POSSIBLE CONTRIBUTIONS OF CITIZEN SCIENCE FOR LANDSLIDE HAZARD ASSESSMENT

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ABSTRACT:

Landslide is perhaps one of the most complex natural phenomena and is quite common throughout the World. Before the human appearance on the World, it was only an earth surface process, whereas it became one of the most destructive natural hazards with the anthropogenic activities and the increase in human population. Landslides cause serious harmful and destructive effects on roads, railways, buildings, infrastructures, lifelines, quality of surface waters, etc. To reduce the losses caused by landslides, high quality landslide susceptibility and hazard maps are crucial. With the recent technological developments, the quality of regional landslide susceptibility and hazard assessments has been increased. Preparation of a complete landslide inventory map with accurate temporal dimension can be extremely difficult, or even impossible. Inaccurate and incomplete temporal landslide inventory maps result in serious uncertainties on the assessment results of regional landslide hazard. Therefore, lack of timely accurate data is the main source of problem affecting quality of the regional landslide assessments.

With the emerging developments in geospatial technologies, as well as the transforming power of information and communication technologies (ICT) on the society, it became possible to use the citizen science methods in scientific processes, which has enormous potential in landslide data collection and thus reduce the losses. The main aim of this review is to discuss the uncertainties lead by missing data and affecting quality of regional landslide assessments, and to describe the potential of citizen science to reduce the uncertainties. For this purpose, a brief review on the landslide susceptibility and hazard studies have been performed and the sources of uncertainties have been described. Finally, the role of citizen science is discussed with specific examples. As a final conclusion drawn from the present study, it is possible to say that citizen science may provide substantial contribution on the quality of regional landslide assessments.

1. INTRODUCTION

Depending on the increment of World population and climate change, occurrence of the extreme weather events has increased considerably. As a result of this adverse situation, the number of natural hazards such as flooding, landsliding etc. has been rising. Among the natural hazards, landslide is perhaps one of the most dangerous because landslides cause serious loss of property and lives throughout the World.

A typical example of landslide losses from Turkey was presented by Can et al. (2005), which was the result of an extreme regional meteorological event (heavy rainfall) that caused also flooding by the second day. Thousands of shallow earthflow landslides occurred during the rainfall and this event caused 10 deaths, extensive damage to both public and private property, and cost social and economic disruption (Can et al., 1999). The total economic cost was estimated as 500 million US Dollars and the affected area and population were 37,000 km^2 and 2.2 million, respectively. In addition, a considerable amount of forest area was destroyed. Such meteorological events are frequent in the Black Sea Region of Turkey. For example, in 1955 another flooding event was also recorded in the region but historical data about the landslides are not available. In the future, this type of rainfalls is very likely to occur in the region. When considering the principle “the past is the key to the future”, future landslides are also very likely to occur under such conditions, which leads to past and present instability (Can et al., 2005).

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To reduce the losses caused by landslides, regional landslide characterization based on the regional assessments of susceptibility, hazard and risks are of crucial importance. The management of risks, disasters or also the land requires the knowledge on the probability of spatial (defined as susceptibility) and temporal (defined as hazard) occurrence of landslides. Existence of both the spatial and temporal data are mandatory for correct characterization and for accurate modeling.

Assessment of the landslide susceptibility is the first stage of landslide mitigation efforts. Endeavors to produce representative landslide susceptibility maps have increased especially during the last two decades. The landslide susceptibility mapping methods can basically be classified into two main groups, namely heuristic and data-driven (automatic) mapping. Great difficulties are being encountered while producing heuristic landslide susceptibility maps, which bring up severe uncertainties in the resulting maps. Among those, subjectivity, lack of expertise and knowledge on map preparation, the need of enormous effort can be listed as major factors. In addition, the production of the landslide susceptibility map by heuristic approach is an extremely exhaustive process. Due to these reasons, automatic landslide susceptibility mapping has become more attractive. However, automatic landslide susceptibility mapping requires a robust mapping approach and high-quality inventory data.

The second stage of regional landslide characterization is the assessment of landslide hazard. Landslide hazard can basically be defined as the occurrence probability of the landslides in a given period. The exact time of occurrence is crucial for computation of landslide probability, thus hazard determination.

Under the assumption of having high quality data for meteorological phenomenon and earthquakes, which are the most important triggering factors of landslides, the exact time of landslide occurrence is the most important parameter for accurate linking of these data. The main obstacle in determination of the landslide hazard is knowing the exact time of occurrence of the past events. Additionally, some shallow landslides or flows may lose their features and traces in a short time. Some typical examples for such type landslides from Buyukkoy near Rize Province of Turkey are given in Figure 1 (Nefeslioglu and Gokceoglu, 2011). From the Figure, it can be seen that the earth surface characteristics change in a short time, which may make it impossible to detect the landslide by post-event observations, such as by using aerial or satellite images, etc.

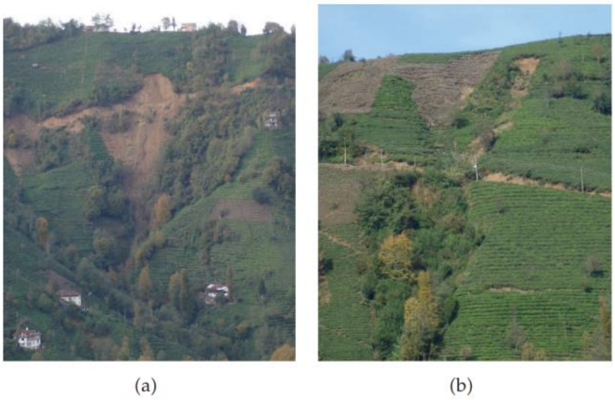

Figure 1: Typical views of the earthflows occurred in Buyukkoy Region; *a* fresh, and *b* a few years old (Nefeslioglu and Gokceoglu, 2011).

The risk assessment and management stages are performed after the hazard determination. Prediction of the runout distance, which involves the direction, displacement and the magnitude of the landslide, is crucial for land and disaster management as well. Infrastructure and construction planning at regional level should be performed based on this data, as well as disaster management during and after the landslide event such as evacuation of people. The runout distance can best be modeled using the data of past landslides, and the morphology, topography and the land cover of the region. An example to the sliding blocks and runout distance in Dagkoy Region near Zonguldak Province, Turkey is given in Figure 2 (Ocakoglu et al., 2002). Rotational movements of the landslide and the obvious dislocation of the buildings (e.g. the mosque) due to the landslide can be observed in the Figure 2. By evaluating the observations of local eye-witnesses, the velocity of the landslide was calculated as 1.2 m/min (Ocakoglu et al., 2002). This simple observation has helped to explain the mechanism of a complex mass movement.

The main goals of this study are; a) to discuss the importance of the spatially and temporally dense and accurate data for landslide susceptibility and hazard mapping; b) and to introduce the need of using *citizen science* methods for coping with the uncertainties caused especially by the lack of reliable temporal data. In addition, potential contributions of volunteers in landslide susceptibility and hazard mapping will be identified briefly. Four different major landslide events occurred in Dagkoy Region (Ocakoglu et al., 2002), Catakli Region (Nefeslioglu and Gokceoglu, 2011), Buyukkoy Region (Nefeslioglu et al., 2011) and Kuzulu Region (Gokceoglu et al., 2005) have been analyzed for the purpose of this paper. Mainly the role of the eye-witnesses to understand the nature of the landslides are emphasized here.

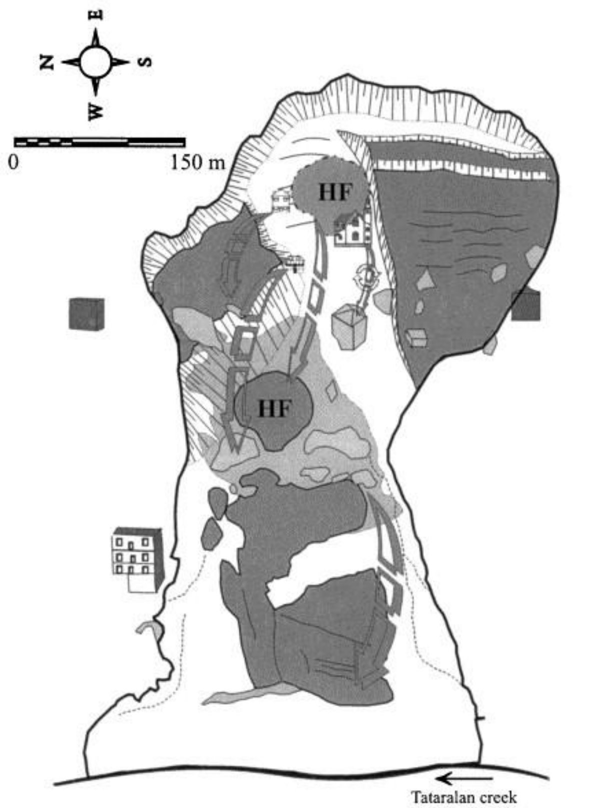

Figure 2. Restoration of the sliding blocks in Dagkoy Region, Zonguldak. Note the trend of transverse cracks and rotation (HF: Hazelnut Field) (Ocakoglu et al., 2002).

Citizen science can simply be defined as the volunteer contributions to scientific processes at various levels (e.g. data collection, interpretation, analysis, quality control, hypothesis generation and testing, etc.). A conceptual schema for the user contribution levels (i.e. crowdsourcing, distributed intelligence, participatory science, extreme citizen science) to citizen science projects in general is proposed by Haklay (2013). This concept can be modified for different types of citizen science projects, such as landslide characterization and risk assessment as here. With the help of technological advancements, in particular mobile technologies, do-it-yourself (DIY) kits and the increasing possibilities for free online education sources, ordinary citizens may contribute to scientific processes based on their interests and abilities. The activities may range from biology to environmental monitoring to classification of galaxies, all of which have a spatiotemporal dimension.

The increasing demand on this research agenda is encouraging scientists from diverse backgrounds to collaborate under the term of "Citizen Science (CS)". The emerging developments in spatial information sciences also allow the public to understand their environment better and efficiently. The awareness in citizen contributions to geodata collection has increased significantly in the last two decades. Goodchild (2007) has analysed the citizen contributions to geographical data collection and coined the term volunteer geographical information (VGI) for such activities. Other terms, such as neogeography, crowdsourced geographic information, geographic citizen science, web mapping, participatory sensing, mashup, etc. are also frequently used (See et al., 2016).

Citizen science methods can provide the necessary means for a complete and accurate regional landslide characterization and risk management. Volunteers especially living in the region can help to assess the time and location of a landslide event by collecting timely accurate data. With the widespread use of mobile phones equipped with GNSS receivers, it is also possible to detect the location and thus provide the spatial aspect of the landslides with sufficient accuracy. It is evident that citizen science is one of candidates for reliable data support for landslide mitigation efforts. Although recent projects are being carried out by different organizations and research groups (Landslide EVO, 2018; Research Councils UK, 2018; USGS Landslide Hazards Program, 2018), this is an emerging research and application area, where the contributions of citizens can have a huge impact on the theory and the practice. For the purpose of the study, a brief survey on landslide susceptibility and hazard mapping studies is performed and possible combination of landslide hazard mitigation efforts and citizen science is explained.

2. A SHORT OVERVIEW ON LANDSLIDE SUSCEPTIBILITY MAPPING METHODS

Methods used for landslide susceptibility, hazard and risk mapping have been improved drastically with the developments of geographic information systems, and other geospatial and computing technologies. Most of the zoning studies are qualitative in nature, although more recently there have been examples of quantifying the hazard by assigning a temporal probability to the potential landslides and quantifying the risks for existing development (JTC-1 Joint Technical Committee on Landslides and Engineered Slopes, 2008). When producing landslide susceptibility maps, the conditioning or preparatory factors are employed. Landslide conditioning factors such as geological, geomorphological and environmental parameters are mainly static. However, when assessing landslide hazard, the triggering factors and their threshold values must be known. In general, landslide triggering factors are earthquake, rainfall and anthropogenic effects (excavation, surcharge or change in hydrologic conditions etc.). Anthropogenic effects are local and it is possible to work on these effects by geotechnical and analytical approaches. However, earthquake and rainfall, depending on their magnitude, intensity and duration, can influence large regions. The following assumptions are considered for landslide susceptibility zonation (Varnes, 1984; Hutchinson, 1995):

a) landslides will always occur in the same geological, geomorphological, hydrogeological and climatic conditions as in the past,

b) the main conditions that cause landsliding are controlled by identifiable physical factors,

c) the degree of susceptibility can be evaluated, and

d) all types of slope failures can be identified and classified.

As can be seen from these assumptions, when producing landslide susceptibility maps, the spatial distribution of landslides must be known. A classification of methods for the landslide susceptibility assessment is given by Aleotti and Chowdhury (1999) and a slightly modified version is provided in Figure 3.

Qualitative methods are usually not preferred since they are time consuming, subjective, and labor intensive processes, and require high level of expertise. On the contrary, the quantitative methods have become much more attractive especially in the last two decades. It is possible to add several extra methods to the classification given by Aleotti and Chowdhury (1999). An important aspect of all new qualitative methods is that they require high quality spatial data. Deep-seated landslides have several clear features, which can be observed in field or on aerial photos. Also, these features can be visible for a long time. However, to determine the location and the features of shallow landslides can be problematic in a short time (Figure 1). For this reason, to provide high quality spatial data for landslide susceptibility maps of shallow failures can sometimes be a big problem.

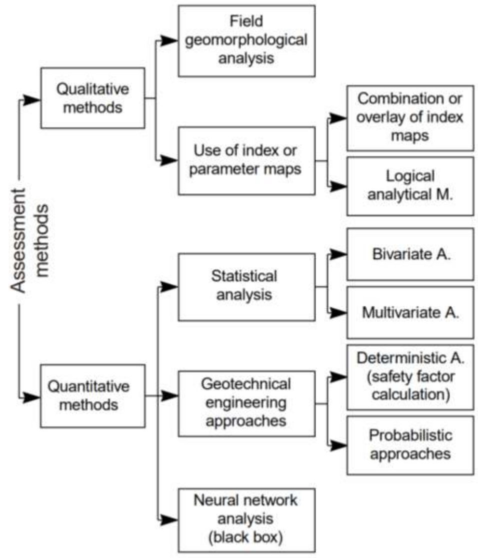

Figure 3. Classification of the methods employed for landslide susceptibility assessments (modified after Aleotti and Chowdhury, 1999).

If reliable spatial data are not available, any landslide susceptibility map produced by automatic or data-driven method is open to discussion because it contains several uncertainties. Additionally, time of occurrence of a shallow of deep-seated landslide is extremely important for the assessment of landslide hazard. This data is necessary to assess the threshold values triggering landslides for a region and a described condition. Consequently, these data should be collected from large areas and in rural regions and it is almost impossible to collect these data without the observations of humans.

A schematic presentation of the landslide risk assessment procedure is given in Figure 4 (van Westen et al., 2008). Landslides are conditioned by various geological, geomorphological and environmental factors while they are triggered by rainfall and earthquake. When producing landslide susceptibility maps, the conditioning factors are employed and they are mainly static. Determination of landslide conditioning factors to be used in production of landslide susceptibility map depends on the type and magnitude of landslides observed in the area. When considering the nature of the conditioning parameters, it can be said that the conditioning parameters are time-independent mainly. However, a complete risk assessment requires landslide hazard assessment and determination of the elements at risk.

The regional landslide risk management process is simply depicted in Figure 5. The process has five major steps, from landslide inventory mapping to risk management. Although landslide triggering time and estimation of the runout distance can be performed probably only by using citizens' observations, each step given in Figure 5 should be analysed separately to find out the parts that citizens can contribute optimally and to identify the most suitable methods for volunteer data collection, quality control and analysis. A number of case studies is introduced in the following Section, where the contributions of local people played a major role for the characterization of the landslides and further analysis of the events. From the presented experiences and by analysing further studies, a systematic approach can be defined for utilizing citizen science in regional landslide risk management process.

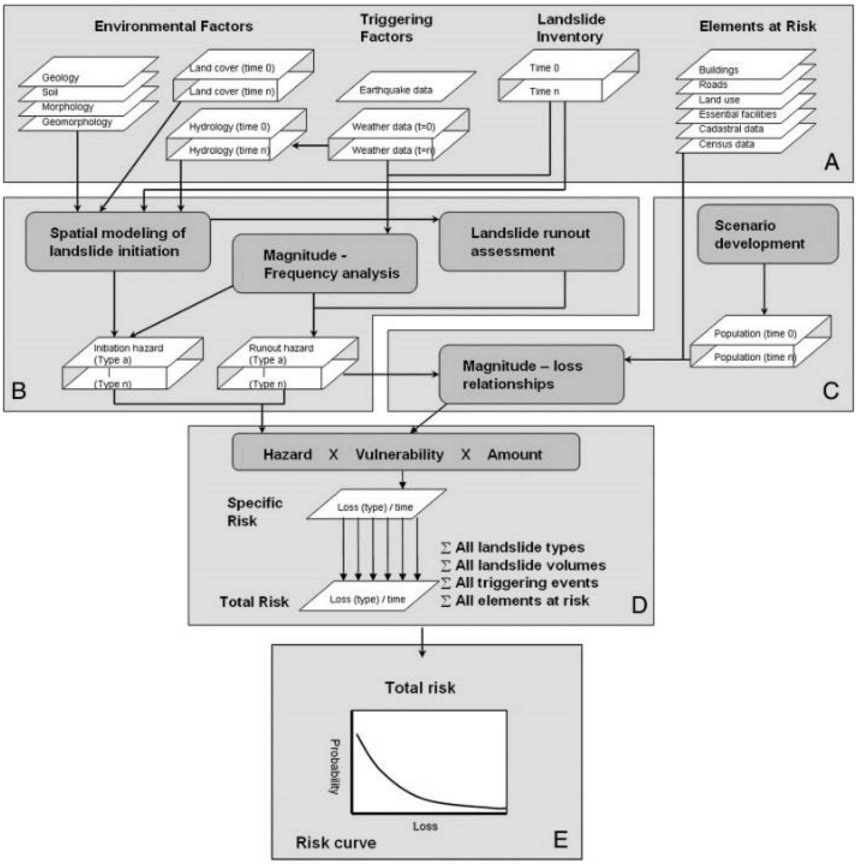

Figure 4. Schematic representation of the landslide risk assessment procedure. A: Basic data sets required, both of static, as well as dynamic (indicated with “time…”) nature, B: Susceptibility and hazard modeling component, C: Vulnerability assessment component, D: Risk assessment component, E: Total risk calculation in the form of a risk curve (van Westen et al., 2008).

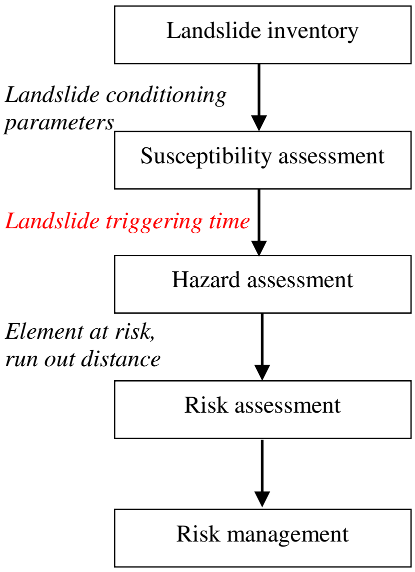

Figure 5. A simple representation of regional landslide risk management stages.

3. POTENTIAL OF CITIZEN SCIENCE IN TEMPORAL LANDSLIDE DATA COLLECTION

Several properties and time of landslides should be known for better understanding the anatomy and triggering mechanisms of landslides. According to Gokceoglu and Sezer (2009), in the near future, other innovative researches such as landslide risk, prediction of runout and time of landslides, and early warning systems about the landslides may be expected. Gokceoglu and Sezer (2009) also emphasized that an increase in the studies on the landslide evolution may be expected even though their complex nature. The rise of citizen science is a great opportunity to understand this complexity and develop suitable methods to be use it.

The majority of landslides occur in mountainous areas and the installation of necessary equipment to monitor the landslides and possible triggers is almost impossible in general. For this reason, many studies rely on the observations of local eye-witnesses. As an example, a deadly, large and complex landslide occurred in Kuzulu village (Sivas, Turkey) on March 17, 2005. The mechanism of this catastrophic landslide (Figure 6) was investigated by in-situ observations, morphometric and geological assessments and using the observations of local eye-witnesses by Gokceoglu et al. (2005). Especially, the velocity of landslides provides crucial information for the mechanism of complex and catastrophic movements, because such types of movements are the result of combination of several factors. The velocity of the earth-flow part of the Kuzulu landslide was an extremely fast one, which was approximately 6 m/s (Gokceoglu et al., 2005).

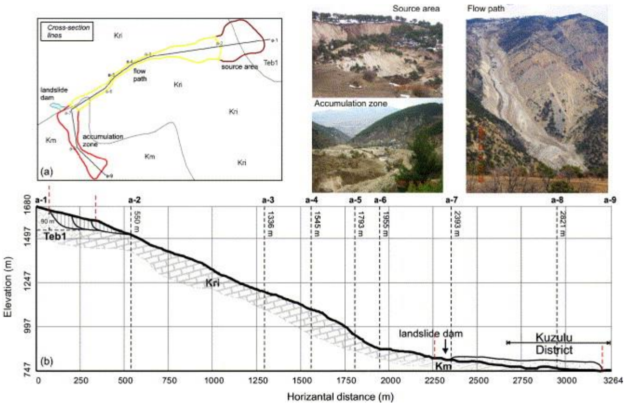

Figure 6. Plan view and cross section showing the mechanism of the landslide, and photos from the source area, flow path, and accumulation zone of the Kuzulu landslide (Gokceoglu et al., 2005).

To make hazard assessment of shallow landslides, Nefeslioglu et al. (2011) have mapped the temporal and spatial distribution of shallow landslides in the catchment and they performed aerial-photo interpretations (Figure 7). As can be seen from the Figure, it is impossible to find exact time of occurrence by aerial photo interpretations and only a rough approximation of the time interval can be estimated. In addition to various data sources, Nefeslioglu et al. (2011) conducted field investigations in the year 2007 to map the recent shallow landslides, to georeference the movements published by the geological reports and to extract the exact date of certain failures by interviews with the local community.

As can be seen from the case studies summarized herein, the researchers rely heavily on the observations of local communities because these observations are highly valuable and sometimes even the only source of information to understand the mechanism of movements.

4. CONCLUSIONS

The endeavors for regional landslide characterization, i.e. landslide susceptibility mapping, hazard and risk assessment, have been increasing and are of great importance for the risk and disaster management. The density (frequency) and the quality of spatial and temporal data required for the regional landslide characterization should be high to reduce the uncertainties and provide accurate models. Concluding from the case studies in this paper, researchers rely heavily on the observations of local communities for collection of these data, which sometimes are even the only available data for performing the analyses and identifying the processes. However, the temporal and spatial accuracy of the given data are usually low as they are based on vague statements of eye-witnesses.

With the development of mobile and geospatial technologies and the rise of citizen science, the data needed for regional landslide assessment and risk management can be collected more frequently and accurately. A systematic approach for identifying the gaps and particular fields where citizens can provide their contributions in this process should be performed. Afterwards appropriate tools, e.g. mobile apps, do-it-yourself kits, etc., and methods for the quality control and analysis of the contributions should be developed for the optimal use of citizen science in regional landslide assessment and risk management.

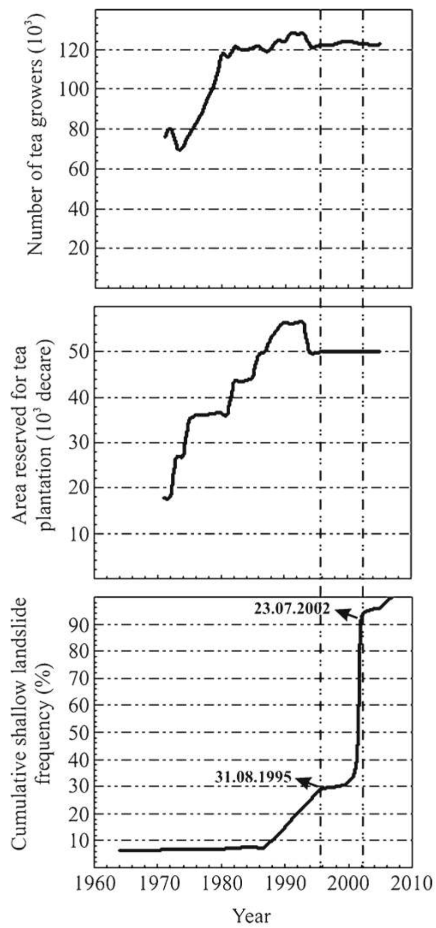

Figure 7. Cumulative shallow landslide frequency (%) with respect to the anthropogenic activity observed in the catchment; the anthropogenic data were provided by TUIK (2006) (Nefeslioglu et al., 2011).

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