Original Research Article

Assessment of rainfall thresholds for Rain-induced Landslide activity in North Sikkim Road Corridor in Sikkim Himalaya, India

ABSTRACT

Land sliding is a perennial problem in the Eastern Himalayas. Out of 0.42 million km^2 of Indian landmass prone to landslide, 42% fall in the North East Himalaya, specially Darjeeling and Sikkim Himalaya. Most of these landslides are triggered by excessive monsoon rainfall between June and October in almost every year. Various attempts in the global scenario have been made to establish rainfall thresholds in terms of intensity – duration of antecedent rainfall models on global, regional and local scale for triggering of the landslide. This paper describes local aspect of rainfall threshold for landslides based on daily rainfall data in and around north Sikkim road corridor region. Among 210 Landslides occurring from 2010 to 2016 were studied to analyze rainfall thresholds. Out of the 210 landslides, however, only 155 Landslides associated with rainfall data which were analyzed to yield a threshold relationship between rainfall intensity-duration and landslide initiation. The threshold relationship determined fits to lower boundary of the Landslide triggering rainfall events is $I = 4.045\ D^{-0.25}$ (I=rainfall intensity (mm/h) and D=duration in (h)), revealed that for rainfall event of short time (24 h) duration with a rainfall intensity of 1.82 mm/h, the risk of landslides on this road corridor of the terrain is expected to be high. It is also observed that an intensity of 58 mm and 139 mm for 10-day and 20-day antecedent rainfall are required for the initiation of landslides in the study area. This threshold would help in improvement on traffic guidance and provide safety to the travelling tourists in this road corridor during the monsoon.

Keywords: Rainfall ID threshold, Antecedent Rainfall, Landslide, North Sikkim Road Corridor

1. INTRODUCTION

The Himalayan terrain is one of the tectonically most active mountain ranges of the world (Kanungo et al. 2013). Sikkim Himalayan region is very prone to different geo-hazards such as landslide and Earthquakes. During monsoon seasons heavy rainfall is the most important exogamic process responsible for the landslide triggering in Sikkim Himalayan region. According to Geological survey of India (GSI) landslide are one of the most natural hazards that affect 12.6% of Indian's landmass exceeding 0.42 million km^2. Sikkim Himalayas cover more than 40% of landslide-prone areas in the country. Landslides are a very serious common phenomenon of the North Sikkim road corridor and have an impact on the built environment to the society due to loss of life; natural resource, infrastructure and future growth of urban and rural development. It has been estimated that, on an average, the damage caused by landslides in Himalayan range costs more than US$ one billion besides coursing approximately 200 deaths per year, which amounts to 30% of such occurring worldwide. (Naithani et al. 1999, Kanungo et al. 2013). For a recent example from Sikkim Himalayas of India, a heavy precipitation in the catchment of Tista, on September 1995 triggered off a mud avalanche near Gangtok killing 32 people (Sikkim State Disaster Management Authority Report, 2011). Similarly, since June 1997 nonstop heavy rainfall-induced damaged 300 houses completely, 1000 houses partially and caused the death of 51 people in East and North District of the Sikkim State. On 21st September 2012, Very heavy rainfall affected Sikkim on Friday night, triggering widespread landslides and flash floods. It has been reported that 21 people were killed in the Gangtok area alone. Most of these materialize to have been the result of landslides on the road between Mangan and Chungthang, whilst a further eight people are missing in North Sikkim. Those killed on the road appear to have been soldiers from the Border Roads Organization (Military Engineers who maintain the highways) and border guards. Except for such major landslide disasters, many small-scale landslides in remote areas of the Sikkim Himalayas go unreported and unnoticed (Sharma et al. 2013)

The Sikkim Himalayas lies at the marginal part of the tropical high-pressure belt characterized by a combination of seasonal wind pattern and differential orographic zones. The climatic condition of the State has been roughly divided into tropical, temperate and alpine zones. For the most part of the year, the climate is cold and humid as rainfall occurs almost in every month. Because of its close proximity to the Bay of Bengal and the obstruction of the path of monsoon clouds by mountains, most part of the state receives heavy rainfall around the year. It is only in the months of October – March that the state remains comparatively drier. The mean annual rainfall is a minimum at Thangu (82 mm) and maximum at Gangtok (3580 mm based on 1951-1980 rainfall data of IMD). An isohyetal analysis of these data reveals that there are two maximum rainfall areas – (i) South-East quadrant including (Mangan, Singhik, Dikchu, Gangtok) and (ii) South-West corner including hilly terrain of (Dentam, Gyalsing, Yoksum, Chakung, Soreng). Rainshadow areas are – south-eastern part of South District (Namchi) and south-western part of East District (Song, Singtam, Makha). Rainfall is heavy and well distributed during the months from Jun to early October. July is the wettest month in most of the study area. During the rainy season (Jun to September), a very high-intensity rainfall in the order of 150 mm to 300 mm in 24 hours is not very uncommon in this part of the Himalayas, which is sometimes also accompanied by the cloudburst. The intensity, duration, and frequency of such heavy rainfall in some areas of the Sikkim Himalaya play a vital role in triggering the landslides. (Special publication 103, GSI 2015)

In Sikkim Himalayan, most of the landslides are caused by high rainfall Intensity in monsoon period. Depending on Indian meteorological and physiographical conditions, individual rainfall events can cause slope failures in areas of limited extent or in large regions. The annual average rainfall (2010 – 2016) of North Sikkim hydro-meteorological division of India which encompasses the present study area (part of Sikkim Himalayas) is 3333.7 mm. During the monsoon period (Jun to September) the mean rainfall is 2136.9 mm, contributes 64.1% of annual rainfall (3333.7 mm). The contribution of per monsoon (March to May) rainfall and post-monsoon (October to December) rainfall in annual rainfall is of the order of 27.5% and 5.93% respectively. The monthly average rainfall for the monsoon period from Jun to September is 625, 547.6, 507.7 and 456.6 mm respectively. Such a rainfall pattern in Sikkim Himalayas, particularly in the eastern Himalayan terrain of Sikkim State is thought to play a most important role in initiating and triggering landslides in the hilly regions (Sikkim State Disaster Management Authority Report, 2011).

1.1. A REVIEW OF RAINFALL THRESHOLDS LANDSLIDE

The minimum and maximum amount of rainfall required for landslide occur to require place or state to alter in amount defines as a threshold. (Varnes et al.1978; Whate et al.1996; Reichenbach et al. 1998). A minimum threshold present that the lowest level below that a method doesn't occur and Maximum threshold refers to a level higher than that a method continuously happens, or there's 100% likelihood of prevalence of the method at any time when the threshold value is exceeded (Crozier 1996). Due to the rainfall slope failures, a threshold might represent the minimum intensity or duration of the rainfall, the minimum level of pore water pressure, the angle of the slope, the reduction of shear strength or the displacement needed for landslide occur (Reichenbach et al. 1998). Thresholds are outlined for parameters controlling the occurrence of landslides, such as the antecedent hydro-geological conditions or the (minimum or maximum) soil depth needed for failures to require place (Kanungo et al 2013).

Form the literature, established the existence of two rainfall thresholds which are can be defined: (i) empirical (historical, statistical) thresholds and (ii) physical (process based mostly, conceptual) thresholds (Crozier 1999, Aleotti 2004; Wieczorek and Glade 2005; Guzzett et al. 2007) Empirical rainfall threshold is developed by finding out the rainfall events that have resulted in landslides. The threshold is generally obtained by drawing lower-bound lines to the rainfall conditions leading to landslides plotted in Cartesian, semi-logarithmic or exponent coordinates (Kanungo et al. 2013). Depending on the type of rainfall may additionally be classified in three deferent's classes: (1) thresholds that associate precipitation measurements obtained for specific precipitation events, (2) thresholds that associated the antecedent conditions (Kanungo et al. 2013) and (3) alternative thresholds, together with hydrological thresholds (Jakob and Weatherly 2003). Thresholds established using precipitation measurements obtained from the individual or multiple rainfall events can be further subdivided into intensity–duration (ID) thresholds, thresholds based on the total event rainfall, rainfall event–duration thresholds and rainfall event–intensity thresholds (Guzzetti et al. 2007). Physical rainfall threshold models mention the character of the physical phenomena and detailed spatial information on the hydrological, lithological, morphological, geological, and soil characteristics that management the initiation of the landslides. These categorical threshold models have calculated spatially rainfall events that the rainfall measurement along with time and location are known and has led to the failure of slopes (Iverson 2000). These models will resolute the amount of rainfall required to activate slope failures and also the location and time of the expected landslides. Usually, threshold using an empirical model is determined by performing statistical analysis on historical data of rainfall and landslides (Guzzetti et al. 2008).

Based on the extent of the geographical region, Rainfall thresholds for rain-induced landslides are categorized as Global, regional or local thresholds, depending on the geographical region (Guzzetti et al. 2008). A global threshold attempts to determine a general ("worldwide") minimum level below that landslides don't occur, severally of local morphological, lithological and land-use conditions and of local or regional rainfall pattern and history (Kanungo et al. 2013). Global thresholds are projected by Caine (1980), Innes (1983), Jibson (1989), Clarizia et al. (1996), Crosta and Frattini (2001) and Cannon and Gartner (2005). Regional thresholds are equally calculated as global threshold, however solely regional scale. Its thresholds are effective for landslide warning systems using empirical method (Dikshit et al.2018, Guzzetti et al. 2008). Local threshold consider for various local climatic region and geo-morphological condition and are applicable to single landslide or to groups of landslides in areas extending from a few to some hundreds of square kilometers (Kanungo et al. 2013). Local thresholds for various places have been given by Bolley et al (1999) Bacchini et al. (2003), Barbero et al. (2004), Zezere et al (2005). The Himalayan mountain chain measures 2400 km in length and remains one of the most active tectonically and fragile mountain ranges on the earth. Though the mountains of the Indian Himalayas have extensive landslide vulnerabilities due to the monsoon rainfall, comparatively few investigations exist for illustrating rainfall thresholds for landslide event in these hilly regions. A few studies report the relationship between rainfall amount or intensity and size of landslide and debris flow. For example, Froehlich et al. (1990) found that shallow landslides on steep slope segments occur when 24-h rainfall reaches 130–150 mm or continuous 3-day rainfall totals 180–200 mm in the same area. Landslides and debris flow at larger scales, however, were observed only after 24-h rainfall exceeded 250 mm or continuous 3-day rainfall reached 350 mm (Froehlich and Starkel 1987). On the other hand, extensive and simultaneous debris flows occurred after > 300 mm in a 24-h rainfall or > 600 mm of continuous 3- day rainfall (Froehlich et al. 1990; Froehlich and Starkel 1993). In a exceedingly study in north Sikkim (part of eastern Indian Himalayas), Sengupta et al. (2010) found that landslide at Lanta Khola close to Mangan in North Sikkim is initiated when normalized cumulative rainfall over a period of at least 15 days exceeds 250 mm. It's conjointly projected that when this cumulative rainfall threshold is exceeded; the debris zone in the affected stretch turn into saturated and fails, inflicting a landslide.

2. METHODOLOGY

The methodology used involved: (a) collection of the rainfall data which produced landslides along with their dates and intensities (b) data analysis using empirical method to establish the relationship between rainfall and landslide events over the studied area. The data used in the analysis to establish rainfall thresholds were collected from different government organization and other sources. The flow diagram of different rainfall threshold models for landslide occurrence that was proposed by Guzzetti et al. (2007) and Kanungo et al. (2013) is shown on Figure 3.

2.1. Study area and its geological condition

The study area was focused along the most vulnerable road corridor in and around Dikchu – Mangan – Chunthang – Lachen – Lachung road corridor along the North Sikkim State Highway of Sikkim Himalayas in the Sikkim State of India. The study area belongs to the steep and rugged Himalayan Mountainous terrain in the state of Sikkim (Fig. 1& 2). The Study covered a cumulative road length of 137 km long stretches covering parts of North Sikkim Highway, Singtam – Chungthang Road (81 km) Dikchu to Rong Rong (9 km), Chungthang – lachung Road (21 km) and Chunthang – Lachen roads (21 km). A digital elevation model (DEM) was adopted to study topography in the study area. The elevation of the road corridor is 532 m to 4269 m. The terrain is rugged with steep slopes exceeding 30° in many places. Results of a slope gradient analysis in the geographic information system (GIS) are shown in Fig. 2. The slope angles mainly range between 10° and 70° on both sides of the road corridor.

The Road corridor goes across seven thrust and so many faults (observed, inferred) is partly located within the study area (Fig.4). The study is marked by the presence of Quartzite, high-grade Meta Sedimentary, and Calcareous Silicates with quartz-biotite schist, Graphitic schist, high-grade gneisses intruded by Pegmatite veins with inclusions of Tourmaline crystals. The Chungthang geological setting (termed by V.K. Raina & V. Bhattacharya in 1996-62) starts from Meyong on Mangan - Chungthang road, to Leema on Chungthang - Lachung road and up to Jorephul area on Lachen road section. The Quartzites in the area are exposed as alternating bands with the gneisses. The bands vary in thickness and have inclusions of Garnet at Bop area on Lachung road section. The gneiss show compositional bandings in the form of mineral lineation. They are seen as massive, well bedded to Augen gneiss. Graphite schist is present as thin folded Lensoidal bands attached to Quartzites or marble of Tarum area. The calc-silicate rocks of this area are marked by intense folding and characteristics of differential weathering. Anbarasu et al. 2010 indicated that the Main Central Thrust (MCT) is delighted within the Lonta Khola Landslide (study area road corridor) upslope of the North Sikkim Highway Road bench at ± 1550 m, which separates the overlaying and relatively competent quartzofeldspathic gneiss form shared and weathered mica schist below. The side study and numerical stability modeling also indicated that deep weathering aided by the ingress of the surface runoff at this contact zone facilitated extrusion of the debris material form contact zone rock mass, which rendered instability and subsequently flew as water-charged debris mass downward with gravity (Anbarasu et al. 2010). Strongly weathered rock slopes with outward inclined joint sets were widely distributed on both sides of the road corridor from Lachen, Lachung to Chunthang, Chungthang to Mangan, Mangan to Dikchu and Phensong, especially on the lower part of Chungthang.

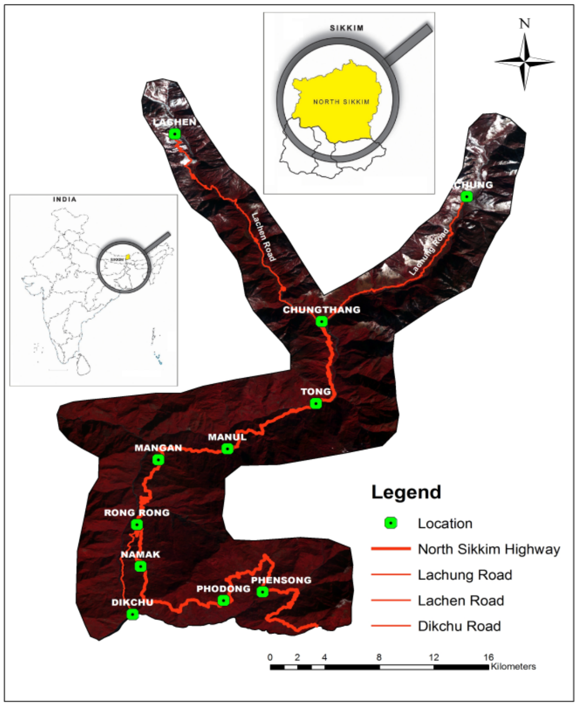

Fig. 1. Location of the study area

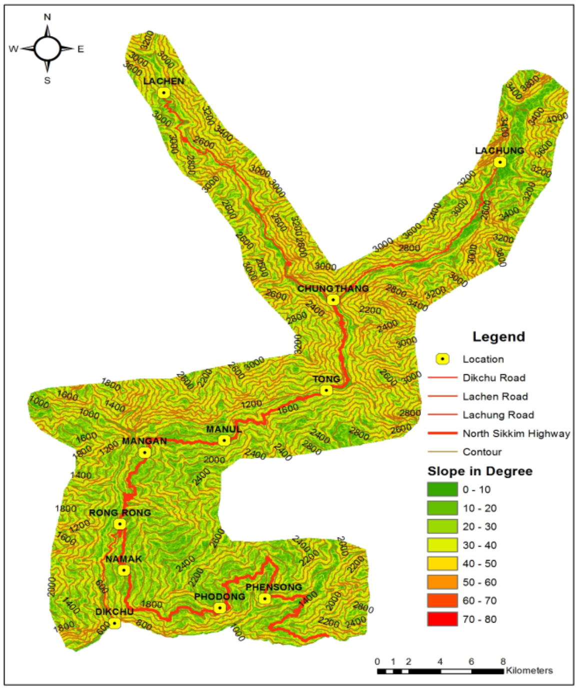

Fig. 2. Slope map of the study area

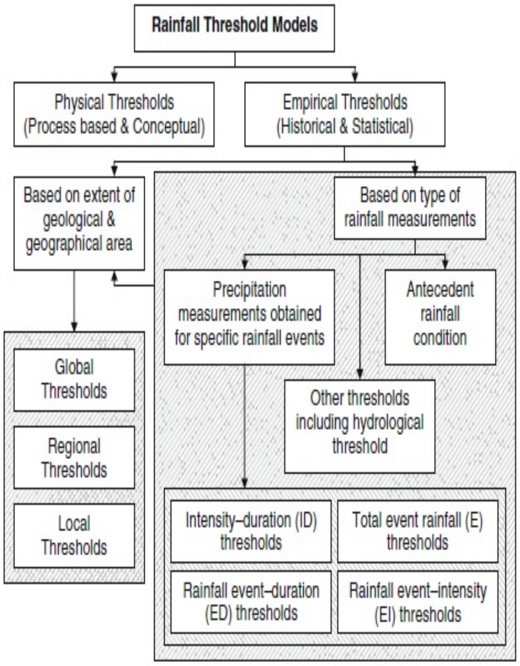

Fig. 3. Different rainfall threshold models for landslide occurrences (Kanungo 2013)

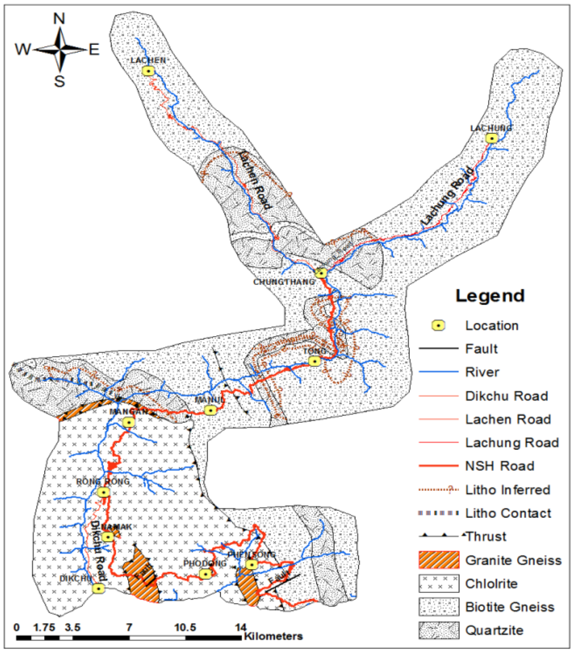

Fig. 4. Geological condition of the study area

2.2. Rainfall and Landslide Data Examined

The rainfall information was collected from four rainfall station located at Mangan, Chungthang, Lachung, Sankalan, of North Sikkim corridor in North Sikkim. The daily rainfall data collected from January 2010 to December 2017 from the Indian Meteorological Department (IMD), Sikkim. The hourly rainfall data was not available for this road corridor, but the daily rainfall data along with the landslide information available for resenting past 7 years (2010 to 2016) were used. Consequently, the daily rainfall events corresponding to landslide events of the monsoon period over the years 2010 to 2016 were identified. The cumulative rainfall for each rainfall event was estimated from the daily rainfall data and rainfall event duration in (hours) was calculated by converting event days into hours. So, the hourly rainfall intensity was calculated for each of the rainfall events responsible for landslide occurrence by dividing the cumulative events rainfall (in millimeters) by the corresponding rainfall events duration (in hours).

The rainfall data of this region conduct show that the cumulative annual rainfall from 2010 to 2016 was 4231.7, 2504.9, 3559.1, 2748, 3172.8, 3697.4 and 3422.1 mm respectively as shown in Figure 5. The cumulative rainfall during the monsoon (June to September) for the study area was 2477.1, 17.45.6, 2403.7, 1414.6, 2268.6, 2369.2, and 2279.8 mm respectively. As a consequence, the monsoon rainfall contributed 58.54, 69.69, 67.54, 51.48, 71.50, 64.08, and 66.62 % of total annual rainfall as shown on Figure 6. Records show that the highest amounts of daily rainfall during the monsoon period in the study area since 2010 to 2016 were 127.4 mm on 22nd August 2010, 68.1 mm on 24th Jun 2011, 196.6 mm on 20th September 2012, 83.4 mm on 10th July 2013, 146.3 mm on 23rd August 2014, 166.4mm on 31st August 2015 and 130mm on 25th September 2016 respectively.

Landslide data were compiled from the records maintained by GSI (Special Publication 103) from 2010 to 2013 and Sikkim State Disaster Management Authority (SSDMA) Reports, and published literature. Landslide data collected from 2010 to 2016 Border Roads Organization (BRO) office HQ, OC 86 RCC (GREF) at Chungthang, HQ, OC 107 RCC (GREF) at Mannul, under HQ 758 BRTF (GREF), Sikkim. Other sources were also used to establish the Landslide data which was published by local newspapers. Locations of the landslides per village name, waterfall name or name of the nearest area are shown on Fig.7. The Landslide data is only for the period from 2010 to 2016 because rainfall data for region is also only available for this period as shown on Fig.8

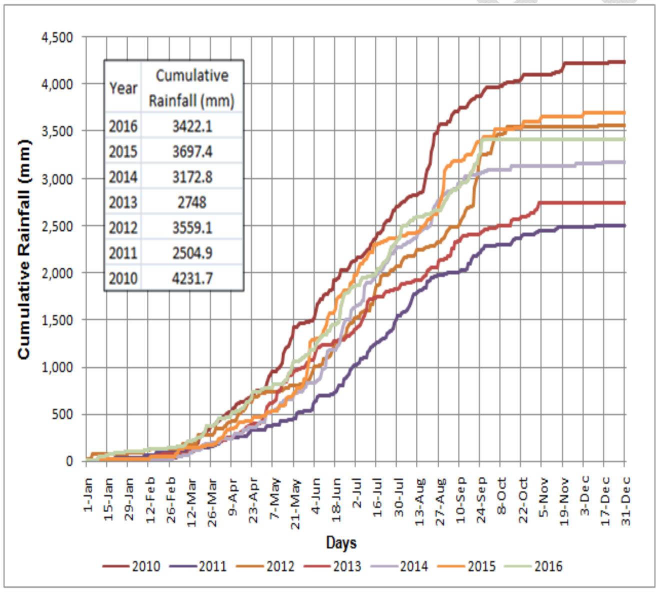

Fig. 5. Yearly cumulative rainfall during 2010 – 2016

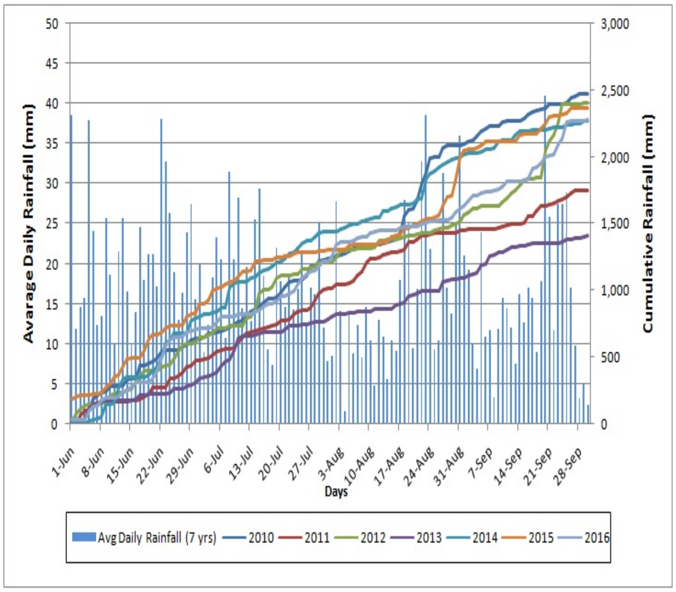

Fig. 6. Average daily rainfall and cumulative rainfall during the monsoon from 2010 – 2016

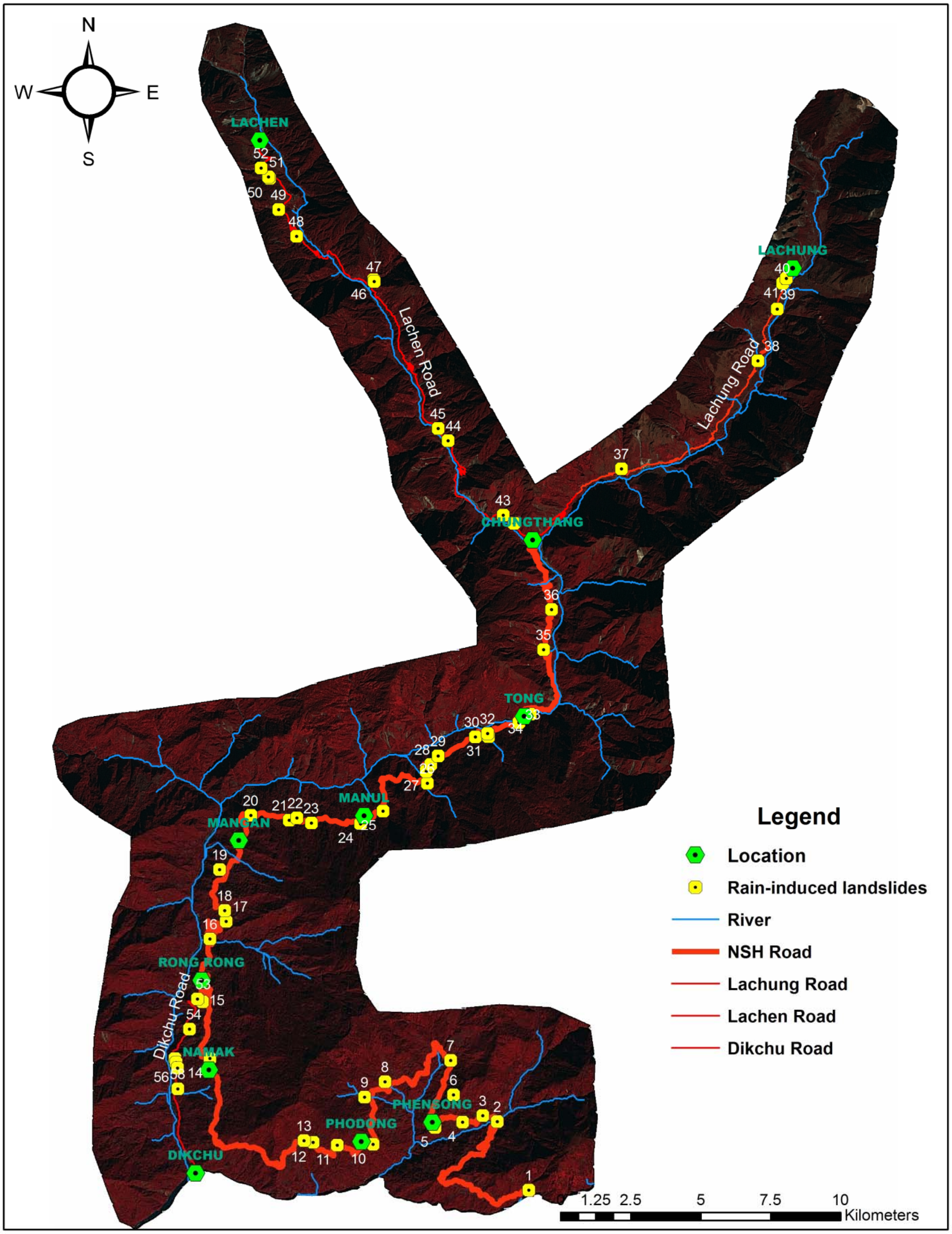

Fig. 7. Location of the Major rain – induced landslide in North Sikkim Road Corridor (Study area)

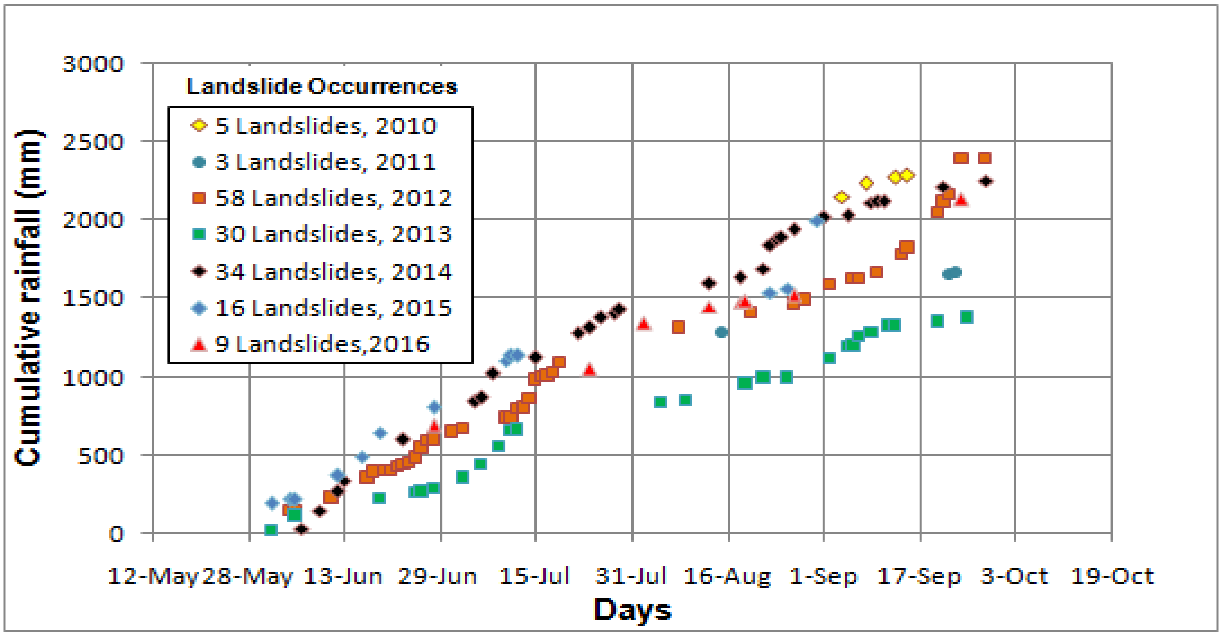

Fig. 8. Cumulative rainfall and Rain – induced landslide during the monsoon from 2010 – 2016

2.2.1. Rainfall threshold Analysis

Rainfall intensity–duration (ID) threshold was analyzed using combinations of precipitation measurements obtained from different rainfall events that resulted in landslides has been attempted proposed by Kanungo et al. 2013. Intensity–duration threshold identifies the minimum rainfall condition which causes sloping or landslide failure (Reid 1994; Iverson 2000; Godt et al. 2006). Of the 210 landslides which occurred from 2010 to 2016, 155 landslides were initiated by rainfall, and these were considered in the calculation of the ID threshold. A total of 122 rainfalls invents was identified based on the occurrences of landslides during the monsoon from the year 2010 to 2016. The rainfall intensity was calculated for each of the 122 rainfall events responsible for the occurrences of 155 landslides during the monsoon. The distribution of rainfall conditions which resulted to landslides initiation fits to the power law equation illustrate on Fig.9. Out of the 155 landslides, however only 122 associated with rainfall data were analyzed to yield a threshold relationship between rainfall intensity, duration, and landslide initiation. Rainfall data and landslide information from 2010 to 2016 were extracted and used to calculate rainfall threshold. The data of rainfall intensity and duration for all the rainfall events causing landslide in the area during the monsoon are plotted in a log-log graph shown on Fig.9. The threshold is calculated using the power-law distribution with an equation of the type:

$$\log(I) = \log(\alpha) + \beta \log(D) \text{ or } I = \alpha D^{\beta}$$

Where I, is the rainfall Intensity (mm/h), D is the duration (h), and *α* (the intercept) and *ß* are empirically derived parameters.

The power low approach for predicting landslide occurrence is based on two assumptions: (1) as the rainfall intensity increases, the probability of landslide increases nonlinearly. This is representing that the probability of landslide occurrence below the threshold value is low, and above the threshold, the probability increases nonlinearly. According to power low equation, the coefficient *α* and the exponent *ß* is define the location of the critical intensity value; (2) there is a decrease in slide initiation if the duration of rainfall increases. In the power law equation, the exponent *ß* are defining the rate at which critical intensity decreases with increasing rainfall duration. The threshold, as defined by the lower boundary of the points representing landslide triggering rainfall events, it expressed as:

$$I = 4.045\, D^{-0.25}$$

Where I, is the hourly rainfall intensity in mm/h and D is the duration of rainfall in hours.

Among the 155 landslide data, the proposed curve optimally defines the rainfall events with the duration between 24 h (daily) and 720 h (30 days). It is revealed from the above threshold relationship that for rainfall events of shorter duration with a rainfall intensity of 1.82 mm/h, the risk of landslide occurrence in this part of the terrain is expected to be high duration monsoon period. If an average precipitation of 1.39 mm/h and 1.05mm/h appears sufficient to cause sliding activities in the area during monsoon if continued for about 72 h (3 days) and 120h (5 days) respectively. Threshold values of different rainfall intensities have been established for the different climatic region around the world. Guzzetti et al. 2007 were the first listed out 52 earlier researchers of intensity-duration thresholds on local contexts, regional and global which resulted in rainfall thresholds landslides. The figure 10 shows the comparisons of various threshold values including the present value provided by various researchers in the local contexts, regional and global shown on Fig. 9. The present local threshold has a similar appearance to that proposed by Jakob and Weatherly (2003) for the North Shore Mountains of Vancouver, British Columbia.

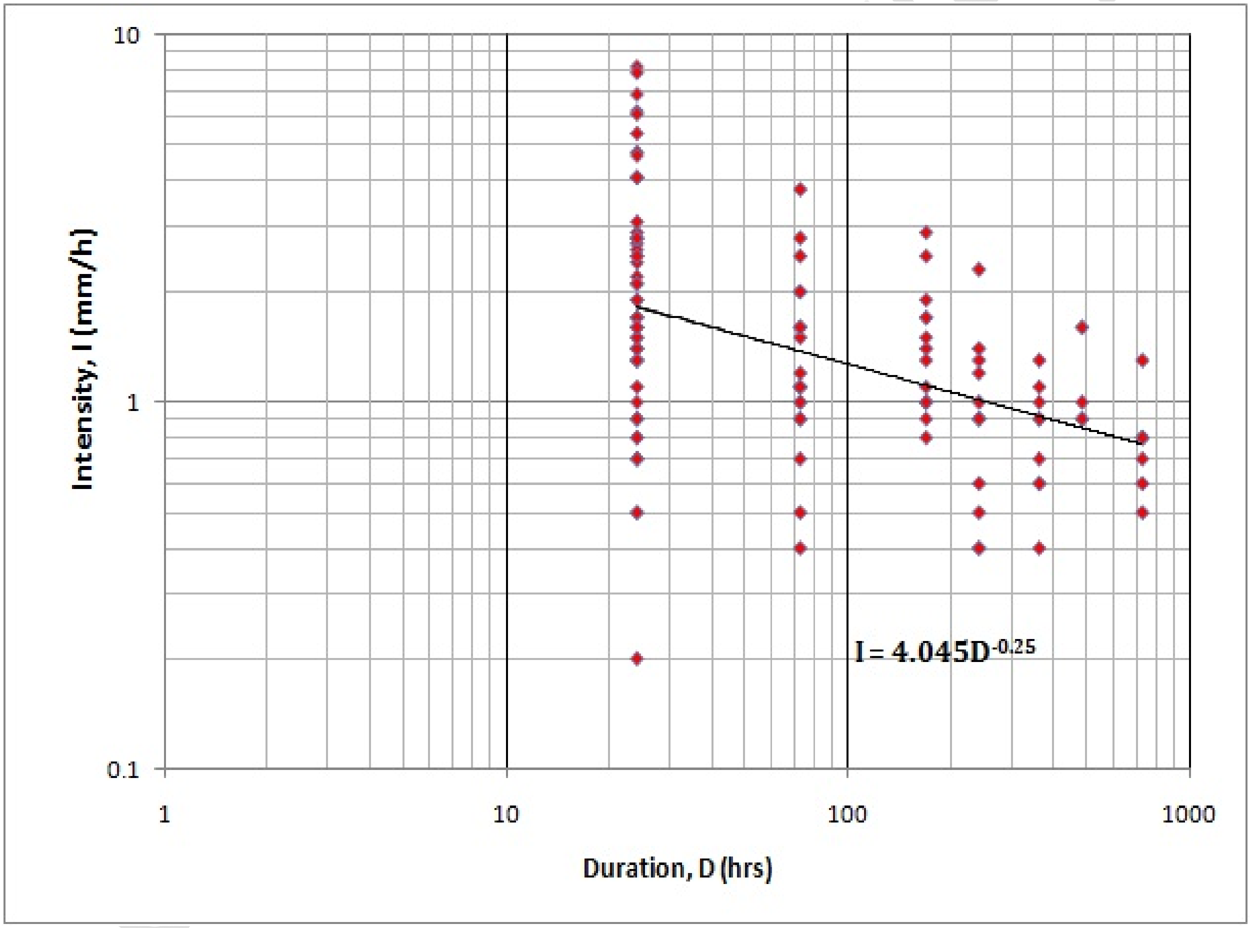

Fig. 9. Rainfall intensity–duration (ID) threshold based on estimation from daily rainfall data for the initiation of landslides in north Sikkim road corridor of Sikkim Himalaya, India

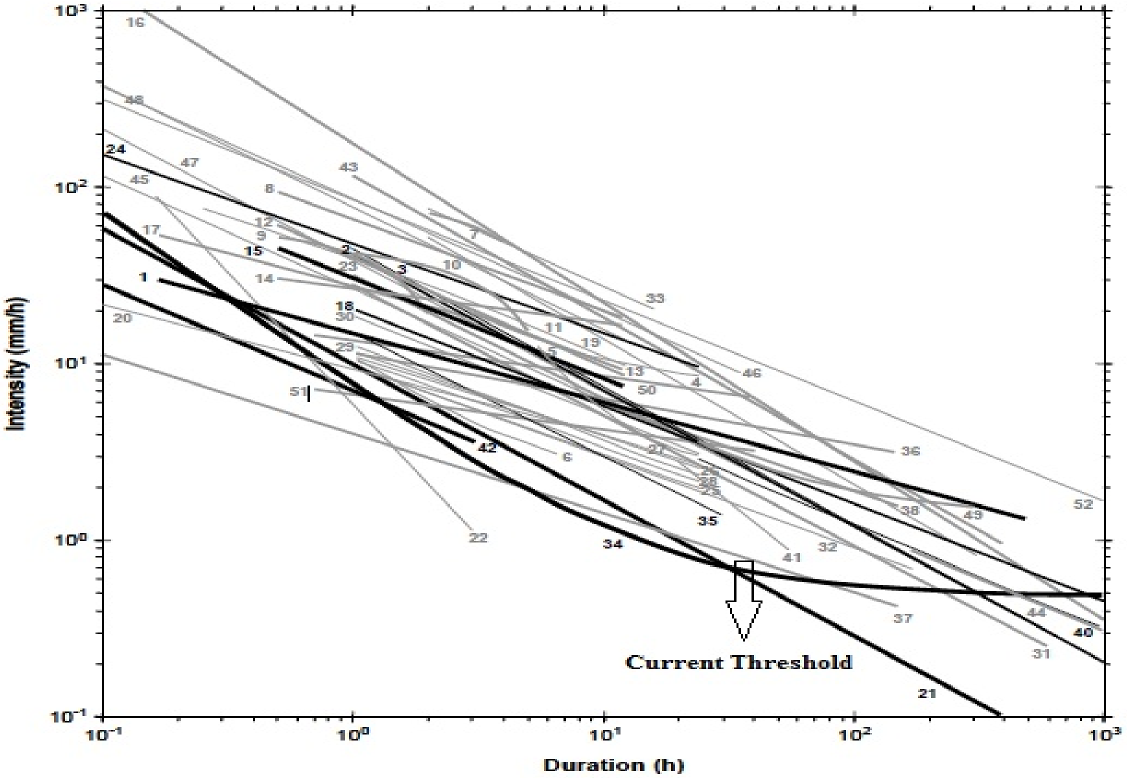

Fig. 10. Comparison of rainfall intensity–duration (ID) thresholds for landslide occurrences from various studies and present studies

3. RESULT AND DISCUSSION

Intensity – duration threshold was calculated using rainfall events leading to Landslides of 2010 to 2016 for the North Sikkim road corridor, North Sikkim region in Sikkim Himalayas. Many pieces of literature consider the antecedent condition to define landslide triggering using empirical thresholds dependent on the amount of antecedent precipitation (Glade et al. 2000, Aleotti 2004, Lumb 1975). Antecedent rainfall influences the soil moisture and groundwater level, these factors are influencing for predisposing the slope failure (Govi et al. 1980, Crozier 1986, Wieczorek 1996). The relationship between antecedent rainfall and landslide occurrences assumes importance only when calculating for a defined area with similar geographical and rainfall condition and its application to other regions is not recommended (Dikhit et al.2018). A significant problem in using the antecedent rainfall measurements for the prediction of landslide occurrence is in the exact recording of the time during which the rainfall is accumulated. Many researchers throughout the world have considered a different period of antecedent rainfall which varies from 3 days to 4 months is significant in explaining landslide occurrences: Kim et al. 1991 examine 3 days; Heyerdahl et al. 2003 examine 4 days; Crozier 1999 and Glade et al. 2000 examine 10 days; Aleotti 2004 examine 7, 10 and 15 days; Chlebored 2003 examine 18 days; Terlien 1998 examine 2, 5, 15 and 25 days; Dahal et al. 2008 and Kanungo et al. 2014 examine 3, 7, 10, 15, 20 and 30 days; Pasuto et al. 1998 examine 1to 120 Days. Interrupter Low intensity and long duration are characteristics of monsoon rainfalls in the study area. The empirical model based on antecedent rainfall initiation of landslide~~s~~ occurrences seems to be applicable in this region. The data of 210 landslide events considered in analyses of the daily rainfalls at failures in relation to the antecedent rainfalls (total cumulative rainfalls) of 3, 7, 10, 15, 20, and 30 days time duration is plotted on Fig. 11. A diagonal line divides the graph into two halves in order to distinguish between the scattering biases of daily rainfall (y-axis) and antecedent rainfall (x-axis). Itself, the diagonal line divider indicates that the daily and cumulative rainfalls are similar at the time of failure (Kanungo et al. 2014). Figures 12a to f show~~s~~ the graph of daily rainfall with relation to antecedent rainfall of different time durations (3, 7,10,15,20 and 30 days) respectively.

As observed from the Figure 12a, 22.86% of the total landslide events (48 landslides out of total 210) for 3 days antecedent rainfall are biased towards the daily rainfall and rest 77.14% landslide events (162 landslides out of total 210) are biased towards 3 days antecedent rainfall prior to failure. Homogeneous relationships were observed for various other time durations (Fig. 9b to f). When analyzed for various other cases of time durations, the ratio of biasness towards daily rainfall and antecedent rainfall was observed to be 8.75: 91.43 in 7days, 4.76 : 95.24 in case of 10 days, 1.43 : 98.57 in case of 15 days, 0.95:99.05 in case of the both 20 and 30 days antecedent rainfall cases respectively. So, it may be stated that 95.24% of landslide events occurred under the influence of 10 days antecedent rainfall prior to failure and its effect remained constant for 15,20 and 30 days of antecedent rainfall events. On the other side, out of the total landslide events, only 22.86% of the events occurred under the influence of daily rainfall incident on the day of failure to 3days antecedent rainfall and this effect decreases to 4.76%, 1.43% and 0.95% of the events in cases of 10, 15, 20 and 30 days antecedent rainfall onwards. The study area suffers from incessant rainfall which leads to such results. Hourly data (Short-term rainfall data) would help to refine the present studies of rainfall condition.

It can also be inferred from the stated observation that the 10 days antecedent rainfall may be used as a threshold for initiation of triggering of landslides, and consideration of Figure 12c, may infer that a minimum of 10 days antecedent rainfall of 58 mm is needed to trigger the landslide in the study area (North Sikkim road corridor). Whenever the plots for 10 days to 30 days antecedent rainfall cases (Fig. 12c to f) are differentiated, it is observed that in case of 20 days antecedent rainfall (Fig. 12e), the slide points are clearly concentrated along the x-axis beyond a certain point (antecedent rainfall prior to failure) in comparison o other cases where the sample points (failure points) are more scattered all along the x-axis. Accordingly, it can be inferred that more accurate correlation with landslide occurrences may be obtained for a 20-day antecedent rainfall of 139 mm in the study area; (as to be found 15-day antecedent rainfall in the study conducted by Pasuto and Silveno 1998, and 10, and 20-day antecedent rainfall in the study conducted by Kanungo et al. 2014).

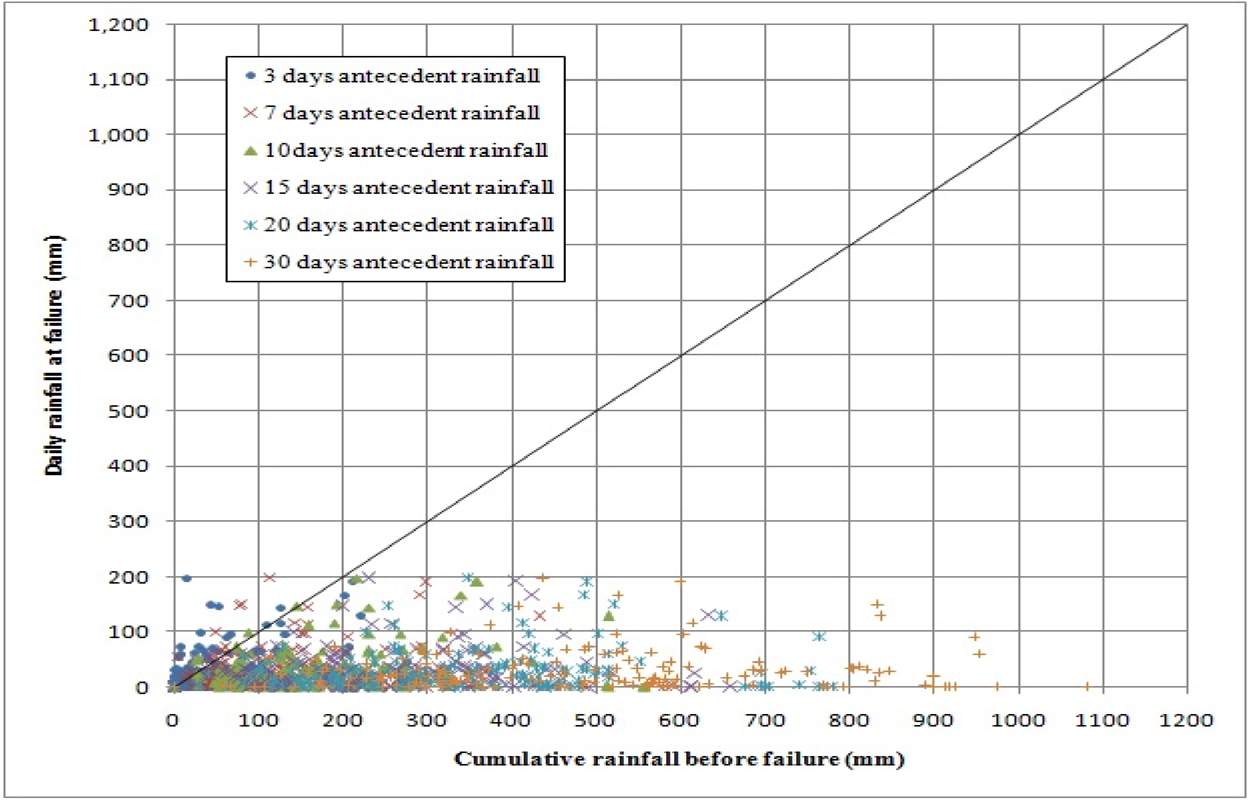

Fig. 11. Representation of daily rainfall at failure and antecedent rainfall prior to failure (3, 7, 10, 15, 20 and 30 days)

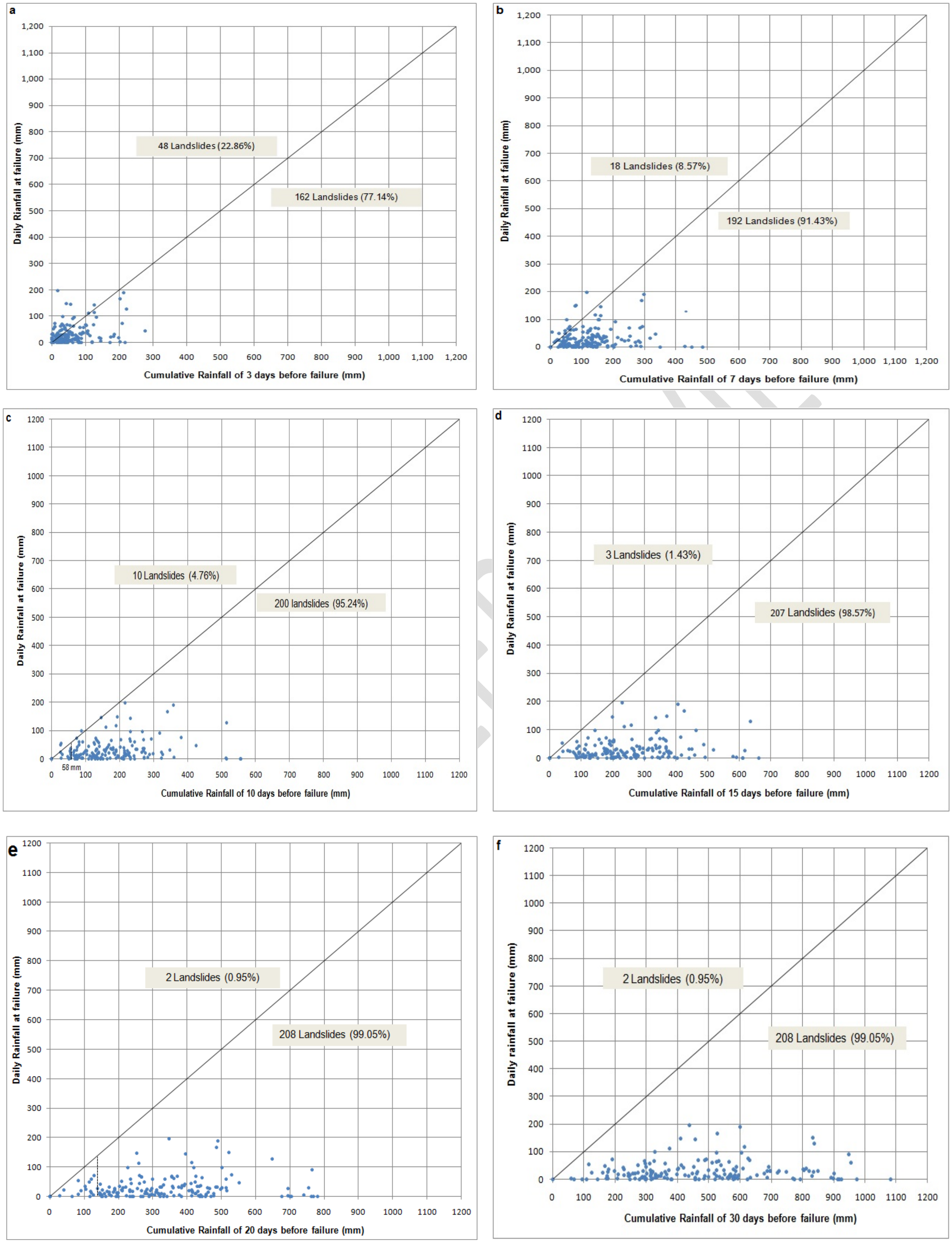

Fig. 12. a – f Relation between antecedent rainfall prior to failure (3, 7, 10, 20 and 30 days) and daily rainfall for landslide occurrences

4. CONCLUSION

In the Indian Himalaya, exists a 15 km stretch of the North Sikkim road corridor that is exceptionally susceptible to landsliding, which causes deaths and property losses and damage of agricultural fields. In the Last three to four decades, the use of the rainfall ID and antecedent rainfall thresholds to obtain the triggering of the landslide has been making a formal application at global, regional, and local Scales. This study, determined rainfall thresholds in terms of intensity-duration and antecedent rainfall for the triggering of landslides based on estimations from available daily rainfall data around North Sikkim Road Corridor in North Sikkim region of Sikkim Himalaya, India at local Scale. It focused on rainfall conditions that triggered landslides in the north Sikkim road corridor in the past, and rainfall intensity-duration (ID) threshold was calculated form a period of 7 years (2010 to 2016). The rainfall threshold relationship determined in accordance to power low is to be found $I = 4.045\ D^{-0.25}$, depicting that the rainfall events of short duration up to 24 h with a rainfall intensity of 1.82 mm/h can cause landslide activities in this study area, and a long duration rainfall event of about 5 to 7 days (normally triggering the landslide in this region during the monsoon) with an average rainfall of 1.39 mm/h and 1.05 mm/h is enough to trigger landslide activities. The local ID thresholds calculated were also compared with various threshold calculated around the world showing good agreement. An analysis of antecedent rainfall of 20 days gave the best relationship with respect to the landslide incidences in the present study area. It can be stated that landslides in this region would occur when antecedent rainfall of 58 mm exceeds a 10 day period (Duration), and of 139 mm exceeds a 20 day period (Duration). This is the first attempt of establishing the rainfall thresholds triggering landslide in the Northern area of Sikkim Himalaya, which will motivate future researchers with better resolution rainfall and landslide data to continue researching for improved threshold models at both local or regional level to enable the development of early warning systems of anticipated landslide activists for the protection measures to serve human lives, property losses and damaged of agricultural fields from rainfall-induced Landslide to be deployed timely.

Ethical: NA
Consent: NA

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