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HUMAN IMPACT ON THE CHANGE OF DIRECTION OF RIVER CHANNEL MIGRATION CAUSED BY FORMATION OF A LANDSLIDE DAM

Abstract. The paper presents the impact of man on the change of direction of the natural migration of a stream channel resulting from triggering a landslide on stream bank. The landslide that was formed on 15th May 2014 in the Łapsze Niżne village led to the formation of a landslide dam and a small dam lake upstream of it. Waters flowed over the surface of the fill terrace and returned to the old channel, approximately 120 m downstream the landslide. Following 33 days of the landslide activation, the dam was cut, and material was removed and deposited within the channel meander downstream. This caused the waters of the Łapszanka stream to return to the cleared channel. Three series of measurements were performed using a terrestrial laser scanner (TLS). The TLS made possible to calculate the volume of the landslide tongue (1,690 m^3) and the maximum volume of the material forming the landslide dam for which the flow of the waters of the Łapszanka stream would remain within the old channel (761 m^3). Exceeding this value led to diverting the stream waters towards the fill terrace. Thereby, the process of forming a new channel was commenced. During its functioning (33 days), material of a volume of 55 m^3 was eroded. Lack of human intervention in the natural process of migration of the channel would result in continuous removal of material from the terrace and formation of a new channel.

Keywords: landslides, landslide dam, fluvial erosion, channel change, human impact, Gubałowskie Foothills

INTRODUCTION

Landslides are processes that are responsible to a very large extent for shaping the surface of hillslopes (Starkel 1960, 2006; Bober 1984; Rączkowski 2007) and in many cases also valley floors (Dziuban 1983; Margielewski 1991; Korup 2004; Levy et al. 2012). The coupling between hillslopes and river channels is a fundamental aspect of the functioning of geomorphic systems (Harvey 2002; Wistuba et al. 2013). High precipitation acts on the landslide through soaking colluvial deposits in water and changing physicochemical properties of the ground, leading to considerably increased slope loading (Starkel 1960; Gil, Długosz 2006). In the case of landslides with immediate contact with the channel, the triggering of a landslide is not only accountable to the total sum of precipitation but also to thewater level in the stream (Dauksza, Kotarba 1973; Levy et al. 2012; Kukulak, Augustowski 2016), eroding both vertically and laterally and incising into the slope with the landslide. The triggering of such a landslide leads in the majority of cases to the damming of the channel by a landslide dam while a landslide lake is formed upstream (Costa, Schuster 1988, Haczewski, Kukulak 2004, Kroup 2005, Cebulski 2013). There are a few classifications of landslide dam types (and interactions of slope deformations and river systems generally) in literature dealing with landslide dams. J.E. Costa and R.L. Schuster (1988) created a typology of natural dams classifying landslide dams into 6 categories based on their morphologic relation to the valley floor. A significant majority of cases analysed (89%) affect the entire valley floor width, in some cases depositing material high on the opposite valley slopes. Merely 11% of the landslide dams analysed by J.E. Costa and R.L. Schuster (1988) are small in contrast to the valley width and they do not reach the opposite valley slope. Such circumstances were the case in with regard to the landform concerned, situated at the locality of Łapsze Niżne. The sliding of material dammed the whole channel and a part of a fill terrace leading to accumulation of water upstream of the landslide dam and diverting the water to the fill terrace. The water bypasses the colluvium-filled channel and forms a new channel, which is continually deepened. Within a short time following the formation of the landslide dam human intervention in the natural processes took place by digging a cut across the landslide tongue, which led to the return of the stream waters form the fill terrace to the channel. Due to the geological structure (layers of Podhale flysch) of the Gubałowskie Foothills within which the landslide concerned is located, slope surfaces are to a large extent affected by slope processes, particularly landslides (Mastella 1975; Chrobak, Cebulski 2014; Kukulak, Augustowski 2016) but also debris flows (Hełdak, Lizak 2014).

The aim of the study was to present the natural migration of the river channel caused by a sudden delivery of a large amount of colluvium and to determine the impacts of human disturbance on the natural process of evolution of river channel.

STUDY AREA

The study sites (554–612 m a.s.l.) are located in the middle part of the Łapszanka stream catchment (tributary of the Dunajec River), situated within the geomorphological unit of the Gubałowskie Foothills (Fig. 1-A) (Klimaszewski, Starkel 1972). From the geological point of view, the study area is situated in the Podhale Basin (Książkiewicz 1972). The basin is filled with a sequence of Eocene and Oligocene flysch rocks (Mizerski 2002). The flysch sequences found in this part of the Inner Carpathians are not homogeneous but consist

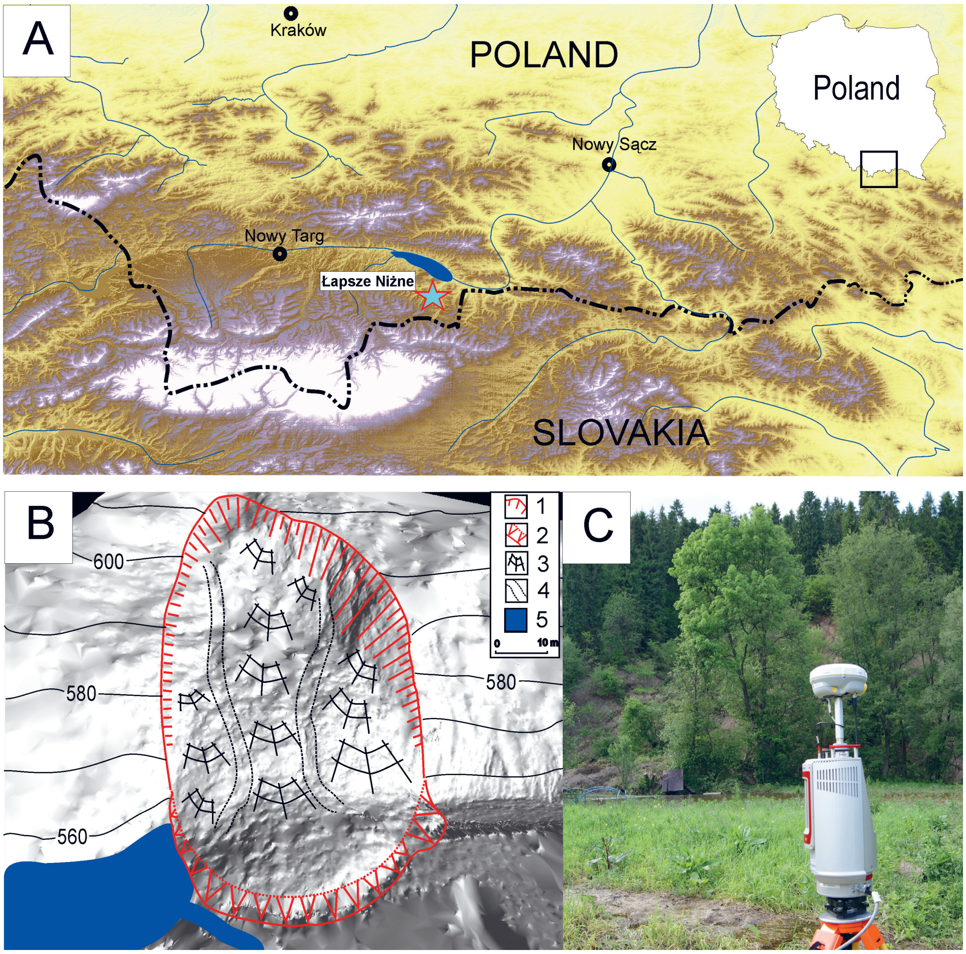

Fig. 1. Location of study area. A – location of the studied landslide; B – sketch of the landslide. 1 – scarp; 2 – front of landslide; 3 – direction of colluvium movement; 4 – gully inside landslide; 5 – landslide dammed lake; C – terrestrial laser scanner Riegl VZ 4000

of several sequences of bedrock layers (Szaflarskie, Ostryskie, Chochołowskie, Zakopiańskie). The terrains where the study landslide and the channel are located are situated within the Szaflary beds built of sandstones, conglomerates and shales of the Oligocene age (Birkenmajer 1957). A wide fill terrace of the Holocene age built of boulders, gravels, sand and clay occurs in the Łapszanka valley floor. The landslide under study is located 12.75 km from headwaters (Nad Łapszanką Pass) of the Łapszanka stream. The stream catchment, upstream the studied landforms, has an area of 35.04 km^2.

The analysed landslide has a small area of approximately 3,640 m^2 (Fig. 1-B) and its length is approximately 80 m, width 41 m, while the average gradient is approximately 26°. This is a consequent, weathered material landslide, formed on the left slope of the Łapszanka stream valley. The occurrence of this landform has led to considerable changes in the valley due to the damming of the Łapszanka stream channel, which consequently resulted in the overflowing of the stream waters onto a fill terrace along a section of 120 m. The landslide, the channel downstream of the landslide and the fragment of fill terrace that the Łapszanka flew through after the formation of the landslide were subjected to a detailed survey, which included making multiple digital terrain models.

METHOD

Changes in the terrain surface resulting from triggering a landslide and damming a stream flow, as well as the subsequent removal of material from the front of the landslide and its deposition within the meander of the channel as an effect of anthropogenic action were assessed using a high resolution digital terrain model (DTM). These data were obtained from 3 series of measurements that were performed using a RIEGL VZ-4000 terrestrial laser scanner (Fig. 1-C). The first measurement was performed shortly after the activation of the landslide (20.05.2014), and the next one was performed two days after the human intervention when the colluvium of the landslide tongue was excavated and deposited within the river meander (20.06.2014) (Fig. 2-C-III). The last, third series of measurements was made on 15.07.2014 and allowed determination of the rate of the secondary movements within the landslide after the excavation across the dam.

The scanner used for those measurements was a Riegl VZ4000 pulse scanner constructed in 2011, characterized by superior and unrivalled long-range measurement performance of up to 4,000 m reflectorless. For geospatial location, we applied a GNSS receiver (TRIMBLE R4, coupled with the scanner), using Real Time Kinematic (RTK) corrections from the ASG-EUPOS system. After averaging data from the GNSS receiver, the scanner location was assessed (accuracy better than 10 mm). Point clouds derived from the TLS scanning were processed by the RiSCAN PRO software including the Multi Station Adjustment (MSA) module.

RESULTS

ORIGIN AND CHARACTERISTICS OF THE MORPHOLOGICAL CHANGES CAUSED BY THE TRIGGERING OF THE LANDSLIDE

In the period preceding the activation of the landslide (11–15.05.2014), the weather station Niedzica (6 km away from the studied landslide) recorded precipitation of 139.1 mm, with the highest value of 84 mm on 15th May. The activation of the landslide was caused not only to the high precipitation totals but also to the lateral erosion of the Łapszanka stream (Fig. 4-A).

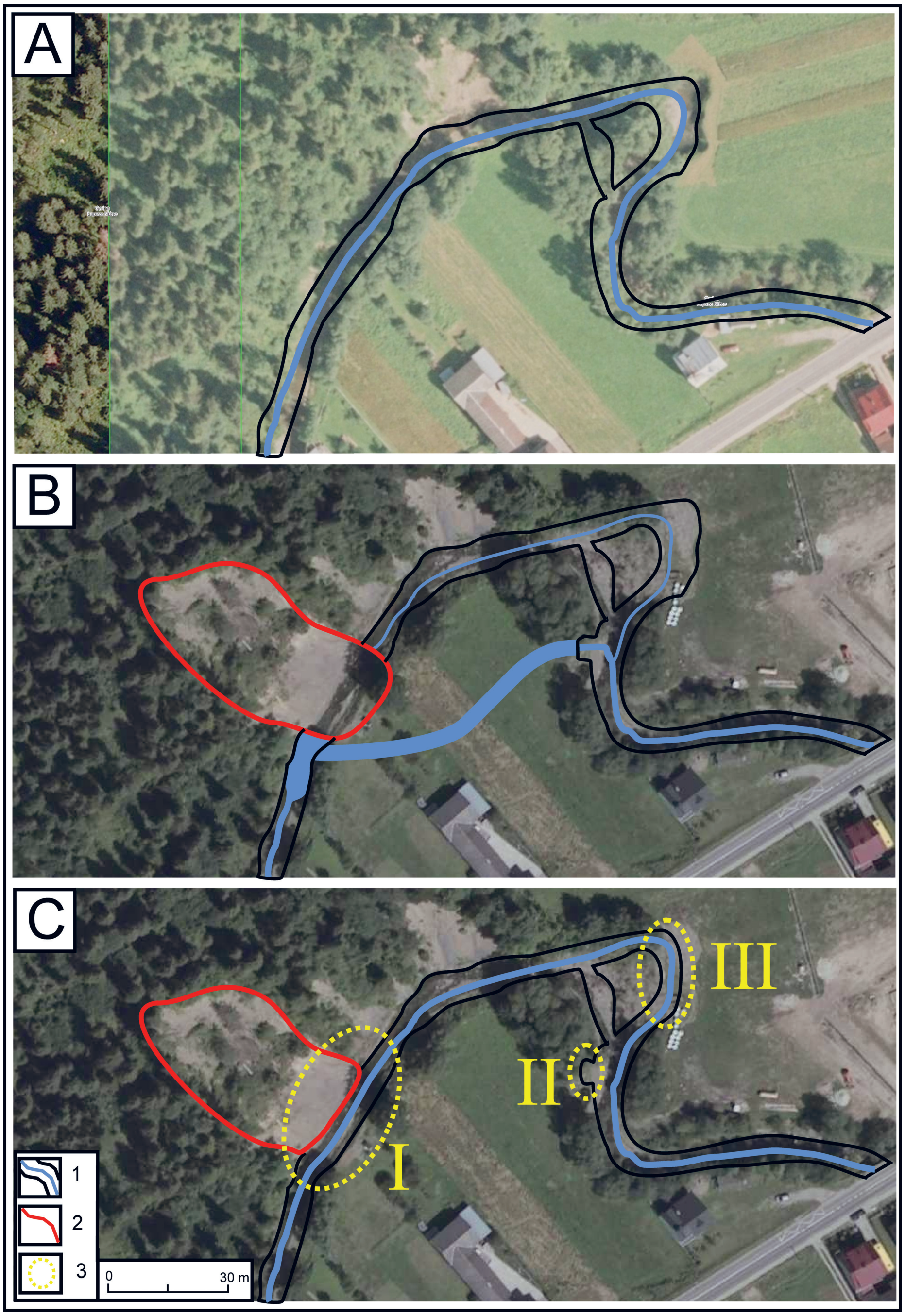

Fig. 2. Orthophotomap with marked Łapsze landslide and river channel. A – situation prior to the formation of the landslide, the course marked according to orthophotomap; B – situation after the formation of the landslide; C – situation after the human intervention. 1 – river channel, 2 – landslide border, 3 – selected sites: I – landslide toe; II – new river channel; III – river meander

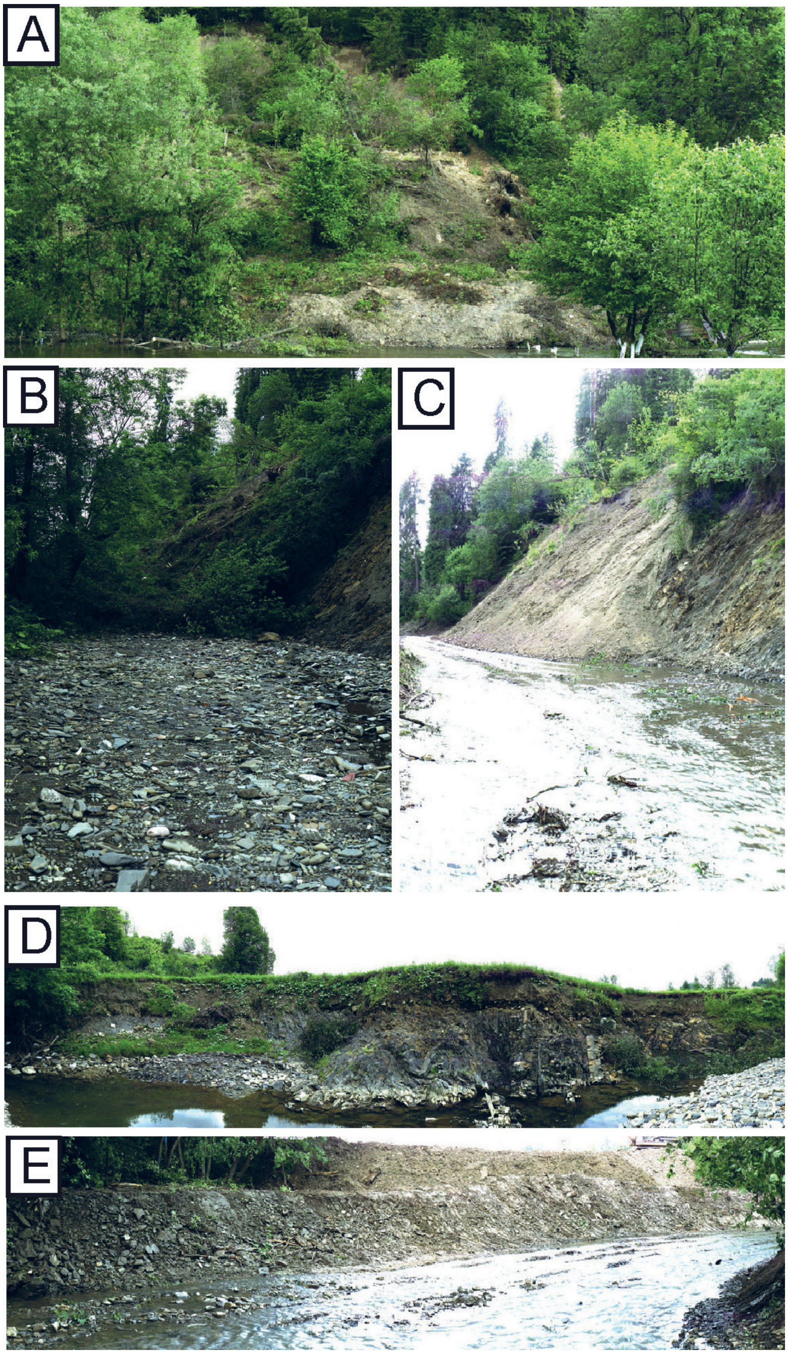

Fig. 3. Changes of selected sites within the study area in the period May-June 2014; A – landslide in May 2014; B – landslide toe in the river channel in May 2014; C – river channel after human intervention in June 2014; D – river meander in May 2014; E – river meander after human intervention in June 2014

As a result of the triggering of the landslide, the Łapszanka stream channel was completely filled with colluviums (Fig. 3-B) forming a landslide dam. The damming of the flow caused the formation of a landslide lake upstream of the landslide dam, with a length of approximately 70 m and average width of 9 m (Fig. 2-B). This landform had a maximum depth of approximately 2.5 m, located several meters upstream of the landslide dam. The considerable volume of the landslide dam (Fig. 3-B) prevented water from escaping from the newly formed lake to the channel immediately below the landslide. The water collected in the lake flowed over onto a vast area of the fill terrace and approximately 120 m downstream returned to the old channel. At the spot where the water returning from the fill terrace flowed into the channel of the stream a small erosional niche was formed with a distinct threshold of a height of approximately 1.5 m (Fig. 2-C-II). During the functioning of the new flow course of the Łapszanka stream the edge of the niche successively retreated upstream as a result of headward and down-cutting erosion.

HUMAN IMPACT ON THE CHANGE IN THE FUNCTIONING OF NATURAL PROCESSES

Engineering regulation of the Łapszanka stream channel was carried out on 17th and 18th June 2014, a month after the formation of the landslide dam. It consisted in digging a cut across the landslide tongue (Fig. 3-C), with colluvium material being transported and deposited within a meander of the stream (Fig. 3-E) and within a small niche formed as a result of erosion by the waters flowing from the terrace to the channel (Fig. 2-C-II). The removal of a large amount of material from the landslide tongue led to a significant increase in the inclination of the landslide front resulting in triggering secondary movements. Colluvium delivered to the channel was successively carried away by the Łapszanka stream. Due to the deposition of the colluvium in the river meander its width was significantly reduced, from 19 m to 11 m (Fig. 2-C-III).

ANALYSIS OF THE DIGITAL TERRAIN MODELS (DTM)

The measurements by terrestrial laser scanner (TLS) comprised taking scans of several locations and then merging them together. The "point cloud" obtained this way was then processed. The layer of vegetation was deleted, as well as the redundant noise that occurred at the time of scanning. The first measurement with the use of the TLS was performed on 20.05.2014 and the results obtained allowed for determination of the state after the activation of the landslide. The following measurement (20.06.2014) was performed after the material was removed from the landslide tongue and deposited in the stream channel. The analysis of the differences in the terrain models from the first and the

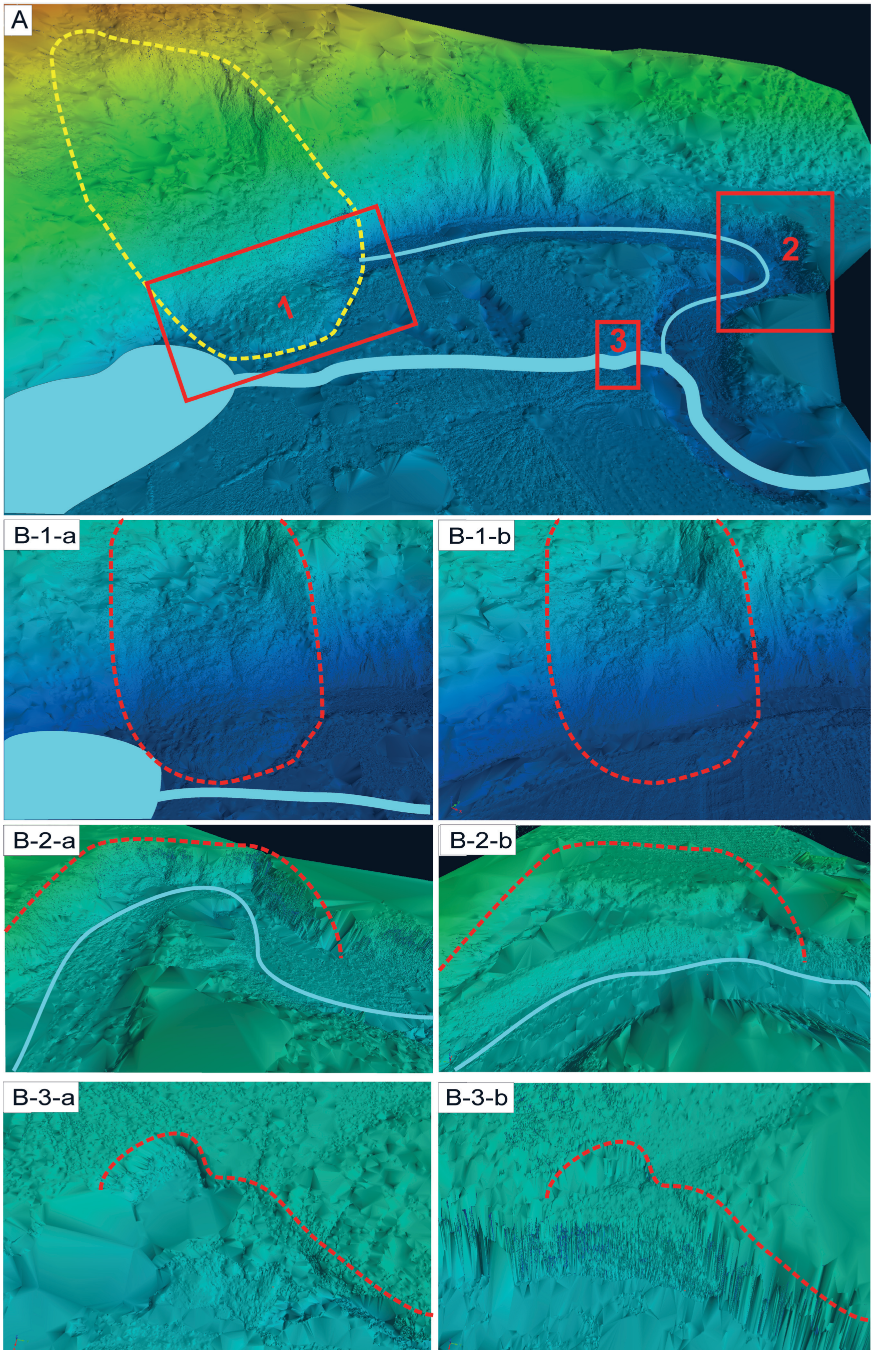

Fig. 4. Digital terrain models. A – visualisation of the studied landslide and the Łapszanka stream channel; B – detailed digital terrain models; 1 – landslide tongue; 2 – meander of the stream channel; 3 – niche at the place of water flowing from the terrace into the channel; a – digital terrain models made on 20.05.2014; b – digital terrain models made on 20.06.2014

second measurements permitted calculation of the amount of material removed by man from the landslide tongue. A total of 1,690 m^3 of colluvium was removed from the landslide tongue, most of which (1,083 m^3) was deposited in the channel meander (Fig. 4-B-2-b). Thereby, its average width was reduced from 19 to 11 metres. The remaining 607 m^3 of the colluvium removed from the landslide tongue was used to reinforce the banks and also to backfill the erosional niche (55 m^3), (Fig. 4-F). The last, third measurement was made on 07.07.2014 and the DTM that was obtained allowed for determination of the extent and direction of the changes taking place immediately after the human intervention in the natural process of channel migration. A differential analysis of the second and third models of the terrain displayed slight changes in the forms being analysed. Greater differences between the terrain models were noted within the landslide. The removal of the material from the landslide tongue led to secondary movements, and some of the colluvium slid to the stream channel. This material was carried away by the Łapszanka stream water. Postprocesing of the digital terrain models in RiscanPro software made possible to determine the maximum volume of the landslide dam (Fig. 5) while at the same time maintaining the flow of the stream within the old channel. It was found the volume of colluvium dam should be equal or less than 761 m^3. Exceeding this value, as was the case in spring 2014, led to the complete blocking of the flow in the channel and diverting the stream waters to the fill terrace.

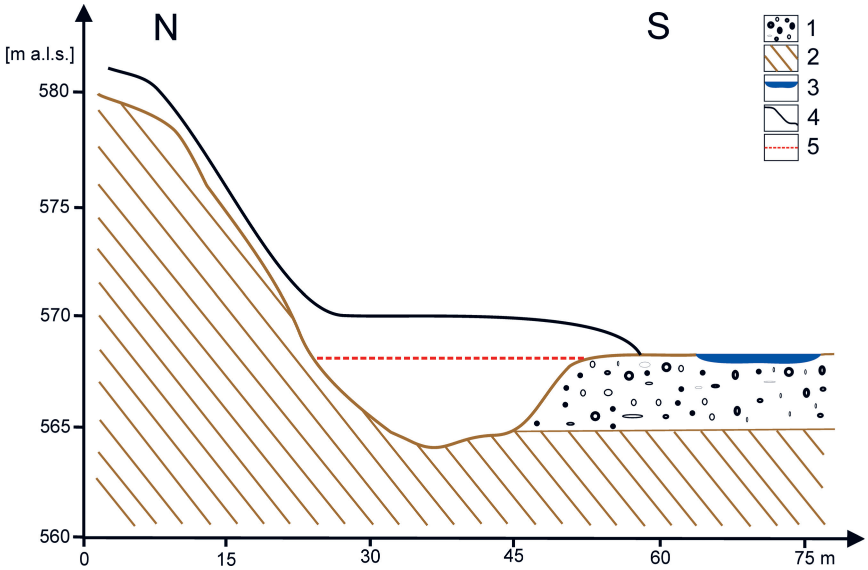

Fig. 5. Longitudinal profile of the landslide tongue (geology based on Birkenmajer 1957), 1 – terrace; 2 – bedrock; 3 – stream channel after formation of the landslide; 4 –landslide area; 5 – line denoting the maximum amount of colluvium in the stream channel the exceeding of which results in damming the water flow

DISCUSSION

The issue of damming river valleys by landslide tongues has been widely discussed in numerous papers worldwide (Dziuban 1983; Kroup 2004, 2005; Cui et al. 2009; Levy et al. 2012; Stefanelli et al. 2015). A vast majority of the papers concerns large landslide dams formed in high-mountain regions of China, Japan, New Zealand and Italy (Kroup et al. 2006; Peng, Zhang 2012; Stefanelli et al. 2015). In the majority of cases, landslide dams occupy the entire width of the valley (Cui et al. 2009; Kroup 2004) significantly affecting the abiotic environment in the immediate vicinity (Peng, Zhang 2012). This impact is particularly intensified where a lake is formed upstream of the landslide dam. It affects the local change of climatic conditions (Stefanelli et al. 2015) as well as the topography. In the dam lake, the material carried by the river is continually accumulated and when it gets completely filled, a wide, flat valley floor is formed. Changes in the morphology of the valley downstream of the dam are insignificant and typically restricted to: (1) increased delivery to the river channel of the material carried from the dam (Cui et al. 2009); (2) a change in the location of the channel within the valley (Kroup et al. 2006). This process becomes intensified especially in the time of human intervention consisting in digging a cut across the landslide dam in order to lower the water table and thereby reduce the danger of the dam bursting and flooding the terrains below (Cui et al. 2009; Peng, Zhang 2012). For smaller landforms, it is possible to dig a complete cut across the landslide dam as it was the case in the Łapsze Niżne village. Even though this landform did not directly threaten the residential and farm houses, decision was made to remove the dam so that the Łapszanka stream waters should return to the old channel (that functioned prior to the formation of the landslide), and thus not occupy the surface of the fill terrace, which had been used as farmland before.

Lack of human intervention in the natural process of interaction between the studied landslide and the stream channel would have led to further incision of the stream into the material forming the terrace, which would have consequently resulted in the development of a new channel. During functioning of landslide dam (May – June 2014), intensive headwater erosion at the place where the stream waters from the fill terrace flowed into the old channel caused material of a volume of 55 m^3 to be carried away and the edge to retreat by 3 m (10 cm/day on average). Continuation of this process would have resulted in development of a new stream channel during 3 to 5 years. During this time, a new channel should have been formed along a length of approximately 120 m, from the confluence with the old channel as far as the dam lake. And the section of the channel downstream of the landslide dam (the old channel) would have been slowly backfilled with material from the banks and from the landslide tongue during this time as well as overgrown with vegetation. The water flow within the old channel in May 2014 would have been possible if the activated landslide had delivered less than 761 m^3 of colluvium to the channel. In such a situation the waters of the stream would have stayed within the old channel flowing through the landslide tongue. Under the action of lateral and down-cutting erosion, material from the tongue would have been transported away continuously, especially during periods of high water levels.

SUMMARY

1. Triggering a landslide which enters to a stream channel causes in many cases damming the flow in the channel. In the case of the small landform at the locality of Łapsze Niżne this led to complete stoppage of functioning of the channel along a section of approximately 120 m downstream of the landslide and formation of a new channel through headwaters and down-cutting erosion within a fill terrace.

2. Differential analyses of the terrain models allowed for determination of the volume of the colluvium accumulated in the stream channel and calculation of the threshold value (761 m^3) above which the flow direction of the waters of the Łapszanka stream would be changed. Additionally, it was possible to determine quantitative and spatial changes caused by deposition of the colluvium in the stream channel.

3. The rate of development of the new channel has been established. In the period of the 34 days of its functioning, material of a volume of 55 m^3 was carried away from the fill terrace. Assuming that this rate of development of the new channel would have remained the same, without any human intervention, a new channel would have developed within 3–5 years.

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