Rainfall Analyses of Coonoor Hill Station of Nilgiris District for Landslide Studies

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Rainfall Analyses of Coonoor Hill Station of Nilgiris District for Landslide Studies

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Abstract. The most common triggering factor of landslides in a hill terrain is rainfall. Assessment of the extreme and antecedent rainfall events and its quantum is imperative to evaluate the temporal occurrence of landslides. It also plays a vital role in the choice of the preventive measures to be adopted. This study focuses on an in-depth rainfall analysis of Coonoor hill station. The analysis includes the study of monthly, seasonal and annual rainfall patterns for a period of 80 years, between 1935 and 2013. Further, one day maximum, 5 day and more antecedent rainfall and its amount is calculated for the years between 2007-2012, 2014 and 2015.The result of the study indicates an increase in the normal rainfall based on the mean of 30 years of data (for the recent decades) and erratic pattern of rainfall during pre-monsoon, post-monsoon south-west monsoon periods. A detailed analysis of daily rainfall for the selected period indicates that extreme highest daily rainfall of more than 300 mm above occurred after consecutive rainfall trigged massive landslides comparing highest rainfall amount around 100 to 180 mm rainfall events.

1. Introduction

For an efficient drainage design, watershed management and to propose landslides prevention measures in the hilly region, it is vital to know the extreme precipitant events, antecedent rainfall and its period of occurrence. Accurate estimation of debris flow, potential zone of soil scour and landslide susceptibility along hill roads are crucial aspects for hill area development and to protect the ecosystem from environmental degradation. Due to non-availability of short duration rainfall at most of places around the world, it is common practice to utilize the amount extreme daily rainfall events for modelling the landslide events in the hilly terrain. Rainfall during strong northeast monsoon season in Coonoor-Mettupalayam region of Nilgris district of Tamilnadu often triggers many landslide. Hence, short duration rainfall is essential to predict and understand the landslide and debris flow occurrences in the mountainous region. Intense rainfalls of short durations usually occur within longer-duration storms rather than as isolated events. The relationship between rainfall and landslides has attracted the interest of numerous researchers because rainfall is the most common landslide-triggering factor in many regions in the world [1]. Literature shows that the most commonly investigated rainfall parameters for landslide initiation are cumulative rainfall, antecedent rainfall, rainfall intensity and rainfall duration. Chowdhury and Flent Je [2] emphasized that landslides triggered by rainfall needs complete understanding of the link between rainfall and landslide, frequency of landslides with respect to frequency of heavy rainfall event, monitoring of subsurface shear movements and pore pressure at the existing landslide points and studying the relationship between rainfall magnitude and landslides.

Jaiswal [3] described that landslides in Nilgiris as debris slides or debris flow triggered by high intensity or prolonged rainfall.

2. Study Area

Coonoor taluk of Nilgiris district, the second largest hill station in Nilgiris is a preferred tourist destination. It is also a municipality. It is also one of the regions most affected by landslides in Tamilnadu. It is located at an altitude of 1850 m above MSL and has a population of about 45,494 people according to 2011 census. The climate falls under the sub-tropical highland type according to Köppen classification system. The average elevation is 1850 m above MSL. Charnockite is the most prevalent bedrock material, covered with laterite which forms an irregular soil horizon. The rocks are of metamorphic origin. The economy of the region heavily relies on the tea plantations and tourism related activities.

3. Normal Rainfall for Coonoor Station

Figure 1 presents the historical rainfall for Coonoor station. It is clear from the plot that annual rainfall exceeds almost 1000 mm. Mean of 30 years of annual rainfall denotes the normal rainfall of a station. Recent 30 years of rainfall will be used for computation of normal rainfall of the station. From available monthly historical rainfall data, the normal rainfall for recent 30 years (1985-2014) and previous two stages of 30 years are calculated and presented in the Table 1.

Table 1. Normal Rainfall for Coonoor station

Year of analysis	No. of years	Annual Normal rainfall (mm) with (standard deviation)	Pre-monsoon normal rainfall (mm) with (standard deviation)	South-West Monsoon rainfall (mm) with (standard deviation)	North East Monsoon rainfall (mm) with (standard deviation)
1935 – 1964	30	1545 (307)	484 (191)	325 (77)	735 (236)
1955 – 1984	30	1678 (469)	446 (225)	356 (101)	876 (393)
1985 – 2014	30	1773 (325)	416 (181)	369 (99)	988 (319)
1935 - 2014	80	1665 (390)	443 (199)	351 (94)	870 (350)

This analysis indicates how normal rainfall hada change over 80 years. The recent normal rainfall is 1773 mm. This value is higher than the normal rainfall worked out for different 30 years of span. Further, the average of 80 years of rainfall account as 1665 mm. It is again lesser than recent 30 years average. This depicts that the rainfall in the Coonoor station has been increasing over the years. To confirm the increasing trend of annual rainfall, 5- year and 10-year moving average plot are prepared and present in figures 2 and 3. The trend clearly shows the increasing amount of rainfall over each five years. Normal rainfall for pre-monsoon, south-west and north east monsoon periods is evaluated and for selected 30 years of interval and also for 80 years of data. Normal rainfall for pre-monsoon period is found to be lesser for recent 30 year period than other considered periods. But, there is an increased value of rainfall ascertained for south-west and north-east monsoon periods. This increase in rainfall during recent years has resulted due to highest annual rainfall amount reported for 7 years out of 30 years which exceeded 2000 mm and it is greater than 12 % the normal rainfall of this thirty years average. The standard deviation except south west monsoon period is having higher value irrespective of period of analysis. This also indicates that rainfall pattern is highly erratic during pre-monsoon and north-east monsoon periods. The number of rainy days per year varies from 65 to 100 days. The plot (Fig.4)shows the average monthly rainfall over the year. The average plot indicates that minimum rainfall of around 60 mm occurs in January and June and maximum rainfall of about 325 mm is expected during October and November months. The monthly rainfall variability (ratio between standard deviation and mean rainfall) is worked out based on 80 years of data and same is presented in

Fig.5.High variability in monthly rainfall is noticed during January, February, March, May and December months. The remaining months of the year poses variability around 50 %.

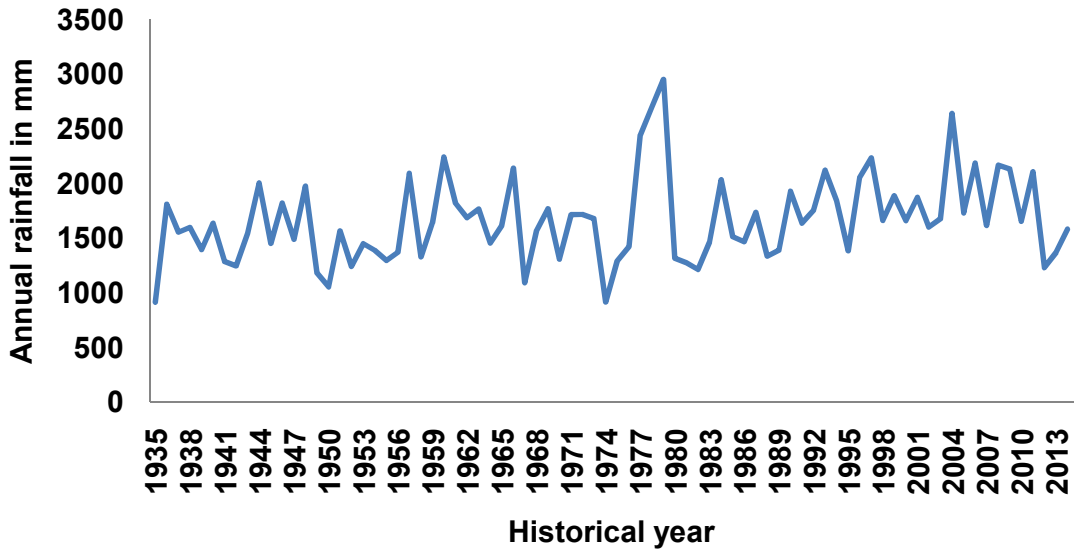

Figure 1. Annual historical rainfall of Coonoor hill station

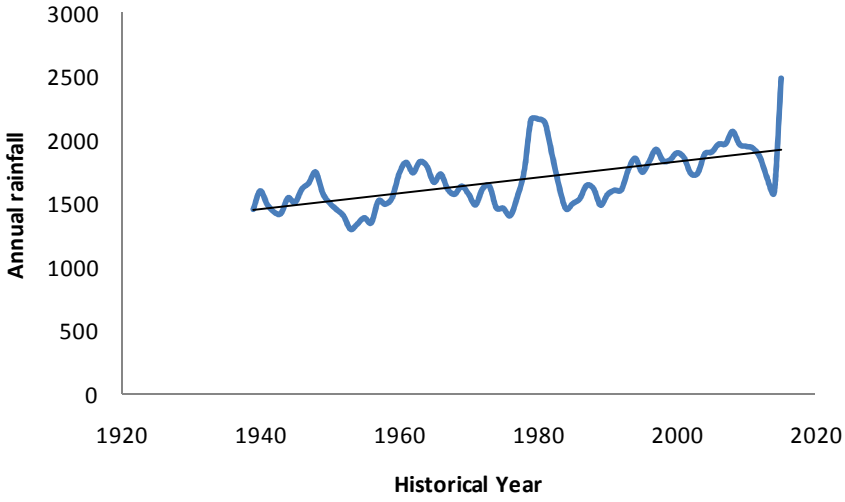

Figure 2. 5-year Moving average annual rainfall plot

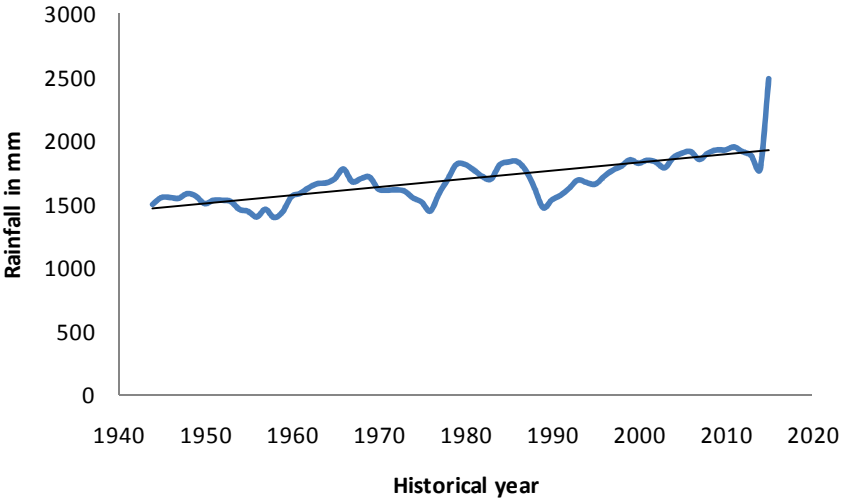

Figure 3. 10-year Moving average annual rainfall plot

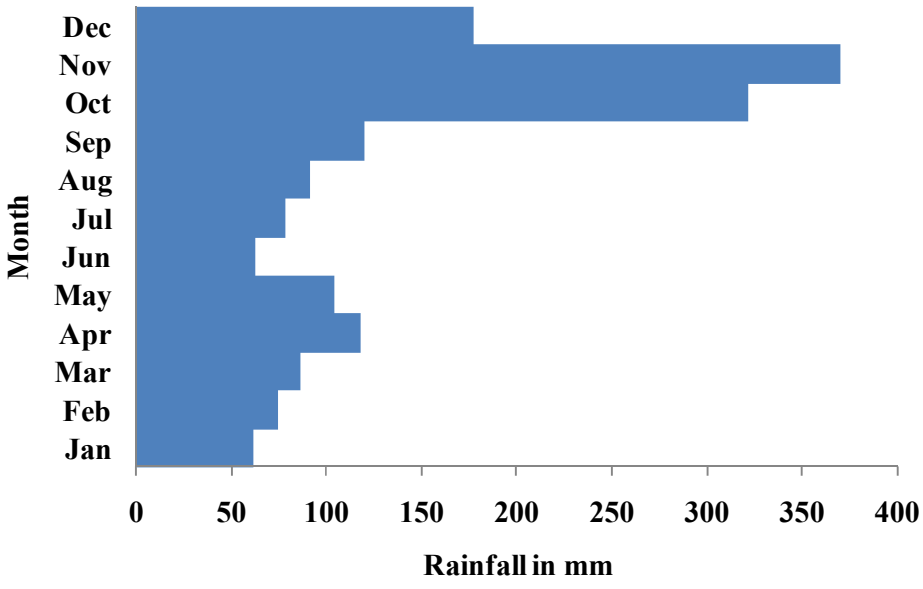

Figure 4. Average Monthly rainfall in mm for Coonoor Station-80 years

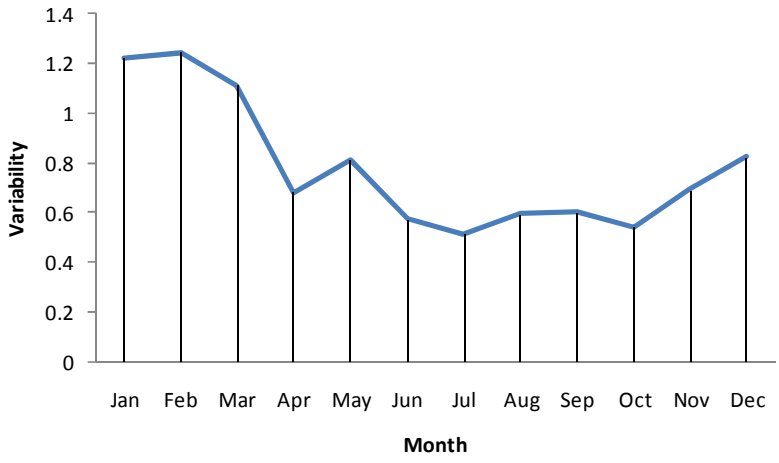

Figure 5. Monthly rainfall variability of Coonoor Station

4. Year Wise Rainfall Analysis

4.1 Year 2007

Year 2007 received annual rainfall of 1521 mm (Table 2) in which October and December month rainfall exceeded 300 mm. Though these two months received more than 300 mm, there is large difference in the number of rainy days. The rainy days in December is only 6, in which three days reported consecutive rainfall. But, October received 13 days rainfall consecutively. The moisture content of the soil could be uniform in case of October than December of that year. Further, 3 months are having 5 days antecedent rainfall whose cumulative amount are 20.8 100.8 and 308.6 mm respectively. The last two months data (August and September) are more significant in saturation of soil than in the July month in which 20.8 mm received. Rainfall in July is continuous but its total amount is less than notable 5 days antecedent rainfall as per soil conservation treatment concern.

Table 2. Year 2007 Rainfall statistics for Coonoor Station

Month	Total amount (mm)	No. of rainy days	No. of consecutive rainy days	Amount of rainfall (mm)	Maximum daily rainfall (mm)
January	23.6	1			23.6
February	129.8	5	3	126.6	83.2
March	0.0	-	-	-	-
April	66.8	6	2	50.2	40.8
May	73	5	5	40.6	21
June	87	7	4	26	49.6
July	70	8	5	20.8	11.4
August	132.8	13	8	100.8	29.8
September	117.6	9	3	56.6	27.8
October	318.2	13	13	308.6	62.6
November	110.	7	4	84	42.4
December	392.2	6	3	305	170
Total	1521	80	Year Maximum	308.6	170

4.2 Year 2008

Year 2008 received more rainfall during post monsoon months February and March. These two months account for most rainfall of the year followed by October. Six months received more than 5-

day antecedent rainfall, but not in sequential order. The annual rainfall of this year is 1910.5 mm (Table 3) which is widely spread throughout year. January, May and September months received low rainfall. The maximum daily rainfall of 113 mm occurred inMarch and two days received rainfall around 110 mm.

Table 3. Year 2008 Rainfall statistics for Coonoor Station

Month	Total amount in mm	No. of rainy days	No. of Consecutive rainy days	Amount of rainfall (mm)	Maximum daily rainfall (mm)
January	13.6	2			8.2
February	339.3	10	9	303.4	113
March	433.5	12	12	221.2	111.5
April	86.4	3	3	84.8	55
May	36.6	3			17
June	97.1	6	2	49.6	45
July	144.5	12	10	52.4	45.5
August	231.5	17	6	89	48.4
September	19	2			11.4
October	336	13	7	150.5	82.6
November	97	6	8	61.4	30.6
December	76	5	3	27.4	40.6
Total	1910.5	91	Year maximum	303.4	113

4.3 Year 2009

Table 4 gives the monthly rainfall amount and number of rainy days during the year 2009. Year 2009 received very heavy rainfall during November month that exceeded 1000 mm rainfall amount. The number of consecutive rainy days during that month is 9 days out of 15 days of rainfall. Five days antecedent rainy days are witnessed in 6 months consecutively starting from July to December. The amount of rainfall in each of these months exceeded minimum rainfall of 36 mm which is considered in estimating 5 days' antecedent soil moisture condition in the area to address the degree of saturation of the soil. It is clear that the area was completed continued in the deep wet for continuous period of 6 months and several landslides were report in this region during November. The maximum daily rainfall of 395 mm occurred in November. November 9, 10, and 11 received 141.2 mm, 363.0 mm and 395 mm rainfall respectively. High soil moisture with fully saturated soil mass and extremely heavy downpour triggered massive, major and mini landslides at several places of the hilly road sections. This year alone there have been nearly 111 landslides in Ooty, Coonoor and Kotagiri region claiming 80 lives, disrupting traffic along the State highway connecting Mettupalayam and Ooty through Coonoor and hampering the livelihood of this hill community. North-East monsoon rains in November 2009 (monthly Rainfall of 1181 mm and 9 days consecutive rainfall of 991.2 mm) caused a major landslide affecting the entire slope, disrupting traffic on the Mettupalayam– Coonoor –Ooty Highway (NH 67) and completed destroyed the tea plantations on the slope. This slope lies along the Mettupalayam– Coonoor-Ooty highway which is a busy traffic corridor and the damage to this stretch can severely hamper the traffic flow to and from Coonoor and Ooty along the 14th hairpin bend. The slope also houses a hospital and an old age home, in addition to private horticulture farms and tea plantations on the entire slope. Necessary prevention measures are required in order to safe guard this region in case similar or higher magnitude consecutive rainfall events occur in near future. This makes the slope an important location to be monitored and studied.

Table 4. Year 2009 Rainfall statistics for Coonoor Station

Month	Total amount in mm	No. of rainy days	No. of Consecutive rainy days	Amount of rainfall	Maximum daily rainfall (mm)
January	10.2	2	-		4.6
February	0.0	0	-		-
March	84.7	4	3	80.2	49.6
April	20	1	-		20
May	86.2	7	3	53.2	25
June	39.8	3	3	36.4	23.2
July	74	9	7	36.4	10
August	147.6	9	8	118	43.2
September	110.8	8	8	104	39
October	138.3	11	5	74.4	27
November	1181	15	9	991.2	395
December	190	10	5	130.2	48.6
Total	2081.8	79	Year Maximum	991.2	395

4.4 Year 2010

The maximum daily rainfall for this year is found to be 81 mm which is lesser than 140 mm. Generally, it is considered that 140 mm rainfall a day could trigger landslide in cut slopes. There are five events of five consecutive day rainfall, in which two events rainfall amount exceeded 140 mm. The annual rainfall is 1409.4 mm (Table 5) and November month contribution is found to be significant. In the November month itself, there are two long periods of rainy events. This year rainfall could be deficit with respected to normal rainfall of the region.

Table 5. Year 2010 Rainfall statistics for Coonoor Station

Month	Total amount in mm	No. of rainy days	No. of Consecutive rainy days	Amount of consecutive rainfall (mm)	Maximum daily rainfall (mm)
January	40.6	2			25
February	1.0	1			1
March	0.0	-			0
April	4.5	1			1
May	133.6	8	5	51.4	37.6
June	57.2	7	3	22.8	35
July	123.6	8	5	41.4	36.4
August	50	4			25
September	101	10	6	54	23
October	224	12	4	195	70
November	475	15	7	211.6	81
December	198.9	8	7	156.6	72
Total	1409.4	76	Year maximum	211.6	81

4.5 Year 2011

This year received very high rainfall comparing the previous 4 years. The rainfall in the months January, October and November received more than 450 mm (Table 6) which made extraordinary contribution to the total amount. There are six events of 5 days consecutive rainfall. The highest rainfall falls in the consecutive rainfall periods. It is to be noted that there was a continuous rainfall of 18 days starting from end of October to the beginning of November. The cumulative rainfall of this

event is 649.1 mm. Such a long spell certainly could invite landslides if there are no landslide prevention measures. As the rainfall is continuous, the soil will be full saturated. Further, this rainfall event would have produced large surface runoff and base flow event after rainfall over. A maximum rainfall of 145 mm occurred two times in this year.

Table 6. Year 2011 Rainfall statistics for Coonoor Station

Month	Total amount in mm	No. of rainy days	No. of Consecutive rainy days	Amount of consecutive rainfall (mm)	Maximum daily rainfall (mm)
January	461.4	14	8, 5	179 &277.8	145
February	193.4	5	6	193.4	133
March	31	4	-	-	8.8
April	192.5	7	5	91	74
May		-	-	-	-
June	129.6	8	4	68.8	33.4
July	84	6	-	-	27.6
August	96.1	9	4	48	28
September	117.8	11	4	36.6	25
October	691.5	21	11	470.1	84.8
November	460.6	14	8	179	145
December	87.2	5	-	-	40.6
Total	2545.1	104	Year maximum	470.1	145

4.6 Year 2012

The rainfall during post and pre monsoon periods (Table 7) is found to be low comparing previous years of data. The data related to south west monsoon periods is not available in the analysis.

Table 7. Year 2012 Rainfall statistics for Coonoor Station

Month	Total amount in mm	No. Of rainy days	No. Consecutive rainy days	Amount of consecutive rainfall (mm)	Maximum daily rainfall (mm)
January	0.0	0			
February	13.4	2			8
March	81.4	3			51
April	83.2	6	5	76.8	62.2
May	49.4	5			17
June	NA				
July	NA				
August	NA				
September	NA				
October	776.5	14	7 & 7	286.4 & 436.7	180
November	134.6	6			51
December	NF				
Total			Year maximum	436.7	180

There are three events which had a five day consecutive rainfall, in which two events occurred in October with one day interval between them. Almost 15 day continuous rainfall with one non rainy at the middle of the period has brought 723.1 mm of rainfall. The highest downpour of 180 mm is recorded during this period. The October month of this year poses extremely wet weather conditions.

4.7 Year 2014

This year received total rainfall of 1581.6 mm (Table 8), in which North-east monsoon period recorded more rainfall than other seasons. Year maximum rainfall of 102 mm has recorded once. 3 events of 5-day consecutive rainfall have occurred. It is to be noted here that 2 events of 5-day consecutive rainfall are less than 160 mm. The six day continuous rainfall in the October month is recorded as 353 mm. But, this continuous rainfall did not bring much landslide. Heavy rainfall within continuous rainy days is recorded only 91 mm and its distribution over the day could be crucial in trigging landslide.

Table 8. Year 2014 Rainfall statistics for Coonoor Station

Month	Total amount in mm	No. Of rainy days	No. of Consecutive rainy days	Amount of consecutive rainfall (mm)	Maximum daily rainfall (mm)
January	0.00	0			
February	108	5	4	82.2	37.4
March	93	4	3	84.8	47.6
April	-				
May	190	7	5	153.2	97
June	16	2			10
July	42.8	6			7.6
August	154.5	7	5	77.8	39
September	64.1	5			21
October	460.8	11	6	353	91
November	236.6	11	4	202.6	84.2
December	215.8	7	3	179.2	102
Total	1581.6	65	Year maximum	353	102

4.8 Year 2015

The total rainfall received during year 2015 is 2488 mm (Table 9) which is 40 % higher than the normal rainfall. Number of rainy days is 99 and maximum one day rainfall is recorded as 175 mm in the March month. Though the total rainfall during November month is highest (676 mm) in the year, the maximum rainfall received during that month is 145 mm which is found to be lesser than the rainfall recorded during March month.

Table 9. Year 2015 Rainfall statistics for Coonoor Station

Month	Total amount in mm	No. of rainy days	No. of Consecutive rainy days	Amount of consecutive rainfall (mm)	Maximum daily rainfall (mm)
January	0.0				
February	4.5	1			3.1
March	489	3			175
April	167.3	6			121.2
May	301	15	9	247	95
June	144	11	5	52	22
July	90	7	3	34	25
August	51	4			17
September	207	12	2 x 4	59,102	45
October	236	12	3	53	47
November	676	18	5	357	145
December	122	10	6	91.5	24
Total	2487.8	99	Year Maximum	357	175

There are four incidence of 5-day consecutive rainfall in the year. November month's consecutive rainfall magnitude is found to be high. September received two incidents of 5-day consecutive rainfall events, but its value is small. There were 52 days of rainy days in four months. The total rainfall recorded during North-East monsoon season is 1034 mm. It is to be noted that several minor landslide incidents were reported during this season.

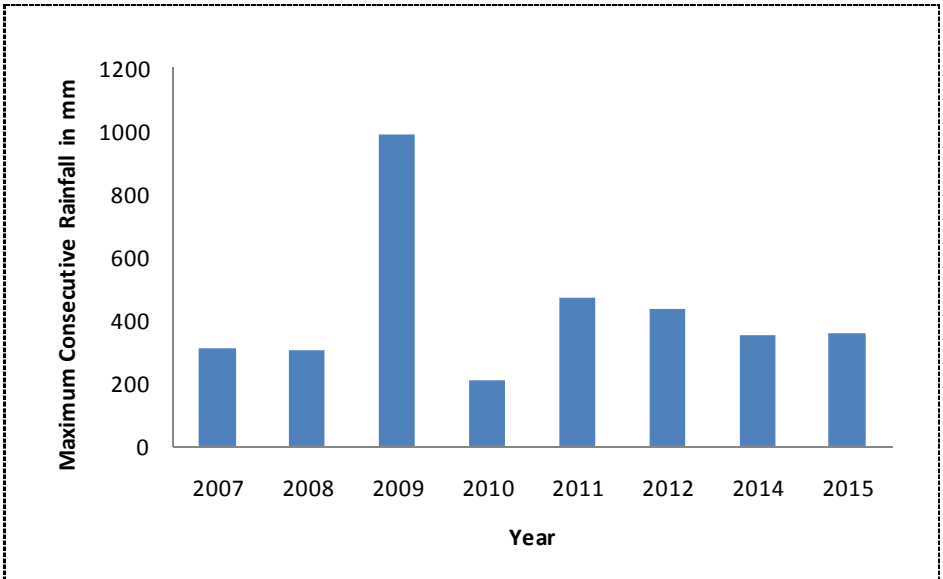

Figure 6. Consecutive maximum rainfall events during year 2007 to 2015

5. Discussion

Landslides induced by heavy rainfall often occur along Coonoor-Mettupalayam State highway during North-East Monsoon season. As this road one of shortest route connecting these two towns, the traffic flow between 4.00 am and 8.00 pm is always high. Any major obstructions along the road seriously affect the traffic flow movement. Despite the stable slope that consist of various soils such as colluvial and residual soil available along the road section, the consecutive rainfall coupled with intermittent heavy day rainfall during vigorous monsoon period accelerates mud flow along the slope that could uproot plants and tree due its high velocity of mud flow. Further, continuous rainfall fills the pore of the soil and mounting the pore pressure at critical zone in the slope that could suddenly trigger the movement of boulder and disturbing the stability of slope. The rainfall recorded during year 2009 in Coonoor station on November 9, 10, and 11 received 141.2 mm, 363.0 mm and 395 mm rainfall respectively. And another raingauge station located at RunneyMedu which is near to highway section received 170, 415 and 285 mm on November 8, 9 and 10, respectively. The heavy downpour noted in these two stations make fool-proof evidence to landslides events along the State Highways and Hospital complex located near vicinity of 14th Hairpin bend. Due to continuous soil moisture and extreme heavy downpour triggered several massive, major and mini landslides at several places along this road section during these days. While comparing maximum consecutive rainfall that occurred between 2007 and 2015(Fig.6) excluding year 2013 indicates that the year correspond to the rainfall exceeding 900 mm triggered large number of landslide events. High pore water pressures generate during prolonged and intense rainfall which could be the main reason to trigger massive landslide during these periods. Due to non-availability of pore water pressure data, it is very difficult to assess the threshold rainfall which can trigger landslides. It is clear from the present analysis that the slope instability occur only during very heavy down pour with continuous rainfall event. Hence, it is important to prioritize the critical slopes for preventive and remedial action, developing early warning systems using sensors based on pore pressure. Six days continuous rainfall during October, 2014

triggered minor landslides in the Coonoor region. The rainfall amount of 91, 48.4,81.2, 79.6, 32.6 and 20.2 are recorded between 19th October and 24th October, 2014. The landslide reported on 20th October, 2014 had rainfall of 48.2 mm with one day previous rainfall of 91 mm. This landslide happened with one day antecedent moisture. The antecedent moisture prevailed before occurrence of 91 mm rainfall due to two independent rainfalls occurred in the same week. It is to be noted that triggering of any landslide in the study area requires sufficient antecedent moisture and followed a heavy downpour. The type of landslides depends on the magnitude of heavy rainfall which would have been occurred within consecutive rainfall events. There were 38 events of 5-day and more consecutive day rainfall noticed. But all these consecutive rainfall events did not produce landslide events. Those events which recorded heavy rainfall within continuous rainfall alone produced landslides.

6. Conclusion

The daily rainfall data for a selected recent year and monthly rainfall data for 80 years used for analysis of rainfall data to evaluate rainfall which could be potential triggering factor for minor, medium and major landslide in and around Coonoor station of Nilgris district of Tamilnadu, India. Most of landslides events have occurred during continuous rainfall events and its cumulative rainfall amount exceeding 500 mm. Major landslides reported whenever daily rainfall exceeds 250 mm with several days of antecedent rainfall. Based on 5-yrs and 10-yrs moving average analysis of 80 years of annual rainfall, there is increasing trend of rainfall amount witnessed in the selected station. The contribution of North-East monsoon rainfall is found to predominant and most of landslides are triggered during this period. In most of the year, number of rainy days in the month of October and November is found to be greater than 10 days. August and September months are next to these months recorded as most rainy month of a year. The station normal annual rainfall based on recent 30 years is evaluated as 1773 mm and pre-monsoon, South-West monsoon and North-East Monsoon seasonal rainfall are obtained as 416, 369 and 988 mm respectively. Further, analysis concludes that landslides were happened only those events of continuous rainfall in which maximum rainfall noticed. It is to be noted here that rainfall threshold for landsliding are dynamic and it could depend on geo-environmental conditions of local terrain within close vicinity of landslide spot. Improving measuring of rainfall at closer spatial condition in conjunction with pore pressure measurement is needed at longer period.

Acknowledgment

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