ORIGINAL ARTICLE

Estimating monthly and yearly dependable rainfall for different climatic zones of the world

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Abstract

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The study has demonstrated that estimating monthly or yearly dependable rainfall is not an easy task, especially where rainfall data series are not available. The world is divided into four climatic zones namely: tropical, sub-tropical, mediterranean and temperate. The results showed that no single equation or procedure is quite adequate to describe the different climatic conditions of the world. Three procedures were developed for estimating yearly and monthly dependable rainfall for yearly/monthly rainfall data series. To develop the various procedures, first a frequency-analysis using the yearly/monthly rainfall data series was conducted by means of RAINBOW software. Secondly, the results from the frequency analysis were used in an Excel program to develop the various relationships between the coefficient of variation and the mean or the log (mean) rainfall for normal and log normal distributed rainfall data series. From the results of yearly rainfall data series, all climatic zones found to be normally distributed. On the other hand, all monthly rainfall data series were assumed to be log normally distributed.

Key words : dependable rainfall, climatic zone, and rainfall amount

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Rainfall is a source of fresh water; its distribution shows random variation both in space and time. Irrigation planning using mean values for rainfall is thus very unreliable. The planner needs to know the amount of rainfall, which can be depended upon with a certain degree of probability. This knowledge about dependable rainfall will ensure that the irrigation schedule is planned in such a way as to make optimum use of rainfall and thus avoid over irrigation, which has destroyed many agricultural lands in the past decades through rising water tables. This phenomenon may also cause waterlogging and salinity problems.

Agricultural production in the developing countries is forecast to increase by 2.8% per year between 1980 and 2010. Most of the suitable land in those countries is already under cultivation so the majority of this increase must come from "vertical expansion", i.e. improvements in cropping intensity, irrigation efficiency and crop yields per unit of input. Water is a scarce resource in many developing countries and, therefore, scientific water planning and management will play a crucial role in achieving this expansion. The possibility of improving agricultural production by better scheduling of irrigation water has been the subject of a number of papers in recent years. However, many research results indicate that the total yield of a particular crop basically depends on the amount of water supplied in the whole growth period and on the allocation of irrigation water at the various growth stages (Thomas *et al*., 1980). Owing to the fact that rainfall is one of the available water resources during the crop growth cycle, crop irrigation scheduling, as well as crop yield, are directly influenced by the amount and distribution of rainfall.

Doorenbos and Pruitt (1977) suggested that for irrigation planning purposes the use of a dependable level of rainfall rather than the use of the mean monthly rainfall values gives fairly good result. Ganng (1986) has analyzed the relationship of mean monthly rainfall and the 70% monthly (10 day) dependable rainfall of three climatological stations. He recommended that the use of two separate regression lines give a better approximation of the 70% monthly dependable rainfall, especially when the rainfall is low and biomodal. According to Jensen (1974), since water need of a crop varies within the growing season, it is not always sufficient to have probability estimates for the whole season or even for a particular part of it. Therefore, it may be important to have a probability estimate for the occurrence of a particular sequence of rainfall throughout the season. The problem of skewed data in such calculation is that it shorter the time period and lowers the rainfall. These problem can be overcome by using long data series of years. According to Moodley and Appa Rao (1971), normal distribution showed a good fit to seasonal and annual rainfall at stations in some parts of India. However, it has not shown a good fit over most parts of the country for that reason, instead of a normal distribution, a gamma distribution is recommended. Therefore, it is important to calculate net irrigation requirement by using dependable rainfall and the mean values of other climatological parameters.

Climatic Zone

For practical purpose, agro-ecological zones based on temperature may be broadly differentiated by four main climatic zones namely: tropical, subtropical, mediterranean and temperate. Tropical and sub-tropical zones can further be divided into four groups based on rainfall, namely: humid, sub-humid, semi-arid and arid. Most crops have different varieties, which vary in their general and specific climatic requirements and in their length of total growing period from sowing to harvest. The variation allows specific varieties of the crop to be adapted to a wide range of climatic condition and to the time period required and available for crop production. The temperature in addition to the quantity and distribution of precipitation are important factors for the production of rainfed crops or for assessing the need for irrigation. In general, temperature determines the rate of crop growth and development; but in some crops temperature may also determine whether a particular developmental process will begin or not. Tropical and sub-tropical crops such as rice, sugarcane, some vegetables, and fruits (particularly large-scale banana production) are best grown at an average yearly temperature of 27ºC with mean annual rainfall of at lease 800 mm (Doorenbos and Kassam, 1979). A general classification of the main climatic zones is given in Table 1.

Materials and Methods

Dependable rainfall is defined as the rainfall, which can be expected in a set number of years out of a total number of years. The objectives of this study are: (a) to estimate yearly dependable rainfall from yearly normal distributed rainfall data series (b) to estimate monthly dependable rainfall for months of the year when the probability of events is zero and (c) to estimate the monthly dependable rainfall for transition month before and after the rainy season. To achieve the various objectives, the frequency-analyses of the yearly/monthly rainfall data series were first carried out by means of RAINBOW program (Raes *et al*., 1989). In this study, a total of 60 stations with yearly rainfall data series and 360 months of rainfall data from different climatic zones were analyzed. Monthly and yearly data of the stations were made available in FAOCLIM 1.2 CD-ROM containing worldwide agro-climate data obtained from the Institute for Land and Water Management, Belgium. Each rainfall station has long time data series (1950-1995).

Table 1. A general classification of climatic zones of the world*

Sub-zone	Rainfall Pattern	Average annual rainfall (mm)	Average monthly temperature converted to sea level
		Tropical Zone	
Humid	Every month, generally with two peak periods. 2-3 months with lower rainfall	> 1800	> 20ºC
Sub humid	Marked dry season of 3 months	> 1400	> 20ºC, but some months down to 15ºC
Semi-arid	One rainy season. Marked 6-8 months dry season	> 300	> 20ºC
Arid	Rainfall patchy and scanty, no marked rainy season	< 300	> 20ºC
		Sub Tropical Zone	
Humid	One relatively short dry season. 3-4 months summer rain	> 1200	14-20ºC, no frost but low temperature during winter months
Sub humid	One (summer) rainy season. 4-6 months dry	> 1000	14ºC, no frost. Cool winter
Semi-arid	One (summer) rainy season. 8-9 months dry	400-600	14ºC, no frost. Cool winter and hot summer
Arid	No marked rainy season	< 300	14ºC, very hot summer and cool winter
		Mediterranean Zone	
	One (winter) rainy season. 6-8 months dry	300-1000	14ºC, possible frost and snow during winter months when monthly average 8ºC and below
		Temperate Zone	
	Rain every month or well-marked rainy season. Snow in winter	300-1000	12-13ºC, cold winter, frost, cool to hot summer

Source (Aminul, 1996)

Yearly Rainfall Analysis

Dependable rainfall is usually calculated by using frequency analysis for a long period of time. Since rainfall shows variation in intensity, amount and duration, it is not so simple to predict precisely the amount of rain to fall in the future. However, the probability was analyzed using frequency distribution. The frequency analysis of each station was done with the help of the RAINBOW program. In the RAINBOW program, the Gringorten plotting position was used, which is theoretically better for this type of study. The data showed homogeneity; therefore, no transformation techniques (logarithmic, square and square root) were necessary. A least squares fit was selected, as this gives a value for the correlation coefficient of each station. Here, the normal distribution was selected for all stations. To draw a yearly rainfall graph, the coefficient of variation was first determined, and then a simple regression analysis was performed by using log mean rainfall and log coefficient of variation of each station.

Monthly Rainfall Analysis

In the monthly rainfall analysis, the logarithmic transformation technique was applied to the data, as the rainfall and its probability of occurrence in all months showed a very high correlation. In RAINBOW, the theorem of total probability is used to analyze a set of data with NIL rainfall. When the total recording periods do not exhibit straight-line relationships because the amount of rainfall at the beginning or at the end of the rainy season is zero or near zero, then the following equation can be used to calculate the cumulative probability:

$$G_x(X) = p + (1-p)F_x(X) \quad (1)$$

where $G_x(X)$ is the cumulative probability distribution of all X (prob ($X \leq x \;\; X \geq 0$)), p is the probability that X is zero, and $F_x(X)$ is the cumulative probability distribution of the non-zero values of X (prob ($X \leq x \;\; X \;\; 0$)). To draw monthly rainfall graphs, the regression analysis was performed using the log mean rainfall and the coefficient of variation of each rainfall station.

Results and Discussion

The frequency analysis was carried out by considering rainfall values of different time periods. The considered time periods are either year or month. A yearly rainfall graph (Figure 1) was obtained by using the equation:

$$LogCV = 2.441 + (-0.373)Log(\overline{X}) \quad (2)$$

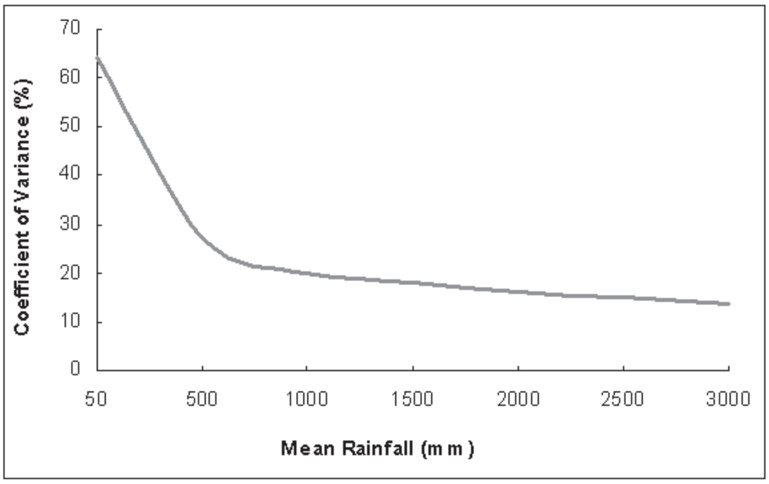

Figure 1. Yearly rainfall graph of various climatic zones.

Table 2. Values of 'a' for various probabilities of exceedance

Probability of Exceedance (%)	a	Probability of Exceedance (%)	a
45	+0.125	55	-0.125
40	+0.255	60	-0.255
35	+0.390	65	-0.390
30	+0.530	70	-0.530
25	+0.660	75	-0.660
20	+0.840	80	-0.840
15	+1.040	85	-1.040
10	+1.260	90	-1.260
5	+1.640	95	-1.640
1	+2.330	99	-2.330

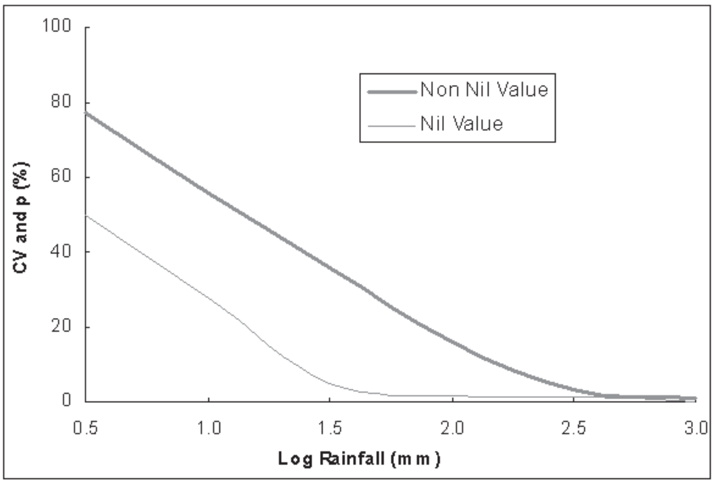

Figure 2. Monthly rainfall graph of various climatic zones.

where CV is coefficient of variation (%) and $\overline{X}$ is mean yearly rainfall (mm). Dependable rainfall was then derived from the yearly rainfall graph by the following equation:

$$F(P \phi P_i) = \overline{P} \pm as \quad (3)$$

$\overline{P}$ is the mean yearly rainfall (mm), a is regression coefficient and s is standard deviation (mm). Values of ëaí for different probabilities of exceedance are given in Table 2. A sample run for the determination of dependable rainfall from yearly mean rainfall is presented in Table 3. A monthly rainfall curve is drawn (Figure 2) which was obtained from two graphs such as probability of non-nil and probability of nil values. The following equations were derived to obtain the two graphs.

$$CV = 97.58 + (-40.60)(\log \overline{X}) \text{ [Non-nil values]} \quad (4)$$

$$p = 0.723 + (-0.445)(\log \overline{X}) \text{ [Nil values]} \quad (5)$$

where CV is coefficient of variation (%) and p is probability on nil-events (%). Based on these graphs, monthly dependable rainfall was calculated by the following equations:

$$F_x(x) = \overline{P} + as \text{ [Non-nil values]} \quad (6)$$

$$p(X) = \overline{P} + zs \text{ [Nil values]} \quad (7)$$

A sample run for determination of dependable rainfall from monthly mean rainfall is presented in Table 4. Comparison of frequency analysis and computed values of dependable rainfall using yearly and monthly rainfall graphs showed good correspondence. Comparisons are also done with new yearly and monthly rainfall station data that

Table 3. Determination of dependable rainfall from yearly mean rainfall using yearly rainfall graph.

Given yearly mean rainfall = 1000 mm
Coefficient of variation, CV = 21% (From Figure 1)
Standard Deviation s = 210 mm
Dependable rainfall = $\overline{P} + as$ ('a' is given on Table 2)

Probability of Exceedance (%)	Rainfall (mm)	Probability of Exceedance (%)	Rainfall (mm)
10	1264.6	60	946.5
20	1176.4	70	888.7
30	1111.3	80	823.6
40	1053.5	90	735.4
50	1000		

Table 4. Determination of dependable rainfall from monthly mean rainfall using monthly rainfall graph

Given mean monthly rainfall = 30 mm
Coefficient of Variation CV = 37.5% (From Figure 2)
Standard Deviation s = 11.25
Probability of NIL-events p = 0.06 (From Figure 2)
Dependable rainfall of Non-nil values = $\overline{P} + as$ ('a' is given on Table 2)
Dependable rainfall = $\overline{P} + zs$ ('z' is cumulative normal frequency distribution)

Probability of exceedance $F_x(x)$ %	$\overline{P} + as$	Probability of exceedance Gx (x) =(1-p) $F_x(x)$ %	Global probability of exceedance Gx (x) %	$F_x(x) = G_x(x) / (1-p)$	0.5-$F_x(x)$/ 100	z	$\overline{P} + zs$
10	44.20	10	10	10.60	0.394	1.25	44.06
20	39.50	19	20	21.00	0.290	0.81	39.11
30	36.00	28	30	32.00	0.180	0.47	35.29
40	32.90	38	40	42.50	0.075	0.29	33.26
50	30.00	47	50	53.00	-0.030	-0.17	28.09
60	27.10	56	60	63.80	-0.138	-0.34	26.18
70	24.00	66	70	75.00	-0.250	-0.68	22.35
80	20.60	75	80	85.00	-0.350	-1.04	18.30
90	15.8	85	90	95.00	-0.450	-1.65	11.44

are not considered for drawing graph. In the yearly and monthly rainfall analyses, it was found that the rainfall and its probability of occurrence in almost all cases showed very high correlation except in a few cases. However, the correlation coefficient in all cases was greater than 0.90. It was also observed that there is no big difference of dependable rainfall in different climatic zones except in a few cases, especially 90% dependable rainfall. However, the deviation in all cases was within ± 10%.

Conclusions

The major climatic factor which influences crop growth is rainfall. Without an appropriate management and operation system a nicely designed irrigation scheme has no meaning. For management and planning purposes the information on the amount of rainfall which one can expect in a specific period under dry, normal and wet conditions is important. The period under consideration may be any period such as a week, a decade, month or year. Therefore, dependable rainfall is calculated using the derived equations in this study. Three procedures were developed for estimating yearly and monthly dependable rainfall for yearly/monthly rainfall data series. From the results of yearly rainfall data series, all climatic zones were found to be normally distributed. On the other hand, all monthly rainfall data series were assumed to be log normally distributed. Based on dependable rainfall, net irrigation requirement can be obtained of each crop cultivated in the irrigation scheme.

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