DEBRIS FLOWS IN THE WATERSHED OF THE BOROVITSA RIVER, THE EASTERN RHODOPES

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ABSTRACT. The territory of the Eastern Rhodopes is defined in the specialised literature as highly affected by debris flows. These events propagate usually in deep erosional forms and can be defined as a rapid movement of highly liquified earth masses, caused by intense rainfall and snowmelt. Despite the built anti-erosion facilities and the mitigation measurements in the Eastern Rhodopes, there are still large areas of deforested and eroded slopes, which are a prerequisite for the propagation of debris flows. Large parts of the slopes in the watershed of the Borovitsa River are such areas. This article analyses small watersheds of the left tributaries of the river, after the Borovitsa Dam. The study is focused on the morphometric parameters of the watersheds and characterisation of the deposits. The presence of loose Paleogene volcanic materials, slope gradients between 15° and 30°, and sparse vegetation define the areas with the occurrence and propagation of debris flows. The results of the morphometric and grain-size analyses provide information on the energy of the flow and allow to delineate the zones of feeding, transport, and accumulation of the material.

Key words: debris flows, morphometric analysis, grain size analysis, the Borovitsa River.

КАЛНО-КАМЕННИ ПОТОЦИ ВЪВ ВОДОСБОРА НА РЕКА БОРОВИЦА, ИЗТОЧНИ РОДОПИ

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РЕЗЮМЕ. Територията на Източни Родопи е определена в специализираната литература като силно засегната от кално-каменни потоци. Те се проявяват обикновено в дълбоки ерозионни форми и представляват бързо движение на силно оводнени земни маси, предизвикано от интензивни валежи и снеготопене. Въпреки изградените противоерозионни съоръжения и укрепителни дейности, в Източни Родопи все още съществуват значителни площи обезлесени и ерозирани склонове, които са предпоставка за разпространение на кално-каменни потоци. Такива са значителна част от склоновете във водосбора на р. Боровица. В настоящата статия са анализирани малки водосбори на леви притоци на реката, след яз. Боровица. Изследването е фокусирано върху морфометричните параметри на водосборите и характеристика на наслагите. Наличието на неспоени палеогенски вулканити, наклони между 15 и 30° и оскъдна растителност определят териториите с проява на кално-каменни порои. Резултатите от морфометричния и зърнометричния анализи дават информация за енергията на потока и позволяват да се очертаят зоните на подхранване, транспорт и акумулация на материала.

Ключови думи: кално-каменни потоци, морфометричен анализ, зърнометричен анализ, р. Боровица.

Introduction

Debris flow is a fast-moving mass of sediment mixture - loose soils, sand, rock clasts, and water that moves downhill due to gravity. It is a widespread hazardous geological phenomenon in mountainous terrains. The preconditions for debris flow are steep slopes, loose earth materials, and rare vegetation. They occur periodically and are usually induced in gullies and first- or second-order drainage channels (Hungr et al., 2013). Triggering factors of these hazardous events are heavy rainfall or rapid snowmelt. Debris flow hazard is specific to a given terrain which influences the conditions of transport and accumulation. In very steep areas, debris flows can reach high speeds. The speed and volume of the flow make these phenomena very dangerous for people when they affect infrastructure and settlements, and for the ecosystems by affecting the vegetation and possible change in the water and sediment regime of the streams and rivers. This determines the need for a detailed study of the flow parameters, characteristics of the debris deposits, feeding area, and threshold parameters of the triggering factors, which are the subject of many publications (Costa, 1988, Zang et al., 2015, Wang et al., 2017, Gerdjikov et al., 2012, Kenderova et al., 2013, Dotseva et al., 2017, Notti et al., 2021, etc.).

In the current study, two debris prone watersheds, located in the Eastern Rhodopes (southern part of Bulgaria), were analysed. The area is highly prone to debris flows which are conditioned by large deforested slopes, high slope gradients, and weathered volcanic rocks. To minimise hydrogeomorphic risk, significant measures were taken in the past, including afforestation and building concrete check dams. Today, to a large extent, these processes have been controlled or their intensity has decreased. Despite that, the debris hazard still exists in the Eastern Rhodopes due to the cases of intensive rain and the availability of debris flows conditioning factors. Many of the anti-erosion facilities built in the 1960s are damaged, or check dams are filled with clast material which increases the risk. The main risk in this area is related to the sediment transfer and possible changes in the retention capacity of the dams which increase the flood risk. Planning mitigation measures requires knowledge not only about the triggering factors but also about the type of flows and terrain features. In this relation, the current study was directed to the morphometric properties of the watersheds and debris deposits.

Study area

The study was done for the areas of two small watersheds of left tributaries of the Borovitsa River. The area is located in the Eastern Rhodopes, between the villages of Sokolite and Slepcha (Fig. 1). The relief is low-mountainous to hilly. Generally, the catchment area of the river Borovitsa is wide and with rare vegetation or deforested which is a prerequisite for propagation of debris flows.

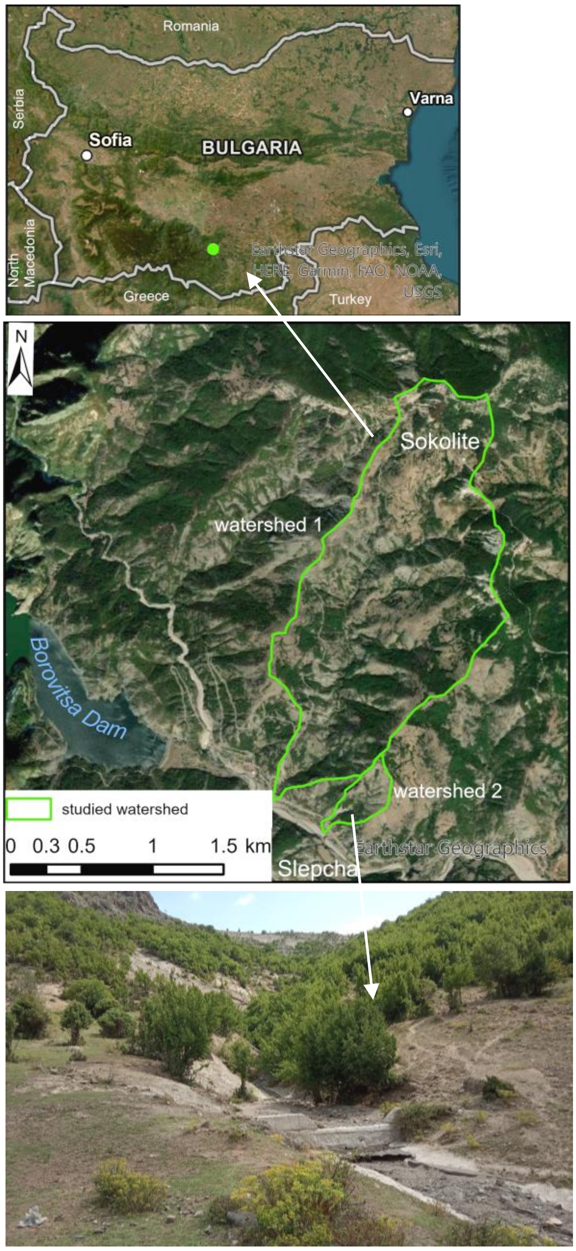

Fig. 1. Location of the study area and view of the watershed 2

The studied watersheds are characterised by temporary streams which activate in case of intensive rain. The area of watershed 1 is 2.84 km^2, and the watershed 2 area is smaller and is a catchment of a gully of 0.17 km^2 in size. A concrete check dam was built in the lower part of the gully to protect the near road. In present days, the check dam is filled with sediments and is not in a good condition. This decreases the retention capacity of the concrete facility and increases the risk of hazardous hydrogeomorphic processes.

Regarding the geology of the studied area, gullies are cut in medium-acid volcanic rocks of the Ribnodolski Volcanic Subcomplex (Jordanov et al., 2008). They are presented by small to medium porphyry latites to andesites, latitic to andesitic lava breccias, and alternation of tuffs and tuffites of Priabonian age. The lava breccias form a series of lava flows and covers, among which thin layers and lenses of lavas and various tuffs and tuffites are found. The upper part of watershed 1 is built by the terrigenous-tuffite formation of the Borovishki Volcanic complex (Paleogene). Generally, the rocks that are discovered on the surface at both watersheds are highly weathered which favours debris flows feeding with clastic materials.

The climate of the area is continental-Mediterranean with the maximum of precipitation in November-December (Rachev and Nikolova, 2008). Alternation of dry periods and periods of intensive rain facilitates the disintegration of earth materials and the occurrence of debris flows.

Materials and Methods

Morphometric and grain-size analyses were carried out to characterise the watersheds and to evaluate the geomorphological conditions for debris flow occurrence and propagation. Main morphometric parameters like watershed area, watershed relief, relief ratio (Schumm, 1956), slope, and Melton ratio (Melton, 1958) were computed on the basis of the ALOS PALSAR digital elevation model (DEM) with 12 m horizontal resolution (ALOS PALSAR, 2009). For the analysis of the impact of topography on the transport power of the streams, a secondary derivative of the slope gradient – stream power index (SPI) was calculated (Chen, Yu, 2011). A description of the computed watershed parameters is given in Table 1.

Samples of sediments were taken from three locations in the gully at watershed 2 – two from the gully bed, before and after the check dam, and one from the gully slope for the purpose of grain size analysis. The analysis was carried out in the Laboratory Geochemistry at the University of Mining and Geology “St. Ivan Rilski”, according to the Bulgarian State Standard BDS EN ISO 17892-4:2017. The sample statistics were computed using *Gradistat, Version 9.1* (Blott, S., 2020). The grain parameters, commonly used in the interpretation of sedimentary environments, like M (mean size), σ (standard deviation), Sk (skewness), and K (kurtosis) were calculated by the Folk and Ward (1957) method. The interpretation of the results was done taking into consideration the published materials and field research. The results of the grain size analysis are presented in tables and histograms.

Table 1. *Morphometric parameters of the watersheds*

Parameter	Description
Watershed area, km^2	Impacts on the amount of the surface runoff and the time it takes to reach the riverbed
Watershed relief, km	A difference, in kilometers, between the elevation of the highest point in the watershed and the river/stream mouth.
Relief ratio, km	The ratio between the watershed relief and the length of the watershed. The higher the relief ratio, the higher susceptibility to debris flow.
Melton index	The ratio between the watershed relief and the square root of the watershed area. The higher the relief ratio, the higher susceptibility to debris flow.
Slope	Computed as the rate of change of the surface in the horizontal and vertical directions from the center cell to each adjacent cell in the DEM raster. The higher the relief ratio, the higher susceptibility to debris flow.
SPI	SPI = Ln (As * tanβ), As – contributing area, β – slope in degrees.

Results and Discussion

Morphometric indicators

The morphometric analysis of the studied watersheds shows that the area is highly susceptible to debris flows. The high values of relief ratio, Melton ratio, and slope gradient are indicators of that (Table 2).

Table 2. *Morphometric parameters of the studied watersheds*

Morphometric parameter	Watershed 1	Watershed 2
Watershed area, km^2	2.84	0.17
Watershed relief, km	0.56	0.28
Relief ratio, km	0.17	0.40
Melton ratio	0.33	0.80
Slope >15° (in % of the watershed area)	71.4	77.6
SPI	to 12.8	to 5.4

The high values of the relief ratio, and particularly for watershed 2, show high general steepness of the watersheds which is a precondition for rapid movement of loose slope material. Regarding the Melton ratio, many publications determine 0.3 and higher as a threshold value which indicate the debris character of the watersheds. For instance, Jackson et al. (1987) set the value >0.3, Bovis and Jakob (1999) determine Melton ratio >0.53 as an indicator for debris flow area, and according to Wilford et al. (2004) debris flow watersheds have Melton ratio >0.6. Similar results about debris flow prone watersheds are received for other parts of the Rhodopes (Nikolova et al., 2021) and for the Middle Struma watershed (Baltakova et al., 2018). SPI is a relative indicator of the transport power of water flows in a certain watershed and it is not applicable for the comparison of different watersheds, because it depends on the contributing area. Despite the predominant areas with slopes greater than 15° in watershed 2, the SPI is lower due to the smaller area. The spatial distribution of the values of slope gradients and SPI are given in Fig.2.

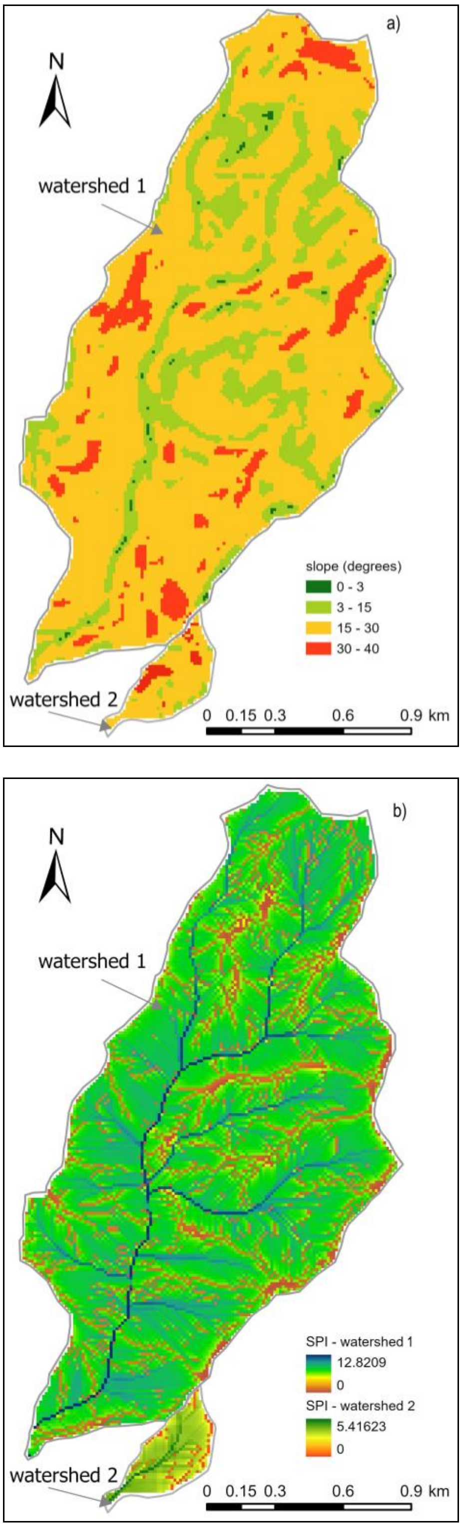

Fig. 2. Spatial distribution of the morphometric parameters: a) slope gradients; b) SPI

Grain size analysis

Three samples taken from the watershed 2 area were analysed as follows:

S1 – left slope of the gully,

S2 – from the gully bed before the check dam,

S3 – from the gully bed after the check dam.

Grain-size statistical parameters (mean, standard deviation, skewness and kurtosis) were calculated based on grain-size distribution curves (Tables 3, 4, and 5).

Sample S1 – gully slope. The sample is trimodal, very poorly sorted. The gravel is the predominant fraction and takes 80.2% of the sample, the sand takes 19.8%. There is no mud fraction. The sediment is determined as coarse gravel, and the textural group is gravel. The grain size distribution is given in Fig. 3

Table 3. *S1 - Statistic parameters (phi) by Folk and Ward (1957)*

Parameter	Logarithmic	Description
Mean	-2,867	Fine Gravel
Sorting	2,029	Very Poorly Sorted
Skewness	0,470	Very Fine Skewed
Kurtosis	0,896	Platykurtic

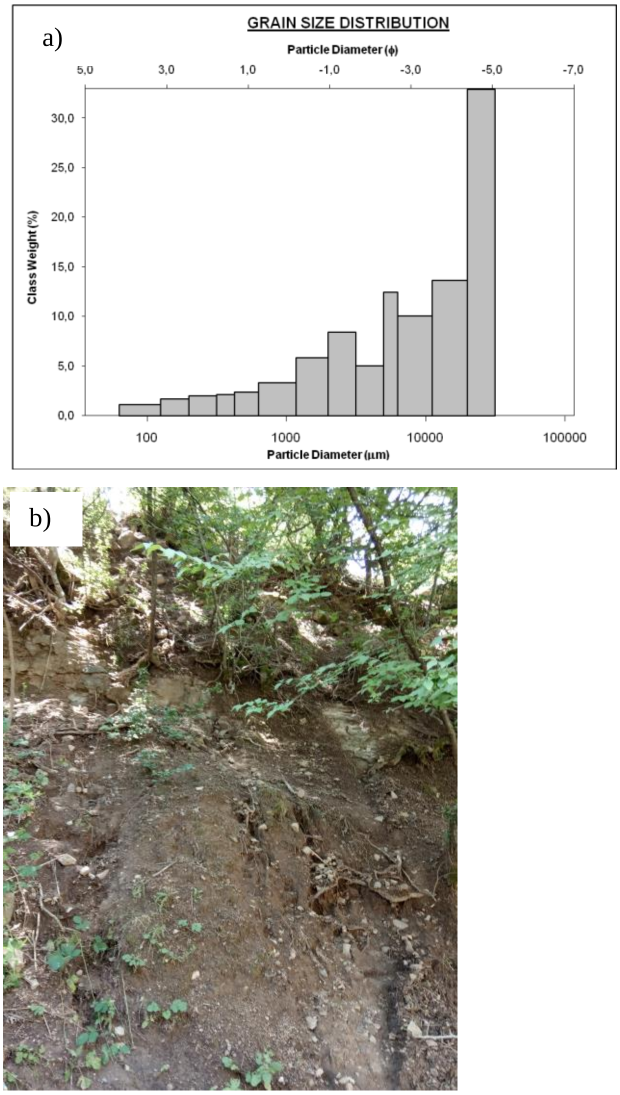

Fig. 3. Sample S1: a) grain size distribution; b) sampling site

Sample S2 – gully bed, before the check dam. The sample is bimodal, poorly sorted. The part of gravel is 60.9% of the sample, the sand takes up 39.1%. There is no mud fraction. The sediment is sandy fine gravel, and the textural group is sandy gravel. A view of the sampling site and the grain size distribution is presented in Fig. 4.

Table 4. *S2 - Statistic parameters (phi) by Folk and Ward (1957)*

Parameter	Logarithmic	Description
Mean	-1,435	Very Fine Gravel
Sorting	1,706	Poorly Sorted
Skewness	0,115	Fine Skewed
Kurtosis	0,967	Mesokurtic

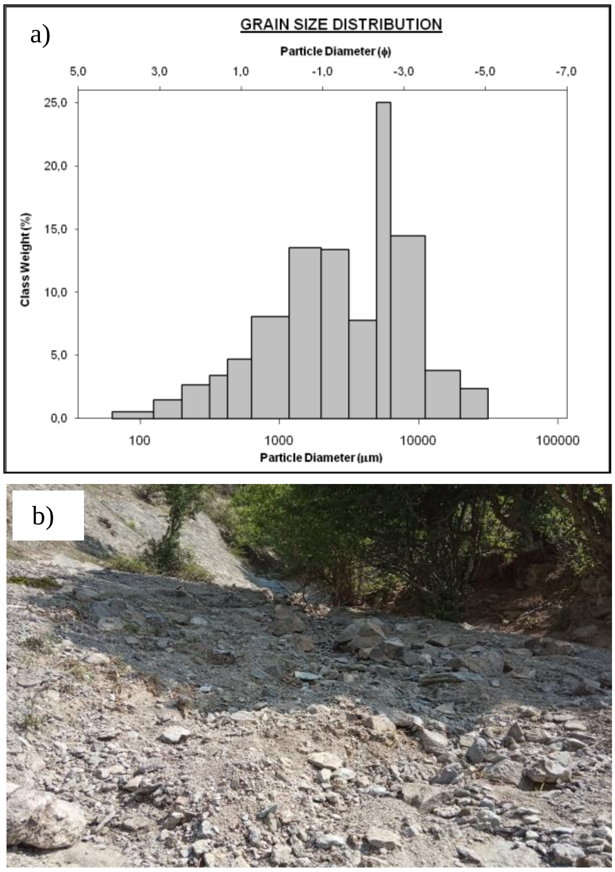

Fig. 4. Sample S2: a) grain size distribution; b) sampling site

Sample S3 – gully bed, after the check dam. The sample is trimodal, very poorly sorted. The gravel takes up 79.4% of the sample, and the part of the sand fraction is 20.6%. There is no mud fraction. The sediment is determined as sandy very coarse gravel, and the textural group is sandy gravel. The grain size distribution and view of the sampling site are given in Fig. 5.

Table 5. *S3 - Statistic parameters (phi) by Folk and Ward (1957)*

Parameter	Logarithmic	Description
Mean	-2,900	Fine Gravel
Sorting	2,294	Very Poorly Sorted
Skewness	0,155	Fine Skewed
Kurtosis	0,884	Platykurtic

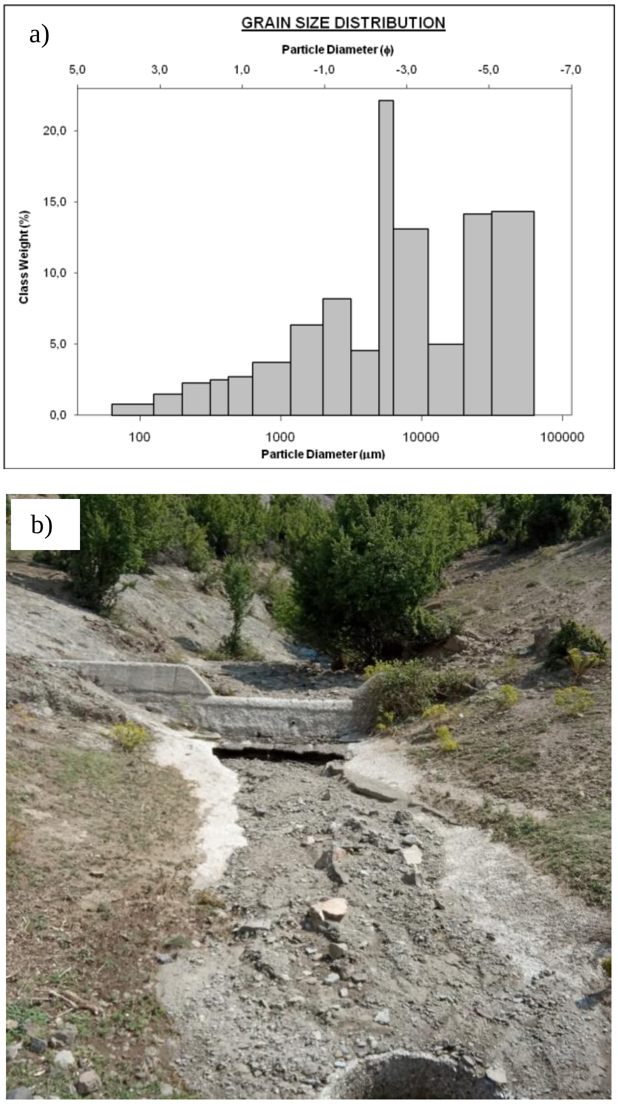

Fig. 5. Sample S3: a) grain size distribution; b) sampling site

Varnes (1978) stated that to be considered a debris flow, the moving material must be loose and capable of "flow", and the particle size must contain a relatively high percentage of coarse fragments (sand-size particles or larger).

According to the values of the statistic parameters of the samples, the following conclusions can be made:

Grain size distribution shows that there are samples with two and three modes. Sample S2, which was taken in the channel, before the check dam, is bimodal, while sample S3, which was taken after the barrage, is trimodal, but both have a main mode around -2,5 φ fraction (fine gravel). The sample, taken from the slope (source area), is trimodal, too, but the main mode is around -4,650 φ fraction (coarse gravel).

The inclusive graphic median (ϕ50) corresponds to the 50 percentile, half of the particles are coarser and the other half are finer. Analysed samples range from -1,522 φ to -3.393 φ. Based on the data, all the samples are fine and very fine-grained.

Mean grain size (M) is indicative of the average size of the grains. In analysed samples, it shows a general predominance of fine gravel in samples S1 and S3, and very fine gravel in sample S2.

Standard deviation (σ) depicts the sorting or uniformity of grains which indicates the prevailing energy conditions at the time of transportation and deposition. The standard deviation of the grain size distribution in the analysed samples is from 1.706 to 2.294, which indicates that all samples are very poorly sorted (S1 and S3) and poorly sorted (S2). That is typical for the debris flows deposition and gives an indication of variable and inconstant current and velocity of the flow.

Graphic skewness (Sk) measures the degree to which a cumulative curve approaches symmetry in terms of the predominance of fine- or coarse–grained fractions. The studied samples are fine skewed (S1 and S3) and very fine skewed (S2).

Graphic kurtosis (K) is a measure of the peak of a curve. Values of kurtosis in the studied sample range from 0.884 to 0.967. Peakedness is mainly dominated by platykurtic behaviour (S1 and S3) which indicates a thinner than normal tail, followed by platykurtic, and mesokurtic behaviour (S2) which corresponds to equal thickness throughout the curve.

Conclusion

The data acquired during the field research, morphometric and laboratory analyses show that in the watershed of the Borovitsa River, debris flows are still active. The occurrence of the debris flows is spontaneous and is triggered by intense rainfall in the areas where weathered and unsoldered materials are available. The petrographic composition of the clasts in the studied area is relatively homogeneous – medium acid lavas, lava breccias, tuffs, tuffites, andesites, and latites but the rocks are highly weathered. The grain size statistics parameters confirm the debris character of the flows and turbulent conditions of transport and deposition. The standard deviation shows very poorly sorted deposits, which is typical for debris flows. The dominant fraction is one of the fine gravel in the source area and after the check dam, and very fine gravel in the debris channel, which is an indicator for not very high energy of the flows. Morphometric parameters of the studied watersheds also confirm the high susceptibility to debris flows.

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