

Geomorphometry of the cirques of Shar Mountain

Ivica Milevski^{1,§}, Marjan Temovski^{2,4}, Balázs Madarász³, Zoltán Kern⁴, Zsófia Ruszkiczay-Rüdiger⁴

¹Institute of Geography, Faculty of Sciences, Gazi Baba bb, 1000 Skopje, North Macedonia

³Institute for Geological and Geochemical Research, Research Centre for Astronomy and Earth Sciences; Budaörsi út 45. 1112 4Geographical Institute, Research Centre for Astronomy and Earth Sciences; Budaörsi út 45. 1112 Budapest, Hungary

⁴Isotope Climatology and Environmental Research Centre, Institute for Nuclear Research, Debrecen, Hungary

[§]ivica@pmf.ukim.mk

Abstract— Considering the importance of glacial cirque landforms, identifying and mapping the distribution of the cirques with an analysis of their quantitative features is a very important task. Aside from fieldwork, nowadays this can be accomplished through analysis of digital terrain models. Based on the very detailed 5-m DEM and 0.5-m ortophoto imagery, 55 glacial cirques are identified on the North-Macedonian side of Shar Mountain, and their shape, size, height, slope, and dominant aspect are calculated and presented in this work. Most of the cirques are located between 2100 m and 2500 m a.s.l., and have E, N and NE aspects, steep headwalls and almost flat floors. There is a difference in the altitude and size of the cirques considering their general aspect and overall position.

I. INTRODUCTION

Shar Mountain or Šar Planina (2747 m) is the second-highest mountain range in North Macedonia (after Korab, 2753 m), located in the northwest part of the country along the border with Kosovo. Within the natural borders, it covers an area of 1670 km² of which 840 km², or nearly half, belongs to North Macedonia. This SSW-ENE trending range is about 80 km long, and is part of the Dinaride-Hellenide mountain belt. Mostly it is composed of Mesozoic sediments that overly Paleozoic metamorphic rocks, and are intruded by Jurassic mafic-ultramafic magmatic rocks. Shar Mountain has a considerable area over 2000 m, and despite it is currently unglaciated, it is characterized by a glacial landscape. Its intense glaciation during the Pleistocene was mainly the consequence of its high elevation and the relatively large amount of snowfall caused by the proximity to the Adriatic Sea [1]. As a result of the glacial processes, numerous circues, glacial valleys, and moraine deposits were formed. Despite that most of the attention in the geomorphological studies of Shar Mountain were dedicated to its glacial landscape [2-6], a systematic and quantitative analysis of the glacial landforms is still missing. Besides, all data for the Macedonian part of the mountain are still based on research performed at the the beginning of the 20th century. Therefore, additional research was made using the GIS tools with special emphasis on the geomorphometric analysis of the cirques. Glacial cirques, as typical glacial landforms have several definitions based on their

formation, development, and distribution. As defined by Evans and Cox [7] a cirque is a hollow, open downstream but bounded upstream by the crest of a steep slope (headwall) which is arcuate in plan-view around a more gently-sloping floor. It is considered as glacial if its floor has been affected by glacial erosion.

II. METHODOLOGY

In this work, semi-automated identification and morphometric analyses of the circues on the Macedonian part of Shar Mountain are made. For that purpose, 5-m DEM of the State Agency of Cadaster of North Macedonia is used. This model has a very good average horizontal and vertical accuracy of ±0.8 m, with maximum errors up to ± 3 m [8, 9]. The procedure was based on the visual inspection of the 3D view of the mountain terrain in SAGA GIS and MicroDEM software. Additionally, 3D terrain visualization of Google Earth Pro is used which helps the identification and delineation of circues and U-shaped valleys. The accuracy of the DEM-based identification of cirgues was verified at a few sites on the field during 2017 and 2018. After identification, delineation, and vectorization of the cirques, SAGA GIS software is used for their detailed geomorphometric analyses, including size, altitude, slope, and aspect. Cirque aspect is given as median axis aspect, cirque length (L) as the length of the median axis, cirque width (W) as the longest line perpendicular to the median axis, cirque height (H) as the vertical distance between the lowest and highest point within the cirque boundaries, cirque size as the cube root of volume $(\sqrt[3]{L \times W \times H})$, and circue floor altitude as the modal floor altitude [10-12].

III. RESULTS

Out 100 potential cirques, 55 were identified as typical glacial cirques by careful visual analysis and calculation of terrain slopes from the 5-m DEM of the Macedonian part of Shar Mountains, and the rest were classified as nivation hollows (Fig. 1). Most of the identified glacial cirques occur in the upper parts of the Pena catchment and its tributaries (a total of 16 cirques), as well as in the upper parts of Bogovinska River (15 cirques). A significant number of cirques also occur in the source parts of the Mazdrača and its tributaries (10), followed by Jelovjanska Reka (4),

Ivica Milevski, Marjan Temovski, Balazs Madarasz, Zoltan Kern and Zsofia Ruszkiczay-Rudiger (2020) Geomorphometry of the cirques of Sar Planina:

in Massimiliano Alvioli, Ivan Marchesini, Laura Melelli & Peter Guth, eds., Proceedings of the Geomorphometry 2020 Conference, doi:10.30437/GEOMORPHOMETRY2020_25.

Gabrovnica (3), Palčiška Reka (2), Tearečka Bistrica (2), Rečica-Šapka (2) and Vrutočka River (1).



Figure 1. Map of of glacial cirques and nivation hollows on the Macedonian side of Shar Mountain (left) with the highest cirques around Titov Vrv (2747 m)(right).

The average elevation of the cirques ranges from 1885 m to 2564 m. The mean elevation of all 55 cirques is 2274 m. Most of the cirques are in the altitude range of 2300 - 2400 m (Fig. 2). Their area is between 0.2 km² and 6.0 km², with an average of 1.1 km². Their total area is 64 km². Cirque floor elevations are between 1613 m and 2475 m, and cirque floor areas are between 0.03 and 4.3 km². They are from 177 m to 737 m high, and from 520 m to 3740 m long.

The cirque size is variable (Fig.3), but they are generally larger than what was found for Jablanica Mt. [12]. Most of them are 500-1000 m wide, but they can be much larger, e.g. the cirque of Gorna Lešnica has a diameter of 2.2 km and Krivošijski has a diameter of 2 km. Taken as a complex one, the Bogovinje cirque has a diameter of 3.5 km. However, it features 8 smaller secondary cirques arranged circularly. The width of most circues is greater than their length. The average width of all 55 circues is 1.1 km, while their average length is 0.96 km. In terms of size, it should be noted that Circues with N and NE aspect are in average larger than those of SE and S aspects.



Figure 2. Elevation (m a.s.l.) of the lowest and highest point of the cirques as well as the mean altitude (red dot) of the 55 glacial cirques in the Shar Mountain in North Macedonia, from the highest to the lowest one.



Figure 3. Cirque size (as a $\sqrt[3]{(L \times W \times H)}$) vs mean elevation of the 55 glacial cirques in the Shar Mountain in North Macedonia with the trend line.

Table 1. The average size of glacial cirques of Shar Mountain in relation to aspects: W cirques width (km), L cirques length (km), L_1 cirque ridge (crest) length (km), A area of the cirque (km²), Min - the lowest point of the cirque floor (m, a.s.l.), Max - the highest point of the cirque (m, a.s.l.), H height of the cirque (m), Avg – Mean elevation of the cirques (m, a.s.l.).

Asp.	W	L	L	А	Min	Max	Н	Avg
N, NE	1.08	0.9	3.03	1.08	2096.3	2478.0	381.7	2264.4
S, SE	0.96	0.95	2.98	0.84	2150.4	2530.2	379.8	2327.0

From Table 1, it can be seen that the north-sided cirques lie on average 63 m lower than those on the south sides.

The average cirque size not only decreases with respect to southern aspects but also with elevation (Fig. 3). Specifically, the 25 cirques with average elevation up to 2300 m, are significantly larger than the other 30 cirques with higher elevation, as shown in the Table 2.

Table 2. The average size of glacial cirques of Shar Mountain, by elevation: W cirques width (km), L cirques length (km), L₁ cirque ridge (crest) length (km), A area of the cirque (km²), Min - the lowest point of the cirque floor (m), Max - the highest point of the cirques (m), H height of the cirque (m), Avg – Mean elevation of the cirques (m).

Elevation	W	L	L_1	А	Min	Max	Н	Avg
1885-2300 m	1.32	1.01	3.56	1.48	1968.2	2387.7	419.5	2151.9
2300-2564 m	0.95	0.96	2.95	0.93	2192.3	2584.9	392.6	2365.1

The reason for this is that the glaciers in the higher cirques were smaller, with a smaller feeding area of snowfall. One reason could be that glaciers are more erosive closer to their equilibrium lines, than high above it, within the accumulation zone [13].

¹⁰Be exposure ages of the smallest moraines in the nearby, somewhat lower Jablanica Mt suggest that the glaciers have disappeared from the area before the Holocene. Future research will confirm whether some of the cirques in the Shar Mt. hosted small glacierets during the Holocene or even during the Little Ice Age between the 15th and 18th centuries. The steepness of the sides of some of the highest cirques with northern exposure, as well as the freshness of moraine material beneath them, indicate that this is very likely. In fact, the small modern-day glacier "Snejanika" on Pirin Mountain in Bulgaria (which is the southernmost in the Balkan Peninsula and among the southernmost in Europe [14, 15]), is at an elevation of 2450 m, at a similar latitude as the Shar Mountain.

The Shar Mountain cirques feature steep sides in the headwalls and more or less flattened bottom (floor). Some cirque headwalls have almost vertical sides, especially if they are incised into massive rocks, or if they are intersected with faults. Such are the cirques on the east side of Ceripašina, and the two cirques under the peak Ezerski Vrv (2586 m). In general, the slopes of the cirque headwalls are 30-50°, however, since the floor is relatively flat, the average slope of the cirques as a whole is significantly lower (Fig. 4). It should be noted that some of the larger cirques are hosting one or two secondary or nested cirques. Therefore, the longitudinal profile of these cirques is with steps between two cirque floors.

In terms of cirque aspects, the most common are cirques open to the E, N and NE, followed by those with a SE aspect (Fig. 5). Cirques with southwest and west aspect have not been identified in the study area, but this is mostly due to the fact that the study area comprises the eastern slopes of the range. Cirques with N and NE aspect are generally with larger dimensions and a significant amount of moraine material along their floor. At the bottom of some cirques, lakes are formed in the post-glacial period. Probably their number was much higher in the past, while today there are about 30 permanent and periodical glacial lakes.



Figure 4. Average slope of the 55 glacial cirques in the Shar Mountain.



Figure 5. The number of cirques on Shar Mountain in regard to the dominant aspects.

Apart from the cirques, the U-shaped glacial valleys are a significant feature of the glacial landscape of Shar Mountain. With the same procedure as for the cirques, 26 U-valleys are identified in the study area. Their length is between 0.5 km and 4.7 km, while their average length is 1.5 km. Similar to cirques, they extend mostly to the N, NE, and E, and there is none with southwest or west direction, because the study area occupies the eastern side of the range. The average elevation of the glacial

valleys is between 1990 m and 1734 m a.s.l. This means that their vertical range is about 250 m. One of the most characteristic glacial valleys of the study area is the upper valley of Mazdrača (Fig. 6).



Figure 6. Cirques (up) and trough (bottom) of Crno Ezero Lake in the upper part of Mazdrača Valley on Shar Mountain.

III. CONCLUSION

In terms of glacial landscape, Shar Mountain has the most spectacular glacial landscape of all high mountains (higher than 2000 m) in North Macedonia. In this study 55 glacial cirques and 28 glacial valleys have been identified. Most of the cirques are located between 2100 m and 2500 m a.s.l., with E, N, and NE aspect, steep headwalls and almost flat floors. There is a difference in the elevation and size of the circues considering their general aspect. Generally, cirque elevations rise southward which is in line with the findings of Kuhlemann et al. [6]. The morphometric analysis of the cirgues showed that most of the cirques are well developed. The wide and open cirques together with deep and stepped glacial valleys with several thresholds might suggest that glacial erosion during the most extended glacial phases was displaced from the cirques down valley to a position closer to the former equilibrium line altitude, as it was proposed for the Jablanica Mt. [12, 13]. The development stage of the cirques may refer to more dynamic cirque glaciers in the deeper, better developed cirques and less dynamic and/or shorterlived glaciers in the poorly developed ones.

Acknowledgements: This research was funded by the National Research, Development and Innovation Office of Hungary grant NKFIH FK 124807.

REFERENCES

- [1] Milevski, I., 2015. "General Geomorphological Characteristics of the Republic of Macedonia". Geographical Reviews, 48, Skopje, 5-25.
- [2] Cvijić, J., 1881. "Eine Besteigung des Sardagh. Sonderabdruck aus dem XVI. Jahresberichte des vereines d. Geographen a. d. Universität, 1-8, Wien.
- [3] Cvijic, J., 1903. "New results on the glacial epoch of the Balkan Peninsula". Voice. SAN, LXV, Belgrade (in Serbian).
- [4] Nikolić, R.T., 1912. "Glaciation of Shar Mountain and Korab". SGD 1 Gazette, Belgrade, 72-79 (in Serbian).
- [5] Smiljanić, T., 1929. "Glacial traces on Shar Planina, Korab, Krcin and Stogovo". SGD Gazette 15, Belgrade, 118-119 (in Serbian).
- [6] Kuhlemann, J., Milivojević, M., Krumrel, I., Kubik, P., 2009. "Last glaciation of the Šhara Range (Balkan Peninsula): Increasing dryness from the LGM to the Holocene". Austrian Journal of Earth Sciences v.102, Vienna, 146-158.
- [7] Evans, I. C. N., 1974. "Geomorphometry and the operational definition of cirques". Area, Volume 6, 150-153.
- [8] Milevski, I., Gorin, S., Markoski, B., Radevski, I., 2013. "Comparison of Accuracy of DEM's Available for the Republic of Macedonia". Proceedings from the 3rd International Geographic Symposium -GEOMED 2013, Kemer, Antalya, Turkey, 10-13 june, 2013, 165-172.
- [9] Milevski, I., 2014. "Slope Values Accuracy vs Resolution of the Digital Elevation Models (Example of the Republic of Macedonia)". Proceedings of 5th ICC-GIS Conference; Eds: Bandrova T & Konecny M., Vol. 2, Varna, 568-575.
- [10] Ahmadabadi, A., Sargsyan, V., 2016. "Geomorphometry of the glacial cirques in Zardkuh Mountain, Iran. Annals of Valahia University of Targoviste. Geographical Series (2016), 16(2): 94-101.
- [11] Barr I.D., Spagnolo M., 2015. Glacial cirques as palaeoenvironmental indicators: their potential and limitations. Earth-Science Reviews, 151, 48-78. DOI: 10.1016/j.earscirev.2015.10.004
- [12] Temovski M., Madarász B., Kern Z., Milevski I., Ruszkiczay-Rüdiger Z., 2018. Glacial geomorphology and preliminary glacier reconstruction in the Jablanica Mountain, Macedonia, Central Balkan Peninsula. Geosciences, 8, 270.
- [13] Ruszkiczay-Rüdiger Z., Kern Z., Temovski M., Madarász B., Milevski M., Braucher R., ASTER Team, 2020. Last deglaciation in the central Balkan Peninsula: geochronological evidence from the Jablanica Mt. (North Macedonia). Geomorphology, 351, 106985.
- [14] Gachev, E., Stayanov, K., Gikov, A., 2016. Small glaciers on the Balkan Peninsula: State and changes in the last several years. Quat. Int. 415, 33-54.
- [15] Hughes, P.D., 2010. "Little Ice Age glaciers in Balkans: low altitude glaciation enabled by cooler temperatures and local topoclimatic controls". Earth Surface Proc. and Landf. 35, 229-241.