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ASSESSMENT AND MAPPING OF THE MUDFLOW PHENOMENA INTENSITY IN CHARYN STATE NATIONAL NATURAL PARK

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Abstract: The aim of the article is to present the results of assessing the occurrence intensity of mudflow phenomena in the territory of the Charyn State National Natural Park (SNNP). The assessment and mapping of mudflow phenomena was carried out using field methods, comparative analysis of field materials, and a cartographic method. Based on indicators such as lithological composition of rocks, vertical dissection, surface slope and vegetation the assessment using number score was carried out and map of the territory of the Charyn SNNP was created. Thus, areas of tourist and recreational activity are susceptible to a high degree of mudflow phenomena.

Keywords: mudflow phenomena, state national natural park, assessment, mapping, occurrence intensity of mudflow phenomena

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INTRODUCTION

Mudflows are one of the most dangerous natural phenomena in mountain areas that could destroy infrastructure and affect the ecosystems (Nikolova et al., 2020). Literary review of local and international experience shows that many works are devoted to the assessment and mapping of mudflow phenomena in different territories. Medeu A.R. reviewed the scientific and applied aspects of managing mudflow processes to ensure the safety of the population and socio-economic facilities. The author also discusses issues related to the assessment and mapping of mudflow hazards in the Kishi and Ulken Almaty River basins (Medeu, 2011; Medeu et al., 2019).

Tasbolat B. presented materials on the process of risk mapping, based on an analysis of the methodology of various authors, for the mountain and foothill regions of South-Eastern Kazakhstan (Tasbolat et al., 2015). Yafyazova R.K. in her monograph gives a systematic description of the nature of mudflows in the Ile Alatau and an assessment of the mudflow activity of the ridge (Yafyazova, 2007).

Perov V.F. reviewed the nature of mudflows, methods of their study, the geography of mudflow phenomena, the state of forecasting and protection measures (Perov, 2012). Stupin V.P. in the article examines the principles of mapping and the methodology of morphodynamic analysis of mudflow processes. The sources and capabilities of freely available remote sensing materials, digital terrain models and programs for their processing in geoinformation mapping of mudflow hazard in the Baikal mountainous country are analyzed (Stupin et al., 2017; Stupin et al., 2020). Genevois R. describes a procedure for assessing mudflow hazard in the Eastern Dolomites. The procedure consists of a geomorphological and geological study to identify potential debris flow sources and estimate the volume of future debris flows in each basin (Genevois and Tecca, 2008). Cheng W. interpreted mudflow valleys based on ALOS satellite images, then extracted their drainage basins based on ASTER GDEM data using ArcGIS software (Cheng et al., 2016).

Lima I.F. in the article characterizes morphometric indicators in areas where mudflows occurred (Lima et al., 2020). Dlabáčková T. describes the morphology of the observed mudflow and assesses the conditions of mudflow formation (Dlabáčková and Engel, 2022). In the work of Nikolova V., a morphometric analysis of the mudflow basins of the Eastern Rhodopes was carried out using geospatial technologies (Nikolova et al., 2020).

Mussina A. et al. created a database based on GIS technologies on mudflow phenomena and risks, developed for the mountainous regions of Central Asia (Mussina et al., 2023). Among the geomorphological processes occurring in steep mountain catchment areas, mudflows can be considered one of the most dangerous phenomena (Blasone et al., 2014; Medeu et al., 2022). Therefore, it is extremely important to study the risks of mudflows and propose professional mitigation measures based on hazard mapping (van Westen et al., 2006; Qing et al., 2020).

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THE STUDY AREA

The study area covers the territory of the Charyn SNNP, including the Sharyn River valley from the bridge near the Kurtogay settlement in the south to the beginning of the delta in the north as well as the area of foothill plains and intermountain depressions on both sides of the river (Figure 1). The total area of the Charyn SNNP is 127 050 hectares.

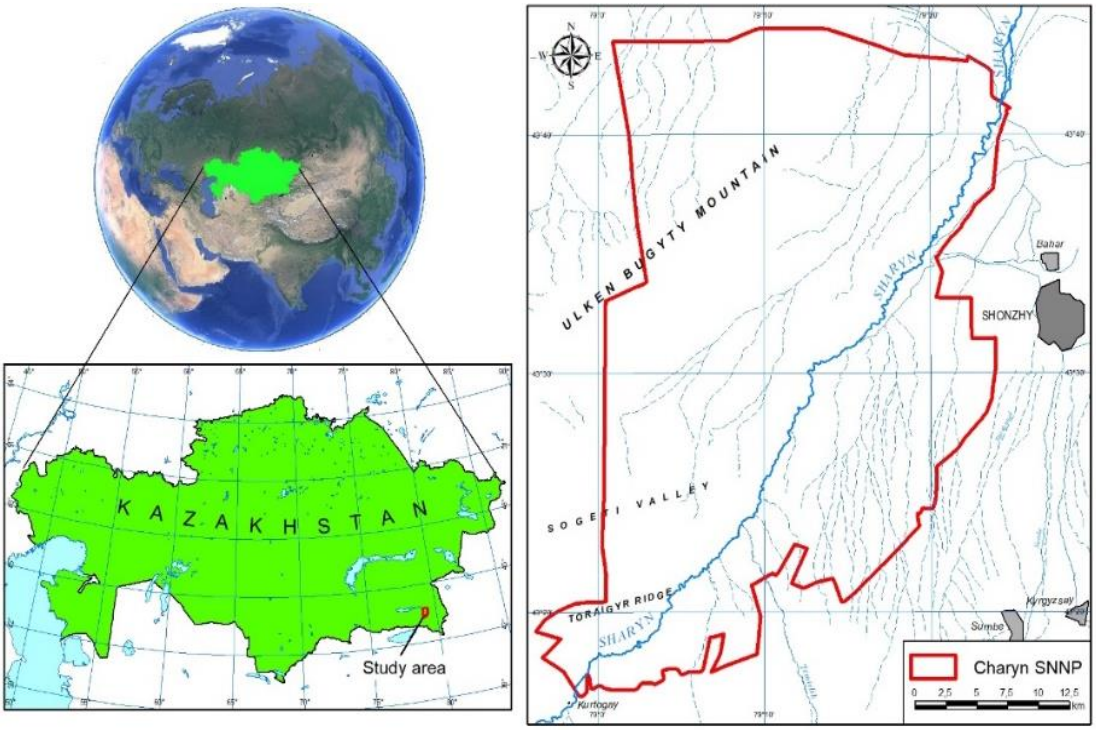

Figure 1. Overview schematic map of the Charyn SNNP location

The territory of the Charyn SNNP is exposed to various hazardous phenomena and processes that pose a threat to tourists and create risks for the further development of the national park. In 2021, in the Charyn SNNP, in the zone of tourist and recreational activities, mudflow occurred, initiated by heavy rain and hail, which resulted in the death of 2 people. This tragic incident showed that mudflows in such a popular tourist area cannot be ignored.

Most mudflows are characterized by large magnitudes, high velocities and mixed flows of sediment and water, which pose a potentially serious threat to residents and tourism infrastructure (Jakob, 2015; Gregoretti and Fontana, 2008; Gregoretti et al., 2016, Dias et al., 2022). The aim of the article is to determine the degree of manifestation of mudflow phenomena on the territory of the Charyn SNNP for the safe use of nature.

MATERIALS AND METHODS

To assess the degree of danger, indicators such as frequency of occurrence, volume of mudflows, density of the network of mudflow channels (vulnerability) are used. Assessment of the mudflows danger is carried out mainly by mapping (Perov, 2012; Stupin et al., 2017). To assess the mudflow hazard, such characteristics as the way routes and boundaries of the distribution of mudflows of various volumes and frequency in river basins are considered (Medeu et al., 2019), as well as geomorphological and geological studies to identify potential mudflow sources and to estimate the volume of future mudflows in each basin (Genevois and Tecca, 2008).

The integration of cartographic and remote sensing methods in GIS environment forms the basis for cartographic and remote sensing monitoring of natural processes and phenomena, which is required at the regional level. The mentioned above also applies to mapping the spatial distribution of mudflows with subsequent assessment of their hazards and risks (Stupin et al., 2017). In recent years, it has become possible to process satellite images of high spatial resolution when studying mudflows (Stupin et al., 2020). Based on satellite image data, catchment basins are determined and mudflow valleys are visually interpreted using ArcGIS software (Cheng et al., 2016).

Many countries use modern scientific methods and approaches, using the latest high-precision instruments and technologies such as LIDAR (active optical systems), satellite imagery (remote sensing data), terrestrial laser scanning and photogrammetric data obtained from UAVs (aerial photographs) and digital elevation models (DEM).

The basis for assessing the mudflow phenomena occurrence in the study area was the methodology developed in the laboratory of avalanches and mudflows of the Faculty of Geography of Moscow State University (Budarina, 2005). In accordance with this methodology, the assessment is carried out taking into account two main indicators – the slope inclination (steepness) and vegetation, which largely determine the characteristics of the mudflow formation (Petrushina et al., 2017). During the work, this method was supplemented with two more indicators: vertical dissection (depth of dissection) of the relief and lithology of the constituent rocks. In mudflow formation, continuous rainfall is also of great importance. But, due to the lack of observations of hazardous meteorological phenomena in the study area, this indicator was not taken into account.

RESULTS DISCUSSIONS

Assessment of mudflow phenomena in Charyn SNNP was carried out taking into account geological, geomorphological and geobotanical conditions of the study area.

The geological conditions of the territory largely determine the intensity of the mudflow phenomenon occurrence in the basin, the type of mudflow site, granulometric and mineral composition of the solid mudflow component. The lithological composition of the rocks determines the potential stability of the substrate rocks in relation to various denudation agents, as well as the possibility of involving colloidal fractions in the flow. The most resistant to the effects of mudflows are rocks (granites, shales, quartzites, tuff sandstones), the least resistant are loose clastic uncemented rocks (loess-like loams, sands).

Morphometric parameters of the relief (angles of inclination and height) make a significant contribution to the features of mudflow occurrence. Larger surface inclination angles provide higher mudflow intensity (Karavayev and Seminozhenko, 2019; Glade, 2005). That is, geomorphological conditions (the area of the watershed basin with steep slopes and large inclination angles of channels or thalwegs of gullies, ravines) determine the values of the morphometric characteristics of mudflow centers and mudflow basins and accordingly, the dynamic parameters of mudflows (speed, maximum flow rate, mudflow pressure to the obstacles). In most cases, the calculation of morphometric parameters is carried out using the analysis of digital elevation models. Geobotanical conditions have an anti-erosion effect, mainly expressed in the fixation of soils on slopes by the root system of plants. In this case, a stable layer of vegetable soil is formed, which significantly reduces the eroding area caused by rainfall waters. By assessment of the mudflow hazard of the considered territories, the soil-botanical factors should be considered as one of the main ones, since they determine the possibility of the occurrence of mudflow-hazardous surface runoff in the studied basin, as well as the involvement of loose clastic material (developed on the slopes by exogenous processes) in the transit.

Thus, the assessment of the degree of mudflow occurrence on the territory of the Charyn SNNP was carried out on the basis of 4 indicators: lithological composition of rocks, vertical dissection of the relief, surface slope and normalized difference vegetation index (NDVI) using a 3-point rating scale (Table 1), where 1 point corresponds to a weak degree, 2 points to a moderate degree, 3 points to a strong degree. The first stage of the assessment was dividing the territory into grids of calculated squares with an area of 1 km ^{2}. Next, each square was assigned from 1 to 3 points for each indicator. Calculations were carried out using the tools of the standard module ArcGIS 10.8 – Spatial Analyst.

Table 1. Parameters forming mudflow phenomena (Source: Modified by Lyy from Yermolovich et al., 2018; Yegemberdiyeva et al., 2020; Leontyev and Rychagov, 1988; https://eos.com)

Lithological composition of rocks		Vertical dissection of the relief		Surface slope		NDVI	
rocks	points	m/km^2	points	degree	points	index	points
Tuff sandstone, shales, quartzites, granites	1	6.4-48.3	1	< 8	1	0.4 – 0.54	1
Boulders-pebbles, conglomerates, sands, clays, granite syenites, quartz syenites	2	48.3-130.5	2	8-35	2	0.1 – 0.4	2
pebblestones, sands, loess-like loams	3	130.5-451.6	3	> 35	3	-0.17 – 0.1	3

Lithological composition of rocks. The formation of sources of involvement of the solid component into the mudflow is directly dependent on the nature of the rocks, their petrographic and lithological-mineralogical composition. Significant role in the formation of mudflows belongs to loose Quaternary sediments of different genesis. In most cases, it is these rocks that provide the solid component of modern mudflows. In easily weathered or eroded rocks, mudflows form more often. Based on a geological map at a scale of 1:200 000 (Medoyev, 1967) (Figure 2), a classification of lithological composition was carried out (Yermolovich et al., 2018) according to the degree of rock erosion (Figure 3, Table 1).

The low degree includes hard cemented rocks (rocky and semi-rocky): granites, shales, quartzites, tuff sandstones. Areas with a low degree of erosion include the Toraigyr and Ulken Bugyty mountains, ridged hills between the Ulken Bugyty and Toraigyr mountains, as well as the southwestern part of the national park. They occupy 335.3 km^2, or 24.5% of the territory. The moderate degree of erosion includes cemented sedimentary rocks: conglomerates, sandstones, boulder-pebble stones, pebbles, clays, granite syenites, quartz syenites, which have a denser composition and accordingly are more resistant to mudflow phenomena. Areas with a moderate degree of rock erosion occupy significant part of the considered territory, extending from the north to the south-eastern part of the park. They are located on valley-ridged hills on the right bank and left bank of the Sharyn River, as well as on the second above-floodplain terraces and erosional hills “badland” (on the right bank). Territories with a moderate degree of mudflow phenomena occurrence cover 603.6 km^2, or 44.1% of the total area of the park. Loose unconsolidated clastic rocks such as loess-like loams and sands are subject to mudflow phenomena to a significant extent. The territories composed of these rocks include valley-ridged hills and proluvial-sloping plains around the Ulken Bugyty mountains, floodplains and the first above-floodplain terraces of the Sharyn River (starting from the Sarytogai tract to the northeastern part of the SNNP), as well as the southeastern part of the national park. Territories with a strong degree of mudflow phenomena occurrence occupy 429.7 km^2, or 31.4% of the total area of the park (1368,6 км^2). In the morphometric analysis of the relief, the Airbus WorldDEM4Ortho DEM with a resolution of 24 m was used to assess the degree of intensity of mudflow phenomena on the territory of the Charyn SNNP.

Vertical dissection of the relief. The intensity of vertical dissection allows us to characterize the activity of geodynamic processes, in this case mudflow phenomena. Indicator of the vertical dissection of the relief is the amplitude of fluctuations in the heights of the earth's surface, i.e. relative excess of the top points of positive forms over the nearest negative forms. This value is equal to the depth of relief dissection (Pozachenyuk and Petlyukova, 2016; Spiridonov, 1970). This indicator was determined using the Zonal Statistics tool, where within the selected squares was calculated the difference between the smallest and largest values of all raster cells that belong to the same zone as the output cell (RANGE) (Figure 4) (Yegemberdiyeva et al., 2020).

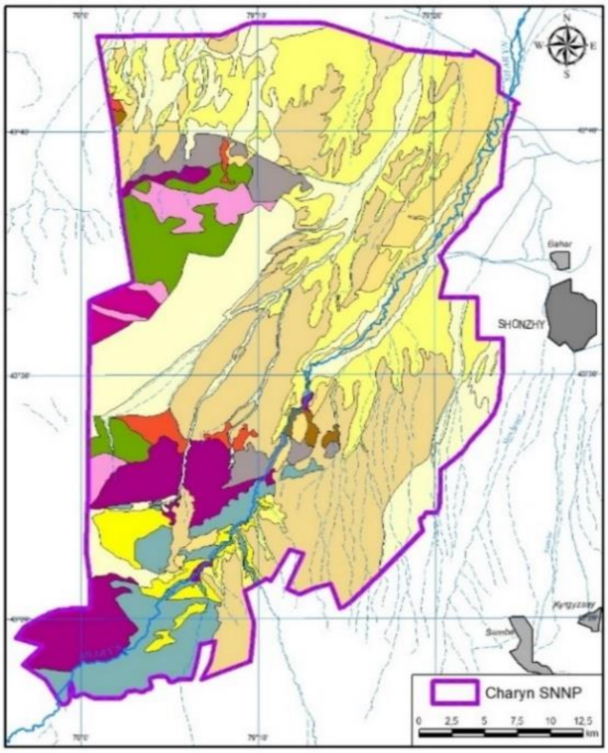

Figure 2. Lithological composition of rocks *

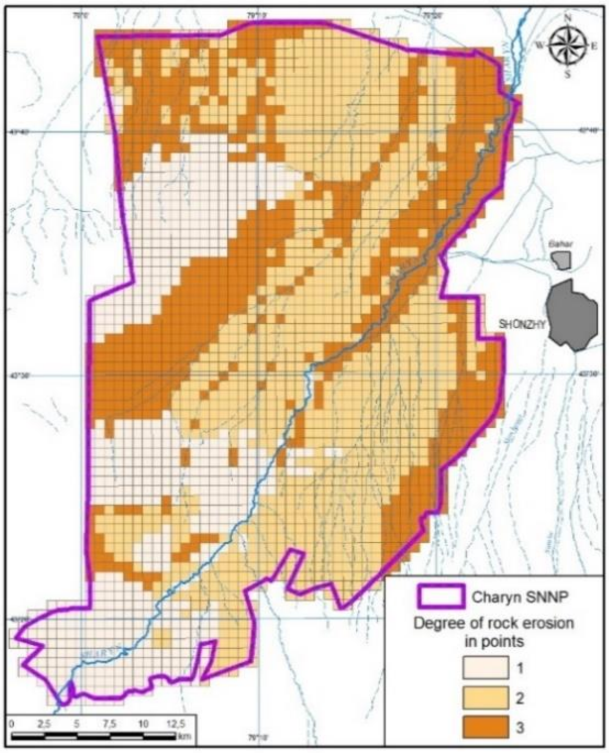

Figure 3. Degree of rock erosion

(Source: Geological maps, scale 1:200 000) * Legend to the Figure 3

	Lithological composition of rocks
	Pebblestones, sands
	Pebblestones, sands and loess-like loams
	Boulders-pebbles, conglomerates
	Conglomerates, sands, clays
	Sands, clays
	Conglomerates, sands
	Tuff sandstones (variegated tuff lavas and tuffs of liparitic and dacitic porphyries, rare interlayers of tuffs of mixed composition and porphyrites, tuff sandstones)
	Tuff sandstones (tuffs and lavas of andesitic porphyrites, dacite, tyrachydacite porphyries and mixed composition of effusives)
	Shales (chlorite-sericite and phyllitic shales)
	Shales, quartzites (chlorite-siliceous, micaceous-quartz shales, silica and quartzites)
	Shales (sericite-quartz, chlorite-siliceous, chlorite-sericite and phyllitic shales)
	Granite syenites, quartz syenites
	Coarse-grained granites

Surface slope. Next, the surface slope was calculated using the “Slope tool “of the “Surface” tool group (Figure 5). For each cell, the slope tool calculates the maximum degree of change in z value between that cell and its neighboring cells (http://desktop.arcgis.com). Calculating the range of slope values is similar to calculating the range of vertical dissection values. The range of slope values were grouped into 3 groups: < 8° – very flat and flat; 8°-35° – medium steepness and steep; > 35° – very steep (Figure 6) (Leontyev and Rychagov, 1988). On the territory of the Charyn SNNP, the highest indicators of vertical dissection (130.5-451.6 m/km^2) and surface slopes (more than 35°) are typical for the low mountains of Ulken Bugyty and Toraigyr, as well as for the high floodplains of the Canyon of Sharyn River before it reaches the plain.

Territories with average vertical dissection (48.3-130.5 m/km^2) and slopes (8-35°) are located on the denudation sloping peneplain southwest of the Toraigyr Mountains, on ridged hills south of the Toraigyr Mountains on the right bank of Sharyn River, on the accumulative-erosive hills of ravine erosion above the interfluve of the Sharyn and Temirlik rivers above their confluence, as well as on the right bank of the Temirlik River.

Also, territories with average indicators of vertical dissection and slopes are related to erosive hills (badlands) south of the Sarytogai tract, to valley-ridged hills north of the Ulken Bugyty mountains. Most of the territory of the Charyn SNNP is occupied by areas with low values of vertical relief dissection (6.4-48.3 m/km^2) and slopes (up to 8°).

Vegetation in the park was assessed using the normalized difference vegetation index (NDVI) (Figure 7), calculated from Sentinel-2 satellite images with a resolution of 10 m as for May 2023.

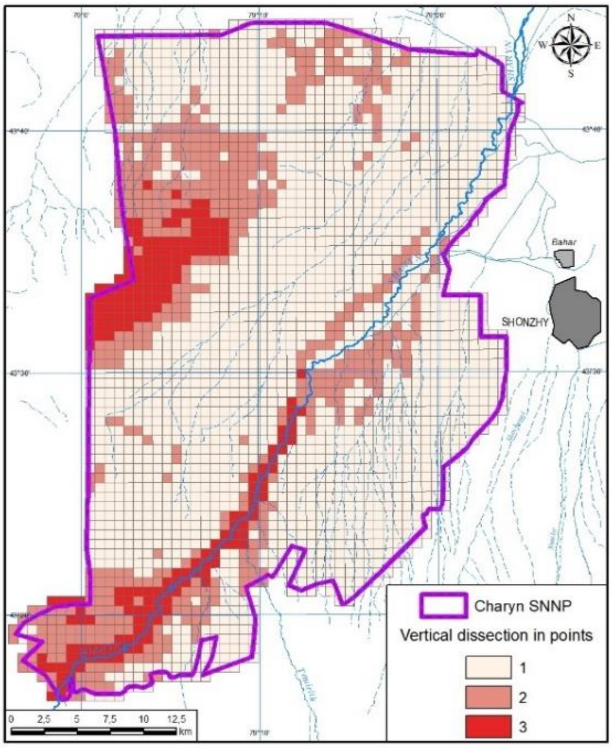

Figure 4. Range of vertical relief dissection (Table 1)
(Source: Based on Airbus WorldDEM4Ortho, 2017)

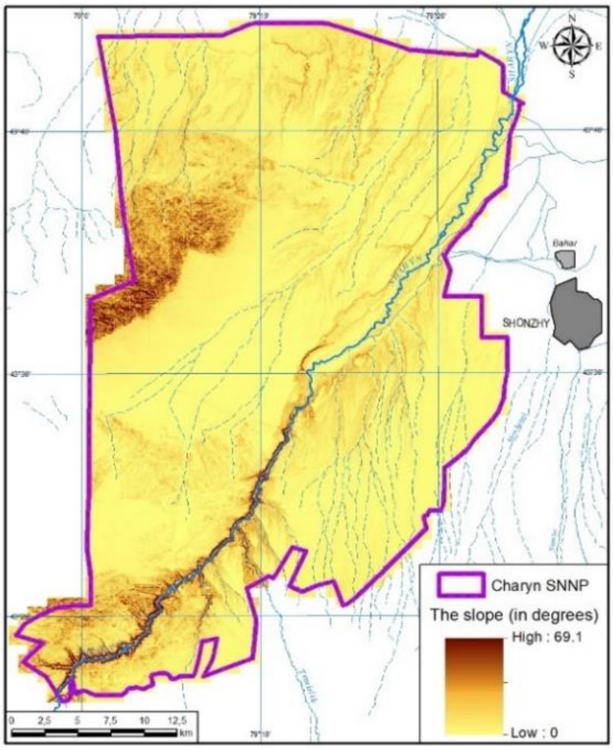

Figure 5. Surface slope
(Source: Based on Airbus WorldDEM4Ortho, 2017)

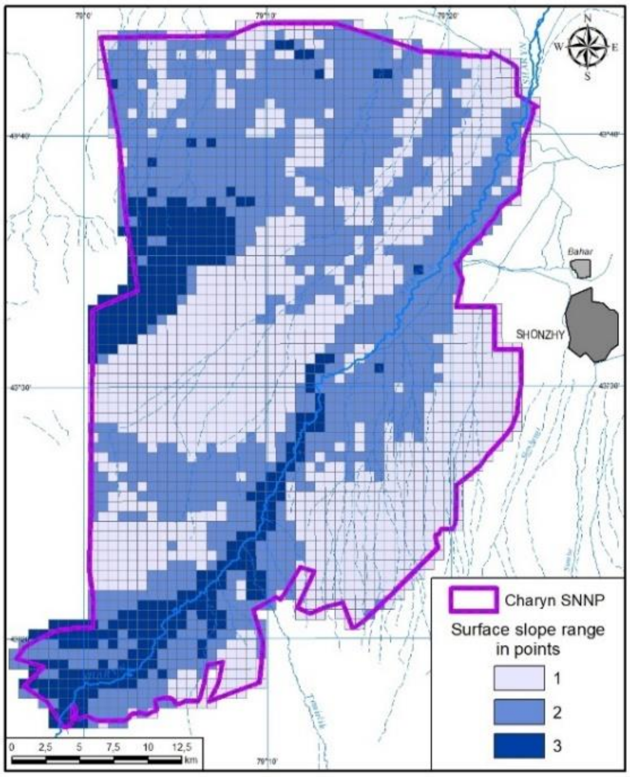

Figure 6. Surface slope range
(Source: Based on Airbus WorldDEM4Ortho, 2017)

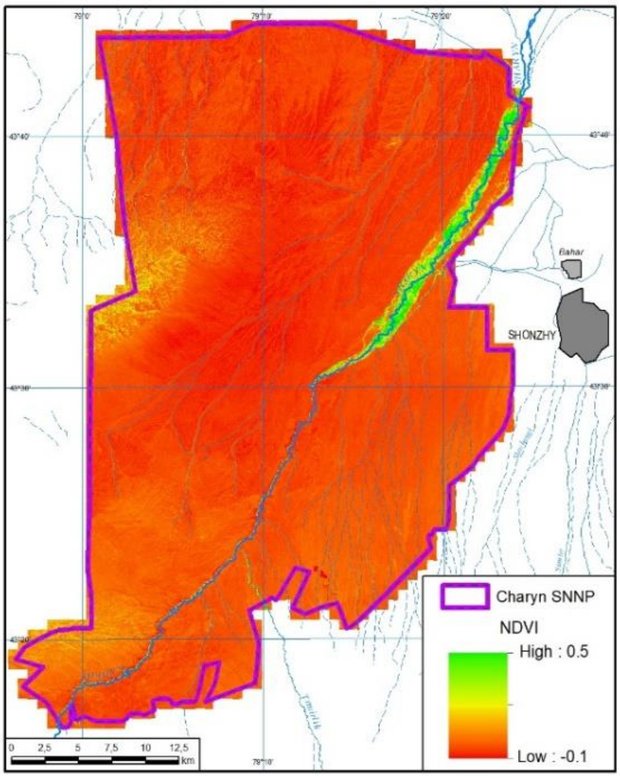

Figure 7. NDVI
(Source: Based on Sentinel-2, 2023)

NDVI is a simple but effective method for quantifying green vegetation, determining the true state of vegetation on the ground. It is calculated using the following mathematical equation (https://gisproxima.ru; https://eos.com):

$$NDVI = (NIR-Red) / (NIR+Red),$$

where NIR is near infrared light; Red is visible red light.

The range of NDVI values is known to be from -1 to 1. Negative NDVI values (values approaching to -1) correspond to water. Values close to zero (from -0.1 to 0.1) typically correspond to barren areas of rock, sand or snow. Low positive values correspond to shrubland and grassland (approximately 0.2 to 0.4), while high values indicate temperate and tropical rain forests (values approaching 1) (https://custom-scripts.sentinel-hub.com).

After calculating the NDVI, using the expert assessment method, points were assigned to each grid of calculated squares for the degree of assessment of the mudflow phenomena occurrence: 1 point – 0.4-0.5 (dense vegetation in the grove along the Sharyn River, along temporary watercourses of the Ulken Bugyty and Toraigyr), 2 points – (along the of Sharyn River bed, along temporary watercourses of the Ulken Bugyty and Toraigyr mountains), 3 points – -0.1-0.1 (the main part of the park territory, very sparse vegetation or barren areas of rocks, sand) (Figure 8).

As a result of the made calculations, maps of rock erosion, vertical dissection of the relief, surface slope and vegetation density were created. Next, using the “Add connection” tool, the layers of 4 indicators were combined by the common field “ID” and the resulting amounts were ranked by grouping similar values into 3 degrees of mudflow phenomena occurrence: 6-7 points – low, 8 points – medium and 9-12 points – high (Figure 9).

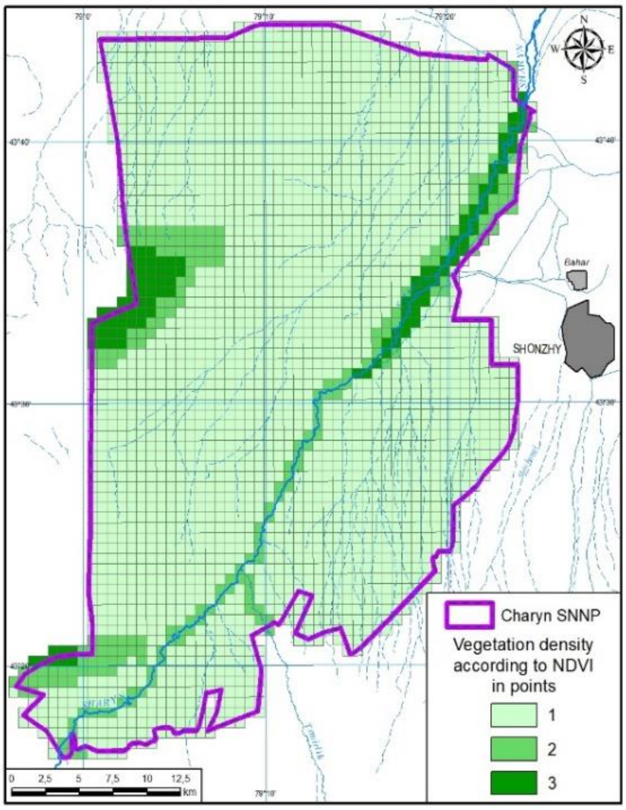

Figure 8. Vegetation density according to NDVI (Source: Based on Sentinel-2, 2023)

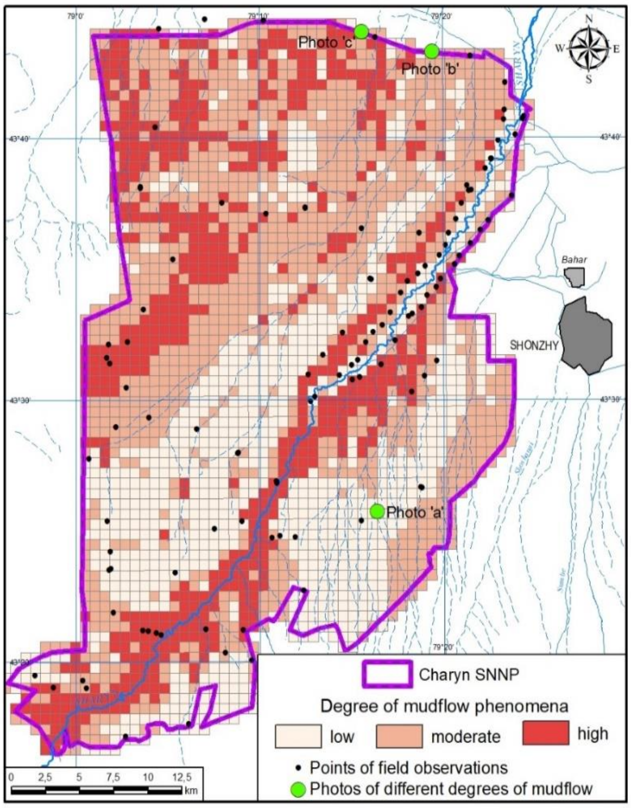

Figure 9. Degree of mudflow phenomena occurrence in the territory of the Charyn SNNP (Source: Developed by Sharapkhanova, 2024)

CONCLUSION

Territories with low degree of mudflow phenomena occurrence occupy 458.5 km^2, or 33.5% of the total territory of the park (1368.6 km^2). These include valley-ridged hills in the eastern part of the national park, on the right bank of the Sharyn River, as well as those located southeast of the Ulken Bugyty Mountains (Figure 10).

a) low degree b) moderate degree c) high degree

Figure 10. The degree of mudflow phenomena occurrence on the territory of Charyn SNNP (Photo taken by employees of the laboratory of geotourism and geomorphology of the “Institute of Geography and Water Security” JSC)

Territories with an average degree of mudflow phenomena occurrence are related to the proluvial inclined accumulative plain around the Ulken Bugyty mountains, valley-ridged hills in the southeastern part of the park, and hills "badland" in the northern part of the park; they occupy an area of 584.4 km^2, or 42.7 %.

The high degree of mudflow phenomena occurrence is characteristic for low-mountain relief (Mountains Toraigyr and Ulken Bugyty), accumulative-erosive hills of gully erosion near the Toraigyr Mountains and in the northern part of the park, high floodplains of the Sharyn and Temirlik rivers, which in areal terms corresponds to 325.7 km^2, or 23.8%.

During the reconnaissance, 118 points of observation of geological and geomorphological processes were determined, of which 30 points are places of mudflow phenomena occurrence. The results of assessing and mapping of the mudflow phenomena occurrence are confirmed by the field data. Thus, the degree of mudflow phenomena occurrence on the territory of the Charyn SNNP is not the same and actually exists only in some areas in which the conditions for the formation of mudflows have developed. The presented methodology for assessing the degree of mudflow phenomena occurrence in the future can serve as the basis for identifying territories that are safe for the tourist and recreational activities. But for creation of larger-scale maps, it is required to use additional assessment indicators and to improve the assessment methodology itself, which may become one of the tasks for the next stage of research.

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