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DEBRIS FLOW ACTIVITY RECONSTRUCTION USING DENDROGEOMORPHOLOGICAL METHODS. STUDY CASE (PIULE IORGOVANU MOUNTAINS)

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ABSTRACT. – Debris Flow Activity Reconstruction Using Dendrogeomorphological Methods. Study Case (Piule Iorgovanu Mountains). Debris flows are one of the most destructive mass-movements that manifest in the mountainous regions around the world. As they usually occur on the steep slopes of the mountain streams where human settlements are scarce, they are hardly monitored. But when they do interact with built-up areas or transportation corridors they cause enormous damages and even casualties. The rise of human pressure in the hazardous regions has led to an increase in the severity of the negative consequences related to debris flows. Consequently, a complete database for hazard assessment of the areas which show evidence of debris flow activity is needed. Because of the lack of archival records knowledge about their frequency remains poor. One of the most precise methods used in the reconstruction of past debris flow activity are dendrogeomorphological methods. Using growth anomalies of the affected trees, a valuable event chronology can be obtained. Therefore, it is the purpose of this study to reconstruct debris flow activity on a small catchment located on the northern slope of Piule Iorgovanu Mountains. The trees growing near the channel of transport and on the debris fan, exhibit different types of disturbances. A number of 98 increment cores, 19 cross-sections and 1 semi-transversal cross-section was used. Based on the growth anomalies identified in the samples there were reconstructed a number of 19 events spanning a period of almost a century.

Keywords*: debris flow, dendrogeomorphology, growth anomalies, Piule Iorgovanu Mts.*

1. INTRODUCTION

Debris flows are one of the most destructive mass movements occurring in the mountainous regions of the earth. As being described by Takahashi (2007), debris flows are massive sediment transport phenomena that manifest themselves in the channel of mountain streams, consisting of a large variety of solid material. The manifestation of these phenomena is related to the morphometric characteristics of the terrain, the

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amount of loose rock and the water input. Under a favourable combination of these variables there are created excellent conditions for debris flow initiation. Unlike some hydrological phenomena such as flash floods which occur regularly in the mountain streams, debris flows are more difficult to predict (Armanini, 2005). After repeated debris flow occurrences the material deposited leads to the formation of a debris flow cone (Costa and Jarett, 1981, Takahashi, 1991, Hungr, 1995).

The debris materials, formed mainly by rocks and boulders of all sizes, affect the riparian vegetation along the channel and on the cone surface causing them different types of disturbances. The impact of debris flows on trees depends on the flow velocity and on the composition of the flowing mixture. The higher the velocity, the stronger the impact is and the bigger the size of the transported materials, the higher the number of the disturbances on the riparian trees. Any mechanical injury causes morphological changes in the cell structure of the wood, consequently, all of the disturbances are being recorded in the tree's growth (Alestalo, 1971; Shroder, 1980; Schweingruber, 1996, 2007; Strunk, 1997; Stoffel and Bollschweiler, 2009 etc.). Thereafter, the analysis of the tree ring data enables us to determine the temporal and spatial aspects of past debris flow activity.

In Romania there are only a few recent studies that have been concentrated on the assessment of debris flow activity (Pop *et al.,* 2008, 2010; Ilinca, 2009, 2014; Văidean and Petrea, 2014; Chiroiu, 2015) though there were some mentions about past occurrences before (Bălteanu *et al.,* 2004).The main purpose of this study is to reconstruct debris flow occurrences using dendrogeomorphological methods on a small catchment located on the northern slope of Piule-Iorgovanu Mountains.

2. STUDY AREA

The study area is represented by a small catchment located on the northern slope of Piule Iorgovanu Mountains (fig.3). The main collector is a left tributary of the Lăpușnicul Mare River, draining an area of 244 ha which extends from an elevation of 2000m a.s.l. to 1320ma.s.l.The permanent stream flow initiates at the elevation of 1870 ma.s.l., reaching the confluence with Lăpușnicul Mare River after 3.2 km.

The torrent surface is mainly built of metamorphic rocks (80%) represented here by crystalline schists and sedimentary rocks (20%). Also in the middle part of the basin, especially along the channel there are huge amounts of proluvial deposits (fig. 1). These unconsolidated materials are the main sources of debris flows initiation as they can be easily mobilised during rapid flows. The debris fan is composed of non-sorted debris of all sizes ranging from the sand size to blocks of over 1 m in diameter. Because of the lithological structure, both the channel of transport and the slopes have high degrees of declivity, the mean value being of 18°. The forest standing on the cone and bordering the channel mainly consists of Norway spruce (*Piceaabies* (L.) Karst.).

Fig.1. Prolovial deposits along the channel

Fig. 2. Deposits on the right side of the cone

The multiannual precipitation value is of 1176 mm (Gura Apelor, 956 m). During summer occasionally occur high intensity rainfalls which represent the main triggering factor of debris flows. One particularly major event had occurred in the interval 11-14 July 1999, when after 4 days of rain, on the night between 11 and 12 of July, there was registered a heavy rainfall which locally exceeded 135 mm in 7 hours (Văidean and Hognogi, 2015). The rainfalls triggered flash floods and other associated mass transfer processes affecting the entire area of the upper and middle basin of Râul Mare, including our study site. The event caused 13 deaths, 21 injuries, 30 homeless and enormous economic and private property damages.

The study site has not been under a high anthropogenic influence and there are no permanent settlements. There is only one road which connects Poiana Pelegii site to the Gura Apelor Lake and crosses the debris flow cone. At the apex of the cone there is a small bridge and concrete frame structures which are designed to drain the water flow. Also, in the upper part there are two dams which are filled with sediments and the pressure on the structure had led to the appearance of a few cracks.

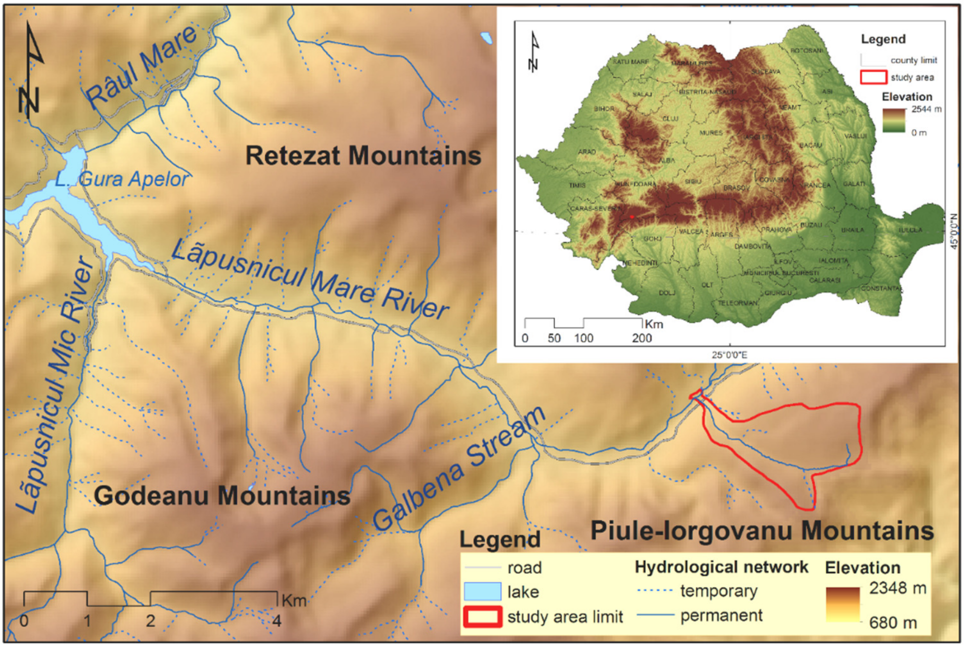

Fig. 3. Geographical position of the study site

3. METHODOLOGY

In dendrogeomorphological studies there are some specific steps which have to be followed in order to obtain the best results. Firstly, a detailed assessment of the study site is necessary by analyzing different cartographic materials (topographic map 1:25000, ortophoplans 1:5000, satellite images, etc.) and other expertise. Any information regarding previous occurrences of hydro-geomorphological phenomena that had occurred in the nearby area were gathered. The archival records on flooding in adjacent rivers or other phenomena were collected either by consulting data of the public and private institutions (SC Hidroelectrica SRL, Hațeg filiation) or by interviewing eyewitnesses, including victims, who had clear recollection of the events.

After a detailed assessment of the area, there were organized several field campaigns to sample the trees affected by past debris flow occurrences. The most affected trees were those growing on the surface of the cone and near the streambed.

Using a Pressler borer there were sampled 98 increment cores, 19 cross sections and 1 semi transversal cross-section (wedge). The trees exhibited many disturbances among which the most frequently encountered were scars at the stem level, buried roots and tilted stems. According to the identified injury, two cores were extracted per tree. The trees which had scars, two increment cores were extracted, one close to the edge of the wound and the other on the opposite side. In the case of curved or tilted stems, the samples were taken from the maximum concavity and on the opposite side respectively, from the direction of inclination. In addition to this, relevant information regarding the sampled trees such as type of disturbance, position, diameter, height etc. were gathered. For normal conditions, other 40 increment cores extracted from undisturbed *Piceaabies* trees which grow near the study site were used.

In the laboratory, the samples were prepared and analysed according to the procedure described by Stoffel and Bollschweiler (2008). First, the samples were fixed on wood mountings and dried up. In order to obtain a clear surface necessary for fine anatomical observations, the samples were sanded using different abrasive belts. After that, the rings of each core and cross section were counted and the ring widths were measured with 0.001mm precision using a LINTAB measuring station and TsapWin™ software. The growth curves of the affected trees were compared and cross-dated with the reference chronology of undisturbed trees in order to identify climate influence on growth. Subsequently, using a binocular microscope device each sample was visually examined in order to identify the growth anomalies and the year in which they appeared.

The reconstruction of the events was based on the number of reactions per tree (minimum 3) and on their intensity. According to this, the reconstructed events were divided in two types: probable when the reactions were more than 5 and possible when there were less than 5 reactions but of high intensity. Therefore, the probable events are more likely to have happened. Also, we took in consideration the frequency index with a minimum 10% threshold. The frequency index was calculated after the following formula:

$$I_t = \left(\left(\sum_{i=1}^{n} Rt\right) / \left(\sum_{i=1}^{n} At\right)\right) * 100$$

where: *Rt* = the number of responding trees in year *t* and *At* = number of the sampled trees in year *t*.

4. RESULTS

The sampled trees have an average age of55 years and a standard deviation of 36 years, the oldest one having 202 years, while the youngest is only 16 years old (fig. 4). The age structure of the trees reveal a predominance of the class age ranging from 31-60 years (45%). Also, there are only 7 trees exceeding 100 years and before 1900 only 2 are available. All of the trees used for the reconstruction of the debris flows exhibited different types of disturbances (fig. 5). In total, there were identified 415 growth anomalies, among which the most frequently encountered were abrupt growth reduction of the rings (45%) followed by tangential rows of traumatic resin ducts (30%). Other anomalies found were in form of compression wood (15%) while growth release was only occasionally found (10%).

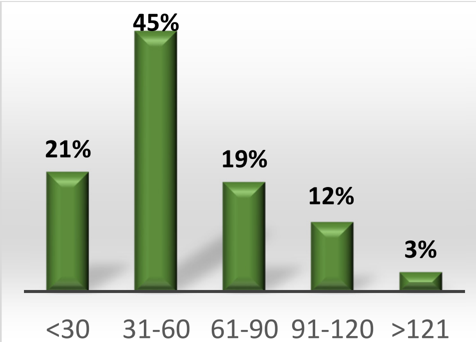

Fig. 4. Age structure of the sampled trees

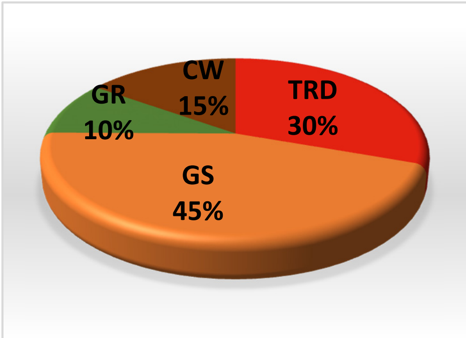

Fig. 5. The percentage of the growth anomalies

The oldest growth anomalies were found in 1828 in form of traumatic resin ducts (TRD). Even though they were of high intensity, there was only one tree available for that period so it could not be included in the events chronology. Some important growth anomalies were found in1853, 1856, 1864 and 1879 but there were just two trees available for the reconstruction. In 1900, one tree responded through a pronounced growth reduction which was maintained for more than 7 decades. Also, in 1913 two growth anomalies were found in form of TRD and compression wood (CW) but the number of the available trees is still low (only 7 sampled trees). After just 2 years, one tree responded through an abrupt growth suppression (GS) which was maintained until 1928. In 1935 a number of 3 spruces responded but the reactions had low intensity. Because of the reduced number of the responses due to the low number of available trees only1935 was considered as possible year-event (fig. 6).

The first year considered as probable year-event is 1944, when 5 trees responded mainly through abrupt growth reduction, the value of the frequency index being of 36%. In 1949, other 6 trees reacted via GS and TRD. After this, in 1952 and 1956 there were found some growth anomalies either in form of CW or GS, but the number of responses is relatively low, so we considered them as possible events. Given the high intensity of the TRD found in one cross-section which clearly showed that the tree was hit in 1959, to which we add some other growth anomalies in form of GS and CW, we accounted this as a probable event year. Other probable event-years are 1963, 1966 and 1969, when different types of disturbances were found. In 1972 and 1973 we identified some strong reactions via TRD and GS, but the number of trees that responded was relatively low. Also, 1976, 1980, 1983, 1989 and 1996 were considered as possible event years rather due to the intensity of the responses and not because of their number.

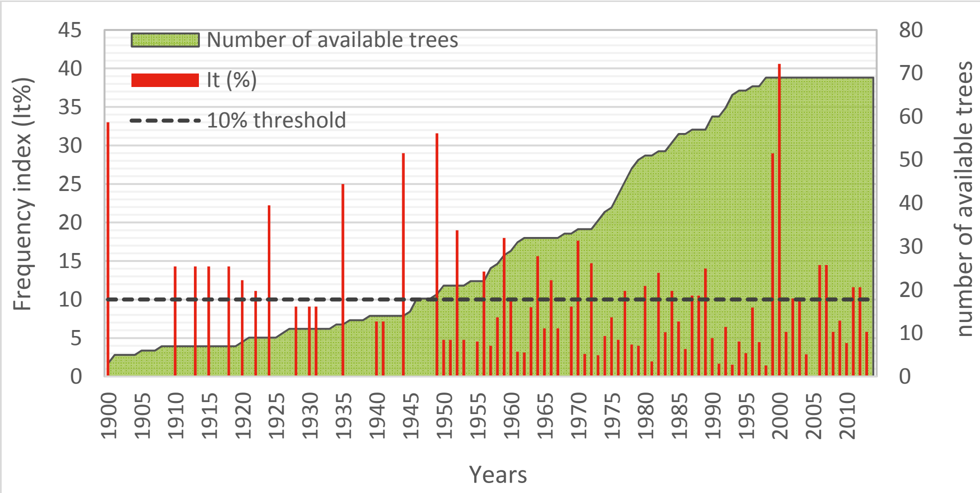

Fig. 6. Frequency index value and the number of available trees

The most numerous growth anomalies were identified in the interval 1999-2001, when 52 spruces (75%) reacted through different types of disturbances. As shown in the figure 7, most of the trees reacted in 2000 with 59%, followed by 1999 (30%). Also, in 1999 most of the trees reacted through TRD and CW, while in the next year there were more cases of GS and other TRD. Interestingly, even in 2001 there were encountered some new TRD but most of the reactions (67%) were in form of growth release (GR). Moreover, the intensity of the disturbances was very high, in many cases the TRD and GS was maintained for several years consecutively or even till the sampling year. Other reconstructed years after this major event were 2006 and 2011 to which we add 2008 as possible event year.

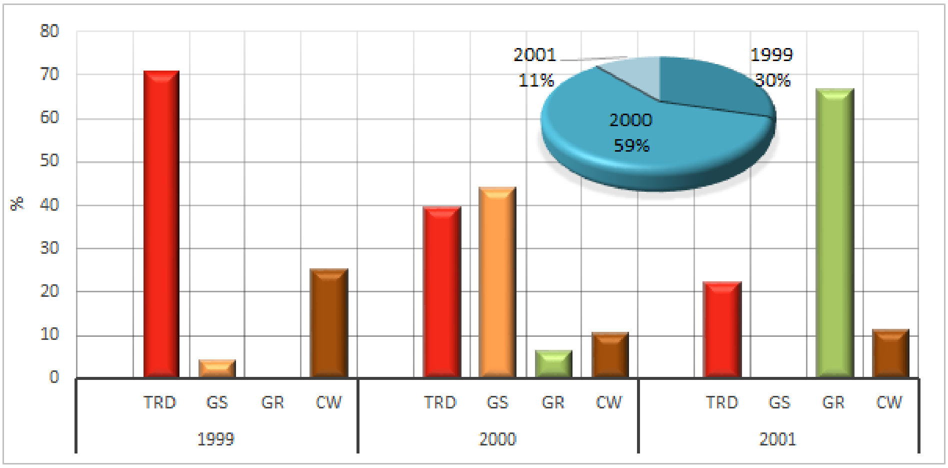

Fig. 7. The percentage of the trees responding to the event that occurred in July 1999 and the percentage of the growth anomalies found in the interval 1999-2001

The analysis of the tree ring data allowed the reconstruction of 10 probable debris flow events, from which 2 were considered as major events, 1969 and 1999 respectively, and also other 9 possible events. The oldest event introduced in the chronology was in 1935while the newest occurred in 2011 (fig. 8). The recurrence interval varies between 3 and 9 years and the return period is of 4 years.

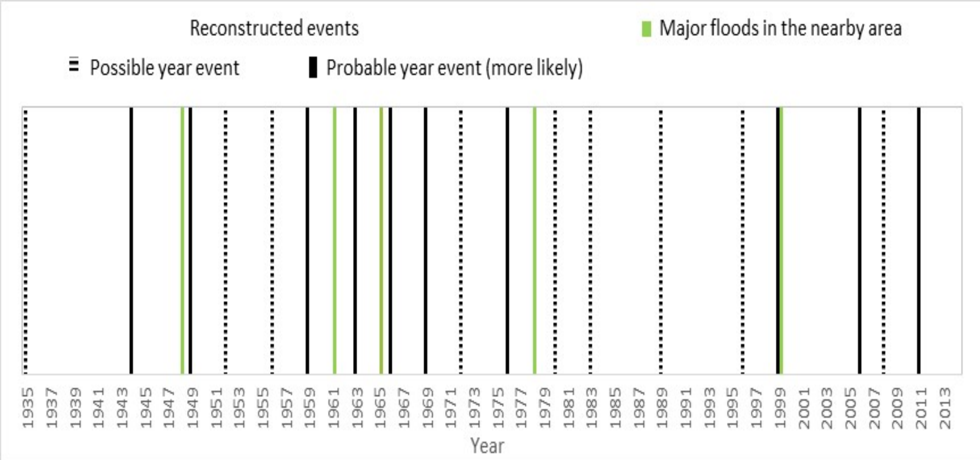

Fig. 8. Reconstructed year-events starting from 1935 (the first possible event-year). The dash lines represent the reconstructed possible event years, the solid line shows reconstructed events which are more certain and the green lines are the years in which there were recorded major flood events in the nearby area.

5. DISCUSSIONS

The analysis of tree ring data provided a sequence of 19 debris flow events spanning almost a century. As one can notice, debris flow events are quite uniformly distributed, the return period being of 4 years. The reconstruction of past debris flow occurrences were based on the number and the intensity of the growth anomalies mentioned above. The higher the number of reactions the higher is the probability of the event occurrence in that specific year and the stronger the reactions are the higher the magnitude of the event.

Although some reactions have been identified since the XIX century, they could not be used in the reconstruction process because only two trees were available. There were identified different types of growth anomalies from which the most frequently encountered were in form of growth suppression and traumatic resin ducts. These are typical reactions for the trees affected by debris flows especially on those growing on the cone.

During the reconstruction period there were registered six major flood events that occurred in the nearby area, all of them being caused by heavy rainfalls. Under a favourable combination of the sediment availability and a large amount of water to which we add the terrain characteristics the debris flow initiation is imminent. Tree-ring data partially coincide with the archival records but in two cases (1948 and 1965) the reactions were delayed one year. Also, in the case of the event that occurred in July 1999 it was clearly shown that most of the trees reacted only in the following year. From this we can deduce that not only the number of the growth anomalies in a particular year is important but also the reactions of the previous year. If there are a few strong anomalies prior to the one which shows a higher number of disturbances, that year might be the event year. Moreover, the intensity of the growth anomalies is also important and even if there are not so many responses, they should still be taken into account. The events which were characterized as possible are based on a lower number of reactions but also they might have been of a smaller magnitude, case in which only a few trees could be affected.

Fig. 9. Severe growth reduction found in a cross section starting from 1972

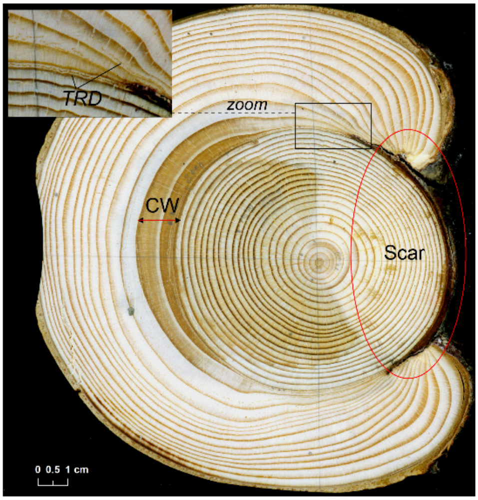

Fig. 10. Multiple growth anomalies identified in a cross section after the event of July 1999

The results interpretation can be really difficult when the trees are severely affected and the rings width is too narrow (fig. 9). There can be missing or false rings which complicates even more the analysis. In the increment cores these types of disturbances are hard to detect while the cross sections provide more useful information (fig. 10). Also, in the cross sections the intensity of the reactions can be more precisely established offering a clearer picture of the responsible event. As most of the growth anomalies are discovered using the microscope, the human error is another factor which might affect the reconstruction process. The events reconstruction represents a minimum frequency of debris flows occurrences as it depends on the interaction between the process and the riparian vegetation.

There is a necessity of gathering as much information as possible regarding past debris flow occurrences as this area has an important touristic attraction and there is only one road that connects Poiana Pelegii camp site to the Gura Apelor Lake. Moreover, this data can be taken into consideration in the assessment of debris flow activity at regional or medium scale.

6. CONCLUSIONS

The dendrogeomorphological analysis applied in the reconstruction of debris flows that occur on a small catchment located on the northern slope of Piule-Iorgovanu Mountains, revealed a chronology of 19 events, covering almost a century.

The results showed that most of the affected trees reacted through growth suppression and tangential rows of traumatic resin ducts. The reconstruction was limited by the young age of the trees, as a consequence the event chronology started only since 1935. Also, the temporal reconstruction of debris flows partially coincide with archival records on flood events that occurred in the nearby area. As in some cases the trees reacted only in the following year of vegetation, the number of growth anomalies seems to be irrelevant for the reconstruction process. It should be also taken into consideration the growth anomalies found in the previous year if there are any and their intensity. Furthermore, the cross sections offer more information about past events than increment cores.

The reconstruction of debris flow activity is important for the estimation of their frequency and magnitude which are required in hazard and risk assessments. Given the high potential of tourist attraction of the area, mitigation plans and countermeasures are imperative necessary in order to prevent negative consequences.

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REFERENCES

1. Alestalo, J. (1971), *Dendrochronological interpretation of geomorphic processes,* Fennia 105, Helsinky.
2. Armanini, A., Fraccarollo, L., Larcher, M. (2005), *Debris Flow,* Encyclopedia of Hydrological Sciences, 142, Trento.

3. Bălteanu, D., Cheval, S., Şerban Mihaela (2004), *Evaluarea şi cartografierea hazardelor natural şi tehnologice la nivel local şi naţional. Studii de caz*, Fenomene şi procese cu risc major la scară naţională, Editura Academiei Române, Bucureşti, pp. 398-402.
4. Chiroiu, P. (2015), *Studiu dendrogeomorfologic asupra proceselor de versant din partea central nordică a munţilor Făgăraş*, PHD Thesis, West University, Timişoara.
5. Costa, J.E. and Jarett, R.D. (1981), *Debris flows in small mountain stream channels of Colorado and their hydrologic implications*, Bulletin of the Association of Engineering Geologists, vol. 18, pp: 309-322.
6. Hungr, O. (1995), *A model for the runout analysis of rapid flow slide, debris flows and avalanches*. Canadian Geotechnical Journal, 32, pp: 610-623.
7. Ilinca, V. (2009), *Estimating of debris flow velocity and discharge. Case study: two debris flows from Lotru Valley (in Romania),* Abstract vol., pp. 14, 25th National Symposium of Geomorphology, Arcalia.
8. Ilinca, V. (2014), *Characteristics of debris flows from the lower part of the Lotru River basin (South Carpathians, Romania),* Landslides, vol. 11, pp: 505-512.
9. Pop, O., Popa, I., Surdeanu, V. (2008), *Dendrogeomorphological analysis of human-induced debris flows in the Călimani Mountains (Romania),* Book of Abs., pp. 80, IAG Regional Conference on Geomorphology, Braşov.
10. Pop, O., Surdeanu, V., Irimuş, I.A., Guitton, M. (2010), *Distribution spatial des coulées de debris contemporainedans les massif du Călimani (Roumanie*), Studia UBB Geographia, vol. LV -1, pp: 33-44.
11. Schweingruber, F.H. (2007), *Wood structure and environment,* Springer-Verlag, Berlin.
12. Schweingruber, F.H. (1996), *Tree rings and environment dendroecology,* Swiss Federal Institute for Forest, Snow and Landscape Research, Wien.
13. Shroder, J.F. (1980), *Dendrogeomorphology: review and new techniques of tree-ring dating,* Progress in Physical Geography, vol. IV - 2.
14. Stoffel, M., Bollschweiler Michelle (2009), *What trees can tell about earth-surface processes: teaching the principles of dendromorphology*, Geography Compass 3, pp: 1013-1037, Switzerland.
15. Stoffel, M., Bollschweiler, Michelle (2008), *Tree ring analysis in natural hazards research - an overview,* Natural Hazards and Earth System Sciences, 8, Fribourg.
16. Strunk, H. (1997), *Dating of geomorphological processes using dendrogeomorphological methods*, Catena 31, pp: 137-151.
17. Takahashi, T. (1991), *Debris flows*, A.A. Balkema, Rotterdam.
18. Takahashi, T. (2007), *Debris flow mechanism, prediction and countermeasures*, Taylor and Francis, London, UK.
19. Văidean Roxana şi Petrea, D. (2014), *Dendrogeomorphological reconstruction of past debris flow activity along a forested torrent (Retezat Mountains)*, Revista de Geomorfologie, vol. 16, pp: 17-24.
20. Văidean Roxana, Hognogi, G. (2015), *Damages assessment associated to the flood event which occurred on 11-14 July 1999 in the Râul Mare basin*, Air and Water Components of the Environment Conference volume, Edit. Presa Universitară Clujeană, DOI: 10.17378/AWC2015_64.