GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

RANKING OF PLOTTING POSITION FORMULAE IN FREQUENCY ANALYSIS OF ANNUAL AND SEASONAL RAINFALL AT PUDUCHERRY, SOUTH INDIA

A. Murugappan[*1], S. Sivaprakasam[2] & S. Mohan[3]
[*1 & 2] Department of Civil Engineering, Annamalai University, Annamalainagar – 608002, Tamil Nadu
[3]Environment and Water Resources Division, Department of Civil Engineering, Indian Institute of Technology Madras, Chennai – 600 032

ABSTRACT

In the frequency analysis of hydrologic data, the frequency of occurrence of the observed distributions is important for the purpose of plotting observed data called the "plotting positions". An acceptable determination of plotting positions has been a debatable question and has generated a great deal of discussion. Many methods for computing plotting positions have been proposed over the years. In the present study, the performance of nine plotting position formulae namely, Hazen, California, Weibull, Beard, Chegodayev, Blom, Gringorten, Cunnance and Adamowski, in estimating magnitudes of annual and seasonal rainfall with higher return periods (or lesser probability of exceedance) at Puducherry in Union Territory of Puducherry, has been assessed using the error statistics such as Mean Square Error (MSE), Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) and Agreement Index (AI) . The plotting-position formulae are assigned ranks based on the mentioned error statistics and the Agreement Index.

Keywords: *Rainfall, frequency analysis, plotting position, Weibull method.*

I. INTRODUCTION

Rainfall is one of the most important natural resources used as a direct/indirect input for meeting the water requirements of crop and an indirect input in satisfying the water demands of domestic, commercial and industrial activities through surface and subsurface storage. The occurrence and distribution of rainfall vary temporally and spatially. For overall water resources development on a larger time scale of any location/region, it becomes necessary to analyze the historical long-term annual and seasonal rainfall of the location/region.

One of the most imperative problem in hydrology deals with inferring the past records of hydrological events in terms of probabilities of occurrence. Probability and frequency analysis of rainfall data facilitate us to determine the expected rainfall with various chances of occurrence.

Probability plotting positions are used for the graphical demonstration of annual maximum hydrologic series and serve as estimates of the probability of exceedance of those series. Probability plots allow a visual assessment of the capability of the fit provided by alternative parametric flood frequency models. They also provide a non-parametric means of forming an estimate of the data's probability distribution by drawing a line by hand and/or programmed means through the plotted points. Because of these striking characteristics, the graphical approach has been preferred by many hydrologists and engineers. It has been commonly used both in hydraulic engineering and water resources research [1-4].

As established by the renewed attention emerged in the recent literature [5-14]. Practitioners are used to take advantage of modern software that adopts graphical estimation methods, even if there are a variety of effective analytical methods available, such as Maximum Likelihood and Bayesian techniques. In fact, particularly in decisive applications, the graphical estimation gives the distinctive chance to share statistical information with non-statisticians by allowing a visual check of the fit of the chosen model and by giving helpful understanding of the resulting conclusions.

Probability plotting positions have been discussed by hydrologists and statisticians for many years. In the past about 100 years, a number of plotting-position methods and related numerical methods have been proposed for analysis of extreme values. Reviews on plotting-position formulae have been made by [15-19]. Cunnane mentioned that a plotting formula should be unbiased and should have the smallest mean square error (MSE) among all estimates [15].

II. PLOTTING POSITIONS

Many plotting - position formulae are available, some of the more commonly used ones are given in Table 1 [20]. Adamowski [1] has shown that all of these formulae can be expressed in the general form

$$P_m = \frac{m-a}{N+b} \quad (1)$$

where a and b are constants, Pm is the probability of the exceedance of the mth observation. m is the rank of N ordered observations (in decreasing order) such as $P_{m=1} > P_{m=2} > \ldots\ldots > P_{m=N}$.

Table 1. More Commonly Used Plotting-position Formulae

Plotting-Position method	Formula for probability of exceedance, Pm $P_m = \frac{m-a}{N+b}$	a	b	Return period, $T = \frac{1}{P_m}$
Hazen (1914)	$\frac{m-0.5}{N}$	0.5	0.0	$\frac{N}{m-0.5}$
California (1923)	$\frac{m}{N}$	1.0	0.0	$\frac{N}{m}$
Weibull (1939)	$\frac{m}{N+1}$	0.0	1.0	$\frac{N+1}{m}$
Beard (1943)	$\frac{m-0.31}{N+0.38}$	0.31	0.38	$\frac{N+0.38}{m-0.31}$
Chegodayev (1955)	$\frac{m-0.3}{N+0.4}$	0.30	0.40	$\frac{N+0.4}{m-0.3}$
Blom (1958)	$\frac{m-0.375}{N+0.25}$	0.375	0.25	$\frac{N+0.25}{m-0.375}$
Gringorten (1963)	$\frac{m-0.44}{N+0.12}$	0.44	0.12	$\frac{N+0.12}{m-0.44}$
Cunnane (1978)	$\frac{m-0.4}{N+0.2}$	0.40	0.20	$\frac{N+0.2}{m-0.4}$
Adamowski (1981)	$\frac{m-0.25}{N+0.5}$	0.25	0.50	$\frac{N+0.25}{m-0.5}$

The most commonly used plotting - position formula in hydrology is the Weibull formula given by

$$P_m = \frac{m}{N+1} \quad (2)$$

where, Pm is the exceedance probability of the mth data point (observed value) is the sample arranged in the descending order of magnitudes. The return period of the mth data point, Tm, is the reciprocal of the probability of exceedance, Pm. Using the Weibull formula, the return period is given by

$$T_m = \frac{1}{P_m} = \frac{N+1}{m} \tag{3}$$

III. METHODOLOGY

Annual rainfall pertaining to the first 30 years (1900 – 1929) of available historical record of 100 years (1900 – 1999) is taken and the data are arranged in decreasing order of magnitude. Each data point is assigned a rank. The data having the highest magnitude was assigned the rank 1 (m = 1) and the data having the lowest magnitude is assigned the rank N (m = N = number of data points in the sample = 30). This arrangement gives an estimate of the exceedance probability, that is, the probability of a value being equal to or greater than the ranked value.

A graphical plot of probability of exceedance, Pm, obtained by the particular plotting – position formula, versus the obtained annual rainfall, R, with both variables on logarithmic scale, is made.

The observed values of annual rainfall, R, and their exceedance probabilities, Pm, are related such that observed values of annual rainfall are taken as the y-values and their exceedance probabilities are taken as the x-values. Logarithmic scale is used for both the axes. Linear equation of the form $R = AP_m + B$ is fitted to the plot where R is the annual rainfall with probability of exceedance Pm; A is the slope of the fitted line and B is the y – intercept. The degree of goodness of fit thus obtained is indicated by the R2 value obtained. The closeness of fit (for any plotting-position method) with the observed values of annual rainfall is examined as follows: The probability of exceedance, Pm, of the observed annual rainfall magnitudes in the 100 years of historical data (1900 – 1999) available is determined by the particular plotting-position method as outlined above. Then, using the linear equation of the form $R = AP_m + B$ fitted considering the first 30 years (1900 – 1929) of data , the annual rainfall magnitudes for different exceedance probabilities obtained with 100 years data are estimated (designated as Rest) . Then, the error statistics such as Mean Square Error (MSE), Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) and Agreement Index (AI) which are determined as follows:

$$MSE = \frac{1}{N}\sum_{i=1}^{N}(R_{est,\,i} - R_i)^2 \tag{4}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(R_{est,i} - R_i)^2} \tag{5}$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|R_{est,i} - R_i\right| \tag{6}$$

$$AI = \frac{R_{est}}{R} \tag{7}$$

The above exercise is done for all the nine plotting - position methods listed in Table 1. The performance of each of the plotting - position formulae is examined using the error statistics mentioned above. This procedure of evaluation will help in assessing the performance of each plotting-position formula in estimating annual rainfall magnitudes with probability of exceedance less than those obtained with sample data of size N = 30 taken for obtaining the linear fit. Or in other words, this procedure of performance evaluation will help in ranking the different plotting-position methods for estimation of magnitudes of annual rainfall with higher return periods.

The plotting-position formulae are assigned ranks based on the error statistics and the Agreement Index as detailed herein. The method which yields the least MSE is assigned the rank "1" and the method that yields the most MSE is assigned the rank "9". The same criterion is adopted for ranking of methods in terms of RMSE and MAE. The plotting-position method that yields an AI closest to unity is assigned the rank "1" and the one that yields an AI farthest from unity is assigned the last rank (Rank "9"). This logic is applied for minimum AI, maximum AI and mean AI. The method which has the minimum standard deviation of AI is given the best rank (Rank "1') and the one that has the maximum standard deviation is given the rank "9.

The overall ranking for each method is assigned by computing the mean of the ranking of that method in terms if MSE, RMSE, MAE, minimum AI, maximum AI, mean AI and standard deviation of AI. The mean ranking for a plotting-position method is computed as the average of all the rankings assigned to that method in terms of the seven statistics namely, MSE, RMSE, MAE, minimum AI, maximum AI, mean AI and standard deviation of AI. The method which yields the minimum mean ranking is assigned an overall ranking "1" and the one which yields the maximum mean ranking is assigned the overall ranking "9".

The methodology as described above is used for assessing the performance of each plotting-position method mentioned in estimating magnitudes of annual rainfall, north-east monsoon rainfall and south-west monsoon rainfall with different probabilities of exceedance.

IV. FUNDAMENTAL STATISTICS OF HISTORIC RAINFALL DATA

Tables 2 and 4 show respectively the fundamental statistics of annual and seasonal rainfall recorded at Puducherry during the 100-year period 1900-1999 and 30-year period 1901-1929. Table 3 shows the proportions of different seasonal rainfall in annual rainfall.

Table 2 Fundamental Statistics of Series of Annual Rainfall, North-east Monsoon Rainfall, South-west monsoon Rainfall, Summer Rainfall and Winter Rainfall at Puducherry in East coast of Indian Sub-continent

(Length of Record: 100 years from 1900 – 1999)

Rainfall series	Min (cm)	Max (cm)	Mean (cm)	Standard deviation (cm)	Coefficient of variation (%)	Skewness	Kurtosis
Annual (Jan – Dec)	56.6	212.6	125.9	36.2	28.8	0.4	- 0.5
North-east monsoon (Oct – Dec)	17.3	152.5	78.7	32.6	41.5	0.3	- 0.6
South-west monsoon (June – Sep)	10.4	73.5	34.4	13.3	38.7	0.6	0.2
Summer (March – May)	0.0	53.3	7.5	8.7	116.2	2.5	8.8
Winter (Jan – Feb)	0.0	38.5	5.3	7.2	135.7	2.3	6.4

Table 3 Proportion of North-east Monsoon Rainfall, South-west monsoon Rainfall, Summer Rainfall and Winter Rainfall in Annual Rainfall at Puducherry in East coast of Indian Sub-continent

(Length of Record: 100 years from 1900 – 1999)

Rainfall series	Proportion in Annual Rainfall						
	Min (%)	Max (%)	Mean (%)	Standard deviation (%)	Coefficient of variation (%)	Skewness	Kurtosis
North-east monsoon (Oct – Dec)	16.17	88.36	60.96	5.60	21.94	-0.712	0.576
South-west monsoon (June – Sep)	9.19	60.61	28.52	10.86	38.10	0.507	0.016

Summer (March – May)	0.00	45.49	6.17	6.91	111.89	2.560	10.352
Winter (Jan – Feb)	0.00	25.95	4.35	5.60	128.72	1.832	3.219

The maximum and minimum annual rainfall of 212.6 cm and 56.6 cm recorded in the years 1997 and 1968 respectively are found to be 68.9% more and 55.8% less than the mean annual rainfall of 125.9 cm. The annual rainfall was more than the mean annual rainfall in 32 years while it was less than the mean annual rainfall in 68 years. The North-east monsoon and the south-east monsoon contribute nearly two-thirds and one-third of the annual rainfall in the study location. The mean proportion of rainfall during North-east and South-west monsoons put together is nearly 90% of the mean annual rainfall while the mean proportion of rainfall during the summer and winter seasons put together is only about 10% of the mean annual rainfall. The coefficient of variation is found to be less than 50% in annual (28.8%), South-west monsoon (38.7%) and North-east monsoon (41.5%) rainfalls while it was more than 100% in winter (135.7%) and summer (116.2%) rainfalls. The skewness of 0.4 for annual rainfall and 0.3 for North-east monsoon rainfall indicate that the distributions of both annual rainfall and North-east monsoon rainfall are approximately symmetric. As per Bulmer, if skewness is between −½ and +½, the distribution is approximately symmetric [21]. The distribution of South-west monsoon rainfall can be considered as moderately skewed. If skewness is between −1 and −½ or between +½ and +1, the distribution is moderately skewed [21].

Table 4 Fundamental Statistics of Series of Annual Rainfall, North-east Monsoon Rainfall, and South-west monsoon Rainfall at Puducherry in East coast of Indian Sub-continent

(Length of Record: 30 years from 1900 – 1929)

Rainfall series	Min (cm)	Max (cm)	Mean (cm)	Standard deviation (cm)	Coefficient of variation (%)	Skewness	Kurtosis
Annual (Jan – Dec)	70.8	185.8	128.1	32.1	25.09	0.168	- 0.672
North-east monsoon (Oct – Dec)	17.3	150.2	80.8	30.9	38.20	0.320	- 0.041
South-west monsoon (June – Sep)	19.6	61.9	35.7	11.7	32.89	0.695	- 0.161

As the skewness of both annual rainfall (0.168) and North-east monsoon rainfall (0.320) recorded during the 30-year period from 1900 to 1929 lie between −½ and +½, the distribution is approximately symmetric. It is already seen that the distributions of both the annual rainfall and North-east monsoon rainfall pertaining to the 100-year series are also approximately symmetric.

V. RESULTS AND DISCUSSION

The probability of exceedance of observed annual rainfall in the 30-year period 1900-1929 were obtained by the various plotting-position formulae considered in the study. Table 5 shows the linear equations of the form $R = AP_m + B$ fitted to observed annual rainfall, north-east monsoon rainfall and south-west monsoon rainfall in the 30-year period 1900-1929, with different probiability of exceedance, Pm, given by different plotting-position formulae.

Table 5 Linear equations fitted to observed Annual rainfall and

Seasonal rainfall in the 30-year period 1900-1929

Plotting-position formula	Linear equation of the form $R = AP_m + B$ fitted to estimate magnitudes of		
	Annual rainfall	North-east monsoon rainfall	South-west monsoon rainfall
Hazen	R = -1.076Pm + 181.8	R = -1.019Pm + 131.8	R = -0.386Pm + 54.96
California	R = -1.076Pm + 183.6	R = -1.019Pm + 133.5	R = -0.386Pm + 55.60

Weibull	R = -1.112Pm + 183.6	R = -1.053Pm + 133.5	R = -0.399Pm + 55.60
Beard	R = -1.090Pm + 182.5	R = -1.032Pm + 132.4	R = -0.391Pm + 55.20
Chegodayev	R = -1.090Pm + 182.6	R = -1.033Pm + 132.5	R = -0.391Pm + 55.22
Blom	R = -1.085Pm + 182.3	R = -1.028Pm + 132.2	R = -0.389Pm + 55.12
Gringorten	R= -1.080Pm + 182.1	R = -1.023Pm + 132.0	R = -0.387Pm + 55.04
Cunnane	R = -1.083Pm + 182.2	R = -1.026Pm + 132.1	R = -0.388Pm + 55.09
Adamowski	R = -1.094Pm + 182.7	R = -1.036Pm + 132.6	R = -0.392Pm + 55.28

From Table 5, it is observed that the multiplication constants, A, in all fitted linear equations are negative indicating that higher the probability of exceedance, lesser the magnitude of rainfall (Annual/North-east monsoon/South-west monsoon). The multiplication constant, A, varies in narrow ranges (-1.076 to – 1.112 for annual rainfall; - 1.019 to – 1.053 for North-east monsoon rainfall and – 0.386 to – 0.399 for south-west monsoon rainfall). The rate of decrease in magnitude of rainfall (Annual/ North-east monsoon/South-west monsoon) with probability of exceedance is found to be the smallest for both Hazen and California methods while it is found to the largest for the Weibull method. The r2 values for the fitted linear equations are found to be same for all the plotting-position formulae at 0.966 for annual rainfall, 0.940 for North-east monsoon rainfall and 0.931 for South-west monsoon rainfall. The high r2 values obtained for all the methods indicate the goodness of the linear fits obtained in estimation of magnitudes of rainfall with different probability of exceedance.

The probability of exceedance, Pm, of the observed rainfall magnitudes in the 100 years of historical data (1900 – 1999) available was determined for each of the plotting-position formulae mentioned above. Then, using the linear equation of the form $R = AP_m + B$ fitted considering the first 30 years (1900 – 1929) of data , the estimates of rainfall magnitudes with different exceedance probabilities obtained with 100 years data are determined (designated as Rest) . This exercise was done for all the nine plotting-position formulae and estimates of annual rainfall, north-east monsoon rainfall and South-west monsoon rainfall were obtained. The estimated rainfall magnitudes were compared with the corresponding observed rainfall magnitudes and the error statistics namely, MSE, RMSE, MAE and AI were obtained.

The computed error statistics and fundamental statistics of Agreement Index for various plotting-position methods in estimation of Annual Rainfall, South-west monsoon rainfall and North-east monsoon rainfall are provided in Tables 6, 7 and 8 respectively.

Table 6 Error statistics and fundamental statistics of Agreement Index (AI) in estimation of Annual Rainfall for various plotting – position methods

Plotting-position	MSE	RMSE	MAE	AI			
				Min	Max	Mean	Std. dev.
Hazen	71.3	8.4	6.1	0.852	1.320	1.030	0.066
California	78.2	8.8	6.9	0.858	1.343	1.041	0.068
Weibull	65.5	8.1	5.9	0.858	1.299	1.028	0.062
Beard	68.9	8.3	6.0	0.855	1.312	1.030	0.064
Chegodayev	69.4	8.3	6.1	0.975	1.139	1.030	0.045
Blom	69.9	8.4	6.1	0.854	1.316	1.030	0.065
Gringorten	71.0	8.4	6.2	0.854	1.320	1.031	0.065
Cunnane	70.3	8.4	6.1	0.854	1.317	1.030	0.065
Adamowski	68.3	8.3	6.0	0.855	1.309	1.029	0.064

Table 7 Error statistics and fundamental statistics of Agreement Index (AI) in estimation of South-west monsoon rainfall for various plotting – position methods

Plotting-position	MSE	RMSE	MAE	AI			
				Min	Max	Mean	Std. dev.
Hazen	15.8	4.0	2.9	0.745	1.595	1.067	0.114
California	17.1	4.1	3.2	0.752	1.639	1.082	0.120
Weibull	15.0	3.9	2.8	0.751	1.551	1.063	0.106
Beard	15.5	3.9	2.8	0.748	1.578	1.065	0.111
Chegodayev	15.5	3.9	2.9	0.748	1.580	1.065	0.111
Blom	15.7	4.0	2.9	0.747	1.587	1.066	0.112
Gringorten	15.8	4.0	2.9	0.746	1.596	1.067	0.114
Cunnane	15.8	4.0	2.9	0.747	1.593	1.067	0.113
Adamowski	15.5	3.9	2.9	0.748	1.578	1.066	0.111

Table 8 Error statistics and fundamental statistics of Agreement Index (AI) in estimation of North-east monsoon rainfall for various plotting – position methods

Plotting-position	MSE	RMSE	MAE	AI			
				Min	Max	Mean	Std. dev.
Hazen	37.9	6.2	4.7	0.861	1.758	1.054	0.102
California	44.4	6.7	5.6	0.869	1.827	1.072	0.110
Weibull	34.7	5.9	4.4	0.869	1.690	1.049	0.091
Beard	36.3	6.0	4.5	0.863	1.729	1.051	0.097
Chegodayev	36.4	6.0	4.6	0.864	1.729	1.052	0.097
Blom	36.7	6.1	4.6	0.863	1.736	1.051	0.098
Gringorten	37.4	6.1	4.6	0.862	1.750	1.053	0.100
Cunnane	36.9	6.1	4.6	0.862	1.741	1.052	0.099
Adamowski	35.9	6.0	4.5	0.864	1.721	1.050	0.096

The error statistics namely, MSE, RMSE and MAE are found to be consistently the least for Weibull method in estimation of rainfall magnitudes with different probability of exceedance (for Annual Rainfall – 65.5, 8.1 and 5.9; for South-west monsoon rainfall – 15.0, 3.9 an 2.8; North-east monsoon rainfall – 34.7, 5.9 and 4.4), while they are found to be consistently the most for California method (for Annual Rainfall – 78.2, 8.8 and 6.9; for South-west monsoon rainfall – 17.1, 4.1 and 3.2; North-east monsoon rainfall – 44.4, 6.7 and 5.6). The MSE, RMSE and MAE are found to lie in the narrow range 68.3 to 71.3, 8.3 to 8.4 and 6.0 to 6.2 respectively.

The mean AI for all methods except the California method is found to lie in narrow ranges (1.028 to 1.031 for annual rainfall; 1.063 to 1.067 for South-west monsoon rainfall and 1.049 to 1.054 for North-east monsoon rainfall). It should be noted that an AI of less than unity indicates that the method underestimates the magnitude of rainfall whereas an AI of more than unity indicates overestimation of rainfall magnitude.

In estimation of annual rainfall magnitudes with different probability of exceedance, the minimum AI (0.975) and maximum AI (1.139) are found to be the closest to unity for Chegodayev method, while for the other methods except the California method, the minimum AI and maximum AI are found to vary in narrow ranges, 0.858 to 0.854 and 1.299 to 1.320, respectively. For California method, the minimum AI and maximum AI are found to be respectively 0.858 and 1.343.

In estimation of South-west monsoon rainfall magnitudes with different probability of exceedance, the minimum AI is found to be in narrow range of 0.752 to 0.746 for all the plotting-position methods. The maximum AI (1.551) is found to be the closest to unity for Weibull method while it is the farthest from unity at 1.639 for California method. For the other seven methods, the maximum AI lies in the narrow range 1.578 to 1.596.

ISSN 2348 – 8034
Impact Factor- 4.022

Both the Weibull and California methods have the minimum AI closest to unity at 0.869, while the other seven methods have the minimum AI in the narrow range 0.864 to 0.861. The maximum AI (1.690) closest to unity is found to be possessed by the Weibull method. The other methods except the California method are found to possess maximum AI in the range 1.721 to 1.758.

The ranking of methods in estimation of magnitudes of annual rainfall, South-west monsoon rainfall and North-east monsoon rainfall with different probability of exceedance are provided in Tables 9, 10 and 11 respectively.

Table 9 Ranking of plotting-position methods in estimation of magnitudes of annual rainfall with different probability of exceedance

	Ranking of method in terms of							Overall ranking
Plotting-position	MSE	RMSE	MAE	AI				
				Min	Max	Mean	Std. dev.	
Hazen	8	5	4	9	7	3	8	7
California	9	9	9	2	9	9	9	9
Weibull	1	1	1	2	2	1	2	1
Beard	3	2	2	4	4	3	3	4
Chegodayev	4	2	4	1	1	3	1	2
Blom	5	5	4	6	5	3	4	5
Gringorten	7	5	8	6	7	8	4	8
Cunnane	6	5	4	6	6	3	4	6
Adamowski	2	2	2	4	3	2	3	3

Table 10 Ranking of plotting-position methods in estimation of magnitudes of South-west monsoon rainfall with different probability of exceedance

	Ranking of method in terms of							Overall ranking
Plotting-position	MSE	RMSE	MAE	AI				
				Min	Max	Mean	Std. dev.	
Hazen	6	5	2	9	7	6	7	7
California	9	9	9	1	9	9	9	9
Weibull	1	1	1	2	1	1	1	1
Beard	2	1	1	3	2	2	2	2
Chegodayev	2	1	2	3	4	2	2	3
Blom	5	5	2	6	5	4	5	5
Gringorten	6	5	2	8	8	6	7	7
Cunnane	6	5	2	6	6	6	6	6
Adamowski	2	1	2	3	2	4	2	3

Table 11 Ranking of plotting-position methods in estimation of magnitudes of North-east monsoon rainfall with different probability of exceedance

	Ranking of method in terms of							Overall ranking
Plotting-position	MSE	RMSE	MAE	AI				
				Min	Max	Mean	Std. dev.	
Hazen	8	8	8	9	8	8	8	9
California	9	9	9	1	9	9	9	8
Weibull	1	1	1	1	1	1	1	1
Beard	3	2	2	5	3	3	3	3
Chegodayev	4	2	4	3	3	5	3	4
Blom	5	5	4	5	5	3	5	5

Gringorten	7	5	4	7	7	7	7	7
Cunnane	6	5	4	7	6	5	6	6
Adamowski	2	2	2	3	2	2	2	2

The performance of Weibull method has been consistent that it secures the overall ranking “1” in best estimation of magnitudes of Annual rainfall, South-west monsoon rainfall and North-east monsoon rainfall with different probabilities of exceedance. The Adamowski method secures overall ranking “2” in estimation of Annual rainfall and North-east monsoon rainfall while it secures overall ranking “3” in estimation of South-west monsoon rainfall. The Chegodayev and Beard methods secure overall ranking from “2” to “4” in estimation of Annual, North-east monsoon and South-west monsoon rainfalls. The Blom and Cunnane methods have consistently secured overall rankings “5” and “6” respectively in estimation of Annual, North-east monsoon and South-west monsoon rainfalls. The Gringorten method has secured overall ranking “7” in estimation of both South-west monsoon and North-east monsoon rainfalls, while it secured overall ranking “8” in estimation of Annual rainfall with higher return periods. The California method obtained the last overall ranking “9” in estimation of Annual and South-west monsoon rainfalls. In the present study, predominantly the methods predicted within ±5% the rainfall magnitudes having lower return periods (about 1.2 years to about 20 years). The magnitudes of rainfall with higher return periods (> 20 years) were underestimated by more than 10% by the various methods, while the estimates of rainfall magnitudes with return periods less than 1.2 years were found to be higher by more than 10% compared to the observed values. Makkonen [6] compared the return period of the largest value in a sample of 21 annual extreme values as determined by the commonly used plotting-position formulae namely, Weibull, Beard, Gringorten, Hazen, and the numerical method proposed by Harris [22] and reported that the percentage error in estimation of the event was zero for Weibull method while all the other methods overestimated the return period of the largest annual extreme event, that is, underestimated its risk of occurrence.

Ani Shabri ranked eight plotting position methods based on their performance in estimating annual maximum flood flows at 31 stations of peninsular Malaysia [23]. The methods were ranked according to values of RMSE and MAE on a scale 1 to 8 with “1” being the best method. He reported that the Weibull method was the best performing one compared to the other methods considered in his study. Adeboye and Alatise fitted the normal distribution to the peak flow discharge of two rivers in Nigeria using seven probability plotting positions. They concluded that the Weibull method is suitable for fitting the normal distribution [24].

VI. CONCLUSION

Based on the assessment of performance of different plotting positions considered in the study in best estimation of magnitudes of annual and seasonal rainfall at Puducherry, South India, in terms of the error statistics and Agreement Index, it is found that the Weibull method attains the overall ranking “1” followed by Adamowski method. The Weibull method is recommended as the best plotting position formula in frequency analysis of hydrologic data provided the data follows normal or approximately normal distribution.

REFERENCES

1. *Adamowski, K. (1981). “Plotting Formula for Flood Frequency.” Water Resour. Bulletin, 17(2): 197-202.*
2. *Ji Xuewu, Ding Jing, H. W. Shen, and J. D.Salas. 1984. Plotting Positions For Pearson, Journal of Hydrology. 74: 1-29.*
3. *Guo, S. L. 1990. A Discussion On Unbiased Plotting Positions For The General Extreme Value Distribution, Journal of Hydrology. 121: 33-44.*
4. *Guo, S. L. 1990. Unbiased Plotting Position Formula For Historical Floods, Journal of Hydrology. 121: 45-61.*
5. *Rigdon, S. E., and Basu, A.P. (1989) The power law process: a model for the reliability of repairable systems. J. Qual. Technol., 21, 251-260.*
6. *Makkonen, L. (2006). “Plotting Positions in Extreme Value Analysis”, Journal of Appl. Meteorol. and Climatol., 45, pp. 334 – 340.*

7. de Haan, L. (2007) Comments on 'Plotting Positions in Extreme Value Analysis. J. Appl. Meteorol. Climatol., 46, 396-396.
8. Makkonen, L. (2008) Problems in the extreme value analysis. Struct. Saf., 30, 405-419.
9. Cook, N. (2011) Comments on Plotting Positions in Extreme Value Analysis. J. Appl. Meteorol. Climatol., 50, 255-266.
10. Cook, N. (2012) Rebuttal of Problems in the extreme value analysis. Struct. Saf., 34, 418-423.
11. Kim, S., Shin, H., Joo, K., and Heo, J. H. (2012) Development of plotting position for the general extreme value distribution. J. Hydrol., 475, 259-269.
12. Erto, P., and Lepore, A. (2013) New Distribution-Free Plotting Position Through an Approximation to the Beta Median. Advances. Theor. Appl. Stat., 3, 23-27. Avner Bar-Hen.
13. Fuglem, M., Parr, G., and Jordaan, I. J. (2013) Plotting positions for fitting distributions and extreme value analysis. Can. J. Civ. Eng., 40, 130-139.
14. Lozano-Aguilera, E. D., Estudillo-Martínez, M. D., and Castillo-Gutiérrez, S. (2014) A proposal for plotting positions in probability plots. J. Appl. Stat., 41, 118-126.
15. Cunnane, C. (1978). "Unbiased Plotting Positions- A Review." Journal of Hydrology, 37: 205-222.
16. Castillo, E. (1988). Extreme Value Theory in Engineering. Academic Press, 389 pp.
17. Stedinger, J. R., Vogel, R. M., and Foufoula, G. E. (1993). "Frequency Analysis of Extreme Events." Handbook of Applied Hydrology. Mc-Graw Hill Book Co., New York, Chapter 18.
18. Folland, C., and Anderson, C. (2002). "Estimating changing extremes using empirical ranking methods." J. Climate, 15, 2954–2960.
19. Jordaan, I. (2005). Decisions under Uncertainty. Cambridge University Press, 672 pp.
20. Singh, V. P. (1994). "Elementary Hydrology". Prentice Hall. 973 pp.
21. Bulmer, M. G. (1979). "Principle of Statistics". Dover Publications, 252 pp.
22. Harris, R. I. (1996). "Gumbel re-visited—A new look at extreme value statistics applied to wind speeds", J. Wind Eng. Ind. Aerodyn., 59, 1–22.
23. Ani shabri. (2002). "A comparison of plotting position formulas for the Pearson Type III distribution", Jurnal Teknologi, 36(C) Jun. 2002: 61–74, Universiti Teknologi Malaysia.
24. Adeboye, O.B., and Alatise, M. O. (2007). Performance of probability distributions and plotting positions in estimating the flood of River Osun at Apoje Sub-basin, Nigeria. Agric. Eng. Int.: CIGR J., 9