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RAINFALL THRESHOLDS FOR THE INITIATION OF LANDSLIDES IN TRABZON PROVINCE OF TURKEY

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Abstract

Knowing the duration, intensity and amount of precipitation triggering landslides is of great importance for understanding landslide mechanisms and landslide warning systems. Global, regional and local studies carried out by the researchers revealed that the rainfalls triggering landslides occur after a certain threshold value. In Turkey, there is no available data on the threshold value of the rainfall. Trabzon province of Turkey is located in a region with the highest rainfall where the landslides mostly occur. Only in the last 20 years, more than 2000 landslides occurred in the region. The majority of these landslides were triggered by rainfall. In this study, using the log-log based graphic obtained by calculation of the duration and intensity of the rainfall in Trabzon province, the threshold value triggering landslides was found to be $\mathbf{I=0.69\ D^{-0.99}}$*. Rainfall threshold values obtained also for various criteria (slope angle, lithology, cover type, type of agricultural product, landslide type etc.) may be used as a reference for slope stability analysis studies which would be based on geotechnical data.*

Key Words: Rainfall; Rainfall Threshold Triggering Landslide; Slope Stability Analysis

1. Introduction

While water is the crucial component of landslides, rainfall is the most important triggering component of landslides. The researchers carry out various scientific studies on identification of the rainfall amount that trigger landslides. The studies conducted to determine the rainfall threshold which trigger landslides are categorized as physical or empirical studies [1]. Physical based models mainly consider soil parameters, infiltration conditions, topography, lithology and others. However, physical models require detailed spatial data (soil parameters, hydrology, morphology, lithology etc). It is rather difficult and expensive to obtain these kinds of information in large areas in a detailed and accurate manner [1]. In addition slope engineering indicated that precise success cannot be obtained only through deterministic methods [2]. Moreover, since in residual soil slopes, shear strength of the soil vary according weathering and altering effects, it is not possible to make a successful stability analysis using the parameters obtained by laboratory experiments. Empirical approaches which are based on experience appear as the most reliable method in residual soils. In these kinds of slopes, shear mostly occurs in infinite slopes and it is difficult to make a precise calculation [3].

Today, the trend of solving stability problem with the theory of probability increasingly gain importance [2]. Empirical identification of the rainfall threshold value which initiate the landslide using statistical data has began to be widely used in solving stability problem [4,5,6 7]. Some countries have been using the rainfall threshold values as the basis of landslide warning system [1,6,8].

Empirical models, on the other hand, are obtained by the analysis of the rainfall events resulting in landslides. These kinds of studies evaluate the rainfall intensity and duration which result in landslides using statistical data and obtain a threshold value. The relation of this threshold value is generally obtained by drawing lower-bound lines to the rainfall conditions that resulted in landslides plotted in Cartesian, semi-logarithmic or logarithmic coordinates [1]. The first global study on rainfall intensity and duration triggering shallow landslides and debris flow were carried out by Nel Caine [9]. Caine conducted a study using rainfall values of a total of 73 landslides identified in various regions of the world. Based on this study, Caine [9] introduced

$$I = 14.82\ D^{-0.39} \tag{1}$$

lower-bound relation (Figure 1-a). Where, I is rainfall intensity (mm hr^{-1}) and D is rainfall duration (hour); the inclined line below (Figure 1-a) represents rainfall threshold value initiating the landslides and the inclined line above (Figure 1-b) represents maximum rainfall threshold.

After Caine, other researchers carried out local, regional and global studies on rainfall threshold triggering landslide [4,5,6 7]. The table below gives the global rainfall threshold values obtained by different researchers (Table 1).

Table 1. Global rainfall thresholds

Line	Researcher	Rainfall Threshold
1-a	Caine [9]	$I=14.82\ D^{-0.39}$
1-b	Caine [9]	$I=388\ D^{-0.514}$ (Max.)
2	Innes [10]	$I=4.93\ D^{-0.50}$
3	Jibson [11] (0,5<D<12)	$I=30.53\ D^{-0.57}$
4	Clarizio, Gulli & Sorbino [12]	$I=10\ D^{-0.77}$
5	Crosta & Frattini [5]	$I=0.48+7.2\ D^{-1.00}$
6	Cannon & Gartner [13]	$I=7.00\ D^{-0.60}$
7	Guzetti & Peruccacci [14]	$I=2.20\ D^{-0.44}$
8	Guzetti & Peruccacci [14] (0,1<D<48)	$I=2.28\ D^{-0.20}$
	Guzetti & Peruccacci [14] (48≤D< 1,000)	$I=0.48\ D^{-0.11}$

Figure 1 is adapted from global rainfall intensity and duration threshold values published by the researchers. The lines represent threshold values.

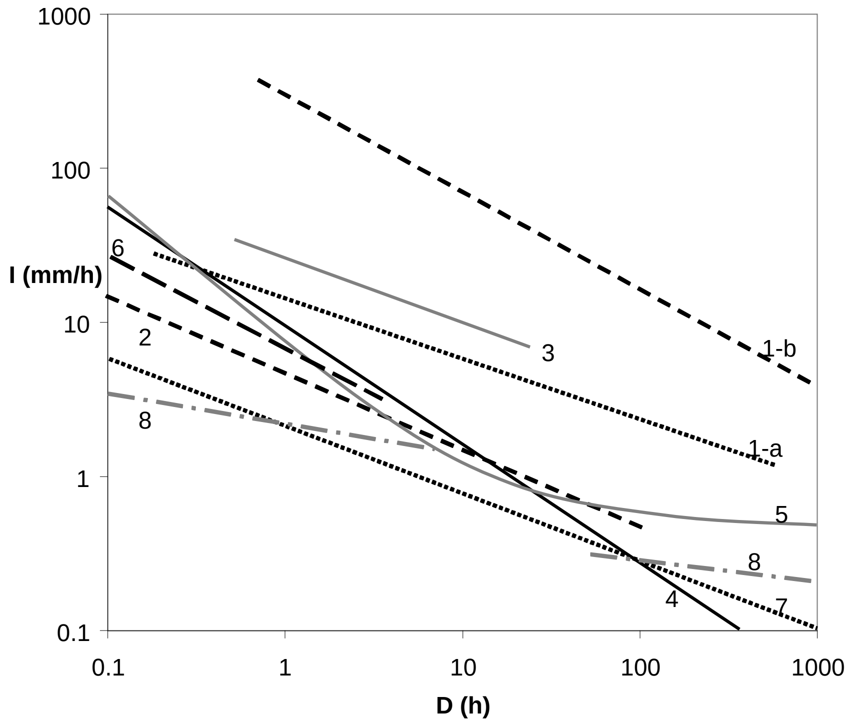

Fig.1. Comparison of the global intensity-duration (ID) thresholds. 1-a. Minimum rainfall threshold Caine [9]; 1-b. Maximum rainfall threshold Caine [9]; 2. Innes [10]; 3. Jibson RW [11] 4. Clarizio, Gulli & Sorbino [12]; 5. Crosta & Frattini [5]; 6. Cannon & Gartner [13]; 7. Guzetti & Peruccacci [14]; 8. Thresholds obtained for two different rainfall periods Guzetti & Peruccacci [14]

Trabzon province has a residual soil and an area of 4685 km^2. With an annual average rainfall of 824.2 mm, Trabzon is located in a region with the highest rainfall and highest occurrence of landslide events in Turkey [15]. Trabzon province is the leading region where landslides occur. Hence the rainfall threshold is very important for this region. In this study, landslide and rainfall data of Trabzon province was supplied from various State Institutions. With these data rainfall threshold that initiate the landslides was determined using empirical (statistical) method. Threshold values obtained also for various criteria (slope angle, lithology, cover type, type of agricultural product, landslide type etc.) may be used as a reference for slope stability analyses which would be based on geotechnical data. The obtained threshold value can also be used as a reference for Trabzon province landslide warning system.

2. Landslide and Rainfall Data

Reliable and detailed record of the rainfalls and landslides occurring in Trabzon province are available since 1988. Therefore, the studies encompass the period between 1988 and 2008. The landslide data used in the study was supplied from Trabzon Provincial Directorate of Public Works and Settlement [16], General Directorate of Disaster Affairs [17], Trabzon Regional Directorate of General Directorate of Mineral Research and Exploration [18] and Trabzon Regional Directorate of Forestry [19].

Between 1988 and 2008, more than 2000 shallow landslides and mud (debris) flow events occurred within provincial borders of Trabzon. Among the landslides in the records, the ones caused by human intervention (pipe leak, excavation etc.) and the ones whose time were unknown were excluded from evaluation. Furthermore, minimum two landslides occurring in the same rainfall criterion was adopted to obtain a more reliable rainfall threshold. Then, the probability of including the landslides which might have occurred due to human intervention in the relation, will be reduced. Figure 2 indicated multiple landslides (number of landslide: n>2) that occurred in Trabzon province during rainfall periods between 1988 and 2008.

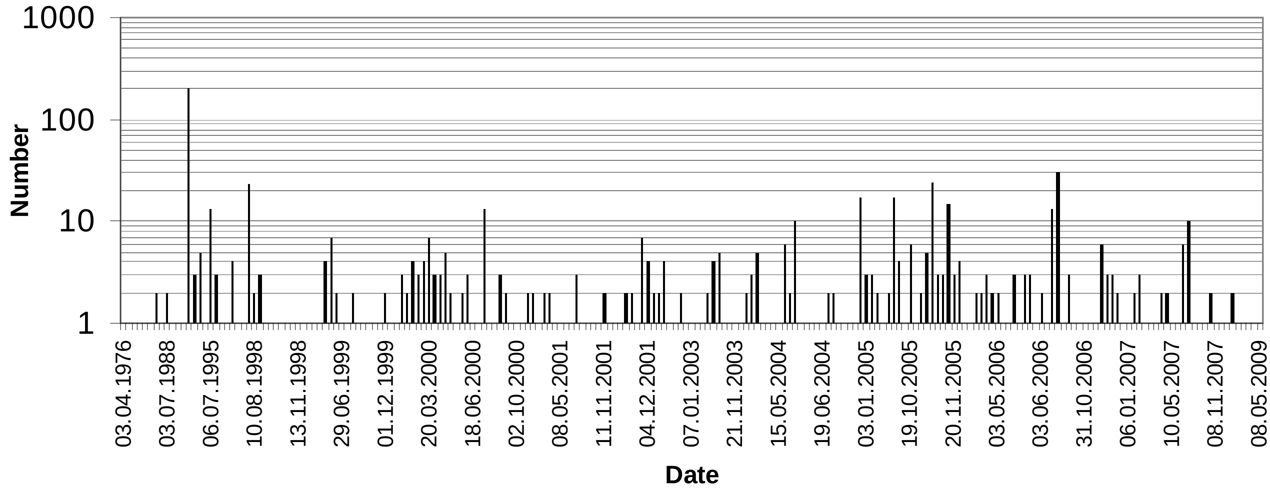

Fig. 2. Trabzon province multiple landslides (n>2)

Location, time, type, lithology, number of the landslide, slope angle, slope elevation, reason, rainfall amount, rainfall duration, type of agricultural product, type of tree, intended use data were collected for each landslide. However, since the landslide and rainfall reports provided by the relevant authorities were inadequate, it was not possible to collect all the data in completely for all landslides.

The collected data was evaluated according to their categorizations (Figure 3). *Landslide type*; the analyzed soil mass movements mostly occur in planar slide and mud-debris flow. *Slope angle*; natural slope angles of the slopes where the landslides occurred varied between 10^o to 80^o. Average natural slope angle of the landslides was 44.7^o. *Thicknesses of the sliding mass;* when, landslides were evaluated according to the thickness of moving mass criteria, it was observed that the majority of the landslides were shallow landslides. *Flora type*; the flora of the areas where the landslides occurred were mostly agricultural lands. The landslides have a great effect on the conversion of forest areas into agricultural lands. *The landslides that occur in forest areas*; the majority of the landslides that happened in forest areas occurred in slopes covered with spruce trees. The reason is that spruce trees have shallow roots. *Agricultural product:* the landslides mainly occur in hazelnut and tea gardens. Almost all of the agricultural products grown in the region have shallow roots.

Precipitation data used in our study was collected from Turkish State Meteorological Service [15] and State Hydraulic Works The 22nd Regional Directorate [20]. Annual average rainfall amount of Trabzon province between 1970 and 2009 was 824.2 mm. However, when the rainfall data of the last 7 years was analyzed it was found that annual average rainfall was close to 950 mm and the rainfall trend indicated an increment [21].

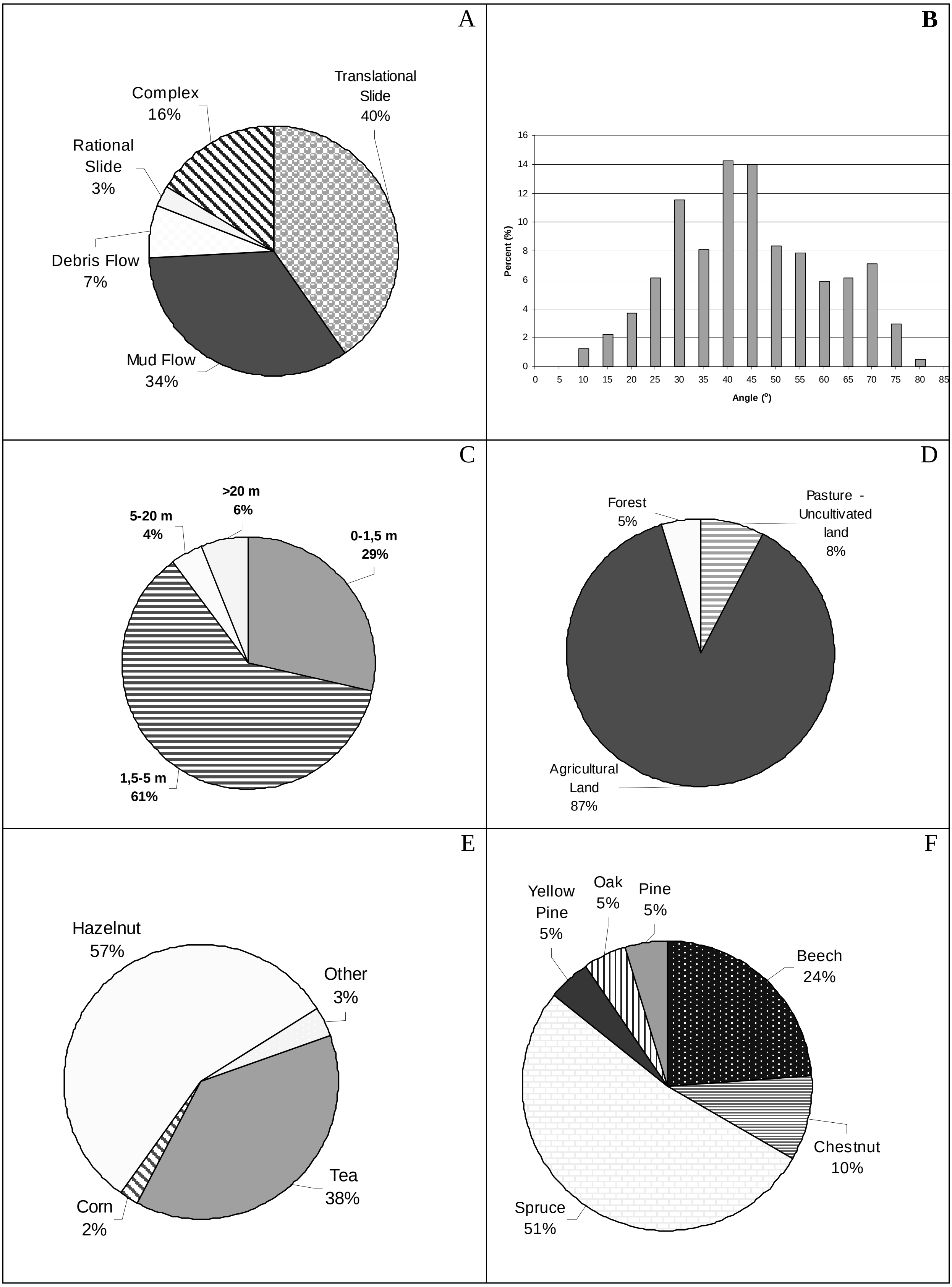

Fig. 3. Categorization of the landslides in Trabzon province (A) landslide type (B) natural slope angles (C) thickness of sliding mass (D) cover type (E) type of agricultural product (F) type of tree

3. Determination of Rainfall Threshold

Rainfall intensity-rainfall duration (ID) graphic was used in determination of landslide rainfall threshold (Figure 4). Provided landslide and rainfall data were plotted on log-log graphic. Lower-bound line of the plotted data represents the threshold value triggering landslides in Trabzon province. In other words, the rainfall having less intensity and duration than the obtained threshold are not expected to trigger a landslide. In figure 4, threshold value for all landslides triggered by the rainfall between 1988 and 2008 in Trabzon province was found to be as follows;

$$\mathbf{I = 0.69\ D^{-0.99}} \qquad (2)$$

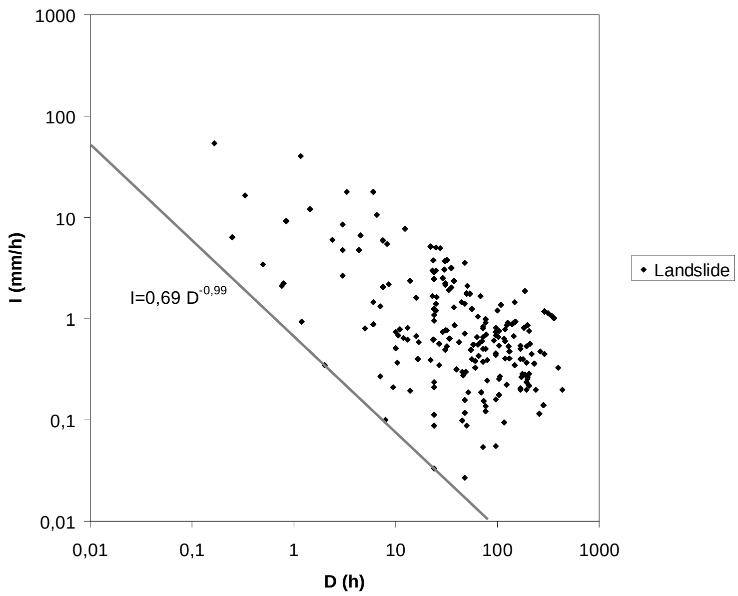

Fig. 4. Rainfall threshold triggering landslides in Trabzon province

This rainfall threshold was formed by within consideration of all slope angles, all intended purpose areas and all lithologic conditions. In this study, considering multiple landslide, slope angle, landslide type, lithology, intended land use and flora criteria, rainfall thresholds were separately obtained as given below.

Figure 5 indicated rainfall threshold for multiple landslides (n>10) that occurred in Trabzon province between 1988 and 2008. As the rainfall intensity and duration increase, number of landslides and rainfall threshold increases as well. In addition, it was found that after 8 hours of rainfall, rainfall threshold showed variations. In this context, different threshold values were obtained for (D>8 and D<8 hours).

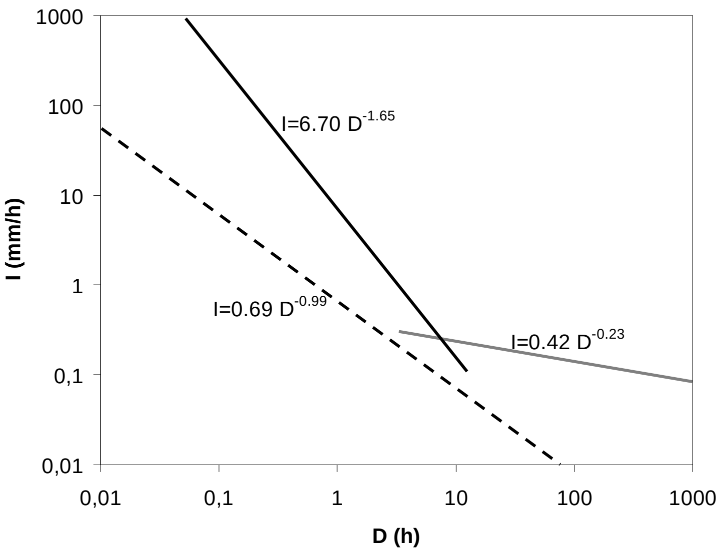

Fig. 5. Rainfall threshold of Trabzon province for n>10

Landslide threshold values show a great variation with slope angles (Figure 6). However, spesifically after 60^o, although threshold value was expected to fall, it increased again. This was associated with the fact that in high slope angles, rain waters flow easier on the surface and thus the amount of water infiltrating into the soil decreases. (Table 2).

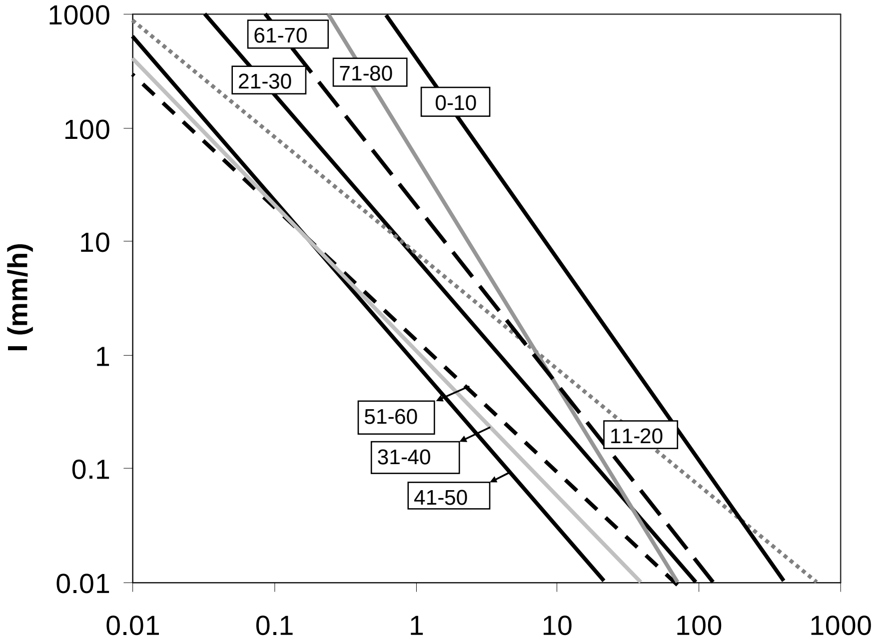

Fig. 6. Landslide- rainfall intensity-duration
according to slope angles

Table 2. Rainfall Thresholds for Angles

Angle (^{o})	**Rainfall Threshold**
0-10	$I=433\ D^{-1,78}$
11-20	$I=8.61\ D^{-1.06}$
21-30	$I=7.01\ D^{-1.41}$
31-40	$I=1.14\ D^{-1.24}$
41-50	$I=0.92\ D^{-1.39}$
51-60	$I=1.25\ D^{-1.17}$
61-70	$I=21.88\ D^{-1.63}$
71-80	$I=52.67\ D^{-2.01}$

Landslide–rainfall threshold was identified separately for translational slide and flow type landslides. When the slide threshold value is equal to the general threshold value (equation 2), the threshold value calculated for the flow becomes higher. This indicates that mud-debris flows require more rainfall when compared to the slides (Figure 7).

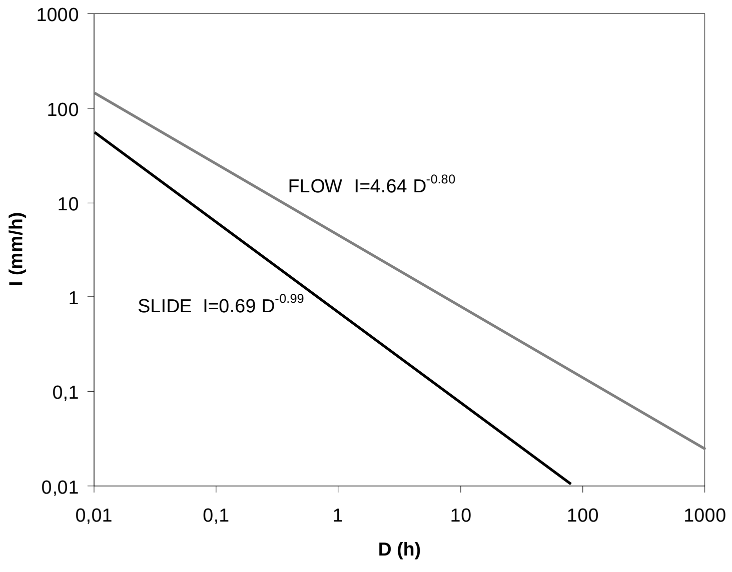

Fig. 7. Landslide-rainfall intensity-duration according to landslide type

An analysis based on lithologic categorization indicates that the soils formed by the weathered plutonic rocks containing granitoids require more rainfall when compared to the soils formed by sedimentary and volcanic rocks (Figure 8). The reason of this is that the rocks of different lithology have weathering products with different soil properties. When the slopes, where landslides occurred, were categorized according to flora, various rainfall threshold values were obtained. Agricultural lands comprising tea and hazelnut with shallow roots have a significantly lower threshold than forest and uncultivated land (Figure 9). In the region, landslide risk particularly increase for tea and hazelnut gardens which were converted from forest areas into agricultural lands.

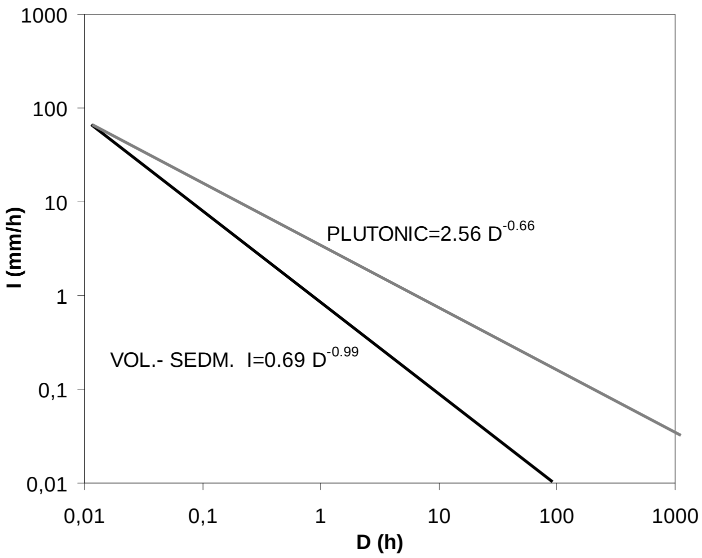

Fig. 8. Landslide-rainfall intensity- according to rock type

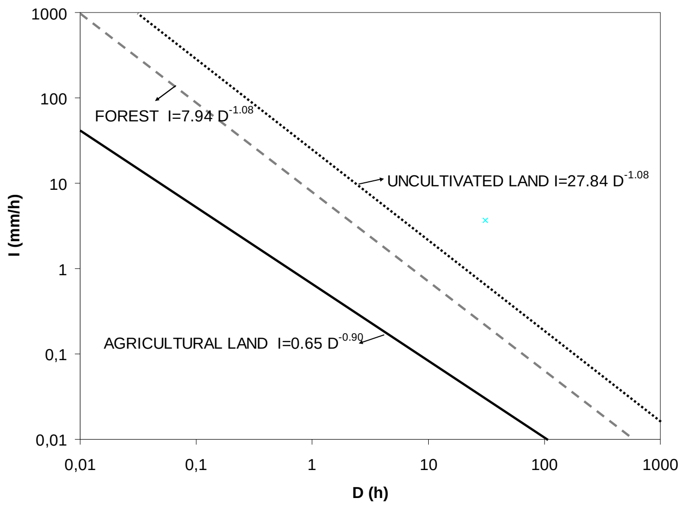

Fig. 9. Landslide-rainfall intensity-duration according to cover type

When the rainfalls triggering landslides in tea and hazelnut gardens representing the majority of the agricultural lands of Trabzon province were compared, it was found that pole values showed variations but an average line in time and intensity interval with accumulated landslides can represent both thresholds (Figure 10).

4. Comparison with Available Rainfall Thresholds

Unfortunately, there is no previous rainfall threshold data for the study area and its vicinity. This study is unique to provide reliable threshold value for the study area. Therefore, the threshold value obtained in the present study was compared with the global and other regional threshold values (Figure 11).

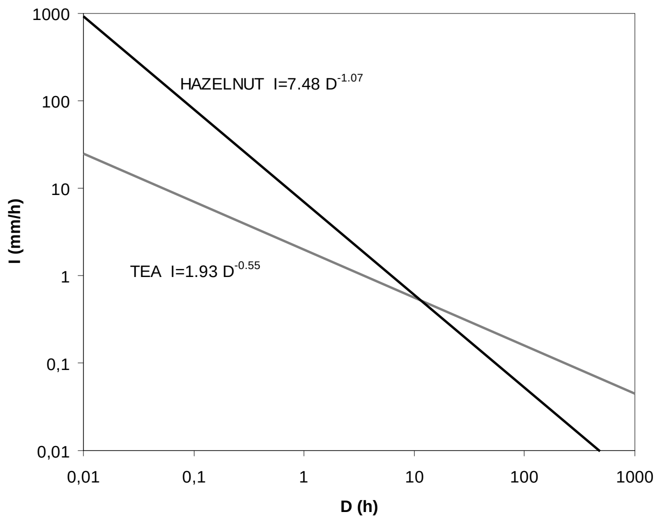

Fig. 10. Landslide-rainfall intensity-duration according to type of agricultural product

Table 3. Global, regional and local rainfall thresholds

Line	Researcher
1	Zezere [22]
2	Cancelli & Nova [23]
3	Aleotti [6]
4	Wieczorek and Glade [7]
5	Crosta and Frattini [5]
6	Ceriani, Lauzi & Padovan [24]
7	Caine [9]
8	Guzetti et al. [1]
9	Dahal and Hasegawa [25]
10	Akcali et al. (Present Study)

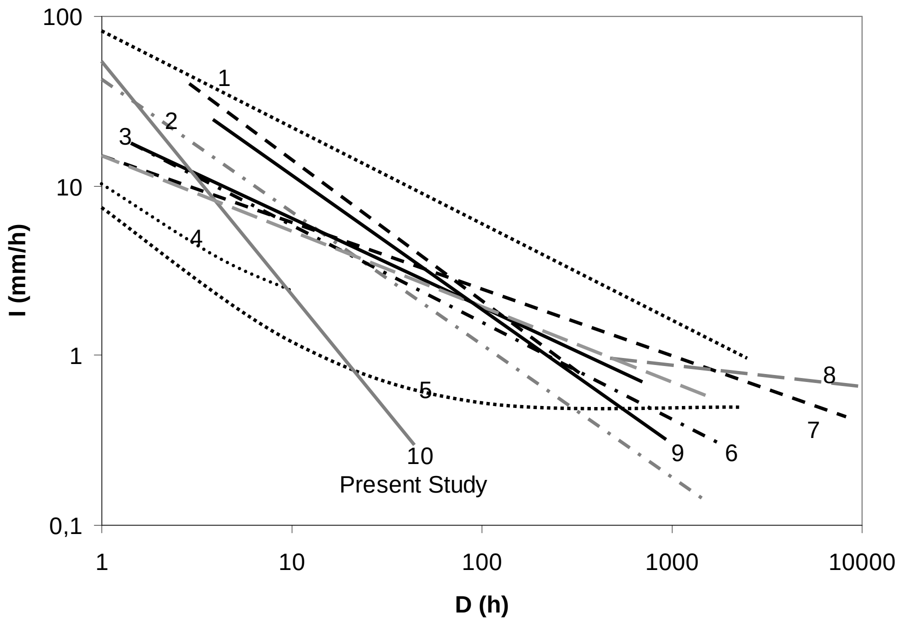

Fig. 11. Comparison of landslide–rainfall thresholds (Numbers refer to # in table 3)

As illustrated in Figure 11, global and other regional threshold are higher than the threshold obtained in the present study. In other words, landslides often occur in the region, in case of rainfalls with lower intensity or a shorter duration than the global threshold value. Therefore, it would be more reliable and consistent to use the local threshold value obtained in the present study than to use the global threshold value. In addition, this study proves the importance degree of the recommendations as to forming local threshold for each different region.

5. Disscussions and Conclusions

This study primarily based on collected data of the landslides that occurred in Trabzon province of Turkey between 1988 and 2008. Among these landslides, the ones which were triggered by rainfall (which were not directly triggered by human intervention) and the ones with known landslide times were included in the study. The amount and durations of the rainfalls prior to these landslides were calculated. Landslide-rainfall duration-rainfall intensity graphic presented rainfall threshold data for all landslides and different criteria (multiple landslide, slope angle, landslide type, lithology, intended use of land and flora type). Rainfall threshold was found to be $\mathbf{I=0.69\ D^{-0.99}}$ for Trabzon province landslides. Rainfall threshold obtained for Trabzon province landslides was lower due to intended land use, geographic and lithologic structure and climatic differences of the region. However, for Trabzon province, it would be more reliable to use local threshold value obtained in the present study, instead of using global threshold values. In addition, different threshold values obtained based on various criteria would be used as a reference for slope analysis with geotechnical data.

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