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Research Article

Morphometric characteristics of block streams: A case study of the Vladayska River basin, Vitosha Mountain (Bulgaria)

Petko Bozhkov[1]

1 *Sofia University "St. Kliment Ohridski", Faculty of Geology and Geography, Sofia, Bulgaria*
Corresponding author: Petko Bozhkov (pbozhkov@gea.uni-sofia.bg)

Abstract

Block streams, also known as stone rivers, are common periglacial landforms in the alpine and subalpine zone of the Balkan Peninsula. These features are especially widely spread in the valleys, slopes and summit of Vitosha Mountain. The presented research aims to estimate the total area of block streams and perform morphometric analysis of these landforms within the basin of Vladayska River. Block streams are digitized manually from orthophotographs and topographic maps using GIS software. Morphometric parameters such as area, length, width, elongation ratio and mean elevation are calculated or extracted from a digital elevation model for each polygon. A linear regression test was conducted to evaluate the relationship between morphometric properties. Results indicate a significant correlation between the area and perimeter (R^2 = 0.93) and between the length and width (R^2 = 0.94) of the block streams. Block streams are present in the elevation range between 1177 and 2244 m, covering a total area of 169.7 ha. The largest ones occupy the area of Zlatnite Mostove and Yurushki Most, as well as the vicinity of Cherni Vrah Peak. Their length varies from 5–6 m up to 2.2 km, while their width changes from a few meters up to 0.6–0.7 km. Comparisons between block streams from different sites within the catchment area yield new insights into the diversity of these landforms. Their dimensions and spatial distribution are key to understanding the processes of their formation and evolution.

Key words: Geomorphological mapping, periglacial landforms, stone runs, weathering

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1. Introduction

Block streams, often called stone runs (Washburn 1973) or stone rivers (local Bulgarian toponym), are common features in Vitosha Mountain as well as Pirin and Rila Mountains. They are associated with past or present periglacial conditions and can be found in different areas of the world. These landforms are considered as linear deposits or rock debris (blocks or boulders) with downslope alignment and occupy some hill slopes and valleys (White 1976, 1981; Wilson 2007). One of the largest block streams in Europe is located in Vitosha Mountain (Oliva et al. 2018), in the area of Zlatnite Mostove within the basin of Vladayska River.

Block streams of Vitosha Mountain are mentioned in many studies dating from the 1920s. Most of these studies have a descriptive character and lack quantitative information. Bonchev (1924) and Pushkarov, cited by Bonchev (1924), suggest a hypothesis according to which Vitosha Mountain was covered by a glacier during the Pleistocene, therefore the block streams must be interpreted as moraine materials. This assumption was later rejected by Penck (1925) and Radev (1926). Penck (1925) compares the blocks stream of the area of Zlatnite Mostove with the deposits of Felsberg in the Odenwald Mountain, Germany and denies the possible glaciation of Vitosha due to the absence of typical glacier landforms. Therefore, block stream development is related to the petrographic characteristics of the intrusive rocks and their subsequent weathering. In the 1930s, the block streams of Vitosha were studied by Kosack, cited by Georgiev (1963), who summarizes the existing information at the given time and interprets blocks assuming that they were formed by weathering and erosion during the Pleistocene (Würm glaciation). In the late 1950s, Hristov (1959) interpreted these landforms as glacial moraines from the Würm glaciation and comments on the presence of syenite blocks formed in situ in the catchments of the Vladayska River around the Belite Brezi hut (Hristov 1959). According to Glovnya (1959), block streams are periglacial forms formed as a result of frost weathering. The roundness of the boulders is influenced by rock texture and microtectonics. Georgiev and Petrov (1962) describe a weathering profile in the Zlatnite Mostove area, in which spherical weathering of the intrusive rocks is observed. The space around the rounded boulders is occupied by coarse-grained material (gruss). Erosion and gravity help further transport the boulders and their accumulation in the foothills of the valley slopes and in the river beds. In subsequent publications, Georgiev (1963, 1965) completely denied the glacial origin of the stone runs. The varying degree of roundness and placement of boulders in the block stream at the Zlatnite Mostove site is interpreted as evidence of their in situ formation by weathering (Georgiev 1965). Ananyev and Ananyeva (1994) analyze the granulometric (grain size) and mineralogical composition of the weathering crust in the Zlatnite Mostove area. The authors distinguish two types of stone runs by genesis. Some start immediately from rock escarpments and are composed of coarse material oriented linearly along the valley slopes. Other block streams are located in close proximity to weathering crusts. The latter differ in the degree of roundness of the comprising blocks and boulders. Despite the existence of numerous studies on the topic of stone rivers, quantitative data on the area of stone rivers and their dimensions are still missing. There are reports of the sizes of the largest forms (Oliva et al. 2018), but the exact number of stone runs is unknown. Therefore, the aim of the following study is to estimate the morphometric properties of stone runs within the Vladayska River basin and expand the existing knowledge about these periglacial landforms in terms of quantitative data analysis.

2. Materials and methods

The study area, Vladayska River basin, covers about 150.7 km^2. Vladayska River springs from Vitosha, northwest of Cherni Vrah (2290 m). It flows northwest through the Torfeno Branishte Reserve. Above the village of Vladaya, it flows in a narrow and steep valley, and the waters of the river are led through a channel to the Studena dam (Hristova 2012). After the village, it abruptly changes its direction to the NE, continuing its course between Vitosha and Lyulin Mountains.

It flows through the Sofia Graben Valley and is a left tributary of the Iskar River. The length from the spring area up to the confluence point is about 37.2 km. Block streams occupy only the upper course of the Vladayska River, between Cherni Vrah (2290 m) and Vladaya village (Fig. 1). Their distribution is associated with the outcrops of the intrusive rocks of Vitosha Pluton with Late Cretaceous age (Zagorchev et al. 1991).

Existing block streams within the Vladayska River catchment were delineated as polygons in a Geographical Information System ESRI ArcMap 10.1 (ESRI 2012). All landforms are manually digitized from orthophotos, representing the territory from the period 2010–2012. Topographic maps in different scales ranging from 1:50 000 to 1:10 000 were also used as a supplementary data source. Created vector file (ESRI shapefile) containing all existing geometries is projected in coordinate reference system Universal Transverse Mercator WGS 84 Zone 34N (EPSG 32634). The area, length and width of each polygon are calculated and recorded in the corresponding fields of the attribute table of the layer. Morphometric parameters such as maximum, minimum and mean elevation are extracted from a digital elevation model (DEM) from the Shuttle Radar Topography Mission (SRTM1N42E023V3) with a cell size of 30 m. The DEM is provided by the United States Geological Survey, Earth Resources Observation and Science Center (2014).

The variability of the area of block streams from different sites within the catchment is assessed with the coefficient of variation (Cv), which is calculated as a ratio between the standard deviation (σ) and mean value (μ). Cv proves valuable in comparing datasets with significantly disparate means.

A linear regression model was used in order to assess the relationship between two quantitative variables—dependent (*Y*) and independent variable (*X*) (Till, 1973). The relationship between area (*X*) and perimeter (*Y*), as well as between length (*X*) and width (*Y*) of the block streams were studied. The confidence level of the two tests is set at 95%. Statistical tests were performed using MS Excel 2016 (Microsoft 2016). The length-to-width or shape ratio (Șerban et al. 2019) is used to estimate the degree of elongation of each block stream.

3. Results

The total area of all block streams in the Vladayska River basin is 169.7 ha (1.697 km^2) or about 1.13 % of the whole basin. The mountainous part of the catchment covers 33.99 km^2; therefore, block streams take up 4.99% of the study area (Fig. 1). Stone rivers are represented by 341 individual polygons, the areas of which vary from 0.1 ha to 36.16 ha. Landforms with an area of less than 1 ha predominate (94.1 % of the total count), therefore the average area of stone rivers is 0.497 ha. The largest block streams in the studied area, those with an area more or equal to 10 ha, are a total of 4 and occupy 90.43 ha or 53.29% of the total area of all mapped forms. Their width and length vary within very wide limits. The width of these landforms spans a wide spectrum, ranging from just a few meters up to 678.74 m at the upper limit, illustrating the considerable variation in their dimensions. The length of these forms varies in even greater limits—from 5.71 m to 2168.1 m. Block streams can be observed in both forest and subalpine zones of the mountain between 1177 m and 2244 m above sea level.

The area of interest was divided into several sites where block streams are clustered (Table 1). Individual sizes of landforms vary from just a few hectares up to 36.16 ha in the area of Zlatnite Mostove. The block streams at Edelweiss Hut cover a relatively small area with a low mean area per polygon. The coefficient of variation indicates a moderate level of variation in the polygon sizes (Table 1). Konyarnika features block streams with a slightly larger mean area compared to Edelweiss Hut. The standard deviation and coefficient of variation suggest moderate variability in polygon sizes. Block streams around Selimitsa Peak (2041 m) have a small mean area per polygon, indicating fragmentation. The standard deviation and coefficient of variation show relatively low variation in polygon sizes. Site Yurushki Most features block streams covering a larger total area with a moderate mean area per polygon. The standard deviation and coefficient of variation are relatively high, indicating significant variation in polygon sizes. Site Zlatnite Mostove stands out with block streams covering a substantial total area, and each polygon has a comparatively large mean area. However, there is a high standard deviation, indicating substantial variation in polygon sizes. Site Zvezditsa Hut features block streams with a moderate total area and a moderate mean area per polygon. The standard deviation and coefficient of variation suggest a moderate level of variation in polygon sizes.

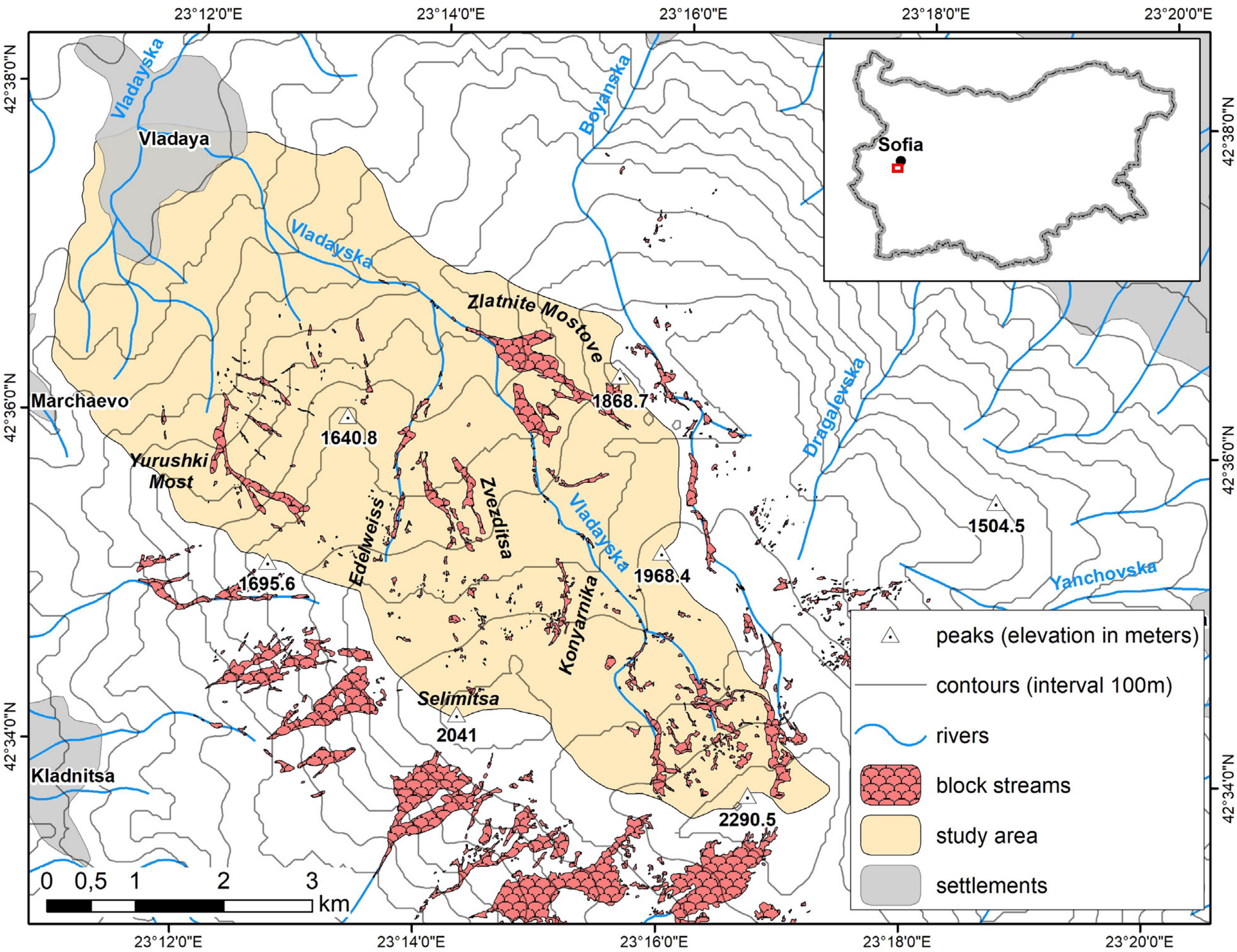

Figure 1. Block stream distribution within the study area.

All sites vary significantly in terms of block stream characteristics. Yurushki Most and Zlatnite Mostove have larger total areas and higher mean areas per polygon, indicating larger and less fragmented block streams. Meanwhile, Selimitsa and Edelweiss Hut have smaller and more fragmented block streams. The standard deviation and coefficient of variation metrics provide valuable insights into the variability of polygon sizes within each site, aiding in the comparison of block stream patterns across these diverse locations.

The elevation data of block streams from various sites offers insights into the vertical positioning of these natural features. The difference between the lowest point and the highest elevation indicates the diverse altitudinal range of the block streams (Table 1). Stone rivers are formed wherever the rocks of the Vitosha Pluton are exposed to the surface. Under modern climatic conditions, periglacial processes (including frost weathering) are most active in the subalpine zone of the mountain.

Table 1. Characteristics of block stream from different sites.

Site	Total area (ha)	Count of polygons	Mean area (ha)	St. Dev. σ	Cv	Elevation (m)		
						min	max	mean
Edelweiss hut	4.05	25	0.16	0.4	2.5	1610	1868	1687.09
Konyarnika	6.01	15	0.40	0.74	1.85	1794	1964	1889.43
Selimitsa	2.46	26	0.09	0.17	1.88	1833	2024	1906.07
Yurushki Most	24.89	57	0.44	2.32	5.27	1177	1743	1409.75
Zlatnite Mostove	50.51	10	5.05	11.54	2.29	1262	1834	1580.40
Zvezditsa hut	16.64	25	0.67	1.54	2.3	1558	1811	1651.03

A linear regression model is used to relate block stream area and perimeter. Most of the observed landforms have an area of less than a hectare and a perimeter of up to 200 m. Multiple R represents the correlation coefficient, indicating a strong positive correlation between the area and perimeter of block streams in the Vladayska River basin. A value close to 1 suggests that the two variables have a strong linear relationship, implying that as the area of block streams increases, so does their perimeter (Table 2; Fig. 2). R Square, also known as the coefficient of determination, explains the proportion of the vari-

Table 2. Relationship between morphometric parameters of block streams in Vladayska River basin.

Regression Statistics		
parameters	**area (X) and perimeter (Y)**	**length (X) and width (Y)**
Multiple R	0.933986122	0.942238171
R Square	0.872330077	0.887812772
Adjusted R Square	0.87195347	0.887481836
Standard Error	281.1073985	23.67794056
Observations	341	341

ation in the perimeter variable (*Y*) that can be predicted from the area variable (*X*). In this case, their areas can explain approximately 87.2% of the variation in block stream perimeters. This high R Square value indicates that the linear regression model effectively captures the relationship between area and perimeter, suggesting that changes in the area account for a significant portion of the changes in perimeter size.

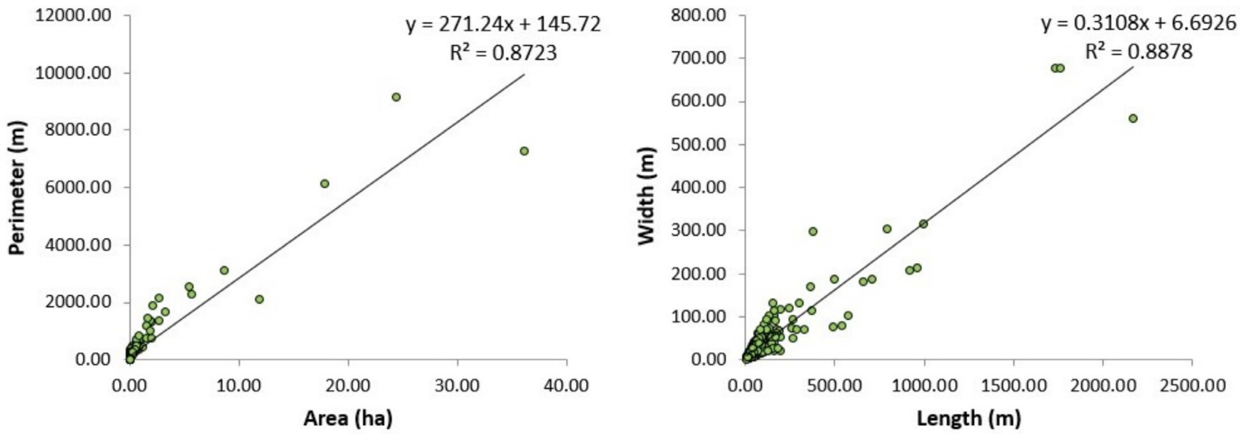

Figure 2. Linear regression analysis of morphometric parameters.

The majority of observed stone runs have lengths and widths of up to 50 m. Only three stone runs exceed 1 km in length, and they are located in different parts of the watershed—in the Zlatnite Mostove and Yurushki Most sites as well as in the vicinity of Cherni Vrah (2290 m) (Fig. 1). The width of stone rivers is not constant and changes along the slope or along the river beds. The multiple R-value of approximately 0.942 indicates a very strong positive correlation between the length and width of block streams in the Vladayska River basin (Table 2; Fig. 2). This suggests a robust linear relationship, indicating that as the length of block streams increases, their width tends to increase significantly as well. The R square value implies that approximately 88.8% of the variation in the width of block streams can be explained by their respective lengths. This high R Square value indicates that the linear regression model effectively captures the majority of the width variation based on length changes. Therefore, length is a significant variable that impacts the width of block streams. The mean length (96.05 m) and width (36.54) of block streams in Vitosha Mountain (Vladayska River catchment) are similar to those from Retezat-Godeanu Mountains, Romania (Șerban et al. 2019).

Length-to-width ratio provides insights into the overall morphology and shape diversity of block streams within the studied area. The elongation ratio varies between 1.07 to 8.89. About three-quarters of all observed landforms (73.9%) have an elongation ratio between 1.00 and 3.00 (Fig. 3), indicating a prevalent trend towards moderately elongated shapes. Within this range, the most common stone runs have an elongation ratio between 1.5 and 1.99, constituting nearly 26.75% of all the measured landforms. Highly elongated forms, with a length-to-width ratio over 5.00, are only 6.16% of all studied stone runs.

The mean value of length to width ratio is 2.54, and it is lower than the average elongation ratio of block streams in South Carpathians—4.9 (Șerban et al. 2019). However, Zlatnite Mostove is considered one of the largest block streams in Europe (Oliva et al. 2018), while the length of block streams in South Carpathians varies between 20 and 504.4 m (Șerban et al. 2019).

Figure 3. Block stream near Cherni Vrah Peak (2290 m) with an area of 24.55 ha, length of 1730.31 m, width of 678.53 m and elongation ratio 2.55.

4. Discussion

Block streams and block fields are considered relic landforms, and those located above 2100 m above sea level are the result of modern periglacial processes (Glovnya 1959; Georgiev and Petrov 1962; Georgiev 1963, 1965). Such forms have also been described at a much lower altitude, including along the northern slope of Stara Planina and in the Medni rid Ridge, located on the Southern Black Sea coast (Georgiev and Petrov 1962; Kanev 1988). The presence of such landforms is explained by the spherical weathering of the intrusive rocks and the transport of the weathered material by ephemeral and intermittent streams. The presence of intrusive rocks from the Vitosha Pluton (syenites and monzonites) has played a significant role in the formation of block streams. According to Gachev (2021) block streams and block seas cover both ridges and inclined surfaces where retention of coarse weathering material is possible while fine-grained debris is constantly removed.

The most recent publications on the subject are related to determining the shape, dimensions, and petrographic composition of the boulders that build up block streams and block fields (Bozhkov 2019, 2020; Sarafov and Krenchev 2020). The elevation data underscores the varying altitude ranges and average elevations of block streams across the different sites in the Vladayska River basin. Some of the lowest stone runs were formed in the Yurushki Most area. They develop in the leucosyenites of the Vitosha Pluton (Zagorchev et. al. 1991), unlike the rest of the block streams, which are the result of the weathering of monzonites and syenites. Probably due to the petrographic differences, these forms are made of smaller boulders, but at the same time, in terms of dimensions (areas, lengths and widths), they do not differ much from the other stone rivers in the Vladayska River Valley. Sarafov and Krenchev (2020) noted variations in boulder sizes and their roundness across various sections of the stone rivers in the Pirin Mountains. The largest blocks are located in the block streams' terminus (lower sections). The boulders in the Zlatnite Mostove site in Vitosha Mountain resemble the shape of a sphere, which is determined by the specific weathering of the granitoid rocks (Bozhkov 2019). The presence of trees along the borders of the block streams and lichen on top of subrounded boulders indicates the inactive state of these landforms (Harris 2016). Boulders remain motionless while running water removes the sandy matrix.

Block streams are a common feature of the landscape in Vitosha Mountain in both forest zones and above the tree line. The lateral boundaries of block streams are difficult to delineate, especially in places where boulders overlap with vegetation, soil and/or peat. A few stone runs are comprised of one compact area of blocks and boulders. The most representative of such landforms are the stone runs in the Zlatnite Mostove and Yurushki Most sites.

Vitosha Mountain is declared a natural park dedicated to conserving the environment. Block streams are considered as rocky habitat type 8110 (siliceous scree of the montane to snow level) of the ecological network NATURA 2000, which also favors the conservation of these landforms as an element of biodiversity and geodiversity of the mountain.

5. Conclusion

The exact age of the formation of block streams in Vitosha Mountain is still unknown due to the lack of absolute dating studies. However, their presence is associated with periglacial climate conditions and active frost action. Previous dating is based only on field observations and morphological characteristics of block streams, such as the presence or absence of vegetation on top of the boulders and their roundness, which is related to their lithology. The presence of block streams in the forest zone of the mountain (for instance Yurushki Most and Zlatnite Mostove stites) suggests their relict origin and current inactivity. The study of relict block streams has its significance in the reconstruction of climate during the Quaternary period and, therefore, for the evolution of the landscape. Block streams were formed during the Pleistocene and continue to evolve during the Holocene, especially in the subalpine zone of the mountain. Nevertheless, block streams are not a reliable indicator of the presence or absence of permafrost under the contemporary climate. Presented quantitative analysis of these landforms enriches our understanding of their morphometric properties. A strong positive correlation between the area and perimeter and between length and width is established. Regardless of the numerous studies on block streams, their significance in the context of climate reconstruction has yet to be fully understood.

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Additional information

Conflict of interest

No conflict of interest was declared.

Ethical statement

No ethical statement was reported.

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Author ORCIDs

Petko Bozhkov https://orcid.org/0000-0003-1374-0916

Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.