Assessment of the geomorphological safety of the Daurian region for the purpose of effective nature management

O I Bazhenova¹, E M Tyumenseva² and S A Tukhta¹,²

¹V B Sochava Institute of Geography, SB RAS, Irkutsk, 664033 Russia
²Irkutsk State University, Irkutsk, 664033 Russia

E-mail: bazhenova_o49@mail.ru

Abstract. The risk assessment of the dangerous geomorphological processes development in the Dauria steppes in conditions of pronounced cyclical fluctuations in climate and high dynamism of geomorphological systems is carried out on a five-point scale. The analysis of the spatial and temporal structure of fluvial and aeolian processes for the purposes of nature management is fulfilled. The role of extreme geomorphological events is shown, which are a serious limiting factor of conflict-free nature management in the Daurian region. The revealed catastrophic manifestations of fluvial and aeolian processes require careful planning of economic activities and serious environmental protection measures. The result of the assessment is the zoning of the Dauria territory according to the degree of geomorphological risk. The types of economic activities that do not violate the stability of the regime of geomorphological systems, and, on the other hand, are undesirable, increasing the risk of critical natural situations, are indicated.

1. Introduction

Dauria is the northern part of Central (Inner) Asia, covering the basin of the Upper Amur and adjacent to it from the south an endless lake area. This is one of the globally significant ecological transboundary regions located on the territories of Russia, Mongolia and China, within which the area of specially protected natural territories (SPNTs) is about 15%. They are represented on the Russian part by the Daursky Reserve, as well as the “Valley of the Dzerens” and “Tsasucheysky Bor”. The priority areas of all three countries economy in the Daurian region are agriculture and mining operations. In the region, it is necessary to optimize the modes of nature management within SPNT and the development of joint tripartite mechanisms in order to prevent the risks of environmental management [1].

When developing the scientific foundations for effective nature management, the problem of geomorphological safety is an important one, since the relief is one of the main criteria for the sustainability of landscapes. It is the relief that is responsible for those properties of landscapes that resist their irreversible changes caused by human intervention. Among all the processes occurring in the landscape, the greatest risk of irreversibility is inherent to the processes associated with the violation of gravitational equilibrium [2].

Geomorphological security of the territory (GST) is understood as a sum of states of geosystem, in which the action of external and internal factors does not lead to its deterioration or impossibility of functioning [3]. In other words, this is a state in which geomorphological risks are reduced to acceptable or minimal ones for a specific type of nature use or economic development in general. The paper provides an assessment of the geomorphological safety of the Daurian region Russian part.
2. Models and Methods

Geomorphologically, the territory is represented by the Onon-Torey plain. There are also areas of small hills, hilly-ridged relief, island mountains (Figure 1). In the northeastern part, a mid-mountainous relief prevails (the Kukulbei ridge), and in the southeast, the low-mountainous relief of the Nerchinsky ridge is widespread. The Onon-Torey plain is a vast relief law between the southern spurs of the Borschovovchhn ridge in the northwest and the foothills of Bayan Ula in the southeast. The structure of the plain includes fragments of alluvial, lacustrine, lacustrine-alluvial and denudation surfaces of the levelling, located at an altitude of 600–800 m. The surface is complicated by many isolated massifs of strongly denuded low mountains. The morphological appearance of the denudation relief is represented by numerous outliers, “crowning” extensive pediments.

Figure 1. The study area and borders.

**Study area:** I – the Onon basin (Upper Amur), II – area of closed lake basins of Inner Asia.

**Borders:** 2 – continental watershed, 3 – borders of river basins, 4 – borders of lake systems, 5 – state boundary.

The position of the lake basins, river valleys and temporary watercourses is predetermined by tectonic disturbances along which a groundwater is unloaded. The transregional Onon-Turgin fault and several large regional faults there are here. The recent tectonic movements, creating many bases of erosion and denudation, give a certain autonomy, freedom for the development of isolated sections of river valleys and individual lake basins [4]. At the same time, integral lacustrine-fluvial systems are often formed, united by fluvial flows, supplying matter to the final closed lake basins.

2
The area is an ecotone. It is located at the southern border of the permafrost zone and along the northern limits of the vast arid region of Central Asia, as well as in the zone of junction of the Upper Amur basin with the area of internal flow (Figure 1). This leads to a high dynamism of geomorphological systems, a frequent change in the direction of the matter displacement.

The need to assess the relief for the needs of nature management is dictated by the desire to reduce the expected damage from the impact of geomorphological processes not only on the existing natural and socio-geomorphological systems, but also on the systems being designed (areas of prospective development). Comprehensive assessment of geomorphological safety (GST) includes several main stages [5]. First, the selection of evaluation criteria is carried out - the factors and conditions that affect the development of the relief. For the Daurian region, their list was obtained by analysing the geological and geographical environment and the spectrum of geomorphological processes inherent in it. At the next stage, the possible range of variation of each of the criteria within the territory was determined, as well as the level of the intensity fluctuations of processes during the years with different moisture conditions. Then, all parameters of conditions and intensity of relief formation were ranked and brought to a numerical score. Further, the choice of elementary territorial units was carried out, for which the total indicator of the geomorphological risk of economic activity was calculated on a five-point scale.

3. Results and Discussion
Dauria is characterized by a wide range of geomorphological processes (Figure 2), which include fluvial, lacustrine, aeolian, cryogenic and biogenic ones. Under the influence of climatic fluctuations, the processes are combined into dynamic phases of relief formation, which successively replace each other in time. Periodically, fluvial and aeolian processes obtained an extreme character, causing significant damage to human economic activity and creating a number of environmental problems.

The characteristic geomorphological processes with a certain level of intensity, direction of influence on the relief and distribution over the slopes’ elements of different exposure occur in the Daurian region in different types of years in terms of atmospheric humidity. Based on the materials of stationary studies and Roshydromet data, we have identified three dynamic phases of the geomorphological cycle with a characteristic of the processes’ intensity (Table 1). In different phases of relief formation, the rate of the same process can vary tens and even hundreds of times. This must be taken into account when planning economic activities within a particular form of relief.

Fluvial processes are represented by channel deformations, slope erosion, gully formation, the creation of deluvial and proluvial cones, river deltas, and sometimes the descent of mudflows. The active erosion activity of water flows is associated with monsoon rains, characterized by high intensity of rainfall; and it almost coincided with high floods on all rivers. Abundant phases of interdecadal fluctuation cycles in the Onon River flow were observed in 1906-1910, 1932-1937, 1959-1964, 1983-1991 and 1998 [6]. During the heavy rainfall the soil removal from the field can reach 240 m²/ha on plowed slopes with a steepness of 3–5°. A dense network of jet erosion is formed up to 30 cm deep and 150-200 m long. For example, during a downpour on 11 July 1979, when 107 mm of precipitation fell with a maximum intensity of 2 mm/min, 10 gullies directed across tillage through the entire field were formed on one of the fields on a slope with a steepness of 5–6° [7]. On rangelands, the washout rate varies from 0.2 to 3.1 mm/year and depends primarily on the state of the vegetation. The erosion belts and badlands “bad lands” where the density of gullies and ravines reaches 45-65 km/km² were formed on abandoned arable lands near a number of villages (Tsagan-Olui, Nizhny Tsasuchey, Ust-Borzya, Chindant, Yasnogorsk, etc.). At the end of the 20th century, the rapid development of gully erosion in a number of arable lands led to a sharp increase in the number of ravines and the formation of new badlands with an area of 0.2-1.5 km². In addition, in the Daurian region, there are active coastal ravine forms on the sides of river and lake terraces, slope forms in areas with disturbed soil cover along the ruts of field roads, and secondary bottom gullies and ravines in temporary watercourses, which should be taken into account when planning modern land use systems.
Figure 2. Types of geomorphological processes in the Daurian region:

- **erosional** (a) – a network of gullies on arable land in the valley of the Borzya River,
- (b) – a mature ravine in the basin of Lake Aru-Torum;
- **aeolian** (c) – inflating on the terrace edge of the Onon River near the Nizhny Tsasuchey village;
- **cryogenic** (d) – thermokarst funnel sink in the Batuy creek valley;
- **lacustrine** (e) – Lake Zun-Torey;
- **biogenic** (f) – emissions of zokor from the burrows in the bottom of the dry land near the Builesan village.

Dauria belongs to the zone of intense deflationary denudation. Aeolian material is carried out by the prevailing northwestern winds in the southeast direction to the neighbouring regions of Mongolia and China. Aeolian processes are especially active around settlements located on lake and river terraces, formed by sand, where large areas of disturbed lands are noted.

The indicator of changes in the moisture content of the territory is the data on the water content fluctuations of the endless Lakes Torey [6], which allowed tracing the dynamics of aeolian processes over the past 100 years. During the earlier Mauder period, the lakes were completely drained. Deflation has significantly levelled low shores and exposed the central parts of the basins, removing lacustrine sediments from there. They were in this state in 1755, 1772 and 1855. And only by 1872 were they filled with water. The change in the level of Lakes Zun-Torey and Barun-Torey is cyclical and correlates well with the long-term course of atmospheric precipitation from the Borzya meteorological station [6]. The first 30th anniversary of the twentieth century was characterized by low precipitation and low levels of lakes. The basins were periodically waterless (1902–1903, 1921–1922 and 1929), which contributed to the development of aeolian processes. The filling of the lakes and the decrease in the intensity of aeolian processes began in 1934 and continued until 1937.
Table 1. Changes of the relief formation conditions and characteristics of the processes’ intensity in different dynamic phases of geomorphological cycles.

| Characteristics                                      | Extreme wet | Normal zonal | Extreme arid |
|------------------------------------------------------|-------------|--------------|--------------|
| Annual precipitation, mm                            | 350-450     | 200-350      | 100-200      |
| The number of days in a year with showers            | 18          | 7-14         | 4            |
| Erosion index of precipitation                       | 10-12       | 6-8          | 3-5          |
| Water runoff on slopes, mm                           | more 0.70   | 0.3-0.5      | 0.2          |
| Suspended sediment runoff modulus, ton/(km²·yr)      | 25-158      | 8-22         | less 8       |
| Linear growth of ravine forms, m                    | 1-5 and more| 0.5-1        | less 0.5     |
| Number of dust storms                                | 1           | 4-6          | 15-18        |
| Aeolian accumulation rate, mm                        | 0-2         | 3-20         | 50-100 and more |
| Deflation rate, mm                                   | less 2      | 3-5          | 5-10         |
| Volume of ice in the bottoms of falls, thousand m³   | 240-850     | 30-40        | 20           |
| Phytomass, g/m²                                      | 330         | 250          | 170          |

The next phase in the oscillatory deflationary process was noted in the first half of the 1940s, when the bottoms of the lake basins were completely drained, and their sediments were subjected to intensive aeolian processing and were carried out beyond their limits [8]. Another increase in the level of lakes and attenuation of the intensity of aeolian migration of matter is noted from the late 1950s to the middle of 1960s. A long period of low atmospheric humidification (1968–1983) was accompanied by an intensification of deflationary processes. In these dry years the wind removes the sediments on the roads, forms aeolian ripples, and the bottoms of lake basins deepen. Each of these cycles, in turn, is divided into smaller, mainly 2–3-year fluctuations in moisture and intensity of processes. Deflation reached its highest intensity during the period of instrumental observations in the spring of 1972–1973, when a regional maximum of days with a dust storm was noted (17–18). At this time, the amount of precipitation for two spring months decreased to 6 mm. In the spring of 1978, the mass of salt-bearing sediments on the bottom of Lake Nozhii in the Aginsk steppe with an area of 28.4 km² was carried by the wind in the southern and southeastern directions, and the soil surface of agricultural land became salinized [9]. An increase in aeolian activity was also observed in 1980, 1987 and 1993. An extreme manifestation of aeolian processes in Dauria was observed on 29 April 2019, when a dust storm with a length of more than 150 km with a wind speed of more than 30 m/s covered Solovyevsky, Borzinsky, Olovyaninsk and other regions, which led to fires; the Imalka village was burned down.

Note that the interval between extreme aeolian and fluvial events is recently shrinking, the area of manifestation of processes is expanding and, therefore, the risk of their adverse impact on the environment increases. The natural prerequisites for the extreme manifestation of processes are multiplied by irrational human economic activity. In this regard, Dauria should be classified as a region with a low index of geomorphological safety of the territory, which requires careful planning of economic activities and serious environmental protection measures. For these purposes, the results of risk assessment of the dangerous geomorphological processes development in the Daurian region, presented here, will be useful (Table 2).
Table 2. Risk assessment of the development of dangerous geomorphological processes in the Daurian region for the purposes of economic use.

| Landforms | Morphometric parameters | Geomorphological processes | Risk, points | Possible economic activity | Unwanted activity |
|-----------|-------------------------|----------------------------|--------------|---------------------------|-------------------|
| I. Onon basin (Upper Amur) | | | | | |
| Floodplain | Abs. height: 568-650 m; Width: 0.2-0.4 to 3 km. | Flooding, swamping, channel deformations | 4 | Cattle grazing, hayfields | Construction of utility and residential facilities |
| Terrace cusps | Abs. height: 650-680 m. | Linear erosion, fall | 5 | Excluded | Any economic activity is prohibited |
| Terrace surface | Abs. height: 680-720 m. | Aeolian | 2 | Any economic activity is possible | Economic activity is permitted |
| Bottoms of intermontane basins | Abs. height: 700-800 m. | Cryogenic, biogenic, aeolian accumulation | 3 | Cattle grazing, hayfields | Protective measures are required |
| Low mountains | Abs. height: 800-880 m; Valleys average depth: 50-65 m; Slope: 3-12°. | Slope, aeolian, erosional (washout and erosion by temporary watercourses) | 3 | Extraction of minerals; anti-erosion measures | Building and plowing are prohibited |
| Middle mountains | Abs. height: 1,200-1,400 m; Valleys depth: 300-500 m; Slopes steepness: up to 40°. | Slope, kurums, rocky outliers, upland terraces, soil erosion, deflation | 4 | Extraction of minerals, ecotourism | Building and plowing are prohibited |
| II. Onon-Torey Plain | | | | | |
| Lacustrine-accumulative plains | Abs. height: 596-745 m; Steepness: up to 2°. | Aeolian processes, cryogenic | 1 | Any agricultural activity is possible | Anti-deflationary measures and forest planting are required |
| Bottoms of the basins of Lakes Torey | Depth: 596-602 m; Slope: 1-15°. | Lacustrine coastal, gully erosion | 5 | Biodiversity protection | SPNT – economic activity is prohibited |
| Small basins of the lake belt | Depth: 640-680 m; Slope: 1-3°. | Aeolian, cryogenic, biogenic | 3 | Agricultural activity | Construction of industrial facilities |
| Deltas of the Imalka and Uldza rivers | Abs. height: 590-610 m. | Fluvial accumulation, waterlogging, cryogenic | 5 | Biodiversity protection | SPNT (economic activity is prohibited) |
| Creek valleys of temporary streams | Abs. height: 750-850 m; Dissection depth: 50-90 m; Bottom width: from 70-100 to 200-350 m; Side slopes: up to 20°. | Soil heaving, gully erosion, icings, soil swelling, thermokarst, mud flow descent | 4 | Cattle grazing, hayfields | Construction of industrial facilities and plowing |

4. Conclusion

According to the results of the study, 11 types of relief with different levels of dangerous development risk of geomorphological processes were identified in the Daurian region (Table 2). According to a five-point scale, an extremely high risk (5 points) is characteristic of the river and lake terraces cusps, the bottoms of the Lakes Torey basins and of the deltas of the Imalka and Uldza Rivers flowing into Torey Lakes. All economic activities are prohibited within these types of relief.
The ban is connected not only with the possible catastrophic manifestation of the processes, but also with the fact that the basin of Torey Lakes belongs to the Daursky reserve.

The high-risk zone (4 points) includes the middle mountains with a wide range of morpholythodynamic processes, including talus, landslides, and deluvial washout on steep slopes. The greatest damage to economic objects here is caused by the processes of surface subsidence over mine workings (mainly in abandoned and mothballed mines). High-risk areas also include river floodplains and the creek valleys of temporary watercourses widespread in the region. It should be noted that on the periodically flooded surface of floodplains, unfortunately, the ban on construction is not always observed, as evidenced by the development of the floodplain of the Agi River in the Aginsky village, which required the construction of an expensive protective dam [1]. A moderate risk of dangerous development of processes (3 points) is noted during the economic development of low mountains and often swampy bottoms of intermontane depressions, as well as small basins of the lake belt. Here, in areas with disturbed soil and vegetation cover, colian migration of matter, hydrothermal soil movements, and gully erosion are extremely active. A low (2 points) and very low risk of creating dangerous geomorphological situations occurs during the economic development of the surface of lake and river terraces, as well as on high lacustrine-accumulative plains, while observing measures of anti-erosion protection of lands.

The periodically extreme nature of the processes’ development is predetermined by the landscape and climatic features of the Daurskaya steppe, associated with the rainfall regime of atmospheric precipitation, the formation of hurricanes and dust storms. The natural prerequisites for the extreme manifestation of processes are multiplied by irrational human economic activity. In this regard, the southern regions of the Transbaikalia at the federal level should be attributed to the number of regions with a low GST index, requiring careful planning of economic activities and taking serious environmental measures.

References
[1] Kirilyuk O K and Tkachuk T E 2012 Dauria as an ecological region. Problems of adaptation to climate change in the Dauria river basins: ecological and hydroeconomic aspects (Chita: Express –Publishing House) pp 7-13
[2] Isachenko A G 2000 Principles of classification of landscapes by their resistance to anthropogenic impacts. Geography and Environment (Moscow: GEOS) pp 41-50
[3] Bolysov S I, Bredikhin A V and Eremenko E A 2015 Approaches to assessing the geomorphological safety of territory Voprosy geografii 140 pp 29-55
[4] Voskresensky S S, Postolenko G A and Simonov Yu G 1965 Genesis and structure of the Southeastern Transbaikalia relief. Geomorphological studies (Moscow: Moscow State University Press) pp 11-122
[5] Eremenko E A, Belyaev Yu R, Bolysov S I, Myslivets V I and Bredikhin A V 2021 A new approach to a comprehensive assessment of the relief for the purpose of effective environmental management Geomorphology 52(1) pp 19-32
[6] Obyazov V A 1994 Relationship between water content fluctuations in the Transbaikalia steppe zone lakes and long-term hydrometeorological changes illustrated by the example of the Torey lakes Izvestiya. RGS 5 pp 48–54
[7] Lyubtsova E M 1988 Influence of human activity on the development of linear erosion in the steppes and forest-steppes of the Eastern Siberia south. Relief and slope processes of the Siberia south. (Irkutsk: Institute of Geography SB RAS Press) pp 98–119
[8] Simonov Yu G 1962 On the formation of lake basins in the modern periglacial conditions of South-Eastern Transbaikalia illustrated by the example of the Aginsky region. Problems of geographic permafrost and periglacial morphology (Moscow: Moscow State University Press) pp 156–65
[9] Strelnikov V G and Ostroumov V M 1978 Salt-bearing dust storms in the Aginsk steppe. Soil cover of Transbaikalia, means of its fertility increasing and rational use (Chita) pp 140–1