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Modelling of rainfall: a measurable tool in sustainable agriculture

Thushyanthy Mikunthan[1]

ABSTRACT

The study revel that summarizing large volume of rainfall data as concisely as possible without discarding the important information such as start, end and length of the rainy season, the distribution of rainfall amounts and the risk of dry spells throughout the year using gamma distribution and fiducial probability. The models fitted with gamma distribution and fiducial probability can be used successfully for the purpose of assisting sustainable agriculture with incident rainfall, for adopting suitable crops and cultivars for defining cropping calendar and to predict crop failure.

Keywords: Rainfall, drought, gamma distribution function, fiducial probability

INTRODUCTION

Rainfall is one among the chief physical factors influencing agriculture in Sri Lanka. The major hazard in agriculture is the variation in the receipt of rainfall in dry zone of Sri Lanka (Tambyapillai, 1965). Understanding the pattern and amount of rainfall in a particular area will therefore helpful to maximize its usage. In order to understand the present pattern of agriculture, to plan for the future, and to determine the proper sequence of agricultural operations and cropping pattern for sustainability, it is essential to have an adequate knowledge of the rainfall factor. This will lead to predict the behavior of this natural phenomenon and help future planning to expect a definite crop yield much more accurately from that area. In many parts of the world the climate is the major constraint on agriculture and agricultural planning. Although the various climatic variables interact with the climate in complex ways rainfall is the limiting factor in most parts of the tropics (Stern, 1984). The necessity of the study related rainfall is very important especially in tropical climates where the crop failure is common due to drought as well as excessive rainfall.

For an agriculturist, the important questions on rainfall are concerned with start, end and length of the rainfall season and the risk of dry spells. A great deal of research has been devoted to these topics, but little of it has been based on daily data. (Stern *et al.*, 1982a). Woodhead, 1970 demonstrated that mean rainfall is not a good guide to agricultural potential and that variability of rainfall must also be considered. Experience

[1]Dept of Agric.Engineering, Faculty of Agriculture, University of Jaffna, Jaffna, Sri Lanka.

has shown that mean monthly rainfall even when derived from a large numbers of years, is an unreliable guide to the variation in rainfall. Because, the frequency distributions of rainfall are in general skewed, with the mode lower than the mean. In other wards, serious deficiencies of rainfall are common. Hence the prediction of rainfall by fitting a suitable distribution is considered as a better approach and fiducial probability or confidence limits of rainfall values provide true break, end and length of the season, unexpected torrential rainfall and valuable guides to estimate the crop failure or the risk of crop loss.

Crops will be at risk from dry spell occurring during the growing season. According to the world meteorological organization "drought is by definition of sustained extended deficiency in precipitation" (Bogardi *et al.*, 1994). The level of the risk can be assessed by evaluating the probability that a long dry spell occurs when the plant is particularly in sensitive stage. Hence a estimation of the chance of long dry spells are often useful. The main objective of the study was to utilize available long term rainfall records and fitting the probability density function of gamma distribution for rainfall probability and for drought spell and also predicting the confidence limits within which rainfall occurs.

METHODOLOGY

Rainfall analysis: Rainfall could be modeled by gamma, log normal and kappa type (Suzuki, 1980) while Gamma, Beta, lognormal, exponential could be used for drought frequency analysis (Chow, 1964). This type of rainfall model is a powerful way of summarizing the rainfall climate at a site. At present gamma distribution has a long history as a suitable theoretical model for frequency distribution (Suzuki, 1980; Savitri *et al.*, 1983 and Aksoy, 2000). The modeling approach makes efficient use of the data. The estimates obtained are more precise. Therefore, the method can be used for relatively short records, and more accuracy obtained than the direct method used (Savitri *et al.*, 1983). In modeling the statistical structure of the rainfall process has two sequences of random variable. The first sequence is concerned with the number of rainfall events within various times. The second sequence is concerned with the rainfall amounts associated with each events. The second random variable, rainfall amount estimates or the probability of an event can be obtained either directly from the relative frequency of occurrence or by fitting a suitable distribution to the rainfall data (Hamlin and Rees, 1985).

Confidence limits can be calculated for any level of probability and are known as fiducial. A confidence limit defined as an estimate of the chance of obtaining a value for a given statistic that falls within prescribed limits (Manning, 1950). The limits within which rainfall may be expected to lie in 3 years out of 4 namely 75% fiducial probability or 1:1 rainfall confidence limits are considered adequate for agricultural purpose (Panabokke and Walgamma, 1974).

Data used for analysis: The daily rainfall records of 17 stations from 1982 to 1996 of Pelwatta Sugar cane plantation were used to fit the gamma distribution function and 52 standard week rainfall of 30 years from 1964 to 1994 was used to predict 75% fiducial probability of Jaffna.

Model fitting- Gamma distribution function: Gamma distribution provides probabilities for random variable. The gamma distribution function has three different types 1-, 2- and 3-parameter gamma distributions. Use of the 1-parameter gamma distribution in hydrology is limited due to its relative inflexibility in fitting to frequency distributions of hydrologic variables, but the 2- and 3- parameter gamma distribution are commonly used in place of log-normal distribution function with 2 and 3 parameters (Aksoy, 2000). The disadvantage of the gamma distribution is that the cumulative distribution function can not be plotted as a straight line on the probability graph paper. Gamma distribution of 2- parameter was selected in this study, since there was no significant advantage in the 3-parameter gamma distribution when compared to 2- parameter gamma distribution. And also this 2- parameter gamma distribution was successfully used in two districts of dry zone of Sri Lanka by Savitri *et al.*, 1983 and Hamlin and Rees, 1985 to predict the rainfall of Anudrathapura and Minariya respectively.

The probability density function of the 2-parameter gamma distribution is given by:

$$F(x) = (K/\mu)^{K} X^{K-1} e^{-KX/\mu} / \text{“}(K) \ldots\ldots\ X > 0,\ \ K,\mu > 0$$

The parameter μ is scale parameter, while the shape parameter, K can be interpreted by noting that 1/ "(K) is the co-efficient of the variation of the distribution (Suzuki, 1980; Hills & Morgan, 1981; Stern *et al.*, 1982b and Savitri *et al.*, 1983).

The catchment average daily rainfalls of each year from 1982 to 1996 were derived using 17 stations daily rainfall value. The non rainy days; rainfall value of zero mm were omitted for fitting the model for rainfall probability. The parameters of gamma distribution μ and K were chosen to fit a suitable distribution between observed and predicted probability of rainfall. The maximum likelihood method has often been used to find the parameters of gamma distribution that best matches the observed probability instead of moment or least square method (Suzuki, 1980 and Aksoy, 2000). The correlation of observed and predicted probability of rainfall was derived using regression analysis.

In drought analysis, a threshold value of 6 mm/ day (Joshua, 1988) was assumed to state whether the day was dry or wet. Average daily rainfall values were compared with threshold value for each day to determine whether the day was dry or wet. The frequency of each observation was counted and relative frequency was calculated. Then cumulative probability of occurrence of drought for the catchment was derived. The parameters of gamma distribution of μ and K were chosen to fit a suitable distribution for every month and year. The observed and expected cumulative probability was checked statistically.

Fiducial probability 75% or 1:1 rainfall confidence limits: The method proposed by Manning, 1950 and programmed in computer by Walker, 1967 was directly used in this study.

Briefly this involves summing up the daily total rainfall for each year into 52 standard weeks so as to give an even run of data. 3 weekly moving averages were derived to overcome the climatic fluctuations. Moving average technique is used to smooth the highly irregular component of the graph in the plotting rather than only the single value has been employed. The data was then transformed by the function Y = log (X + C) where the size of the constant C varied inversely with the degree of skewness and X was the variant. The skewness of the frequency distribution of the rainfall was used in the analysis because the mode was lower than the mean. After transformation, the frequency distribution of amount of rainfall approached normality. Finally upper and lower limits were derived.

RESULTS AND DISCUSSION

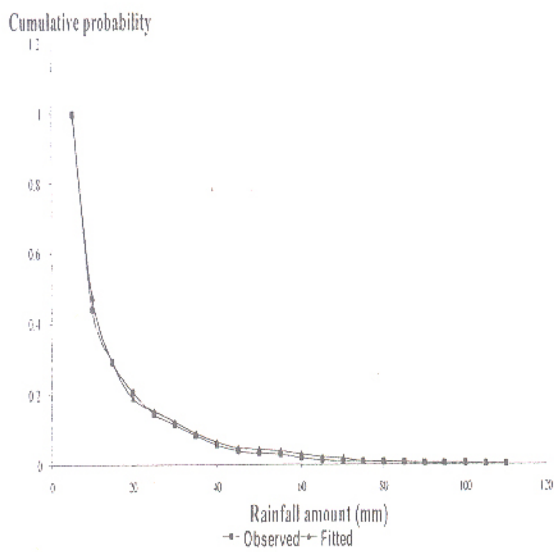
Gamma distribution: The rainfall model was fitted to Pelwatta sugar cane catchment with $\mu = 2.3$ (mean rainfall on rainy days was 2.3mm) and the shape parameter k = 0.5914. The fitted model function was:

$$F(x) = 0.4479\, X^{-0.409}\, e^{-0.5914 X/2.3} / \sqrt{(0.5914)}$$

Figure 1 shows the relationship between observed cumulative probabilities of rainfall together with a fitted curve. The correlation of 98.93% was observed between expected and observed cumulative probability. The process of fitting and using these models provides a straight forward and flexible analysis for rainfall records.

The phenomenon of persistent behaviour of dry spells successfully modeled using the probability function. The density function of gamma distribution was fitted to all months and annual values with suitable parameters. The table 1 shows the parameters with correlation coefficients between observed and predicted probability values. The correlations of probability distributions were more than 99% for annual and monthly distributions except in the month of May which had the value of 96.7%.

Figure 1: Observed cumulative probability of rainfall together with fitted curve



The risk of long dry spell is defined as probability of a dry spell of greater than a specified number of days within any period of interest (Savitri *et al.*, 1983). A n day dry spell is defined as a period of n successive dry days preceded and followed by a wet day. Occurrence of drought incidence of 75% probability was less than 3 consecutive days in all months except June, July and August which have the values of 15 days, 4 days and 4 days respectively.

For example, if 3 day dry spell is interested in the month of the October for the establishment of the crop, probability distribution graph could be drawn using the gamma distribution function with the estimated parameters of μ (2.278) and k (0.634). Then the probability of occurrence of drought spell for 3 days would be derived from the graph. Likewise, if 10 day dry spell is the interested for the harvesting of crop in February, the same procedure derivation of gamma distribution function using the fitted parameters then the probability of 10 days dry spell from the graph would be found. This could be possible even for any event in any month of the interest.

Table 1: Parameters of probability density function of gamma distribution fitted for annual and monthly drought frequency distribution with R^2 value.

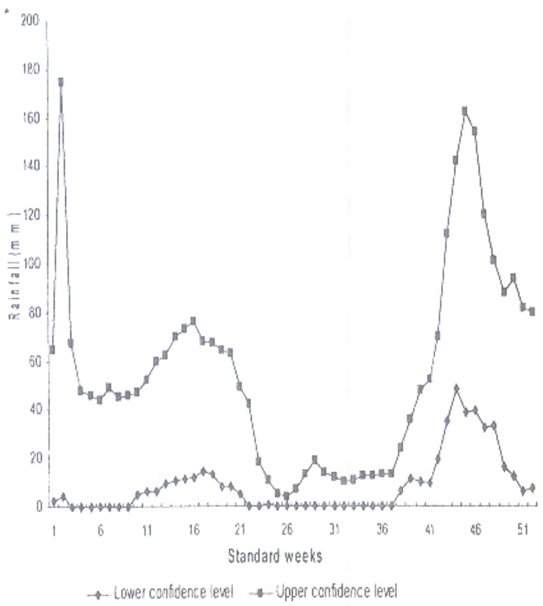
Periods	μ	K	R^2 value
Annual	2.2	0.689	0.9904
January	2.3	0.62	0.9984
February	2.259	0.659	0.9981
March	2.259	0.659	0.9981
April	2.289	0.639	0.9973
May	2.1	0.93	0.9675
June	2.17	0.72	0.9984
July	2.34	0.58	0.9995
August	2.31	0.63	0.999
September	2.241	0.675	0.9991
October	2.278	0.634	0.994
November	2.26	0.66	0.9963
December	2.293	0.629	0.9952

Information about hydrological drought identification is very useful for agricultural areas. A major application of the longest dry spell analysis is to predict extended drought durations during the growing season. If the drought periods are identified, planting after care operations, harvesting and other farming activities and irrigation could be effectively and efficiently planned and to be scheduled for sustainability. Because, drought analysis demarcates the time frame for such operations.

Fiducial probability: The weekly average rainfall amount of the sugar cane catchment showed the bi-model pattern of rainfall exhibiting two pronounced peak rainfall seasons in a year. The short fall occurs during mid March to end of May due to Southwest monsoon called as *Yala* and long rain occur during October to Mid January due to Northeast monsoon called as *Maha*. Figure 2 shows the 1: 1 rainfall confidence limits of Pelwatta sugar cane catchment. The true break of *Maha* season occurs between 41 to 42 weeks and 12th week for Yala. So the October 1st week and April 1st week could be considered a very reliable choice of planting date *Maha* and *Yala* crop respectively.

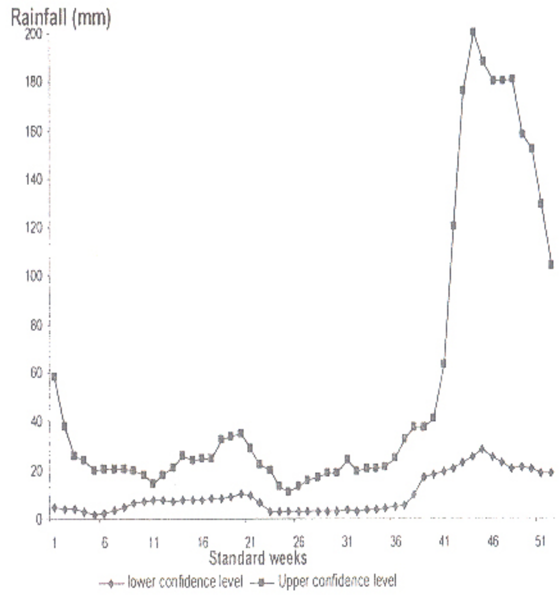
Harvesting is related with dry period. In some years good crop harvest resulting from the optimum time of planting may loose the production by torrential rains during the latter part of the season. This catastrophic rain is clearly revealed in the rainfall confidence limits diagrams. *Maha* crop could be harvested during the period of 24th week to 27th weeks and also possible 31st to 33rd weeks. Around 29th week should be avoided because of the possibility of getting catastrophic rains. *Yala* crop could be harvested during the period of 4th to 6th weeks. There is a possibility of unexpected rainfall during 7th week. Hence it is better to harvest *Yala* crop before it. Soon after the harvesting, land preparation could be done for the next planting with available residual soil moisture and catastrophic rain.

Figure 2. Confidence limits of rainfall of Pelwatta



In the analysis of Jaffna rainfall station around 42% of the week had non rain days with bi-model rainfall pattern. The choosing of the correct sowing date in rainfed agriculture is one of the fundamental important factor to ensure high yields. Since the week before and week are the suitable sowing time. Figure 3 shows the 1:1 rainfall confidence limits of Jaffna. According to the data presented in Figure 3, for a particular week one quarter of the values fall above the upper limit as shown in the upper curve and one quarter below the lower curve. Therefore, for any weekly period the total rainfall is likely to exceed the lower limit in three years out of 4 years. In other words the minimum expectation for three years in 4 years is given by the lower limit. Similarly the total rainfall for the same weekly period will not exceed the upper limit in three years out 4 years. For example, from Figure 3 the rainfall will exceed 4mm in three years out of 4 and it will also not exceed 58mm in three years out of 4 during first week.

Figure 3. Confidence limits of rainfall of Jaffna Peninsula



The reliable index of true break of the season would be the point at which the upper confidence limits curve shows a sharp upward trend. This occurs between 11 -12th weeks and 40th to 41st weeks of the year. Hence the breaks of the seasons are late March and early October for *Yala* and *Maha* respectively. Around 31st week there is a possibility of getting unusual rains. When scheduling the harvesting this factor has to be considered. The length of the *Maha* season is from 41st to 4th week with the total length of 16 weeks and *Yala* season from 12th to 23rd week with the total of 12 weeks. According to the length of the rainy season, the varieties and crops cultivars could be selected for the planning of agriculture.

If planned properly with confidence rainfall limit, the agriculture production will be sustained with incident rainfall successfully. The usage of rainfall could be maximized and withdrawal from the ground water could be minimized. Expressed in this manner it has direct relevance to agricultural productivity..

CONCLUSION

Probability of occurrence of daily rainfall and incidence of drought could be reliably modeled by using a two parameter gamma probability density function. Fiducial limits of rainfall throws considerable light on suitable planting, time for other cultural activities and harvesting dates with crop risk assessments for sustainable agriculture. Finally a comprehensive analysis of rainfall data is important to give useful agronomic results and to make a significant contribution to agricultural planning in present and future.

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