ASSESSMENT OF THE INFLUENCE OF RELIEF ON TERRACING OF THE SLOPES OF THE MAKAZHOY BASIN IN THE CHECHEN REPUBLIC (BASED ON THE MATERIALS OF AIR LASER SCANNING)

Raya Bekmurzaeva[1], Ivan Baranov[2], Vitaliy Bratkov[1,2]

•

[1]Chechen State University of A.A. Kadyrov, Grozny, RUSSIA
[2]Moscow State University of Geodesy and Cartography, RUSSIA
raya.bek@yandex.ru

Abstract

In September 2023, an unmanned aerial vehicle was used to conduct airborne laser scanning and aerial photography in the Makazhoy Basin, where the carbon testing ground of the A.A. Kadyrov Chechen State University is located. As a result, a highly accurate digital elevation model (DEM) was compiled for areas of about 170 hectares located on opposite macroslopes of the basin at comparable hypsometric levels (1700-2200 m). Subsequent processing of the DEM using ArcGis software allowed us to quantitatively characterize the microrelief of the test sites and identify, based on morphometric analysis and semi-automated interpretation, the terraces on the mountain slopes that were previously used for agriculture. It was found that the previously existing settlement and farming system in this area took into account the natural resource potential of the mountain slopes. In this regard, the northern macroslopes of the Makazhoy Basin are characterized by greater productivity of natural ecosystems compared to the southern ones. The consequence of these natural causes is that the terraces on the northern macroslope occupy 46% of the test site area, while on the southern one - 26%.

Keywords: Makazhos basin, carbon landfill, aerial laser scanning, unmanned aerial vehicles, digital terrain model, terraces

I. Introduction

Currently, the process of involving mountain territories in economic turnover is accelerating. If in the second half of the 20th century, depopulation of the mountains and a decrease in economic activity were noted here, now they are again attracting attention from the point of view of economic development. This is, not least, due to the fact that the quality of agricultural products produced in the mountains is often higher due to the lower level of pollution of these territories. However, the process of re-involving mountain territories in agricultural turnover should be based on the principles of sustainable development, implying the preservation of the habitat and the minimization of the negative impact on the environment. This is possible on the basis of comprehensive information about the area of economic development.

In the North Caucasus, including the territory of the Chechen Republic, mountainous territories were used for distant-pasture livestock farming. In the warm season, mainly small cattle were driven to high-mountain pastures, where they stayed for almost the entire warm period. In the cold period, they were driven to the flat part, where they wintered. However, within the mountain basins, it was possible to keep farm animals all year round, which was facilitated by natural conditions. Basins are closed territories to varying degrees, formed either by the main ridges or confined to the valleys of the largest rivers. This kind of isolation leads to the formation of a warmer and drier climate and a wider range of soil and plant groups, the spatial distribution of which is determined by local relief features. In this regard, mountain basins were populated and developed quite a long time ago throughout the entire territory of the North Caucasus. This is especially expressed in the largest and most clearly expressed tectonic depression, located to the south of the Rocky Ridge – the North-Jurassic. The basins in the Inner-Mountain Dagestan are also widely expressed.

In this regard, our research covered the Makazhoyskaya depression, located in the southeastern part of the Chechen Republic, on the border with Dagestan. The orographic boundaries of the depression are expressed differently and are represented by a number of ridges.

In the north, the border runs along the Kashekrlam ridge, which further northeast approaches Lake Kezenoy-Am. The eastern border is confined to the spurs of the Gagotytlyur ridge. The southeastern border extends along the local watershed with heights of up to 2500-2600 m. From it, in the Ansalty canyon, the orographic line extends to the south and is expressed by the Khindoy-lam ridge, extending strictly to the west, where at the extreme western point the orographic line extends strictly to the north, after which it turns east-southeast to the watershed between the Akhkete River basin (a tributary of the Ansalty) and the Keloy-akhk, which flows into the Sharo-Argun. The area of the basin within the specified boundaries is 144 km² (Fig. 1, 2).

Figure 1: *Chechen Republic. Physical map*

Interest in the Makazhoy depression is also associated with the fact that the carbon testing ground of the Chechen State University named after A.A. Kadyrov is located here, one of the tasks of which is to develop a methodology for regenerative livestock farming in mountainous conditions.

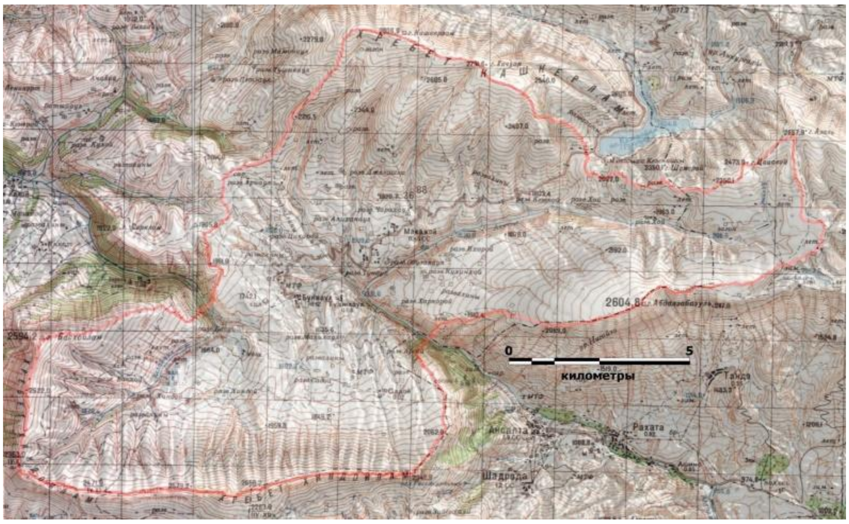


Figure 2: *Position and orographic features of the Makazhoy basin*

Previously, an analysis of the relief of the depression was carried out based on the digital elevation model of the average spatial resolution of the European Space Agency FABDEM V1-0 with a resolution in this part of about 27 m [3] using standard methods [4-6]. It was found that the depression is dominated by heights of 1600-2000 m, which account for 43.0% of the territory, the most common slopes are 10-15 ° (23.8%), 20-30 ° (23.5%) and 5-10 ° (19.7%). As for the exposure, the southern (16.6%) and northwestern (16.2%) slopes are most widely represented. These macro-exposure differences determined not only the distribution of the soil and vegetation cover across the basin, but also its economic development, which manifested itself in the terracing of the slopes. They are reflected in the modern microrelief, are clearly visible during a visual inspection of the territory and are its peculiarity. However, they are not revealed by the global digital elevation model due to its low spatial resolution. In this regard, detailed high-precision studies based on other methods are necessary.

Currently, unmanned aerial vehicles (UAVs) are actively used to obtain detailed information about the microrelief of a territory, which allows for prompt receipt of information at a local level [1, 2]. Aerial photography (AP) and airborne laser scanning (ALS) are used for these purposes. These high-tech methods of collecting geospatial data allow for obtaining detailed digital models of relief and terrain, as well as orthophoto plans, which are then used for geospatial analysis of mapped territories.

II. Methods

In the autumn of 2023, field studies and airborne geodetic works were carried out in the Makazhoy Basin, which included geodetic works, aerial photography and airborne laser scanning [7]. The survey sites were located in the eastern part of the basin in the altitude intervals of 1700-2200 m and covered 2 sites. Highly detailed AFS was carried out on 2 sites. The first of them is the territory of the carbon test site of the A.A. Kadyrov ChSU, where the regenerative livestock farming technology is being developed, located on the northern macroslope of the Makazhoy Basin. The area of this site is 168.0 hectares. The second site is located on the opposite, southern macroslope of the basin, and occupies an area of 169.4 hectares (Fig. 3).

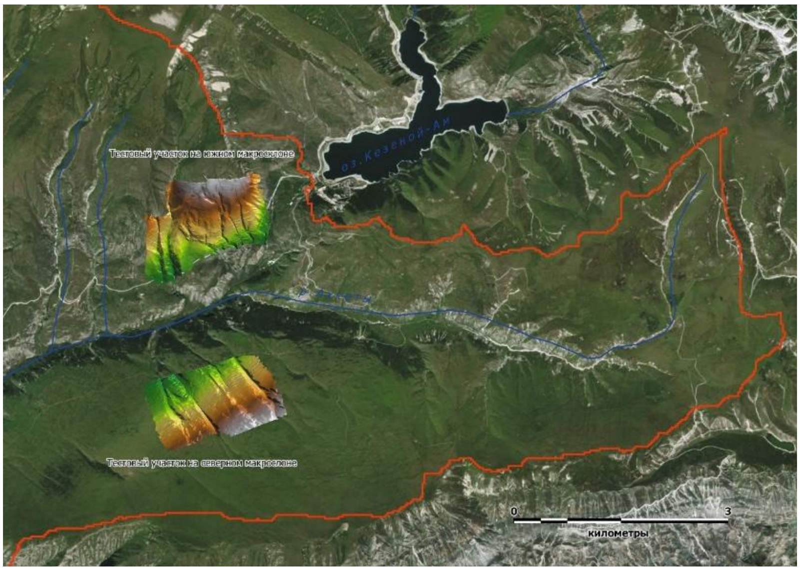


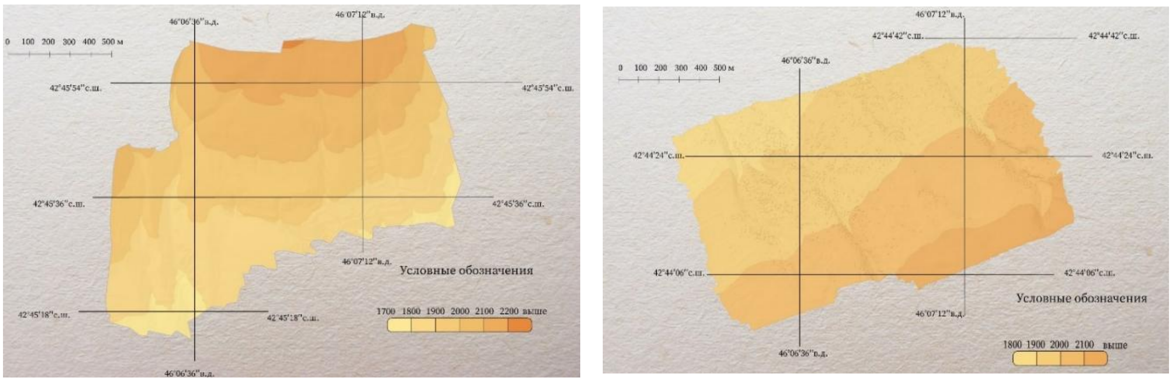
Figure 3: *Location of test sites within the Makazhoy basin*

Aerial photography and airborne laser scanning were carried out using the GEOSCAN 401 Lidar UAV by staff and students of the Moscow State University of Geodesy and Cartography and the A.A. Kadyrov Chechen State University. Photogrammetric processing of the aerial photography results was performed using Agisoft Metashape software. Point clouds obtained using the UAV were processed in Terrascan and Credo 3D SCAN software. As a result, it became possible to separate points into the "land" and "vegetation" classes, and highly accurate digital elevation models with a resolution of 0.1 m were compiled [7]. To remove information "noise" associated with the presence of different-height, mainly herbaceous vegetation, the original resolution was reduced to 0.5 m, which made it possible to more accurately identify the features of the microrelief itself.

Mapping and analysis of the DEM was carried out using ArcGis software. Maps of the areas were created at a standard scale (1:10,000). An individual projection was selected for the coordinate grid (PROJCRS ["ProjWiz_Custom_Lambert_Azimuthal", BASEGEOGCRS ["WGS 84", DATUM ["World Geodetic System 1984", ELLIPSOID ["WGS 84",6378137,298.257223563, LENGTHUNIT["metre",1]], ID ["EPSG",6326]]).

III. Results

The distribution of the test areas by elevation marks is illustrated in Fig. 4 and Table 1



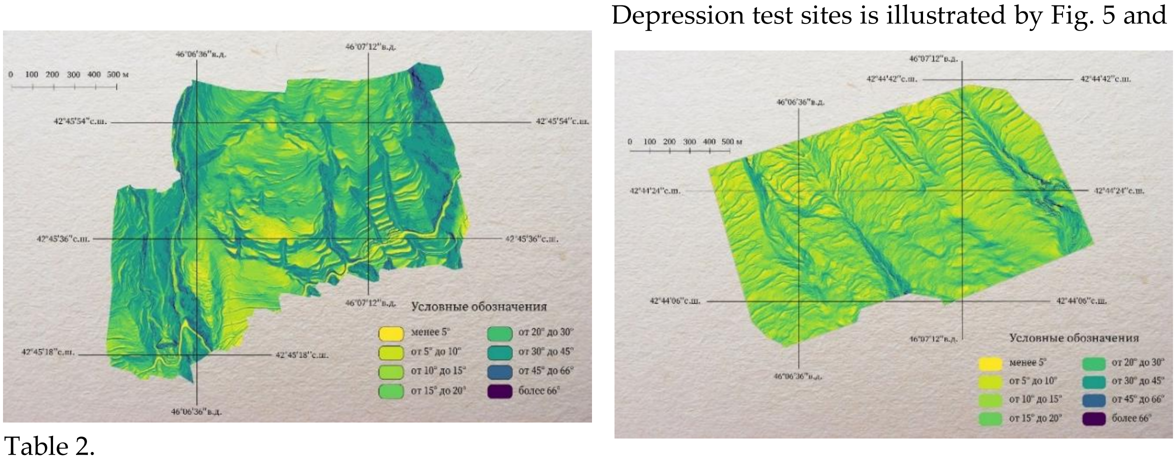
a) section of the southern macroslope *b) section of the northern macroslope*

Figure 4: *Hypsometric map of the southern (a) and northern (b) macroslopes of the Makazhoy basin*

Table 1: *Distribution of the test site area by elevation marks*

Height, meters	Southern macroslope		Northern macroslope	
	hectare	%	hectare	%
1700-1750	0,7	0,4		
1750-1800	9,6	5,7		
1800-1850	22,1	13,1	0,4	0,2
1850-1900	27,2	16,0	17,0	10,1
1900-1950	22,8	13,5	35,3	21,0
1950-2000	24,4	14,4	37,5	22,3
2000-2050	20,7	12,2	36,9	22,0
2050-2100	18,5	10,9	25,8	15,4
2100-2150	14,3	8,4	14,7	8,8
2150-2200	9,2	5,4	0,3	0,2
TOTAL	169,4	100,0	168,0	100,0

As can be seen from the presented data, there is a well-defined asymmetry in terms of the distribution of areas by elevation marks. Thus, on the southern macroslope, where the range of elevations is almost 100 m greater than on the northern one, the main territories are confined to the heights of 1800-2000 m, after which the areas of territories located in the highlands begin to shrink. As for the northern macroslope, here the heights of 1900-2050 m account for more than 65% of the territory, and at the same time the most elevated areas are more widespread compared to those occupying the lowest hypsometric levels. It is also clearly visible that the northern macroslope is much more gentle than the southern one, which well illustrates the distribution of the territory by slope steepness. The change in steepness on the slopes of the Makazhoyskaya Depression test sites is illustrated by Fig. 5 and Table 2.



a) section of the southern macroslope *b) section of the northern macroslope*

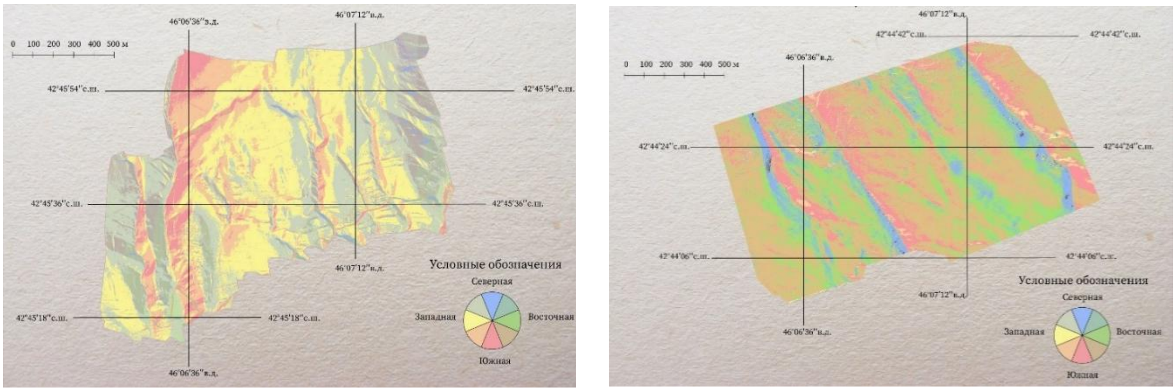
Figure 5: *Map of the steepness of the slopes of the southern and northern macroslopes of the Makazhoy basin*

The presented data indicate that the distribution pattern of steepness on the macroslopes is generally opposite. The steepest (more than 45°) and the most gentle (less than 5°) slopes occupy the smallest areas on both slopes. On the northern macroslope, where the regenerative livestock farming site is located, slopes with a steepness of 10-15⊚ are most widely represented (29.2°), and steeper (15-20°) and gentler (5-10°) slopes are also quite widely represented (21.3 and 20.3%, respectively). As the steepness increases, the area of the slopes decreases. As for the southern macroslope, a gradual increase in the area of slopes up to a steepness of 30-45° is noted here, which account for 33.3%. The larger area of steep slopes on the southern macroslope is explained by the large amount of solar radiation coming here and contributing to more active geomorphological processes. In particular, here, compared to the area located on the northern macroslope, erosional relief forms are presented more widely, aerosional cuts, to which the steepest slopes are confined, have become more widespread.

Table 2: *Distribution of the test site area depending on the steepness of the slopes*

Slope, degrees	Southern macroslope		Northern macroslope	
	km ^{2}	%	km ^{2}	%
0-5	4,2	2,5	8,0	4,7
5-10	11,2	6,6	34,1	20,3
10-15	17,0	10,0	49,0	29,2
15-20	23,3	13,8	35,7	21,3
20-30	46,5	27,4	31,5	18,8
30-45	56,4	33,3	8,6	5,1
45-66	10,3	6,1	0,9	0,5
66 и более	0,4	0,2	0,2	0,1
TOTAL	169,4	100,0	168,0	100,0

Distribution of slopes depending on their exposure on the test sites of the Makazhoyskaya depression is illustrated in Fig. 6 and Table 3.



a) section of the southern macroslope *b) section of the northern macroslope*

Figure 6: *Map of the exposure of the slopes of the southern and northern macroslopes of the Makazhoy basin*

Table 3: *Distribution of the test site area depending on the slope exposure*

Exposition	Southern macroslope		Northern macroslope	
	га	%	га	%
North	0,4	0,2	37,1	22,1
Northeast	2,6	1,5	10,2	6,1
East	24,1	14,2	2,2	1,3
Southeast	44,8	26,4	1,7	1,0
South	60	35,4	2,2	1,3
Southwest	25,3	14,9	5,7	3,4
West	11	6,5	24,7	14,7
Northwest	1,2	0,7	84,2	50,1
TOTAL	169,4	100,0	168,0	100,0

As in the case of slope steepness, the opposite pattern of distribution of this parameter is generally observed. Thus, due to the fact that the carbon polygon area is confined to the northern macroslope of the Makazhoyskaya Basin, the slopes of the north-western (50.1%), northern (22.1%)

and western (14.7%) are most widely represented here, i.e. 86.9% of the entire area of the area. In the second test area, the southern (35.4%) and south-eastern (26.4%) are most widely represented, i.e. more than 60% of the territory. Nearby areas have north-western and eastern slopes (about 14%). That is, the test sites in these areas of the Makazhoyskaya Basin are located on its north-western and south-eastern mesoslopes.

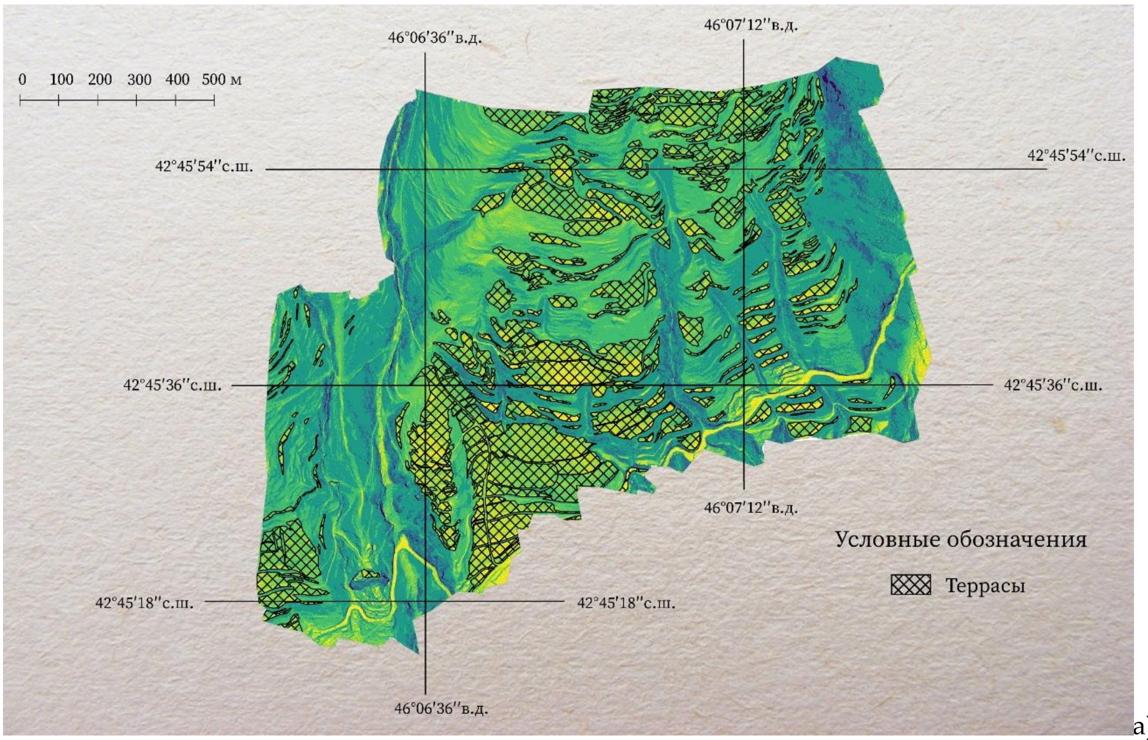
The provided maps, created on the basis of the DEM, also allowed to compile a map of terraces, which were created by the population to intensify mountain nature management. In terms of relief, terraces are sections of mountain slopes, the steepness of which is reduced by creating retaining walls. As a result, these flattened sections can be determined quite well on the basis of the digital elevation model.

Terrace mapping is based on 3 groups of methods: manual, semi-automatic and automatic. Preliminary analysis of the initial data showed that the most accurate result is obtained by combining manual and semi-automatic methods. During the preliminary analysis, the semi-automatic method with vectorization using preliminary selection of terraces using manual tracing was recognized as the most accurate. This method combines both the best accuracy and the time spent on vectorization with the supporting requirements for the data.

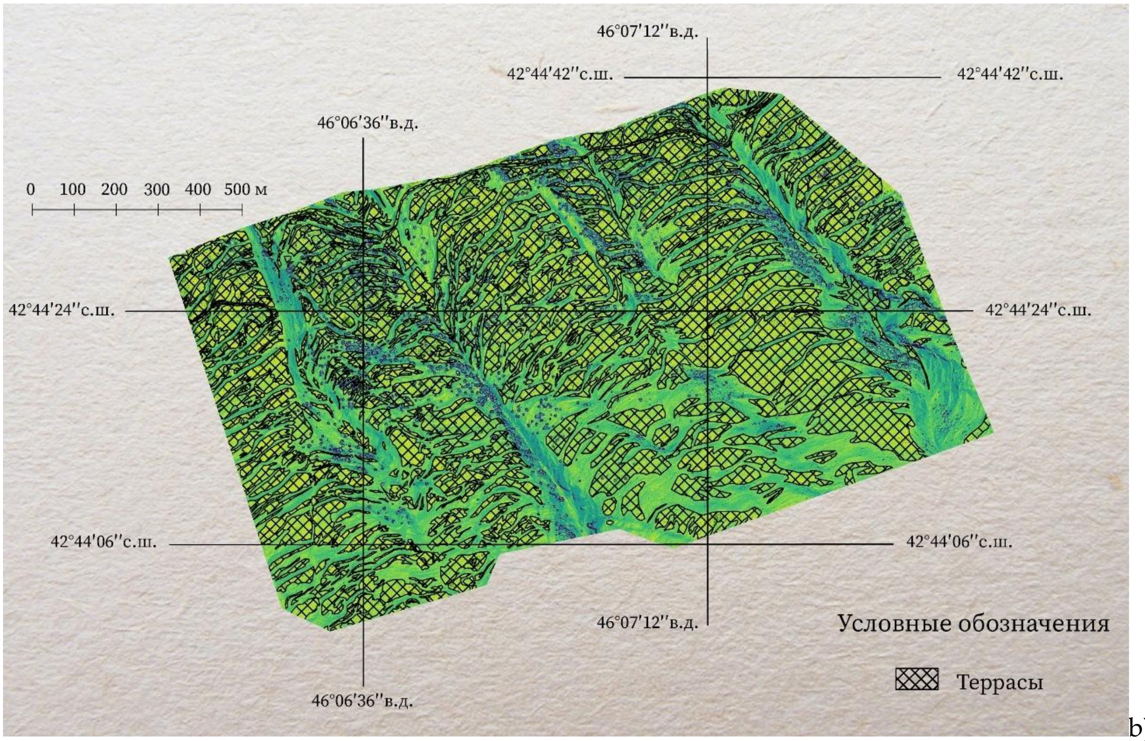
The results of terrace selection based on the DEM within the Makazhoy Basin are illustrated in Fig. 7.

The calculations showed that with a total area of the southern macroslope of the Makazhoy Basin of 169.4 hectares, the area of the terraces is 44.1 hectares, or 26% of the territory. The test site of the regenerative livestock farming site of the A.A. Kadyrov CheSU, confined to the northern macroslope of the Makazhoy Basin, has an area of 168.0 hectares, of which the terraces occupy 76.6 hectares, or 46%.

The maps clearly show that only slopes with minimal steepness were subjected to terracing. To increase the efficiency of agricultural management, it was necessary to create single, largest-area terrace sections, which was achieved to the maximum extent on the northern macroslope. As for the southern macroslope, the fragmentation and mosaic nature of the terraces is quite well expressed here, which is expressed in the presence of a fairly large number of small fragments, most widely represented in the eastern part of the test site. The high degree of agricultural development of the territory is confirmed by the presence of a large number of ruins reflected on late Soviet topographic maps (Fig. 8), reflecting the state of the area in the 1980s. They clearly show that all areas of the basin were intensively developed. The southern macroslope was used to the greatest extent for construction and residence, while the northern slope, apparently, was used for hayfields and pastures due to the better productivity of pastures, since the settlements here are confined to the part that adjoins the Akhket River.



a)



b)

Figure 7: *Map of the terraces of the southern (a) and northern (b) macroslopes of the Makazhoy basin*

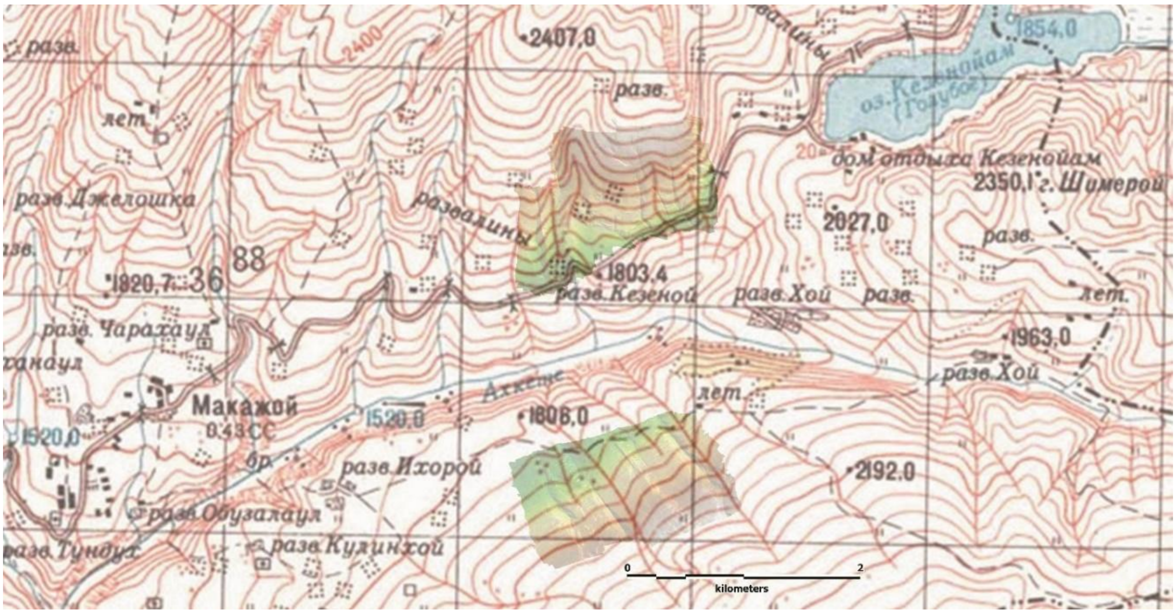


Figure 8: *Fragment of a topographic map illustrating the historical aspect of the degree of economic development of the territory*

IV. Discussion

The conducted study allowed to conduct a comparative analysis of the relief of the southern and northern macroslopes of the Makazhoy Basin based on a series of large-scale morphometric maps obtained on the basis of a digital elevation model. The latter was created by airborne laser scanning during the survey from a unmanned aerial vehicles.

A comparative analysis of the distribution of morphometric indicators (hypsometry, steepness and slope exposure) revealed that on test sites comparable in absolute height and occupied area, the northern macroslopes of the Makazhoy Basin are characterized by generally more gentle slopes. It is this fact that makes it possible to suggest that this parameter is decisive for their terracing in order to intensify economic use. This fact is confirmed by the fact that terraces on the northern macroslope occupy 46%, while on the southern one they are almost twice as small (26%). The created digital elevation models allow for a quantitative assessment of the processes of formation of phytomass reserves and its products at the local level, and in combination with microclimatic observation data, they can serve as a basis for GIS modeling of productivity and the possibility of developing optimal loads on pastures.

The research was conducted as part of the implementation of a state assignment *FEGS-2023-0008.*

References

[1] Wei Zhao, Meini Wang, V. T. Pham, and R. Mo. 2023. Unmanned Aerial Vehicle and Geospatial Analysis in Smart Irrigation and Crop Monitoring on IoT Platform. Mob. Inf. Syst. 2023 (2023). https://doi.org/10.1155/2023/42136454. 3

[2] White, C.T.; Reckling, W.; Petrasova, A.; Meentemeyer, R.K.; Mitasova, H. Rapid-DEM: Rapid Topographic Updates through Satellite Change Detection and UAS Data Fusion // Remote Sens. 2022, 14, 1718. https://doi.org/10.3390/ rs14071718 6

[3] Bekmurzaeva R.Kh., Skripitsyna T.N., Bratkov V.V., Bulaeva N.M. Morphometric characteristics of the relief of the Makazhoy depression (Chechen Republic) // Monitoring. Science and Technology. 2024. No. 1 (59). P. 47-54.

[4] Pogorelov A.V., Dumit Zh.A. Relief of the Kuban River basin: Morphological analysis.

Moscow: GEOS. 2009. 208 p.

[5] Simonov Yu. G. Morphometric analysis of the relief. - M.-Smolensk: Publishing House of Smolensk Humanitarian University, 1998. - 272 p.

[6] Simonov Yu. G. Explanatory morphometry of the relief. - M.: GEOS, 1999. 251 p.

[7] Skripitsyna T.N., Vorotylov A.G., Kochneva D.A., Smirnov E.A. Some results of the integrated expedition of MIIGAiK to the Chechen Republic // GEOPROFI, 2024, M: OOO Information Agency GROM No. 2. P. 10-17.