Determination of the Probabilities of Landslide Events in Kalimpong, West Bengal

Parvesh Lamba[1], Pooja[2], Amit Dabas[3], Hitesh Khatri[4], Prof. S. Anbu Kumar[5]

[1-5](Department of Civil Engineering, Delhi Technological University, Delhi, India.

ABSTRACT: - *Landslide is more common in mountainous areas due to the low density of rocks, soil, debris etc. The Himalayan region, because of its complex geological features and road offers excellent landslide conditions. It is estimated that 42% of all the most common mudflats in the country fall in the north-east Himalayan region, particularly Darjeeling and Sikkim Himalayas. This leads to the severe loss of life and property which is so early the need to bring in strategies to reduce the impact on the affected areas. Therefore, it is important to understand the relationship between landslides events and rainfall conditions during and before that, primarily in the Himalayan region scenario in Kalimpong. In this paper, a rainfall-based roadmap is proposed and a Bayesian model of soil saturation can be mixed in the Kalimpong region of the Darjeeling Himalayas. Daily rainfall data covering a 10-year period were collected at Teesta's unique rainfall station, Kalimpong (from 2010 to 2019) and landslide (42 total of 146 sites) containing dates to date, corrected from records historical for the period 2010 to 2019. The Bayesian theory for the one-dimensional case was developed. Next, a two-dimensional Bayesian regression model was generated. The probability of occurrence of the landslide is 0.43 if the intensity of rainfall is more than 80 mm/day for the one-dimensional Bayesian formulation and 0.42 for a rainfall period greater than 0.3 days for a range greater than 40 mm / day.*

Author keyword: **Landslide, Kalimpong, Bayesian probability, One dimensional probability, Two-dimensional probability.**

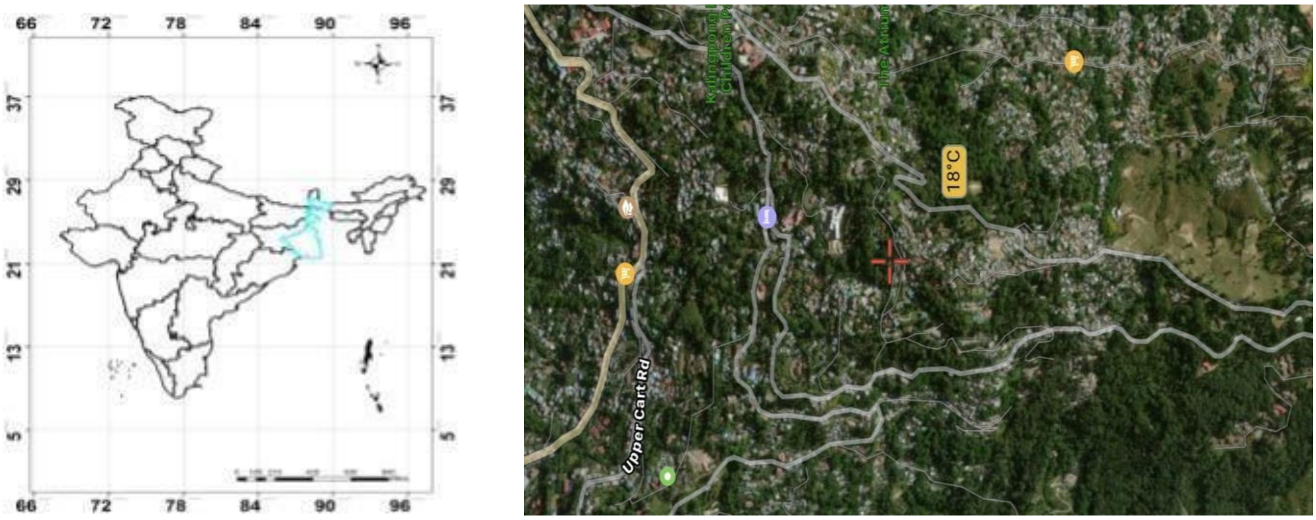
INTRODUCTION

The Indian Himalayan region has been knowingly affected due to the intensification in frequency of landslide incidence. 30% of worldwide landslide events occurs in Himalayan region (GSI Report, 2016) with damage amounting to one billion US$ and loss of 200 people every year. The factors affecting landslides are varied and are usually interconnected. However, the effects due to primary triggering factor are of main concern. As mentioned earlier, three-quarters of landslides in Kalimpong are influenced due to rainfall. The monsoon rainfall in Kalimpong can be defined as low intensity and long duration with disruptions of recurrent heavy gusts which leads to the analysis of shallow landslides. The slightest amount of rainfall required for landslip to befall will define the threshold of the area. Numerous researchers have tried to find a relation between rainfall and initiating of landslips. Few studies have been conducted in the Indian Himalayan region and studied the Darjeeling region; did for North Sikkim and studied a section of the Chamoli region, Uttarakhand. They asserted the importance of finding thresholds using empirical models and emphasized the need to analyse and realize the importance of antecedent rainfall in eliciting landslips. However, some factors like the homogeneity and quality of data may affect the determination of thresholds determined using experimental method. In order to get a well understanding of the effect of rainfall, the analysis of individual rainfall parameters using a probabilistic approach is essential. Moreover, the results obtained from empirical analysis gives a single output which may not always be suitable. Hence, there is a need to move towards a more realistic assessment, by using a probabilistic approach.

STUDY AREA

Kalimpong is a hill station located in the West Bengal region, India. Available at 87.47-89.47 N latitude and 26.07-28.07 E long. The slope of the Western Kalimpong crater has been severely affected by landslides. These sites contain various amounts of interpretations and rubble / rocks of many generations. Global warming is mainly caused by poor physical quality, the erosion of the Teesta River in the toes and hands at short intervals in the event of high rainfall during heavy rainfall. The study area is part of the Darjeeling Himalayan, which includes intratrusted fold thrust belt (FTB) rock from the Precambrian to the Quaternary Ages. soil.

Large amounts of landslides in the area can result in heavy rainfall and untreated water currents or thrusts, which break the bonds, loosen the soil, and break down the particles, leaving the sloping surface area completely saturated. Soil infiltration increases soil fertility thus increasing the surface area. When the soil absorbs too much water, the chances of erosion increase as a result of increased pore pressure. The flow of water causes the rocky weather to collapse along the banks of streams and over time these processes cause the rocks and the other materials to fail leading to landslides. This area is characterized by a large number of small boundaries known as the Kholas and jhoras. During the monsoon these small streams flow with great force causing constant flooding and depositing a pile of small stones on the rocks. This results in severe backal and headward erosion that results in more severe bank failures in large-scale cracking.



(a) Political Map of India (b)Kalimpong

Fig. 2.1 Location of the Study Area (a) India (b) Kalimpong

CAUSES OF LANDSLIDES IN KALIMPONG

Kalimpong has a history of landslides with the first one recorded in 1899. During the period 2010 to 2019 total of 99 soil erosion events occurred when 61 of the landslides were due to rain.

RAINFALL

Rainfall plays a major role in landslide in this region as heavy rainfall loosens the soil by breaking ties and breaking particles. The magnitude of soil erosion in this region is due to the heavy short rainfall that loosens the soil by breaking the bonds and particle cracks that cause the upper part of the river to become more saturated and causing landslides. Due to heavy rainfall the flat surface is completely filled following erosion. It causes a decrease in the flow of water through the joint and cracks. Rain acts as a softener to soften the cracks. The rain drains the apparatus from the parent's body and expands it under gravity. The percolation of water through the pore space of the soil speeds up the possibility. The water draws down the fall of the earth because it is heavy and can add extra weight to the soil, the rock is overcome by gravity.

The Rainfall database was prepared from the reports of the Geological Survey of India (GSI) and Save the Hills NGO, Kolkata city of Kalimpong during the period 2010 to 2019 as shown in Table 3.1. Fig. 3.1 shows the rainfall data between the months of June and September from 2010 to 2019 based on when it will be analysed.

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
June	317	337	355	248	396	568	327.2	154	184	81
July	656	668	433	424	371	534.4	869.2	811	387.7	821
August	425	525.68	241	401	572	242.3	262.6	432.1	524.5	510.5
September	258	384.1	467	113	265	331.2	366.4	289	346	408.5

Table 3.1: Rainfall (in mm) data for monsoon period in Kalimpong town (2010-2019)

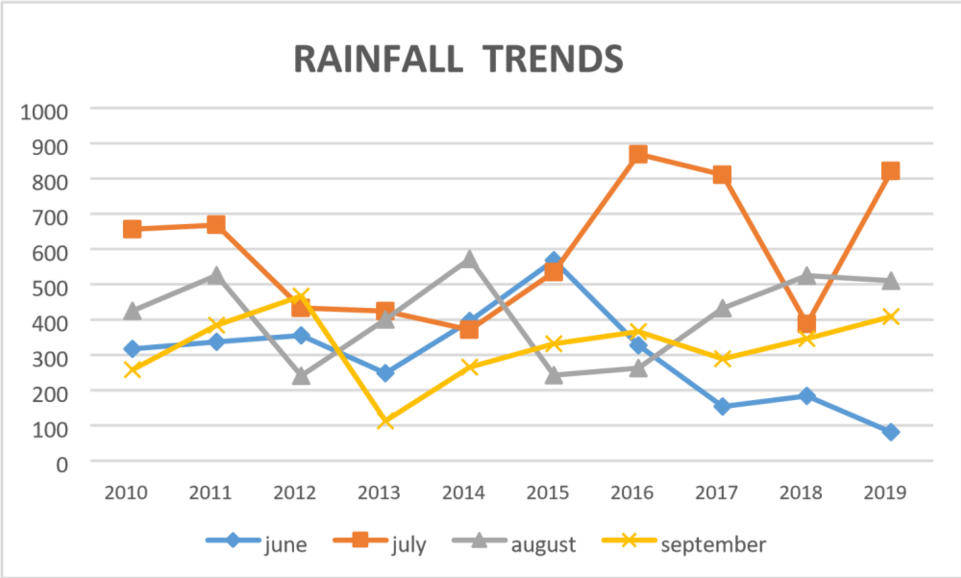


Figure 3.1: Trend in rainfall during the monsoon season

DRAINAGE SYSTEM

The Kalimpong line is thick in topography and is dispersed by low-lying rivals that impact on the Teesta river basin. When the drainage line rises, the frequency of the landfill decreases as the area around the dam network coincides with the distance, so the shear strength of the drainage is reduced around the drainage network.

METHODOLOGY

A probabilistic approach using the Bayesian method is used here to determine the landslide occurrence probability of various precipitation signals. Probability-based methods are advantageous as they integrate different rainfall characteristics or parameters with uncertainties providing a descriptive and qualitative assessment with improved forecasting of the thresholds. Therefore, if its effect is not limited to a particular case of failure or no-failure in a particular rain event, the determination method is inappropriate and a statistical or probabilistic approach may be adopted. It would also ensure that number of landslides N_X is never greater than number of rainfall events N_R, making the probability non-viable, $P(X) = N_X/N_R > 1$.

One-Dimensional Bayesian Analysis

Prior and conditional probabilities are calculated by the application of Bayesian theory which gives the probability of landslide event caused by the various rainfall parameters. The conditional probability is given as P (X|Y) i.e. the probability of landslides due to a particular rainfall parameter (Y) which is found as:

$P(X|Y) = P(Y|X)\,P(X) / P(Y)$

P (Y|X) = Probability of a rainfall event of degree Y given a landslide happens

P (X) = Probability of landslide whether the rainfall event occurs or not,

P (Y) = Probability of rainfall of degree Y whether a landslide happens or not;

For a given N_R, N_X, let the frequency of rainfall events of degree Y be N_Y and the number of rainfall events resulting in landslide be N (Y|X). Now the probability terms can be written in these forms:

$P(X) = N_X/N_R$

$P(Y) = N_Y/N_R$

$P(Y|X) = N(Y|X)/N_X$

Two – Dimensional Bayesian Analysis

Bayesian Probability here estimates the joint conditional probability of two or more influencing parameters.

$$P(X|Y, Z) = P(Y, Z|X). P(X) / P(Y,Z)$$

Here Y, Z denotes the combined probability of any two variables. A pair of rainfall parameters for determining the probability of landslide initiation may be computed using 2-D Bayesian analysis and the significance of this probability is seen when compared with the prior landslide probability values.

ADVANTAGES OF THE METHOD

The major drawback with the deterministic approach is that it only takes into account the rainfall that causes slide initiation i.e. triggering rainfall. Probabilistic (Bayesian) method is advantageous from the fact that it considers all the rainfall events which makes it possible to determine all kinds of uncertainties in terms of probability. A particular rainfall event cannot be said to result in the landslide in such a complex geology every time. In addition, probability calculated using Bayes theorem is dynamic in nature and is easily adaptable to updating processes in future.

LIMITATIONS

Probability computed using Bayes theorem failed when the rainfall event Y did not result in the landslide, meaning that the landslide occurrence probability P (X|Y) should be 0 since P (Y|X) is also 0. This becomes contradicting the real situation. One similar limitation as that of empirical approaches is the accuracy of probabilistic approach with the long-term use of data from the studies in past. Factors such as slope changes, cover on the land, use of the land, rainfall pattern and anthropogenic events affect the occurrence of landslides repeatedly. Bayesian analysis solves this by adding control variables keeping in consideration that probabilistic predictions depend on past data.

APPLICATION OF BAYESIAN APPROACH

One Dimensional Bayesian Probability

Probability of rainfall P (Y) is calculated for N_R = 245 total events of rainfall that took place in study period (2010-2019). The conditional probability P (X|Y) is computed for N_X=42 events of rainfall that initiated landslides.

P (X) = N_X/N_R = 42/245 = 0.17. Now P (Y|X) is calculated considering various rainfall intensities as shown in table 3.2.

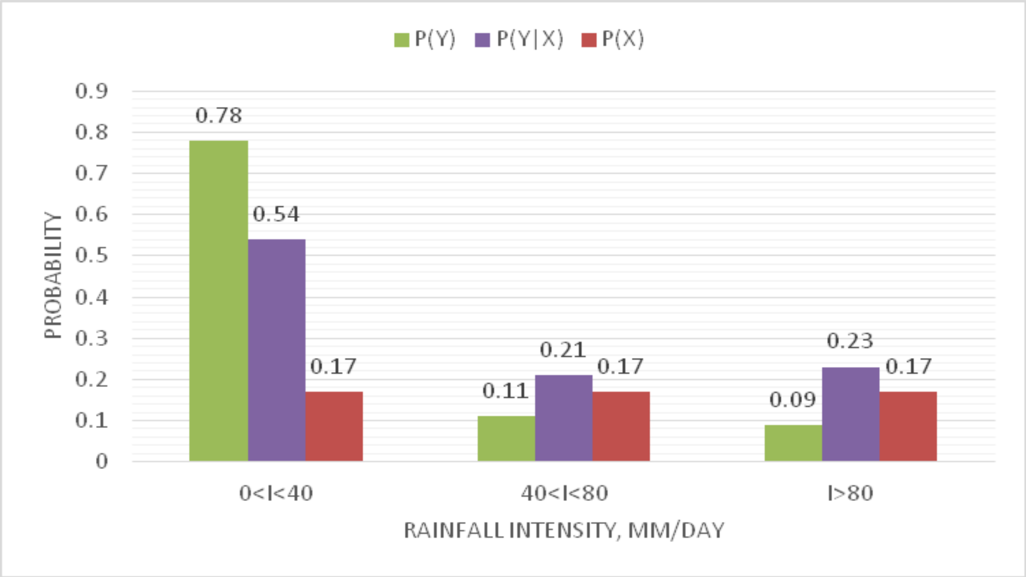
Table 5.1 Rainfall and Landslide Database for 2010-2019

Total rainfall events	Number of daily rainfall intensity with 0<I<40 mm/day	Number of landslide with 0<I<40 mm/day	Number of daily rainfall intensity with 40<I<80 mm/day	Number of landslide with 40<I<80 mm/day	Number of daily rainfall intensity with I>80 mm/day	Number of landslide with I>80 mm/day	Total landslides
245	193	23	29	9	23	10	42

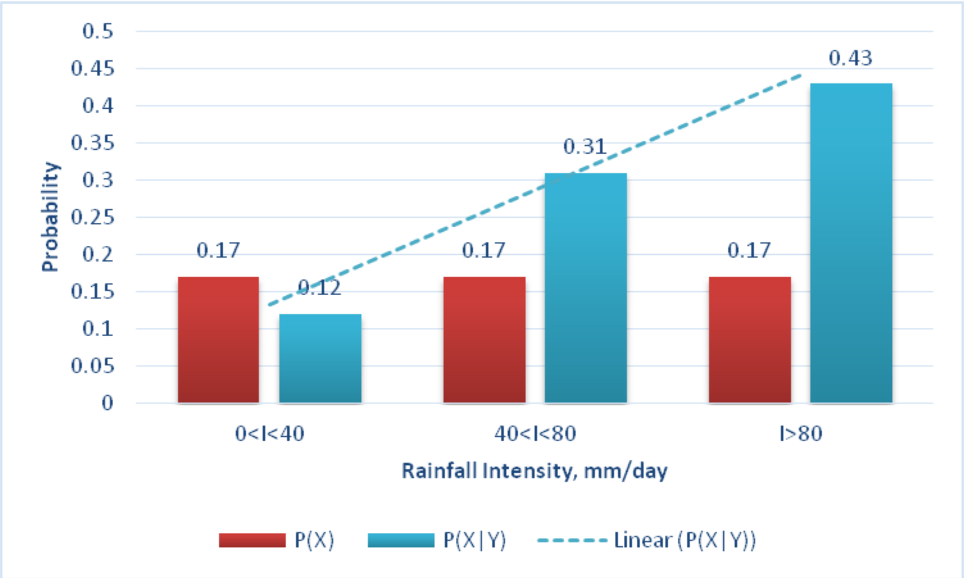
Table 5.2 One-Dimensional analysis for the study period (2010-2019)

Rainfall Intensity Classification	Rainfall events	P(X)	P(Y)	P(Y|X)	P(X|Y)	Total Landslides	Total rainfall events
0<I<40	193	0.17	0.78	0.54	0.12	42	245

40<I<80	29	0.17	0.11	0.21	0.31		
I>80	23	0.17	0.09	0.23	0.43		



(a)



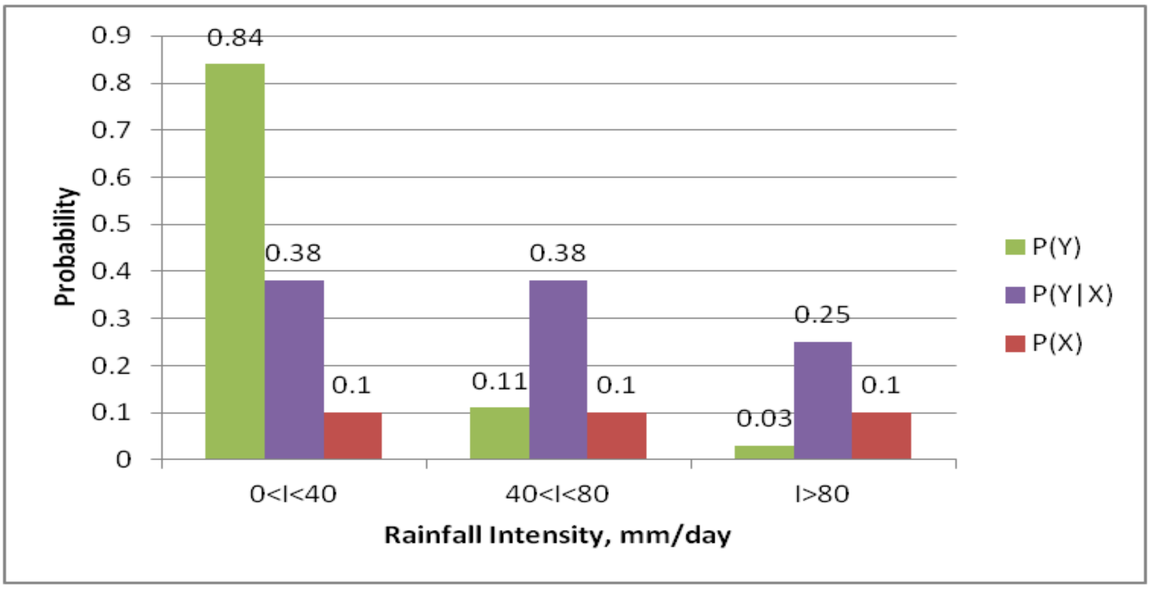
(b)

Table 5.3 Rainfall and Landslide Database for the monsoon period of the year 2019 separately to calculate 2D probabilities.

Total rainfall events	Number of daily rainfall intensity with 0<I<40 mm/day	Number of landslide with 0<I<40 mm/day	Number of daily rainfall intensity with 40<I<80 mm/day	Number of landslide with 40<I<80 mm/day	Number of daily rainfall intensity with I>80 mm/day	Number of landslide with I>80 mm/day	Total landslides
77	65	3	9	3	3	2	8

Table 5.4 One-Dimensional analysis for the monsoon period of the year 2019 separately to calculate 2-D probabilities.

Rainfall intensity classification	Rainfall Events	P(X)	P(Y)	P(Y|X)	P(X|Y)	Total Landslide	Total rainfall events
0<I<40	65	0.1	0.84	0.38	0.05	8	77
40<I<80	9	0.1	0.11	0.38	0.33		
I>80	3	0.1	0.03	0.25	0.67		



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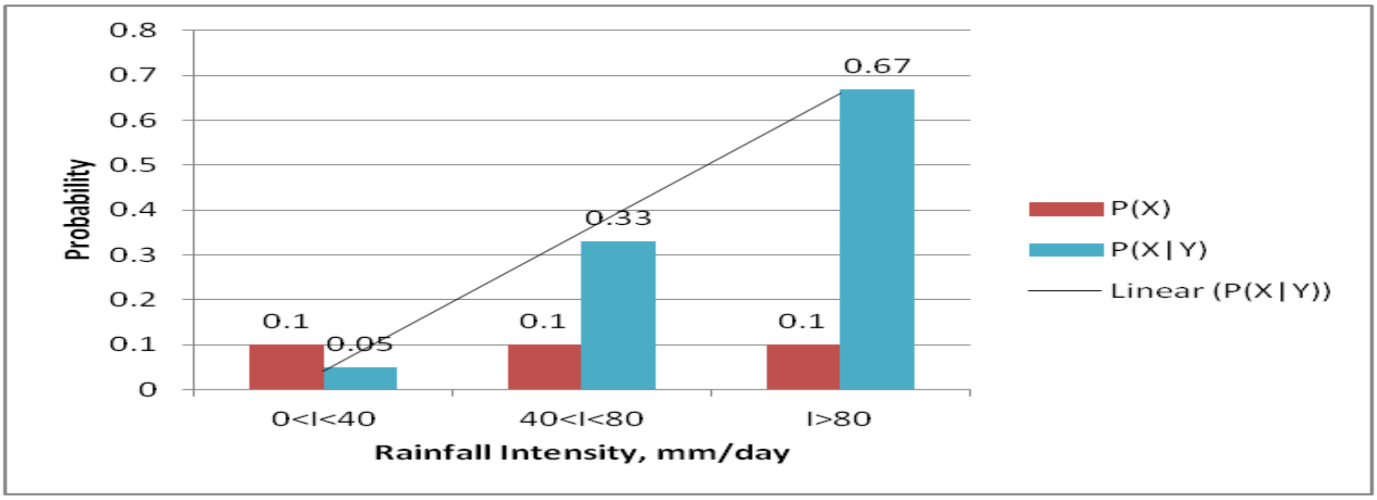

(d)

Two-Dimensional Bayesian Probability

To calculate the probabilities in 2-D, the Bayesian probability model requires more detailed data collection with the intensity and duration of the individual rainfall event. Since the hourly or weekly rainfall statistics from the past were not readily available, we were only able to obtain the required data for 2019 (June-July).

Table 5.3 provides the required data for the calculation while table 5.4 shows the probability computations.

Four different combinations of intensity-duration are taken for the computations.

Table 5.3 Rainfall intensity (mm/day)-duration (days) database for Monsoon 2019

Rainfall intensity-duration	RID resulting in landslide	RID not resulting in landslide	Total RID	Total Landslide s	Total RID Events
I<=40 & D<=0.3	2	41	43	8	77
I<=40 & D>0.3	1	21	22		
I>40 & D<=0.3	2	3	5		
I>40 & D>0.3	3	4	7		

Table 5.4 Probability computations.

Rainfall intensity Duration (RID)	P (I|D)	P (I,D|X)	P (X)	P (X|I,D)
I<=40 & D<=0.3	0.56	0.25	0.1	0.04
I<=40 & D>0.3	0.29	0.13	0.1	0.04
I>40 & D<=0.3	0.06	0.25	0.1	0.42

I>40 & D>0.3	0.09	0.38	0.1	0.42

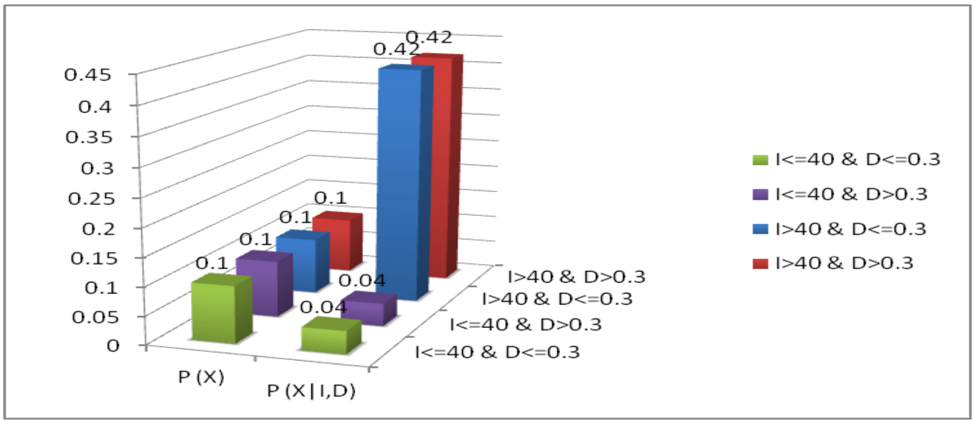

Fig. 5.3 Histogram showing landslide probability with joint parameters

Fig. 5.3 shows the graphical representation of the conditional probabilities. The significance of the parameters considered in the computations can be clearly seen from the difference in the values of probability.

DISCUSSIONS

There are a number of habitat patterns that correlate the difficulty limits with the prevalence of landslides. Such an approach is not always useful in determining the outcome and fully assessing landslides.

The analysis was applied over a ten-year period (2010–2019), with multiple latency parameters such as length, intensity and event degradation. This can often be improved after adding some basic and additional variables and depth degradation and landslide knowledge of a type of analysis often performed for a mountain range area. Analysis has been made of 2 different variants of Thomas Bayes' theory; One-dimensional and two-dimensional. One-dimensional calculation of landslide prevalence is based entirely on the probability of any trough parameter, whereas 2-dimensional calculates the probability of landslide propagation for any 2 trough parameter.

To verify the results, sensitivity analysis was performed by variableizing the input parameters and identifying the corresponding correction by chance. The results showed the inclination of the associative degree to change the severity of the fall, and so the landslides were shifted to a certain number of combinations of landslides. However, there is little choice with modifying rainfall opportunities. Comparative analysis has been done for 2-D possibility; therefore, the results are extra sensitive compared to 1-D results. Investigations showed that the intensity and incidence decrease were very sensitive when compared with other combinations.

CONCLUSIONS

The results indicate that of the rainfall parameters used in the study (depth of rainfall, rainfall duration and excess rainfall), the impact of rainfall intensity is very important in each case. The probability of erosion is 0.43 of rainfall greater than 80 mm / day in 1-D case. However, the use of 2-D approach gives a better picture of the landslide events when compared to the 1-D case. The probabilities reach to a maximum value of 0.42 for the rainfall with duration greater than 0.3 days having intensity of rainfall higher than 40 mm/day for the two dimensional landslide cases. The results also show that its potential depends on the precision and accuracy of the data recorded. Samples having limited amount data are of limited knowledge and several variations in the geology of the region may indicate conflicting possibilities. The use of an over-the-top prediction method is one of the best ways to develop an early warning system for the affected regions when explaining using threshold models.

From the present research the following conclusions are drawn:

The probability of occurrence of the landslide is 0.43 if the intensity of rainfall is more than 80 mm/day for the one dimensional Bayesian formulation and 0.42 for a rainfall period greater than 0.3 days for a range greater than 40 mm / day.

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Authors Profile

Parvesh He is currently pursuing his bachelor of technology in civil engineering from Delhi Technological University, Delhi.

Pooja She is currently pursuing his bachelor of technology in civil engineering from Delhi Technological University, Delhi.

Hitesh Khatri He is currently pursuing his bachelor of technology in civil engineering from Delhi Technological University, Delhi.

Amit Dabas He is currently pursuing his bachelor of technology in civil engineering from Delhi Technological University, Delhi.

Dr S. ANBUKUMAR He is currently working as a associate professor in department of Civil Engineering in Delhi Technological University, Delhi. Completed his masters of technology from IIT Madaras, Chennai and received his PhD from Delhi Technological University.