Analysis of Consecutive-day Maximum Rainfall at Udawalwe, Sri Lanka

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ABSTRACT

Understanding on magnitude and distribution of rainfall is a basic prerequisite in designing drainage structures for effective management of soil and water resources, but available information on this aspect is limited in sugarcane growing areas of Sri Lanka. Annual one-day and two to five consecutive- day maximum rainfall at Uda Walawe was assessed for return periods 2, 5, 10, 20, 30, 50 and 100 years. The analysis was carried out using popular probability distribution functions, i.e. Gamma, Gumbel Max,Weibull, and Normal distributions. The goodness-of-fit for each probability distribution was evaluated by Chi-square test. Above probability distribution functions were fitted to annual maximum rainfall data at Uda Walawe for annual one-day as well as two to five consecutive-day maximum rainfall, and the probability of receiving rainfall maximum for different return periods were assessed.

The analysis found that a maximum of 95.8mm in 1 day, 122.5mm in 2 days, 142.9mm in 3 days, 151.7mm in 4 days and 163.2mm in 5 days are expected to occur in every two years at Uda Walawe. Similarly, the probable maximum rainfall values for 5 consecutive days for 5-, 10- 20-, 30-, 50-, and 100-year return periods are 163.2, 187.3, 203.2, 218.8, 227.5, 238.2 and 253.0 mm respectively. The analysis further revealed that, considerably heavy rainfall events are occurred during 1st and 2nd inter-monsoon rainy periods at Uda Walwe. Except one-day maximum rainfall for two-and 5-year recurrence interval, all rainfall events can be classified under "very heavy rainfall" of more than 115mm/day. The area has a 100% probability to occur "heavy rainfall" event that is beyond 75mm/day in any return period from 2,5,10,20,50 and 100 years.

Keywords: Consecutive-day rainfall, Drainage, Probability distribution, Return period, Sugarcane

INTRODUCTION

A thorough understanding of magnitude and distribution of rainfall is vital for the management of soil and water resources, particularly for designing drainages requirements. Drainage requirements basically depends upon amount of excess water in a field which in turn vary with climate, land use, extent of the area, intensity and frequency of rainfall (Patel, 2005). Weak drainage system often creates ill-drained conditions. Improper surface drainage system cause for excessive soil erosion, particularly during intense rainy seasons in undulating terrain in addition to yield reduction.

Since rainfall is a natural phenomenon, its intensity and amount received cannot be controlled, rainfall-runoff water should be removed exclusively by a proper drainage system. The amount and rate of rainfall-runoff depends on intensity of rainfall, soil infiltration and initial soil moisture content. Drainage designers commonly use two methods to determine amount of runoff. They are; (1) selecting a "drainage discharge" using directly-measured discharge data or (2) selecting a "design rainfall" from a long-term time-series rainfall data and transforming corresponding runoff discharge data via a rainfall runoff transformation (Oosterbaan, 1994). Due to non-availability of directly-

-measured and accurate rainfall-runoff data, second method is usually used in most cases. Estimation of the drainage parameters in an agricultural land requires the knowledge of the probable maximum rainfall that can be occurred throughout the cropping period and probabilities of rainfall maximums (Bhattacharya, 1982). Frequency analysis for 1-5 consecutive-days annual maximum rainfall is usually used to estimate probable maximum rainfall (Kapil, 2014; Barkotulla,2009;. Shivastava et al, 2008; Patle, 2005; Bhakar, 2006; Umarfarooque, 2011). One-day and two to five-day maximum rainfall data corresponds to various return periods are then taken for rainfall runoff estimations (Shivastava, 2008). Drainage structures sufficient to meet the hydrologic requirements of the area is then designed by performing a frequency analysis for previously-decided extreme rainfall levels over different return periods (Oosterbaan, 1994). But a large volume of data is needed to do this analysis by direct method. On the other hand, rainfall is a natural phenomenon and extreme events are not very often. In order to overcome these limitations, scientist are using various probability distribution functions for frequency analysis. A number of probability distribution functions, i.e., Weibuill's, Gammbel's, Gamma, Log Normal and Normal distributions have been well recognized for maximum rainfall probability analysis (Barkotulla, 2009). Further, this frequency analysis method can be used to determine the future expectations of such extreme rainfall events (Kapil, 2014) and are used for designing drainage requirements for various purposes.

The objective of this analysis is to determine annual one-day and two to five consecutive-day maximum rainfall levels and the probabilities of occurring them corresponding to various return periods; 2, 5, 10, 20, 30, 50 and 100 years to be used in designing drainage requirements for sugarcane lands in Uda Walawe area.

METHODOLOGY

Basis of the analysis

Daily rainfall data collected at Uda Walawe agro met station from 1992 to 2014 was used for the analysis. This daily rainfall data was summarized into 1-day and 2 to 5 consecutive-day maximum rainfall levels for each year. Appropriate probability functions were identified as described below by performing goodness-of-fit test. This annual 1-day maximum rainfall and 2 to 5 consecutive-day maximum rainfall data were used for probability analysis. The probable maximum rainfalls were estimated for 2-, 5-, 10-, 20-, 50- and 100-year return periods.

Selecting probability function

A probability function, which is more relevant to the existing data set has to be defined before performing statistical analysis using various probability distribution functions. Kapil (2014) used Gama (3p), Normal and Log normal (3p) distributions to analyze 1- and 2-5-day maximum rainfall in Gujarat, India. Bharkar (2006) and Barkotulla (2009) in Bangladesh have used the same methods to estimate probability of extreme rainfall events. Shivastava *et al.* (2008), used Weibull, Gumbel and Log normal distributions to design drainage parameters in sugarcane fields in India. However, such information is not available to select an appropriate distribution function for rainfall data at Uda Walawe.

Goodness-of-fit test

The goodness-of-fit test is usually used to select the most suitable probability distribution function in estimating extreme rainfall events (Kapil (2014) which ensures a realistic estimation of maximum rainfall data to have a reasonable accuracy. Therefore, Gamma, Gambel, Weibull, and Normal distributions were evaluated by conducting a goodness-of-fit test at critical level of 0.05 () to determine most suitable probability distribution function for annual maximum and two to 5 consecutive-day maximum rainfall analysis. The details of each of the above models are given below:

1. Gamma distribution:

$$f(x) = \frac{(x-y)^{\alpha-1}}{\beta^{\alpha}\tau(\alpha)} \exp(-(x-\gamma)/\beta$$

where, α - continuous shape parameter, β - continuous scale parameter, γ - continuous location parameter and τ– Gamma function

2. Gambel distribution (extreme value type 1 distribution):

$$f(x) = \frac{1}{\alpha} \exp\ (\text{-z-exp(-z)})$$

where $z=(x-\mu)/\sigma$, μ is the location parameter, and σ is the distribution scale ($\sigma>0$)

3. Weibull distribution (extreme value type 3 distribution):

$$f(x) = \frac{\alpha}{\beta}\left(\frac{x-\gamma}{\beta}\right)^{\alpha-1} \exp\left(-\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)$$

where, α - shape, β – scale parameters and location (shift) parameter γ

4. Normal distribution:

$$f(x) = \frac{\exp\left(-1/2\left(\frac{x-y}{\alpha}\right)^2\right)}{\alpha\sqrt{2\pi}}$$

where, is continuous scale parameter and y is continuous location parameter

The observed and the estimated values are compared by Chi-square test (Patle, 2005; Srivasthava, 2008). Probability distribution function that has the lowest Chi-square value was selected as best-fitted distribution.

Estimating probable maximum rainfall

The analytical needs for hydraulic engineering designing is usually fulfilled by analysing the rainfall data up to hundred years return period (Umarfarooque, 2011). Therefore, this analysis estimated the probable maximum rainfall for 2-, 5-, 10-,20-, 50- and 100-year return periods based on 1- and 2-5 consecutive-day annual maximum rainfall in Uda Walawe.

Probability of occurrence of a maximum rainfall event

The probability of any incident for a considered recurrence interval is given by,

$p = 1/T$ ……………equation 01

where, p- probability, T- recurrence interval (Oosterbaan, 1994)

Probability within a period of N years is given by,

$p_N = 1 - (1-p)^N$……… equation 02

where, p- probability, p_N -probability for N years

RESULTS AND DISCUSSION

A summary of annual 1-day and 2 to 5 consecutive-day maximum rainfalls for the period of 22 years from 1992 to 2014 is given in Table 1.

The summarized maximum values of annual 1-day and 2 to 5 consecutive-day total rainfall presented in Table 1 were fitted to 4 different probability functions, i.e., Gamma, Gambel, Weibul, and Normal distributions. The calculated Chi-Square values for testing goodness-of-fit and the corresponding ranking order for each probability function used are given in Table 2. The bolded values indicate best-fitted probability factions that have the lowest Chi-Square values in relation to each annual one-day and two to 5 consecutive- day maximum rainfalls.

Table 1: Annual one-day maximum rainfall and 2 to 5 consecutive-day maximum rainfall in Uda Walawe

Year	Annual 1-day maximum rainfall (mm)	Consecutive 2-day maximum rainfall (mm)	Consecutive 3-day maximum rainfall (mm)	Consecutive 4-day maximum rainfall (mm)	Consecutive 5-day maximum rainfall (mm)
1993	101.8	169.5	169.5	176.4	201.8
1994	78.7	85.7	86.9	103.3	110.3
1995	76.7	125.4	180.3	180.3	180.3
1996	107.0	134.5	146.0	150.8	161.7
1997	130.0	165.0	165.0	210.2	236.2
1998	81.6	107.9	116.2	123.8	145.4
1999	71.0	85.0	111.8	140.8	147.8
2000	65.5	110.2	139.2	147.8	154.6
2001	98.5	98.5	99.9	131.6	164.9
2002	81.0	87.6	109.1	128.5	146.5
2003	131.0	133.3	154.3	154.3	180.3
2004	151.5	154.0	163.2	169.8	176.8
2005	107.0	107.7	161.6	162.8	164.5
2006	71.5	96.7	117.7	122.2	155.0
2007	91.0	117.5	133.8	135.5	177.0
2008	120.2	130.2	151.4	161.4	173.3
2009	75.7	90.2	119.8	119.8	144.8
2010	120.0	153.1	153.3	158.1	159.7
2011	110.4	149.5	154.0	157.6	166.2
2012	143.7	179.3	209.3	214.7	223.0
2013	83.6	142.3	171.9	171.9	173.3
2014	100.0	103.6	129.9	143.7	146.1
Average	99.9 ®1.1	123.9®1.3	142.9®1.3	153.0®1.2	167.7®1.2

The results of Chi-squire values (Table 2) revealed that, Gumbel Max,Weibull, Normal, Weibull and Gumbel Max were best-fitted models for probability analysis of annual maximum rainfall for one, two, three, four and five consecutive days respectively. These probability functions could be considered as the most suitable probability functions for rainfall analysis for Uda Walawe area.

Table 2: The Chi-square values calculated by goodness-of-fit test for annual one-day maximum and 2-5 consecutive-day maximum annual rainfall data for different probability distribution functions

Probability	Chi-Square	Rank
1- day max		
Gamma	2.3221	3
Gumbel Max	**0.94342**	**1**
Normal	2.4676	4
Weibull	1.0612	2
2 consecutive-day max		
Gamma	0.64778	2
Gumbel Max	1.7582	4
Normal	0.65993	3
Weibull	**0.54983**	**1**
3 consecutive-day max		
Gamma	2.3423	3
Gumbel Max	2.6547	4
Normal	**1.2175**	**1**
Weibull	2.2573	2

Probability	Chi-Square	Rank
4 consecutive-day max		
Gamma	0.14015	2
Gumbel Max	1.561	4
Normal	0.26694	3
Weibull	**0.09916**	**1**
5 consecutive-day max		
Gamma	0.18913	2
Gumbel Max	**0.15716**	**1**
Normal	1.0156	4
Weibull	0.9926	3

Table 3 shows a considerable variation of monthly probabilities of annual maximum rainfall received at Uda Walawe. The second inter-monsoon from September to October period has the highest probability of 54.5% to occur one-day maximum rainfall. However, the highest probability of occurrence of two to five consecutive-day maximum rainfall is 54.8%, in the 1st inter monsoon period from March to April.

As estimated by the best-fitted probability distribution function, the maximum rainfall of 95.8mm in 1 day, 122.5mm in 2 consecutive days, 142.9mm in 3 consecutive days, 151.7 mm in 4 consecutive days and 163.2 mm in 5 consecutive days are expected to be occurred in Uda Walawe in every two - year intervals (Table 4). Similarly, probable maximum rainfall values for 5 consecutive days for 5-, 10-, 20-, 30-, 50-, and 100-year return periods are 163.2, 187.3, 203.2, 218.8, 227.5, 238.2 and 253.0 mm respectively. These values could be used in designing of drainage system in Uda Walawe sugarcane-growing areas. Normally, rainfall beyond 50 mm/day is considered as a heavy precipitation. Liesl (2009) classified daily rainfall levels for 3 classes as significant rainfall (RF>50mm), heavy rainfall (RF>75mm), and very heavy (RF> 115mm). Accordingly, except for one-day maximum rainfall values estimated for 2- and 5-year recurrence intervals, all rainfall events could be classified as "very heavy rainfall" events. All combinations (Table 4) have exceeded the level of "heavy rainfall" events. Though,

Table 3: Monthly probabilities of annual maximum rainfall occurs at Uda Walawe using the above selected best-fit models

	Annual 1 day	**2 consecutive days**	**3 consecutive days**	**4 consecutive days**	**5 consecutive days**
March	0.0	13.6	9.1	9.1	9.1
April	0.0	4.5	4.5	13.6	13.6
May	0.0	13.6	13.6	9.1	18.2
June	0.0	0.0	9.1	13.6	0.0
July	0.0	4.5	4.5	4.5	0.0
August	18.2	13.6	0.0	4.5	9.1
September	36.4	9.1	4.5	4.5	0.0
October	18.2	4.5	13.6	13.6	13.6
November	4.5	9.1	4.5	4.5	0.0
December	4.5	13.6	9.1	9.1	13.6
January	0.0	9.1	18.2	9.1	22.7
February	18.2	4.5	9.1	4.5	0.0

Table 4: Variations of probable maximum rainfall for 2-, 3-, 10-, 20-, 30-, 50- and 100-year return periods for one and 2-5 consecutive days

	Return period (recurrence interval) in years						
	2	**5**	**10**	**20**	**30**	**50**	**100**
1- day max	95.8	117.7	132.2	146.1	154.4	164.2	177.7
2-day max	122.5	146.4	157.9	166.9	171.5	176.5	182.7
3-day max	142.9	167.7	180.7	191.5	197.2	203.5	211.6
4-day max	151.7	172.7	182.5	190.0	193.9	198.0	203.0
5-day max	163.2	187.3	203.2	218.8	227.5	238.2	253.0

Uda Walawe area is under the low country dry zone and is considered as low rainfall receiving area in Sri Lanka, the above analysis has clearly shown that this annual maximum rainfall levels is a significant factor that has to be considered in designing drainages. It's importance further increases, as undulating terrain is prominent in the area and hence soil erosion (Joshua, 1977) will be high due to slope of the topography. Samran, S. and Wichai, S (2000) proposed to use 125mm maximum rainfall is sufficient for drainage designing in tropical areas. Except one day maximum for 2 and 5 year return period and, 2 consecutive day maximum for 2 year return period, all other rainfall maximum values at Uda Walawe are extremely beyond to this limit. This gives evidence that due considerations has to be paid in drainage designing under the conditions at Uda Walawe, to the fact that the heavy intensity rainfall has lower effectiveness to infiltration but high to surface runoff and ultimately results in heavy soil erosion in undulating terrain.

CONCLUSION

The study revealed that, Gumbel Max, Weibull, Normal, Weibull and Gumbel Max were best-fitted models for probability analysis of annual maximum rainfall in Uda Walawe for one-day maximum, two consecutive-day maximum, three consecutive-day maximum, four consecutive-day maximum and five consecutive-day maximum respectively.

Except one-day maximum rainfall for 2- and 5-year recurrence intervals, all the events can be classified as very heavy rainfall events. The consideration of this fact is essential in drainage designing in Uda Walawe area. As field conditions are changed by 5-10 years periodically due to re planting of sugarcane, drainage structure within the cultivating area (farmer field) should be designed considering at least the maximum rainfall of 10-year return periods. Major drainage structures like, culverts, diversions, bridges, flood controlling structures etc that are established outside to farmer fields would be designed according to the 30-, 50- or 100-year recurrence intervals which is basically depends upon the financial availability and lifetime expectation of the entire project.

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