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Assessment of Spatiotemporal Distribution of Landslides in North Thane District, Maharashtra

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Abstract: *Landslides are common phenomena in North Thane district of Maharashtra, especially along communication routes in Ghat sections across the Sahyadri mountain range. Here, an attempt is made to prepare a landslide distribution map for Thane district and to analyse annual landslide occurrences from 2004 to 2011. The records pertaining to the past landslide events are obtained from Public Works Department (PWD) and each single event is plotted on the district road map. The relationship between landslide occurrences and rainfall statistics is used to identify the impact of rainfall on landslides. The result shows that landslide events are more concentrated in north and northeastern parts of Thane district. All the recorded landslides in the study area have occurred in the months from June to September. August is the month of maximum landslide occurrences which is also a month of good rainfall. The maximum landslide frequency was observed in the year 2007 followed by 2010 and 2011.*

Introduction

In terms of worldwide importance of natural disasters, slope instability ranks third (Zillman, 1999). Landslides are movement of mass of rock, debris or soil along a slope mainly due to gravitational pull (Westen, 2006). Slope failure is more widespread and is responsible for significant loss of lives and property than any other geologic hazard (Varnes, 1984).

As per the EM-DAT database (CRED, 2007), global recorded fatal landslides during the year 2007 claimed 3017 lives worldwide, a major share of which is associated with southeast Asian countries. This number is still much less than actual because many landslide events either remain unreported or are considered under other disasters like floods, earthquakes etc. The same database indicate that 89.2% of the fatal landslides are triggered by intense and prolonged precipitation.

Landslides constitute a significant geologic hazard in rugged Western Ghats, which is one of the two major concentrations of landslide prone areas in India (CRED, 2007). The

undulating topography in the north and northeastern part of Thane district is susceptible to landslides posing serious threat especially along communication routes. Landslides that occur on the cut slope along transportation routes are generally small in size but with high frequency they might cause significant hindrances to economic activities in the affected localities (Dai, 2001). A study carried out in a part of Thane district by Pardeshi *et al.*, (2009) revealed that landslides lead to removal of vegetation on the slope, road blockage and subsequent economic loss.

Landslide hazard assessment at various spatial scales is essential for land use planning and finding out mitigation measures to minimise the loss of lives and property. The historical landslide records are essential database for landslide inventory. Landslide inventory provides necessary database for landslide hazard assessment. Detailed landslide inventory requires mainly data inputs such as, location, date and frequency of landslides as well as causes and type of mass movement (Westen, 2006). However, complete event-based landslide inventories are difficult to obtain mainly due to the common problem of linking them to particular date of occurrence and lack of records pertaining to actual damage details. The present study deals with identification of landslide prone areas in Thane district of Maharashtra state and is based on historical records and assessment of their relationship with the distribution and frequency of lanslides and rainfall.

Objectives

The chief objectives of the work include (1) identification of spatial patterns of landslide distribution and (2) establishment of relationship between rainfall occurrences and landslide events in the study area.

Previous works

Landslide inventory provides basis for landslide hazard and risk assessment. Therefore, the quality, reliability and completeness of landslide inventory affect the accuracy of resulting landslide hazard assessment (Ardizzone *et al.*, 2002). Several attempts have been made to test reliability of landslide inventory using different statistical parameters. Galli *et al.* (2008) compared three landslide inventories to evaluate their applicability in landslide hazard assessment. The study revealed that the inventory produced from aerial photo interpretations is best suited for accurate landslide susceptibility assessment. Some studies on landslide hazard assessment have claimed that landslide geometry is instrumental in accurate landslide prediction (Bhandari and Kotuwegoda, 1996; Pardeshi *et al.*, 2009; Dahl *et al.*, 2010).

Past landslide records combined with multi-temporal satellite data are proved to be useful in production of complete and reliable landslide inventory (Jaiswal *et al.*, 2011; Martha *et al.*, 2013; Dahl *et al.*, 2013). Several landslide studies were carried out in Konkan region and many of them dealt with event specific analysis (Thigale and Umrikar, 2007; Bobade *et al.*, 2012; Kumar *et al.*, 2010). Recently, Karlekar (2012) applied multivariate analysis for landslide susceptibility assessment at regional scale in Raigad district. Jaiswal *et al.* (2010) used past landslide events acquired from rail slip registers, technical reports, Public Works Department (PWD) etc. for landslide investigations along transportation corridors in parts of Nilgiri hills. The temporal probability of landslides can be estimated from past landslide records using Poisson or binomial distribution models (Jaiswal *et al.* 2010).

Study Area

The area of study lies between 19º0' to 20º13' N and from 72º39' to 73º48' E (Fig. 1). The

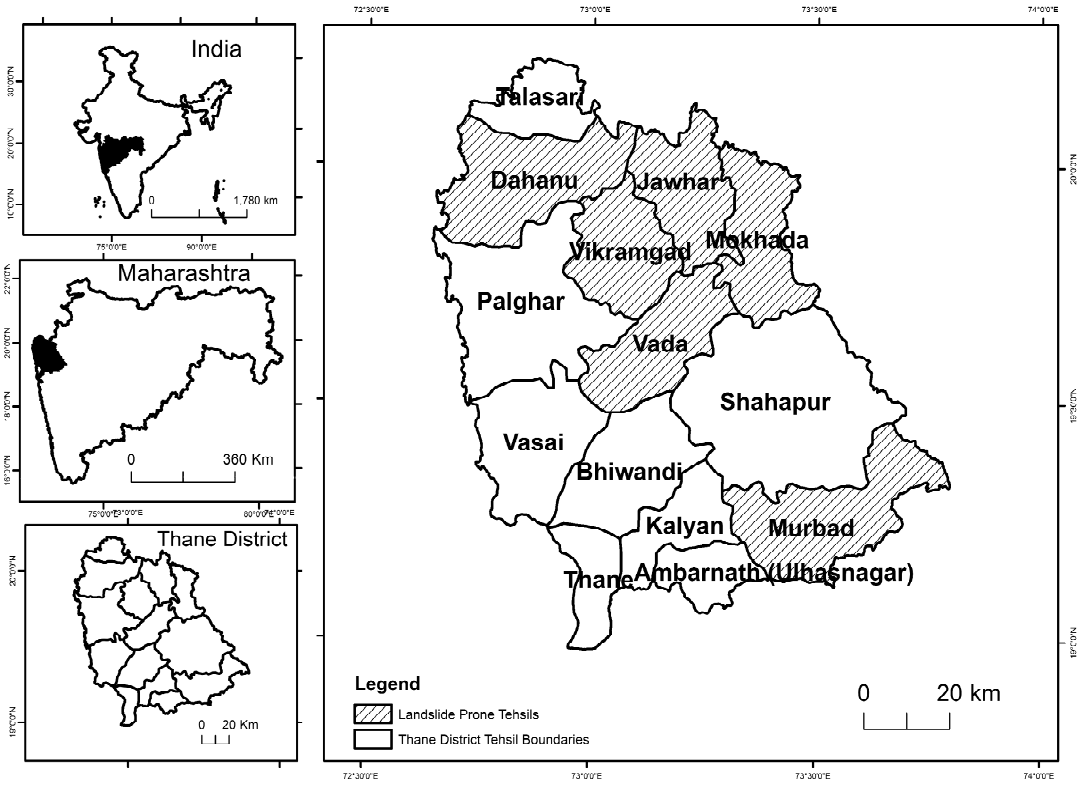

Figure 1. Location

north and northeastern parts of Thane district is a hilly tract within the Sahyadri ranges and some western offshoots of the Sahyadri which run parallel to the west coast. This region receives annual rainfall between 2500 mm and 3560 mm (IMD, 2004–2012).

The study area is covered by upper Deccan Traps of Cretaceous–Eocene age. Basalt flows form the predominant landform elements and at higher elevations are capped with laterite in few places. The hill ranges in this area are aligned in north-south direction and show more or less steep escarpments. This region is drained by Vaitarna, Surya, Ulhas rivers and their tributaries. There are numerous dykes dissecting the area. The general trend of ranges is NNW–SSE and NNE–SSW, sloping steeply towards east (GoM, 1982). The rocks are interspersed by many joints. Although this region is not frequently affected by earthquakes, numerous mild tremors with magnitude less than 4 on the Richter scale have been reported. However, there is no earthquake-induced landslide event reported till date (Nagrajan *et al.*, 2000).

Materials and methods

Consideration of rainfall data is essential in designing methodology for landslide hazard assessment. Records of 346 reported landslides were obtained from concerned branch offices of PWD in Thane district for the period between 1998 and 2011. Monthly rainfall data were collected from India Meteorological Department for the period from 2004 to 2011. Data pertaining to some past landslide events were obtained from National Highway Division – 03 for the period from 2005 to 2011, from PWD Jawhar Division for the period from 1998 to 2004 and from Disaster

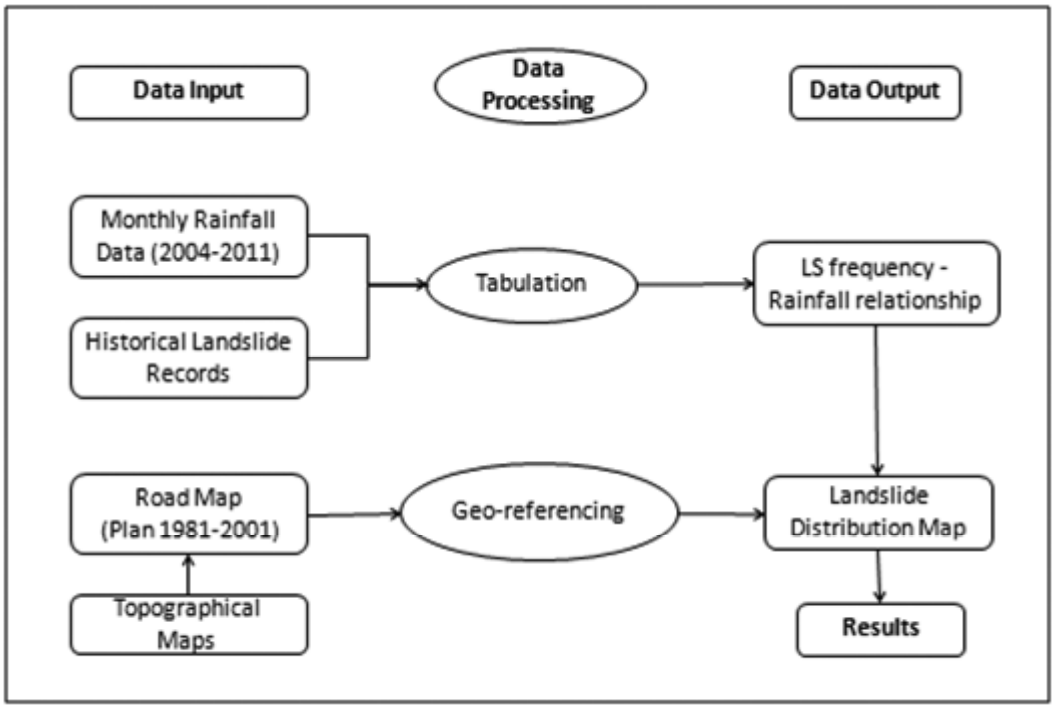

Figure 2. Methodology

Management Cell, Thane Municipal Corporation for the period from 2010 to 2012. A published road map (Road Development Plan 1981–2001) of Thane district was obtained from the construction division of PWD–Thane. The methodology adopted is explained with the help of Fig. 2.

Results and Discussions

Landslide distribution

The region is susceptible to landslides of different magnitudes. Large number of landslides are reported especially along major communication routes. The historical records pertaining to the landslide events along roads in Thane district (Table 1) show significant variation in their distribution pattern. Highest concentration of reported landslides is observed in Malshej Ghat on National Highway (NH) – 222 followed by northern hilly sections of Jawhar Division. Many small landslide events along roads and those in the interior parts mostly remain unreported.

The historical landslide record obtained from PWD Jawhar division clearly shows that

Table 1. Overview of Landslides in Thane District

Division	No of reported Landslides
Public Works Department Jawhar Division	107
Disaster Management Cell of Thane Municipal Corporation	8
National Highway Authority of India Div-3	165
Public Works Department (Thane Construction Division)	66
Total	**346**

(Source: Public Works Department)

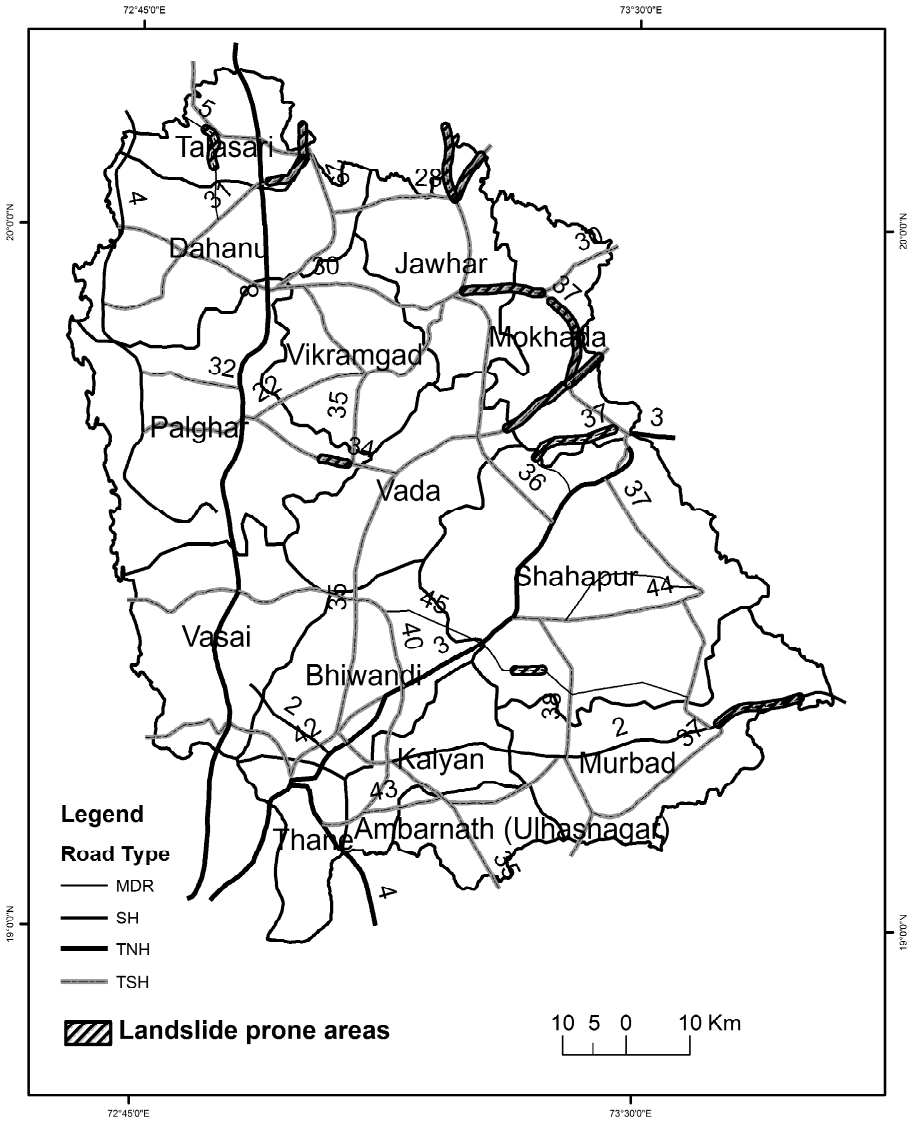

Figure 3. Distribution of landslide

the highest number of reported landslides are along State Highway (SH) – 28, with 24 events followed by SH–34, SH–37 and SH–36 located in the northeast and eastern boundary of Thane district. NH–222 shows another major landslide prone area with 165 landslide events between years 2005 and 2011. Few landslide events are also reported along roads in the interior parts of Murbad and Shahapur tehsils. Eight events are reported within Thane Municipal boundary, most of which occurred along Thane–Panvel bypass near Kalwa Fig. 3).

The landslide sites in Thane district are observed mainly in the hilly tracts of Sahyadris along the northern and eastern boundary regions of the district. The landslide events are concentrated along major communication routes especially in Malshej Ghat section and in rugged topography of north Thane district.

Table 2. Annual landslide frequency in Thane district: 1992–2011

Year	Number of reported landslides				Total
	Jawhar Divison (PWD)	Thane Con. Division (PWD)	N H Div.3	DMC, Thane	
1992	6	NA	NA	NA	6
1993	NA	NA	NA	NA	NA
1994	1	NA	NA	NA	1
1995	NA	NA	NA	NA	NA
1996	5	NA	NA	NA	5
1997	6	1	NA	NA	7
1998	NA	14	NA	NA	14
1999	14	2	NA	NA	16
2000	NA	5	NA	NA	5
2001	2	9	NA	NA	11
2002	NA	7	NA	NA	7
2003	18	5	NA	NA	23
2004	7	12	NA	NA	19
2005	48	6	14	NA	68
2006	NA	2	14	NA	16
2007	NA	3	46	NA	49
2008	NA	NA	36	NA	36
2009	NA	NA	11	NA	11
2010	NA	NA	35	1	36
2011	NA	NA	9	5	14
2012	NA	NA	NA	2	2
Total	107	66	165	8	346

NA - Data not available (Source: PWD Jawhar division, PWD Thane construction division, National highway division-3)

Landslide frequency and distribution pattern

Annual landslide frequency is considered important to identify landslide hazards over a period. Landslide frequency based on available historical records is obtained for different roads from Technical Survey register of PWD.

The area under jurisdiction of PWD Jawhar is spread over the northern hilly parts of Thane district. This region experiences numerous landslides of different magnitudes especially during monsoon season. Boulder fall and debris slides are common-forms of mass movement in this area (Pardeshi *et al.* 2009). However, there is significant variation in the annual frequency of landslides in this region. The highest frequency of 48 landslide events was recorded in 2005 followed by 2003 (16 events) and 1999 (14 events). Malshej Ghat is one of the most important areas in Thane district susceptible to landslides during rainy season with variable annual frequency. Landslides are common here and occur almost every year.

The PWD construction division of Thane covers roads of eastern and central parts of Thane district. The hilly areas of Murbad and Shahapur Tehsils in this division are susceptible to landslides, though the number of recorded landslide events are comparatively less. The overall annual frequency of landslides in Thane

Table 3. Monthly landslide frequency in Thane district: 1992-2011

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Landslide Frequency	0	0	0	0	0	14	87	123	103	17	2	0

(Source: PWD Thane district)

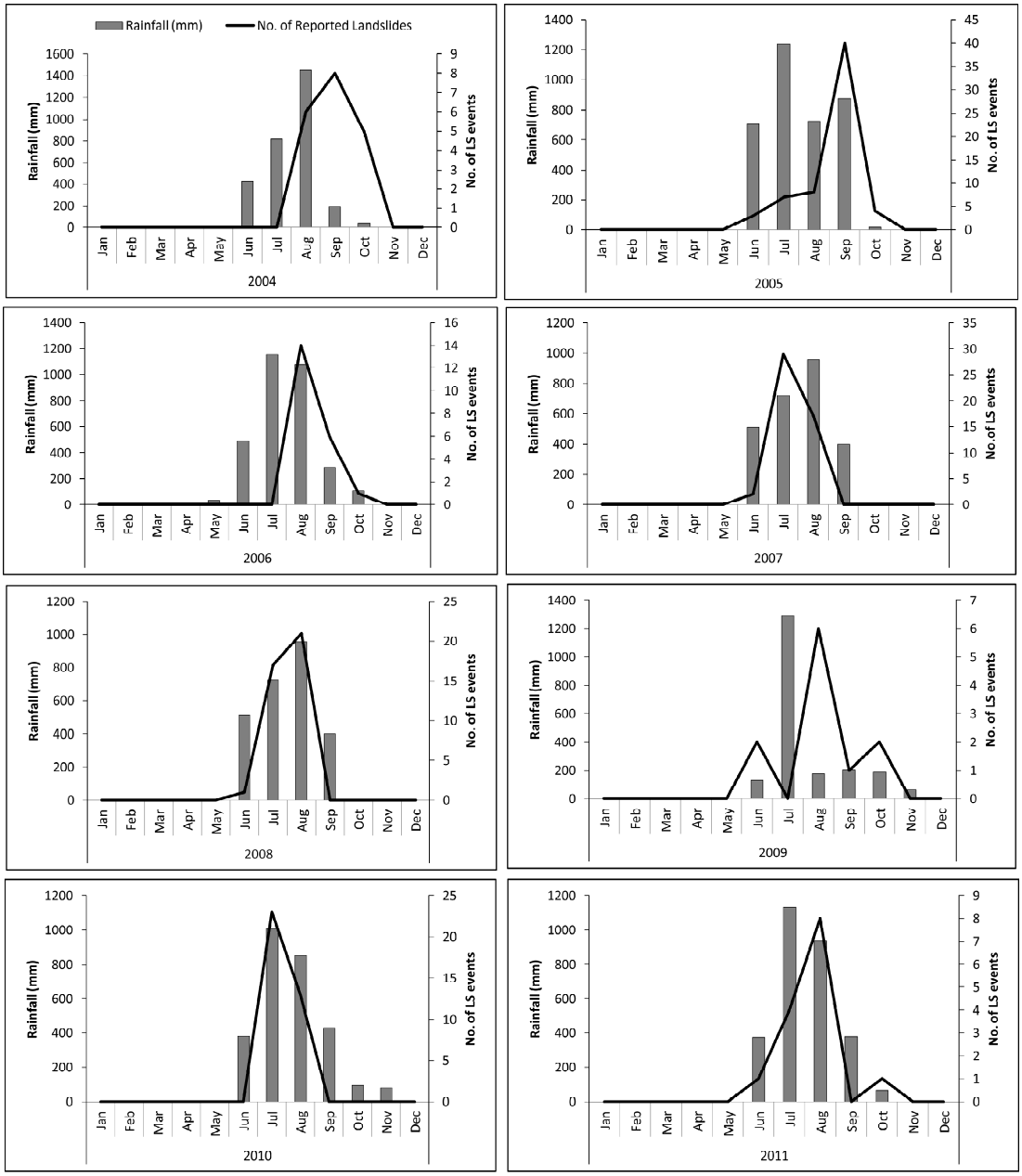

Figure 4. Rainfall and landslide events correlation

district was higher in the years 2005, 2007 and 2010 (Table 2). Since most of the landslides remained unreported, it is difficult to establish a relation between annual landslide frequency and landslide causative factors. However, it can be correlated with the rainfall data for a particular period to find out the extent to which rainfall triggers the landslide events.

Landslide frequency and rainfall variation

Since most of the recorded landslide occurrences are attributed to the monsoon

season it shows relationship between landslide events and rainfall events. It was therefore felt important to establish a relationship between rainfall data and landslide events recorded in the study area. An attempt was made to establish relation between monthly rainfall amount and landslide frequency for the respective periods.

Over 65% of the total landslides have occurred during the heavy monsoon rainfall period between August and September. (Fig. 4, Table 3).

The landslide frequency and monthly rainfall in the study area for the period from 2004 to 2011 shows fairly high correlation. However, there are variations in the annual landslide frequency over the period from 2004 to 2011. The highest landslide frequency with 62 events is observed in the year 2005 which received over 3,500 mm rainfall. The maximum frequency of landslide events is observed in the month of August with 123 reported events out of 346 (over 35%). The mean monthly rainfall for the month of August is also comparatively high. This highest frequency of landslide events during peak rainfall duration suggests that there is significant role of rainfall in the process of slope failure. Besides this, other landslide preparatory factors such as slope, aspect, lithology, land use, land cover, drainage etc. also cause landslides.

Conclusions

Landslide distribution in Thane district shows high concentration of landslide events in the north and eastern hilly complex of the district. Jawhar, Wada, Mokhada, Shahapur Tehsils and Malshej Ghat in Murbad Tehsil show high concentration of landslide events. These areas are located in the western slopes of Sahyadris.

There is significant temporal variation in annual landslide frequency. The highest frequency of landslides was in the year 2005 followed by 2007 and 2010. Most of the landslides in Thane district are attributed to the rainy season especially in the months between July to September.The mean monthly rainfall and landslide frequency show positive correlation. Most of the landslide events occurred in the peak rainy months (i.e. August and September).

Landslides in the northern and eastern hilly complex of Thane district are common. Proper landslide investigation demands for complete and reliable landslide database. However, in case of Thane district, the past landslide events are not recorded with desired detail. Moreover, only those events are recorded that cause huge losses along the roads. Many small and minor movements generally remain unreported.

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