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The effects of intensive rainfalls (flash floods) on the development on the landforms in the Kőszeg Mountains (Hungary)

Research article

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Abstract: The effects of the intensive rainfall episodes in the years 2009 and 2010 in the Kőszeg Mountains were investigated. Channel profiles were constructed at various times during these periods, which were used to describe the channel changes. We measured the length of the incised and filled sections on multiple occasions. We could establish the degree and the direction of the changes using this data. The sediment veneer that developed in the area of Kőszeg town was mapped and its conditions of development were examined. The erosion and accumulation landforms developed during these years were classified and described. These forms are the following: rills, gullies, alluvial fans and sediment veneer. We distinguished and characterised those which had previously formed, but they were changed or increased (the channels). We established the conditions under which the sediment veneer can develop, furthermore those conditions which can increase the chance of the formation of this landform. These conditions are the following: the high density of roads in the catchment areas of valleys leading to settlements, the great thickness of superficial deposit, and the steep slope of the surface of the catchment area. We created theoretical classification of the morphological environment where the development of sediment veneer may happen and identified settlements with structures which promote or prevent the development of the sediment veneer. We determined the probability of the development of the sediment veneer at some settlements in Kőszeg, and suggestions have been given to decrease the chance of the development of this sediment veneer.

Keywords: intensive rainfall, flash foods, Kőszeg Mountains, Kőszeg, rills, gully, channel, alluvial fan, weathering residual, sediment veneer, mountain margin settlement, the chance of the development of sediment veneer

1. Introduction

This study investigates those landforms which developed during flash foods in the Kőszeg Mountains due to intensive rainfall in the years 2009 and 2010, and their influence and effects on the surrounding human settlements.

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The intensity and frequency of rainfall increased in the last years of the first decade of the 21st century. Due to the intensive rainfalls flash floods developed ([1–4], which in turn induced the formation of debris streams and debris flows [5]. The flash floods destroyed a lot of structures during 2009 and 2010. It is therefore important to understand this process. There are examples describing it from the USA [6], the United Kingdom [7], France [8, 9] from the area of Transdanubian Hills in Hungary [10]. Recently forecast attempts were made to decrease

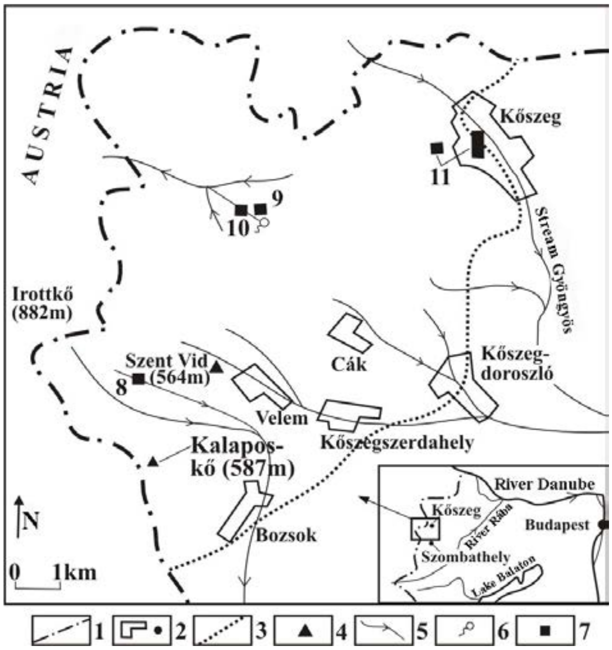


Figure 1. Study areas Legend: 1. frontier, 2. settlement, 3. mountain border, 4. peak, 5. stream, 6. spring 7. research area, 8. Bozsoki Valley, 9. creek above the Szikla Spring, 10. channel section under the Szikla Spring, 11. the town of Kőszeg and its surroundings.

the possible damages caused by flash floods [11].

Gully erosion and sheet-water erosion can increase during intensive rainfall if the surroundings create suitable conditions for the process [12–14]. The sediment can be carried off from the landform and accumulate elsewhere. Various accumulation landforms develop during this process.

Erosion is rapid because of the intensive rainfall, and thus the development of new landforms will be fast. The rapid development of landforms may modify geomorphic evolution, and it may have an effect on vegetation, the drainage network, man-made structures (railways, roads, buildings, etc.) and agricultural production.

The development of the landforms was investigated in the Kőszeg Mountains, including in the Bozsoki Valley and around the Szikla Spring, and in Kőszeg town and the surrounding region (Fig. 1).

The Kőszeg Mountains (part of the Eastern Alps) belong to the Penninicum and it is 'fenster' [15]. They are built up of quartz phyllite, calcareous phyllite, black lead phyllite and metaconglomerate. The age of the metamorphism of the rocks is 28-31 M. years [17]. The age of the mountain uplift is between 15.1-18.5 M. years [18]. The southern part of the mountain is built by anticlines with southern dip direction [19], therefore the dip direction of the cleavage planes is also southern. The Hungarian part of the Kőszeg mountains is constructed primarily of a ridge and tributary ridges. The direction of the tributary ridges is W-E, because the streams which retreated westwards from the Gyöngyös Stream Brook created a series of valleys. These streams retreated towards the main ridge and the tributary ridges developed between the valleys.

There are planated [20] ridge mesas which developed due to river piracy [21], rock built forms [22, 23], and stairs in the valley slopes [24] in the Mountains. Kőszeg is on the east of the lower, northernmost part of the main ridge, largely on the plain of the Gyöngyös Stream at an altitude of between 272-275 metres. Its smaller part is between the plain of the Gyöngyös and the main ridge. This surface slopes from the mountains to the Gyöngyös Stream at an altitude of between 275-400 metres. This surface is a residual pediment of the mountain, which was reshaped by the streams of the mountains, accumulating a debris fan (bajada) in the foreland. This slope is connected to the main ridge dissected by valleys, the altitude of the main ridge is between 400-500 metres.

2. Materials and Methods

Profiles were taken in the stream channel at three places in the Bozsoki valley on 20.10.2009 (Fig. 2). The channel section is part of the outflow channel of the Szénégető Spring.

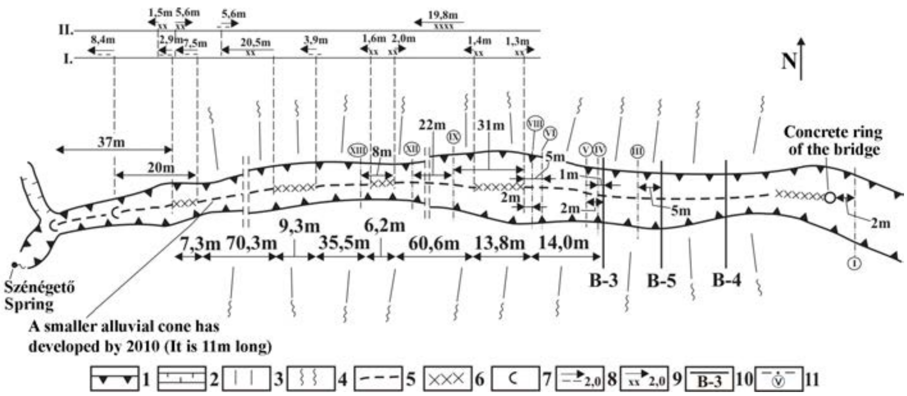
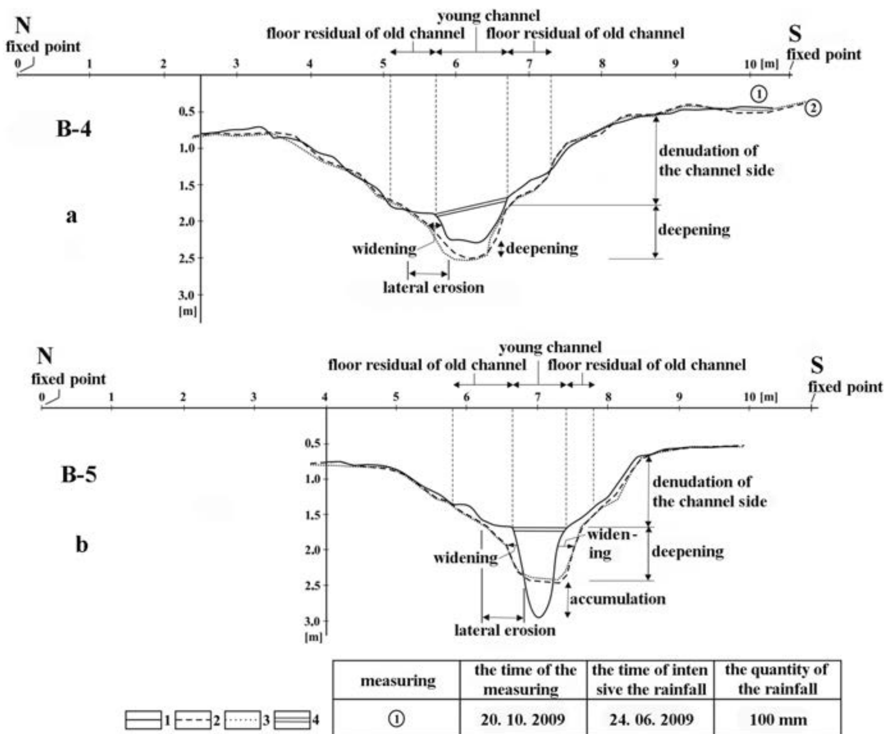


Figure 2. Incised channel sections and alluvial fans on the bottom of the Bozsoki Valley at various dates (sketch, without scale).
Legend: 1. pre-existing channel which formed before 24.06.2009, 2. gully, 3. Valley floor, 4. slope of the valley, 5. channel section which developed during of the rainfall 24.06.2009, 6. wet alluvial fan which developed during the rainfall 24.06.2009, 7. head of channel, 8. expansion of the channel (the arrow shows the direction of the lengthening, the number gives its degree in metres), 9. expansion of the alluvial fan (the arrow shows the direction of the lengthening, the number gives its degree in metres) 10. site of profile, 11.identificiation number and site of sketch profile, I. data from measuring of 19.09.2010, II. data from measuring of 30.09.2010.



measuring	the time of the measuring	the time of inten sive the rainfall	the quantity of the rainfall
①	20. 10. 2009	24. 06. 2009	100 mm
②	13. 09. 2010	02. 06. 2010	50 mm
③	06. 10. 2010	20-26. 09. 2010	113 mm

Figure 3. Profiles of channels at channel parts of the bottom of the NameBozsoki Valley.
Legend: a. profile marked B-4, b. profile marked B-5, 1. channel measured on 20.10.2009 (time of rainfall: 24.06.2009, its quantity is 100 mm), 2. channel measured on 13.09.2010 (times of greater rainfalls: 02.06.2010, 18.06.2010, 15.07.2010, their quantities are the following: 50 mm, 37 mm and 45 mm), 3. channel measured on 30.09.2010 and/or 06.10.2010 (quantify of rainfall was 113 mm between 20-26.09.2010), 4. channel floor which developed before 24.06.2009.

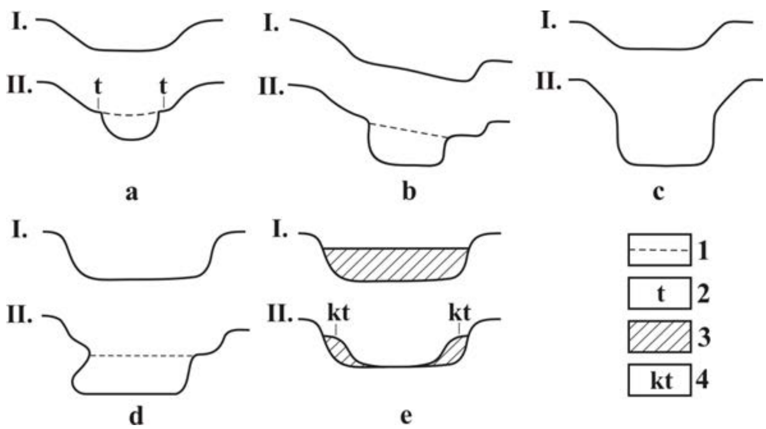


Figure 4. Showing former channel floors by using morphological characteristics of the channels
Legend: 1. former channel floor, 2. residue of floor, 3. channel fill, 4. floor residue in channel fill, placeI. initial channel shape, II. channel shape which was created during the development of a younger channel a. symmetrically floors residues develop because of the partial destruction of the channel floor, b. symmetrical floor residues develop, with various altitudes, because of the destruction of slanting positioned channel floor, c. floor residues are absent, because of the total destruction of the channel floor, d. asymmetrical floor residues develop, but overhanging side channel develop too as the channel line is moving, e. symmetrical residues of channel fills develop because of the partial destruction of the channel fill.

The channel section is located at a distance of 50 metres from the spring, and its length is about 200-300 metres. The valley floor is filled up by residual weathering products at this place only to a smaller degree. Therefore, the floor of the valley is wide and flat. To construct the profiles the depth of the channel was measured at every 20 centimetres along a stretched and fixed string, which we used to measure the effects of the intensive rainfall of 24.06.2009 on the channel. (The intensity of the rainfall was 100 mm/day.) The measurements were repeated three times on 13.09.2010, 30.09.2010 and 06.10.2010. The reason why we repeated the measurement was that we wanted to investigate the effect of a single intensive rainfall (total amount of rainfall was 113 mm between the 20th - 26th September, 2010) on the channel. We could establish the changes of the channel (deepening, widening) if the profiles from various dates were superimposed on one another (Fig. 3).

The changes may be given compared to the time before the 24.06.2009 rainfall if the channel shape can be recognized where there are floor remnants in the channel. Older channel floors can be recognized where cross sections were measured and sections were constructed from the measured data. The degree of the channel deepening is established from the difference between the depth of remnants of the channel floor and the existing channel floor at the time of the measuring. We present the theory of the reconstruction of the older channel floor in Fig. 4.

We established the ends of the entrenched and infilled channel sections at the floor of the Bozsoki Valley which developed during the 24.06.2009 rainfall and their lengths were measured. Their locations were determined compared to a fixed point (marked as B-3 on the profile in Fig. 2). The date of the measurement was 20.10.2009. The borders of these sections were measured a further two times (19.09.2010 and 30.09.2010). By knowing the borders of the sections we could establish how far the infilled sections (alluvial fan) extend and determine the entrenched sections and vice versa (Fig. 2). We also could obtain data on sediment transport. Naturally these processes may happen independently of the intensive rainfall.

We observed and sketched gullies which developed in a creek under the Szikla Spring. We also observed the earth pillars in the channel of the spring. These forms also developed during the intensive rainfall of 24.06.2009. We can establish the numbers and sizes of the gullies which developed during the intensive rainfall (flash food of 24.06.2009), and the deepening of the channel may be established at the earth pillars (Fig. 5).

The expansion and thickness of sediment veneer of the town of Kőszeg which developed during the intensive rainfall in 2009 (during the flash flood of 24.06.2009) was observed and represented on a map.

The thickness of the sediment veneer was measured at ten various places. As most of the veneer was already cleared away at the time of the measuring, the highest mark on the surrounding houses was taken as the guiding point to present its thickness. The valleys which lead to the direction of the town were also presented on a map (Fig. 6).

The catchment area of the town of Kőszeg was investi-

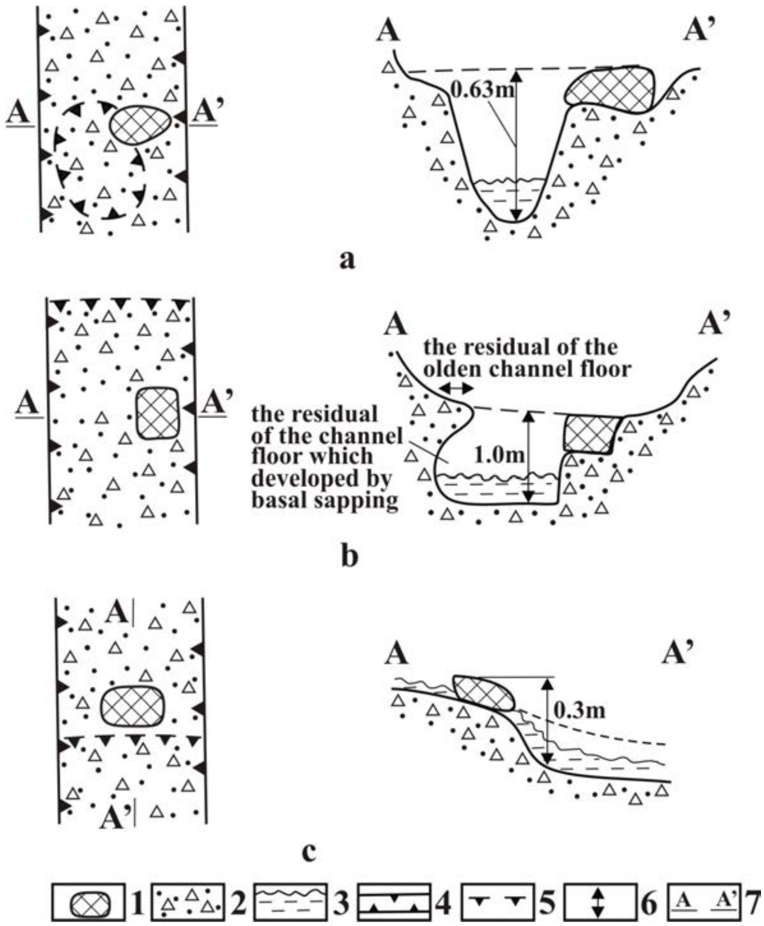


Figure 5. Residues of the channel floor downstream the channel part of the Szikla spring (data from 02.10.2009)
Legend: a. basin was formed in the channel near the boulder, b. deepening occurred everywhere in the channel along the boulder, c. deepening occurred in the channel only to the direction of stream flow near the boulder, 1. boulder, 2. deposit, 3. the stream of the channel, 4. channel, 5. step or basin which developed during the deepening of 24.06.2009, 6. degree of the deepening (in metres), 7. site and mark of profile.

gated. It was represented on a 2.5 m scale area model. Special digitization and georeferencing work called EOV System was carried out on the profiles of the area which were made during the so-called third military mapping of Hungary in the 19th century. Geo-references were also made on the aerial photo series taken in 2008. By employing a GIS software program called Digiterra Map road structures and vegetation cover were classified. Thus the data of the map made in the 19th century and those of the digital photos of 2008 could be compared.

Two tables representing the conditions of the development of the sediment veneer on the example of the town of Kőszeg (Table I, Table II) were created.

The parameters (width and depth) of a few gullies (3 pieces) which developed on the hills around Kőszeg were measured.

A function relation was established between the sizes of the gullies and their catchment areas (Fig. 7).

3. Results

3.1. Changes observed in the Valley of Bozsok

The following changes were observed in the cross-sections of the channel:

The channel became deeper because of the rainfall of 24.06.2009 at profiles marked B-5 and B-4. Its value was about 1.25 metres at profile marked B-5 (Fig. 3b), while it was 0.5 metres at profile marked B-4 (Fig. 3a). Deepening also happened at the profile marked B-3 and

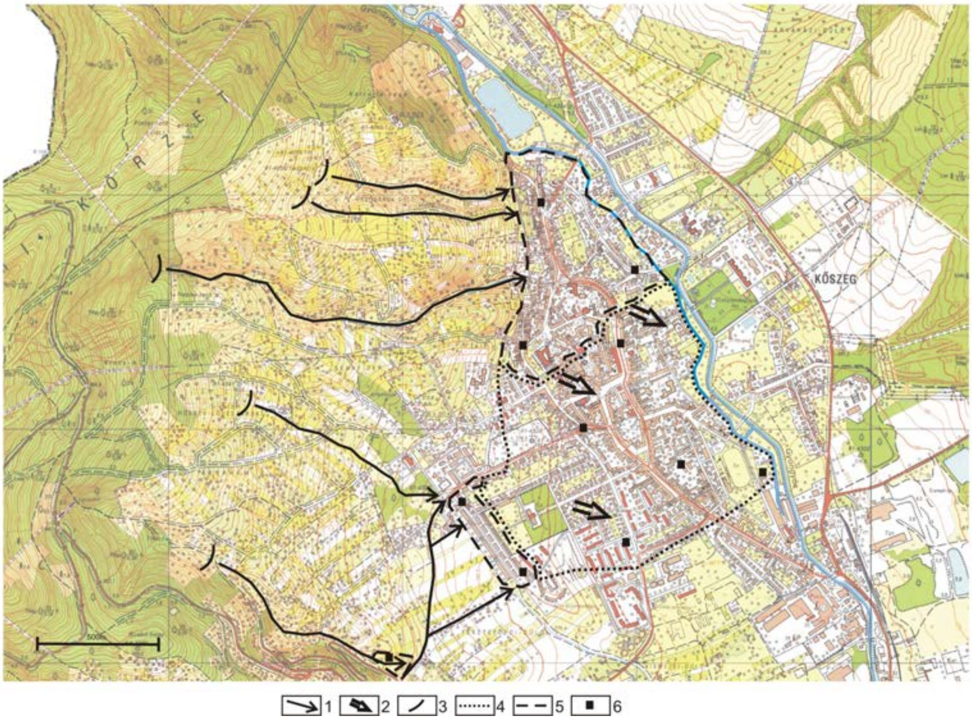


Figure 6. Sediment veneer which developed in the area of the town of Kőszeg
Legend: 1. ways of sediment transport, 2. probable secondary direction of sediment transport, 3. suggested traps for sediment (for example stone dikes) 4. the border of the accumulation with 0-0.1 m values, 5. the border of the accumulation with 0.1-0.5 m values, 7. site of the measurement.

to a value of 0.7 m. The measurements took place on 20.10.2009. It may be seen in the profile diagrams that the development of the channel is very different even at proximal parts of the channel (Figs. 3, 8).

Therefore there may be:

- sections which underwent intensive deepening only once (at profile place marked I)
- sections which suffered etching several times (for example at profile places III, V and VI, Fig. 2),
- sections which were infilled and suffered incision (for example at profile places marked VIII and XIII).

The incision of the channel floor may happen during the repositioning of the channel line. The process may happen during a single incision (for example at profile marked IX) or during two incisions (for example at profile marked III).

The remnants of the floors of the channel may be absent if the incision is wide (for example at profile marked I) or if the floor of the channel is narrow (for example at profile marked VIII). The sides of the channel may become overhanging (for example at profile marked III) because of the repositioning of the channel line.

According to the data of the repeated measurement (which was on 13.09.2010) changes had occurred subsequent to the measurements of 20.10.2009. These are the following: the value of deepening was 0.25 metre at the profile marked B-4 (Fig. 3a), while it was 0.5 metre at profile marker B-5 (Fig. 3b). The channel filled up by 0.1 metre at profile marked B-3.

According to the data of the repeated measurement of 30.09.2010 (compared to 13.09.2010) the following changes happened on the floor: the northernmost margin of the channel floor deepened by 0.1 metre (Fig. 3a) at profile marker B-4, and the channel was filled to 0.1 metre at the profile marked B-5 (Fig. 3b) and deepening happened by 0.1 metre at profile marked B-3.

One can see that the changes happened during a short time period. Small deepening occurred between the measurements in 09.2010. The cause might be that the stream cut through the upper part of the fine- grained sediment (which filled the valley floor). Thus it reached its lower part which contains greater boulders as well as finer sediment.

We could establish the following facts at the channel sections where incisions and infilling occurred (Fig. 2).

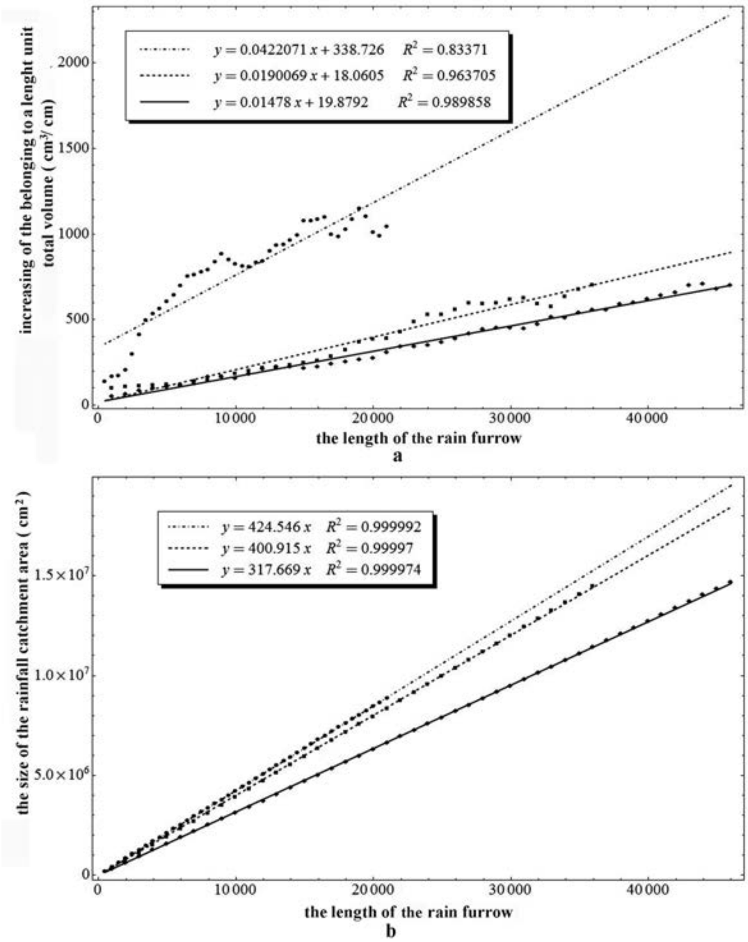


Figure 7. Morphological data on rills: increase of rill compared to unit length in the function of rill length (a) the size of catchment area belonging to rills in the function of their length (b).

Those channel parts, which were created in the filling section on 20.10.2009 could be increased by several metres at the expense of the incision sections by 19.09.2010. This tendency was characteristic of the lower part of the investigated channel. The incised sections spread with a corresponding decrease in the alluvial fans in the upper sections of the investigated channel. We established that the alluvial fans increased in the direction of the flow of the stream and also in the opposite direction, in the expense of the incising channels parts. Till that time the incising channel section developed only in the direction of the alluvial fans above them (but not in the direction of the flow). It could be observed that alluvial fans which could be found in the channels did not suffer incising by the stream. It is probable that the changes which were observed on 19.09.2010, occurred due to the rainfall of the summer in 2010. The frequency of intensive rainfalls in 2009 (between 24.06.2009 and 20.10.2009) was less than in 2010 (between 25.06.2010 and 13.09.2010). While the number of intensive rainfalls exceeding 20 mm was 4 in 2009, it was 9 in 2010 taking the above mentioned time period into account. The changes which happened between 20.09.2010 and 26.09.2010, were represented by the measurement of 30.09.2010. Infilling was the main process in the investigated channel sections.

3.2. The effects of the intensive rainfall on the development of the landforms on the mountain

Naturally the geomorphic process (sheet wash and channel erosion) had been active even before the intensive rainfalls of the recent years. However, the development of the landforms may happen more rapidly due to the effects of the recent intensive rainfall and include the following:

- the pre-existing landforms (for example channels,

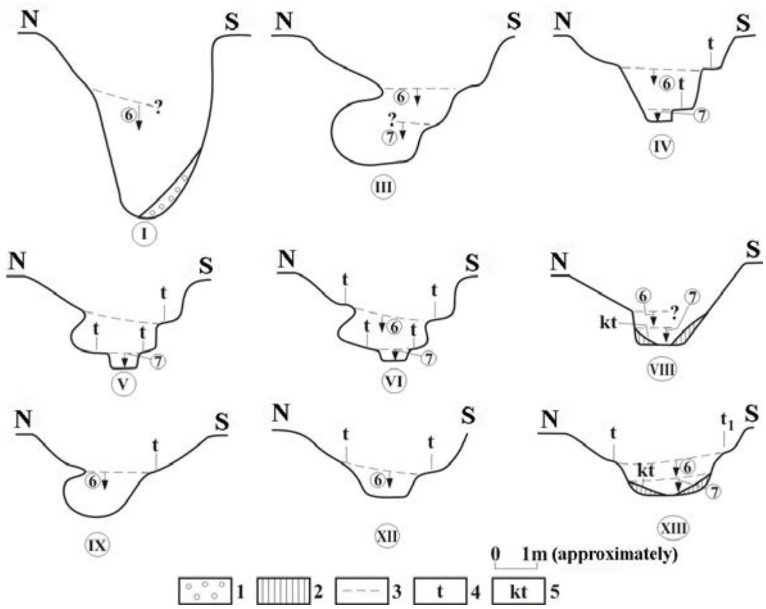


Figure 8. Channel profile sketches of the floor channel of the Bozsoki Valley (the sites of the profiles seen in Fig. 2).
Legend: 1. collapsed sediment, 2. former fill of channel, 3. former channel floor, 4. residue of channel floor, 5. residue of channel floor in the fill, 6.channel section which developed on 24.06.2009, 7. channel section which developed after 24.06.2009.

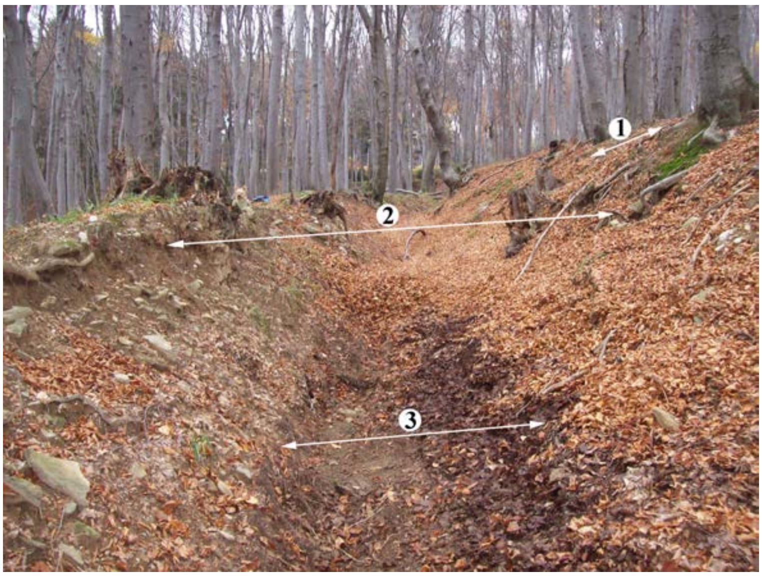


Figure 9. Gully developed in a hollow road in the placePlaceNameBozsoki PlaceTypeValley on 24.06.2009 (date of picture: 30.10.2009).
Legend: 1. valley side, 2. deep road, 3. Gully.

creeks) change,

- the rate of development of the dimensions of features may increase parallel to the growth; therefore the density of the landforms is increasing.

We examined landforms which were created by the intensive rainfall, or those pre-existing landforms which changed or increased during processes which can be identified by measurements. These landforms were created during sheet and channel erosion.

The erosional landforms produced are rills, creeks, gullies and channels [25]. The development of these landforms (and a few more presented below) can be well observed

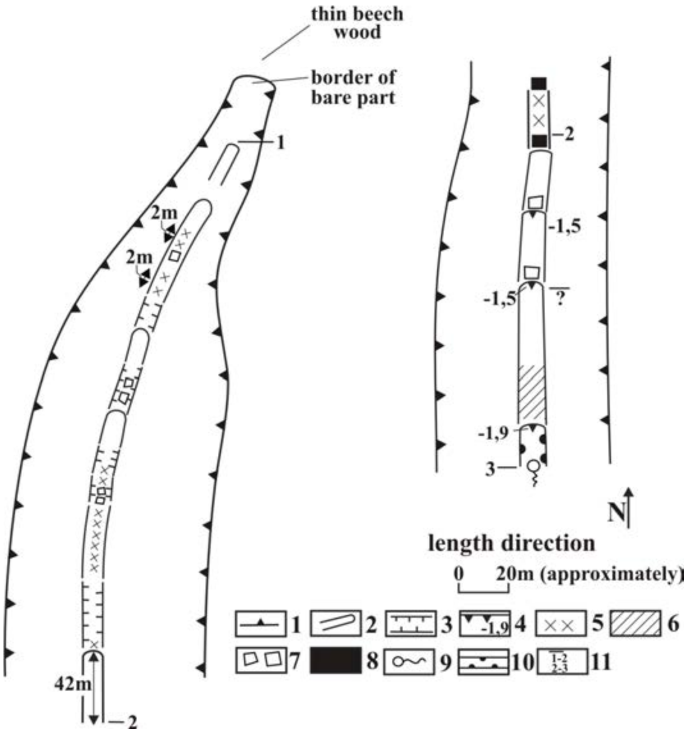


Figure 10. Gullies and embryonic gullies which developed in 2009 in the creek which is above Szikla Spring (time of measuring: 20.10.2009)
Legend: the margin of the creek, 2. gully which developed in 2009 (depth is 0.2-1m), 3. embryonic gully which developed in 2009 (its deep is 0.1-0.2 m), 4. step (depth is in meter), 5. section of partly filled channel which developed in 2009, 6. section of fully filled channel, which developed in 2009, 7. boulders, 8. bedrock, 9. spring, 10. channel, 11. channel and creek sections,
Note: The two figure parts show two various sections of the same gully.

Figure 11. Channel of the Bozsoki Valley at the profile marked III. (time of picture: 30.10.2010)
Legend: 1. older channel which developed before 24.06.2009, residual of channel floor, 2. overhanging channel slide, which developed during the repositioning of the channel line, 3. channel which developed on 24.06.2009, 4. channel which developed after 24.06.2010 (this probably developed on 22.09.2010).

Figure 12. The channel of the Bozsoki Valley at profile marked I. (time of picture 30.10.2010)
Legend: floor of Bozsoki Valley, 2. channel, 3. collapsed part of channel side, 4. moved bridge part (concrete ring), 5. concrete ring of the bridge which is stable.

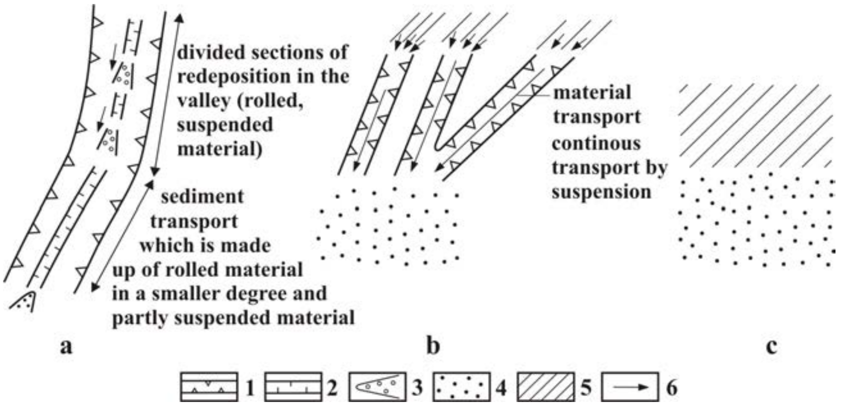


Figure 13. Types of accumulation features and their genetic varieties.
Legend: a. development of alluvial fans on the floor and at the mouth of the valley, b. development of sediment veneer during sediment transport in the valley, c. development of sediment veneer without sediment transport in the valley but transport in the rills, 1. valley, 2. channel or gully, 3. alluvial fan, 4. sediment veneer, 5. zone of rills, 6. redeposition of sediment.

in recent years (2009 and 2010).

Rills developed with great frequency in 2009 and 2010 too. It is known that these forms develop under rivulets which are created during intensive rainfalls. As they increase, their sides and channels are destroyed as the water of the rivulets fill them. The rills may have developed on forest roads, or in hollow roads (these roads are unused today).

Gullies may be distinguished according to their profiles and their longitudinal cross-sections. According to the longitudinal cross-sections continuous gullies and discontinuous gullies can be identified [26]. In the latter case the various parts of the gullies have different floor gradients or are separated by alluvial fans.

The majority of the gullies of the mountain developed before 2009. But we observed that these expanded significantly due to the intensive rainfall. It is commonly found that the gullies and creeks contribute to the development of other landforms. For example a gully at the head of Bozsoki Valley has emptied onto a deep-cut hollow road which obstructed the gully. Therefore the floor of the hollow road deepened intensively in 2009 and also in 2010

Figure 14. External alluvial fan from the floor of the Bozsoki Valley (time of picture: 30.10.2010)
Legend: 1. slope of Bozsoki Valley, 2. floor of Bozsoki Valley, 3. floor channel, 4. alluvial fan which developed on 24.06.2009, 5. channel on the alluvial fan, which developed after 24.06.2009, 6. new channel which developed after 24.06.2010.

Figure 15. Internal alluvial fan (time of picture: 30.10.2010) Legend: 1. floor of Bozsoki Valley, 2. channel, 3. alluvial fan.

(Fig. 9) and the incision of new gullies has also been observed.

Thus a series of small gullies developed on the floor of a creek which occurs above the Szikla Spring (Fig. 10). Embryonic gully-like forms have developed among them in which the underlying soil was not yet cut through. If the series of gullies created a system then we can establish that the erosion worked periodically on the floor of the creek (discontinuous gully).

Water flowing in and raising a hollow road may cause the development of a gully. Such forms developed in the sides of the Bozsoki Valley.

The channels of the mountain valleys have undergone considerable changes since 2009. The channels may have deepened in their whole length or were separated into sections with or without deepening or infilled sections.

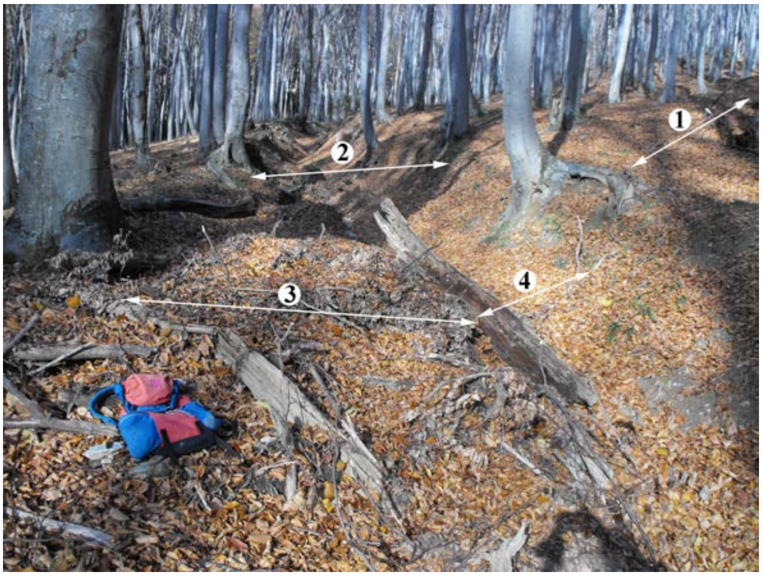


Figure 16. Alluvial fan developed in a hollow road of Bozsoki Valley (date of picture: 30.10.2010).
Legend: 1. valley side, 2. deep road, 3. alluvial fan developed due to the rainfall of 24.06.2009 (weekly observations in the research area proved this fact), 4. gully on the alluvial fan which developed after 24.06.2009.

On alluvial fans downstream the incision

developed in 2009, and channels developed because of the intensive rainfall of 2010.

Amphitheatre-like forms developed at some intermittent springs and seepage sites of the mountain. These forms are found along or next to channel floors, or along valley margins.

Channel development occurred in 2008 from these forms due to the increasing water flow of the springs and the rainfall concentrating at these localities. These channels developed on forest roads on occasions. Because these roads are still in use, the channels of the intermittent or low-yield springs deepened along the wheel tracks of the roads.

Through incision of the channel floor, internal channels developed along some sections of the pre-existing channels (Fig. 11, Fig. 8). Various channel shapes developed by repeatedly renewed incision.

Channel profiles are presented in Fig. 8. Edge like remnants (Fig. 2) of older floor channels accompany the margins of more recent channels along variable lengths.

New incision began because of the recent intensive rainfall in 2010. Therefore recent internal channels (secondary internal channels) developed on the older channel floors. Manifold complex channels were produced in this way. Major boulders may form little mounds on the recent channel floor due to the intensive incision of the channel and they protect fine-grained deposits below the boulders from stream erosion. They are termed as floor channel earth pillars (Fig. 5). Several -metre high steps developed on the channel floors too, mainly where boulder exhumed on the channel floors. A step has redeveloped under the Szikla Spring. When the channel section under the step was filled, the step and the spring were buried (during the flash flood of 24.06.2009) .

Later the water flowing in the sediment created a new step in the sediment fill (Fig. 10).

Recession of the channels may also be observed. The internal channels with steep ends developed in the older channels in 2009. These channels retreated further in 2010 (Fig. 2).

Incised parts developed on the channel sections under the bridges of the channel of the Bozsoki valley (Fig. 12). The concrete rings of the bridges make parts of the channel more resistant. Therefore, the channel slope increased downstream of these well rings.

A considerable proportion of transported sediment accumulated on the channel sections upstream of the bridge, as the sediment filled the tubes of the rings of the bridges, contributing to this process. Thus, the water which flowed through or above the tube of the bridges, increased the efficiency of the work of the stream. Intensive channel deepening happened under the bridges in at least three places on the floor of Bozsoki Valley in 2009. The degree of deepening was greater than 3 metres at some places (Fig. 12, Fig. 8 at profile marked I). Steps also developed

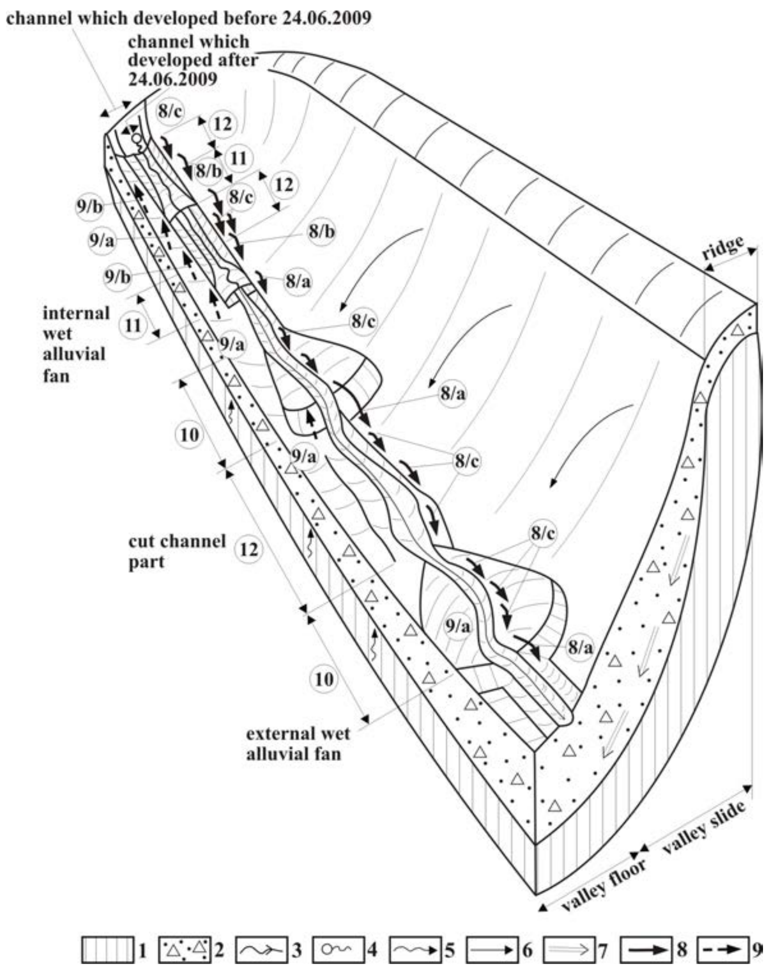


Figure 17. Matter transport of a valley of the Kőszeg Mountain due to the intensive rainfall (example shown on Bozsoki Valley)
Legend: 1. bedrock, 2. weathering residual, 3. stream, 4. spring, 5. substitution of bedrock cover by weathering, 6. sediment which is transported by sheet water to the floor of the valley, 7. mass movement, 8. sediment which is transported by stream, 8a. front part of a wet alluvial fan which develops during the accumulation of the deposit, 8b. upstream part of the wet alluvial fan which develops during the accumulation of the deposit, 8c. redeposition in the channel, 9a. front part of the alluvial fan is destroyed due to the recession of channel, 9b. upper part of the alluvial fan denudates due to the erosion of the stream.

at those places on the channel floor in 2009.

Hollow roads are common on the weathering products of the mountain. The roads change as they are not in use. The process may have become more intensive since 2009. Rills developed on the floor of the hollow roads and alluvial fans were created at the areas of shallow slope. It seems as if hollow roads developed into creeks or the process intensified significantly.

Mass movements (translational slides, breakdown) also developed on the steep slopes (the sides of the channels and creeks in 2009 and 2010). The damaged places may be observed. The rate of the movement of soil and sediment likely accelerated on the side of the valleys (through creeping). Trees fell more frequently in the northernmost valleys of the southern part of the mountain demonstrating this process. These valley slopes developed on cleavage planes, while the opposite valley sides are created on the head of foliate [28], as the valleys cut such rocks whose cleavage planes have southern dip direction (the direction of the valley is E-W.) The roots of trees can intrude to a smaller depth into the rock on the cleavage planes than at the heads of foliate. Therefore the roots can get injured more easily and so the trees fall during surface creep. Naturally the drenches of the soil and the hurricane-like wind also have a role in the destroying of the trees next to the surface creep.

The lateral erosion of streams can be more intensive at some channel sections, at which the roads near the channels are more endangered. (Therefore, for example, channel scarping was carried out in the Bozsoki Valley.)

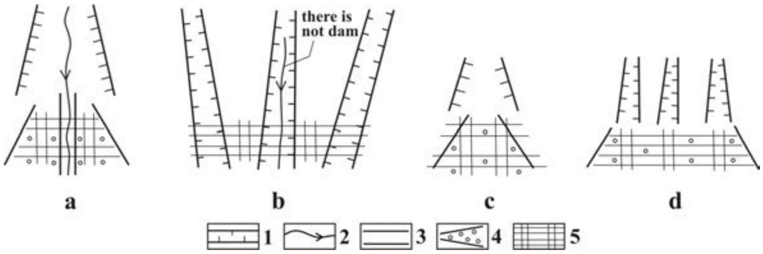


Figure 18. Various morphological environments of a settlement at mountain margin.
Legend: a. wet alluvial fan surroundings, b. valley-bajada environment, c. dry alluvial fan environment, d. alluvial fan-plain environment, 1. valley, 2. brook, 3. dam, 4. alluvial fan and alluvial fan-plain, 5. Settlement.

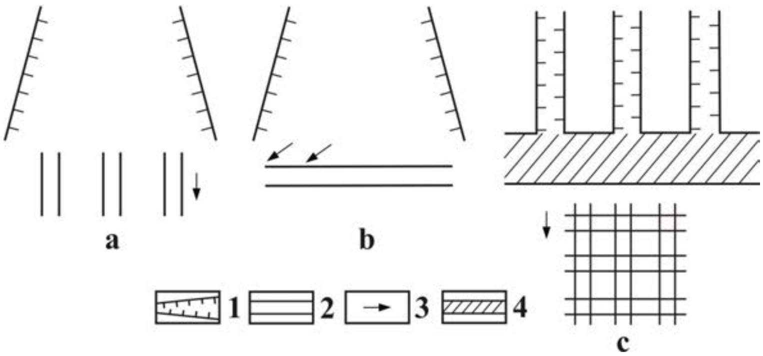


Figure 19. Settlement structure which is suitable for the development of sediment veneer (a) the settlement structure which is not suitable for the development of sediment veneer (b), or natural obstacles which prevent its development (c)
Legend: 1. valley, 2. street, 3. dip direction of the surface, 4. longitudinal valley, dam, bank.

The accumulation landforms were created on the margin of the mountain during the intensive rainfall of the 24.06.2009 and the flash flood following it. Accumulation landforms and their surroundings are represented in Fig. 13. The coarser sediments may accumulate in alluvial fans of valleys or along the mountain margins (Fig. 13a). The transported fine sediments accumulate to a small thickness (as a sediment veneer) along the mountain margins. The sediment veneer may originate directly from rills (Fig. 13c); or it can have an indirect origin, when it is transported by streams (Fig. 13b).

The landforms which developed during the intensive rainfall in the mountain areas are the following: alluvial fans, and the infilling of the channels (channel-fill deposits). At least one sediment veneer developed during the intensive rainfall of 24.06.2009.

The alluvial fans of various sizes are mantle like accumulations. They may occur at the margins of the mountain, at the mouths of the tributary streams, or at the side slopes of the valleys. Avulsions, different junctions and braided channels are characteristics of their area [29, 30]. The cause of their development is not the drop of gradient but explained by decreasing discharge [31] and increasing sediment mass [32].The material in alluvial fans is well sorted, with buried channels filled by gravel, and their structure is cross bedded [30] and dissected by erosion surfaces [33].

In the mountains alluvial fans which developed in 2009 may be found within the channels (internal fans - Fig. 14) or outside the channels (external fans - Fig. 15). The internal alluvial fans of the channel developed in the depression (for example in channels), which were created by the rainfall or streams. The external alluvial fans are greater than the size of such depressions. Primarily internal alluvial fans developed during the intensive rainfall of 2009 in the mountains. The shape of the alluvial fans is controlled by the bearing channels, being of elongated shape in the direction of the bearing channel. The size of the alluvial fans may be several tens of metres along the strike of the channel with a width of a few metres. The downstream end of the structures are steep, while the upstream end smoothes gently into the channel with more fine grain deposit at their upper end.

The characteristics of the internal alluvial fans of the channels are the following:

- small in size,
- steep front slope (their dip angle may be 70 ° too),

- there are no junctions, avulsion, and braided channels
- the deposits are non-sorted, their debris is not scraped, and comprise soil and plant waste (branches, trunks),
- a series of alluvial fans developed on some channel sections.

The above characteristics proved that they developed during only one flood and showed that these internal alluvial fans are related to the accumulation of sediment deposited by the flood.

The alluvial fans may be dry or wet [29]. The dry and wet alluvial fans created in 2009 of the mountain show similar characteristics. The alluvial fans of the two types develop if the discharge increases suddenly, but wet alluvial fans develop if the permanent streams experience a flood after intensive rainfall. The dry alluvial fans developed in gullies, creeks and hollow roads (Fig. 16) in 2009. The wet alluvial fans developed in and around the channels with permanent streams mainly during 2009 (Figs. 2, 13). The expansion of the pre-existing alluvial fans changed in 2010. The internal alluvial fans probably extended at their lower ends, and were destroyed at their upper ends. The evidence is that there are no incisions on their surface and their sizes changed in the investigated area of the Bozsok Valley.

The denudation of the external alluvial fans of the channels can happen on their total areas. Incisions and channel development happened in 2010 on the 2009 surfaces and this proves our statements (Fig. 15, Fig. 17). The relationship between the development of alluvial fans and the transportation of the sediment is presented in Fig. 13. The alluvial fans are frequently form due to obstacles inside of the channels. For example they may develop on the sides of the bridges which are opposite the stream direction, or where trunks are stuck as the water flows in the channel.

Channel accumulations developed in such rills, channels, creeks which already had been created, or in such forms which developed in 2009 (Fig. 10). These forms may be fully or partly filled. A series of channel accumulations developed. The incision channel sections can be separated by accumulation sections (Fig. 10). The accumulation might have developed behind boulders or where channel incision reached down to the surface of the bedrock. The incision can decrease at the outcrop of the bedrock. Thus the sediment removed from upstream sections accumulated here.

As we have already mentioned the sediment veneer is an accumulated landform which is built by fine grained deposit. Such sediment veneer developed in the area of Kőszeg town (see 3.3). As it was built by fine grain deposit, the condition of its development is the occurrence of fine grained deposits on the catchment area and its entrainment and transport.

The intensive rainfall changed and destroyed structures at several places e.g.:

- bridges and gutters were plugged,
- the sediment under structures was removed (for example under concrete support of springs, concrete rings of bridges) therefore the structures became unstable,
- some parts of roads were destroyed because of the flood of the stream (the road between Velem and Szent-Vid was destroyed where the Hétszemű Valley crosses it) during the rainfall of 2009.

3.3. The development of the sediment veneer in the town of Kőszeg

Sediment veneer was accumulated in Kőszeg by the flash flood which followed the intensive rainfall (100 mm) of 24.06.2009. Its thickness changed between 0-0.5 metres (Fig. 6). The sediment veneer extended from the valleys (which lead into the town) to the Gyöngyös Brook. The structure of the town may have also contributed to the development of the sediment veneer. When we look at the map of the town we can see many steep streets. Therefore the water of the flood and the sediment veneer could expand eastwards. The sediment veneer has its greatest thickness at two places where the valleys and channels lead into the town. Its depth was 0.1-0.5 metres at these places. There was a shallower zone between these two deeper zones which might have developed due to secondary re-deposition (Fig. 6).

The development of the sediment veneer could not be caused by the intensive rainfall only. (If it had been possible, then such landforms would have been developed previously, because such intensive rainfall may have occurred before 2009.)

The method of development is clear when the origin of the material of the sediment veneer is explained.

Our investigations show that the sediment did not come from the valley floors, but may come from the rills. The rills occur on the forest roads of the hills surroundings the town. As evidence we can mention the increasing number of rills in the catchment area. It is the catchment area of a creek which occurs on the Pintér-tető (one of the hills). 24 rills developed on the forest roads during the intensive rainfall of 2009. We estimated that the number of the forest roads doubled by 2009 compared that of 1960-1970 on the hills surrounding the town. The spreading of week-end houses also contributed to the increasing road density which induced rill formation and sediment transport, the number of the rills, which in turn increased the amount of the eroded matter. The ratio of forests decreased until the year of 2008 compared to that of 1900's in the catchment area of the valleys leading to the town. The area of the bare forest and the cultivated area grew (Table I). But mainly the length of the roads increased (from 23.86 km to 61.19 km).

The size of the rills was investigated. Their sizes and the quantity of the sediment depend on the size of the catchment area (Fig. 7), with the sediment likely being derived exclusively from road surfaces.

Forms which develop during water flow were not observed from the forest area to the rills of the roads. No rills originating from forests were found. Thus the value of the denudated material depends on the expansion of the roads.

The following facts contributed to the development of the sediment veneer besides the intensive rainfall and the great road density:

- the great thickness of the weathering cover, which may be a few metres in the mountain (it is more than 3 metres at some places),
- the relatively steep slope of the surface between Gyöngyös valley floor and the main ridge (it can reach 11°),
- the relative great number of the valleys on the mountains,
- the structure of the street network of the town (the directions of some streets agree with the dip direction of the surface).

3.4. Sediment veneer hazard at settlements near mountain margins

The investigation of accumulation landforms which developed at the mountain margins during intensive rainfall may be important because settlements and traffic infrastructure occur here. The morphological environment of the settlements situated at the margin may be the following:

The settlement is at such valley mouth where the valley has a perennial stream. Wet alluvial fan develops at the mouth of the valley (wet alluvial fan environment Fig. 18a).

Several valleys lead in the direction of the town, and cross the settlement. The valleys developed on the pediment or its covered versions (bajada) (valley-bajada surrounding, Fig. 18b).

The settlement is at the mouth of the valley, where the valley ends, or its deepening decreases. The valley does not contain a perennial stream. A dry alluvial fan is connected to the valley (dry alluvial fan surroundings, Fig. 18c).

The settlement is at the mouths of valleys connected to an alluvial plain (alluvial plain or floodplain environments, Fig. 18d).

The stream flows between dams on the areas of settlements of the wet alluvial cone environment. Sediment cover may be generated only if the stream flows from the area behind the dams. As there are no dams in towns with the other already mentioned three morphological environments, sediment veneer may develop during every flood. Sediment veneer develops primarily in valley-bajada environments or in alluvial environments. The town of Kőszeg has both, the valley-bajada environment in the western part of the town, and an alluvial environment in the eastern part of the town.

Besides suitable morphological surroundings the following facts may increase the chance of the development of the sediment veneer:

- the high road density (Table 1),
- the great thickness of the bedrock cover,
- high slope angle of the denudation area (or the great altitude difference on it).

The following facts can decrease the development of the sediment veneer:

- vegetation cover,
- low slope angle,
- small thickness of non-cohesive superficial cover.

The total catchment area of the valleys leading to the town is: 7.31 km^2

We suggest two methods to prevent the development of the sediment veneer. First, to decrease the number of the roads, or to build dams on the floor of the valleys which

Table 1. The size of the catchment areas of the valleys leading to the town of Kőszeg and that of the surfaces without plant cover.

The characteristics of the catchment area	1900		2008	
	Its size [km^2]	Proportion of the catchment area [%]	Its size [km^2]	Proportion of the catchment area [%]
placeForest	4.34	59.37	2.92	39.84
Deforested area	0	0	0.22	3
Agricultural area (with road)	2.97	40.63	4.17	57
Length of the roads [km]	23.86	-	61.19	-

Table 2. Probability rating of sediment veneer development at settlements along mountain margins with the example of the town of Kőszeg.

The characteristics causing the development of the sediment veneer	Chance of the development of the sediment veneer
Deep bedrock cover or weathering residual, density of the roads and valleys are similar or greater than around Kőszeg	4
Little bedrock cover the density of the valleys, and the density of roads are smaller than in the surroundings of the Kőszeg	3
There is less bedrock, but valleys occur (There are not plant-free areas)	2
Bedrock present but there are not valleys or barren surfaces	1
Neither bedrock cover nor valleys occur	0

lead to the settlements. This latter suggestion decreases the velocity of water flow, therefore the suspended load accumulates at least partly. Thus the degree of the hazard is highly variable because of the different characteristics of the mountain. For example, it is greater at mountains of metamorphic rock (the weathering deposits are thicker). It is smaller on karst areas, as the weathering sediments are shallower. Naturally the thickness of the bedrock cover depends on the intensity of the karstification and its time-span on karst areas. Therefore the thickness of the deposit is considerably different on the areas of the Bükk Mountain and that of the Aggteleki karst. Hence the degree of endangerment may be great on those karsts which were covered during a geological timescale. There is a local difference in hazard, for example in the Bakony Mountains, which have a block structure where the superficial cover may have been eroded from some blocks while it did not denudate from other blocks. We propose that the chance for the development of the sediment veneer is small on allogenic karsts, because the sediment cover may be transported through sinkholes into the karst.

The structure of the settlement is also important. If, for example, the direction of the streets of the settlement is in accordance with the slope of the surface, sediment veneer develops to a considerable size. If there are drain channels beside the streets, the chance of the development of the sediment veneer is smaller, or it develops to a lesser extent. The development of the sediment veneer is prevented, for example, if streets, banks or building rows are perpendicular to the direction of the valley; or the direction of the streets is different from the direction of the surface dip (Fig. 19).

We believe that the degree of hazard to a settlement can be quantified by a sediment veneer at mountain margins.

We can classify the chance of the development of the sediment veneer at settlements at mountain margins taking the characteristics of the surroundings of Kőszeg into account (Table 2):

To reach these results we need to produce the following data:

- To specify the size of the catchment area(s) which belong to the valley(s) of the given settlement,

- To specify the thickness of the superficial cover, and the density and the total size of the entirely non-vegetated areas (for example roads),
- To specify the quantity of the eroded material which is produced from an area unit during given intensive rainfall.

If we compare the counted data with those of the town of Kőszeg (see Table 1), then the given settlement can be classified to the range of the hazard and the development of the sediment veneer as seen in Table 2.

If the settlement is classified with the degree number 4, that means if the development conditions are similar to that of Kőszeg and the intensity of rainfall is 100 mm/16 hours, the chance of the development of the sediment veneer is 100%.

4. Conclusions

The impact of the intensive rainfalls was measured and observed on several study areas of the Kőszeg Moutains. Channels deepened, alluvials fans (inside and outside the channels), gullies and rills developed, and a sediment veneer was created due to intensive rainfalls in a two-year time period here. The deepening of the channels can reach 0.7 metres at the rainfall value of 100 mm. The lengths of the alluvial fans of the channels of the Bozsoki Valley changed by 2-6 m (increased or decreased). The changes happened at the expense of the incised channel sections. The lengths of the incised channel sections might have increased by 2-10 m during the researched time period. At the same time there were such channel sections which decreased as some alluvial fans increased.

If the intensity and the frequency of the rainfall are similar or increased in the future decade than those in 2009 and 2010 badlands may develop on parts of the Kőszeg Mountain. The badlands and other landforms developing during intensive rainfall, particularly if the windspeed is high leading to forest destruction. In particular badlands can develop on valley sides where there are trees on the heads of the layers of the slate. Forest cutting also contributes to the development of the badland surfaces, predominantly where the forests are completely removed or the density of roads further increases. The deepening of the landforms which developed due to the intensive rainfall and flash floods may slow down because the grain size increases in the lower part of the erosional deposits. However, a considerable proportion of this sediment may be transported from the mountain. The matter transport may happen either periodically or continuously during intensive rainfall. The sediment which can be transported from the mountain endangers engineering projects and agricultural activities.

The hazard of the sediment veneer also depends on the morphological environment of the settlements of mountain margin, and the settlements were classified according to this. Settlements belonging to various types have different hazard degree. The development of the sediment veneer at certain rainfall value at a settlement depends on the thickness of the superficial deposit, the expansion of the catchment area and bare surfaces (for example the length of the roads and their total expansion), further more on the morphological environment of the settlement. Though, the expansion of the sediment veneer also depends on the structure of the settlement.

The surroundings of Kőszeg may be examined as a pilot area. Using the data which are collected from this area, we can predict the possible occurrence of sediment veneers at other settlements found at mountain margins.

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