Dashora, P.K. (2004). Probabilistic forecasting of reservoir inflows – a case study. *Int. Agric. Eng. J.* **13**(1 and 2), 15-26.

Mann, H.B. (1945). Non-parametric tests against trend. *Econometrica.* **13**, 245–259.

NIST/SEMATECH (2006). NIST/SEMATECH e-Handbook of Statistical Methods, Available at http://www.itl.nist.gov/div898/handbook/, accessed on 29 October 2007.

Omolayo, A.S. (1993). On the transposition of areal reduction factors for rainfall frequency estimation. *J. Hydrol.* **145**, 191-205.

Önöz, B. and Bayazit, M. (1995). Best-fit distributions of largest available flood samples. *J. Hydrol.* **167**(1-4), 195-208.

Öztuna, D., Elhan, A.H. and Tüccar, E. (2006). Investigation of four different normality tests in terms of type 1 error rate and power under different distributions. *Turkish J. Med. Sci.* **36**(3), 171-176.

Salas, J.D. (1993). Analysis and modeling of hydrologic time series. In Maidment, D.R. (ed.), *Handbook of Hydrology*, McGraw-Hill, Inc., USA, pp. 19.1-19.72.

Shahin, M., Van Oorschot, H.J.L. and De Lange, S.J. (1993). *Statistical Analysis in Water Resources Engineering.* A.A. Balkema, Rotterdam, the Netherlands, pp. 394.

Singh, P.K., Machiwal, D. and Roy, M.K. (2011). Modelling daily runoff and probabilistic estimation of design maximum daily runoff from selected watersheds of Udaipur, Rajasthan. *Indian J. Soil Conserv.* **39**(3), 176-182.

Siriwardena, L. and Weinmann, P.E. (1996). Derivation of areal reduction factors for design rainfalls in Victoria. Report 96/4, Cooperative Research Center for Catchment Hydrology, Department of Civil Engineering, Monash University, Victoria, Australia.

Sivapalan M. and Blöschl, G. (1998). Transformation of point rainfall to areal rainfall: intensity-duration-frequency curves. *J. Hydrol.* **204**, 150–167.

Srikathan, R. (1995). A review of the methods for estimating areal reduction factors for design rainfalls. Report 95/3, Cooperative Research Center for Catchment Hydrology,Department of Civil Engineering, Monash University, Victoria, Australia.

USEPA (1998). *Guidance for Data Quality Assessment: Practical Methods for Data Analysis.* United States Environmental Protection Agency (USEPA), Quality Assurance Division, EPA QA/G-9, QA97 Version, pp. 2.3-3 to 2.3-5.

Walpole, R.E. and Myers, R.H. (1989). *Probability and Statistics for Engineers and Scientists, 4th Edition.* Macmillan Publishing Company, New York.