Landslides and mudflows in the Chechen Republic: synergetic aspects

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Abstract. Currently, a synergistic approach is often used in various fields of knowledge to study various phenomena and processes. The paper evaluates a synergy of various factors in exogenous processes in a particular territory. Exogenous phenomena are identified to encompass geological processes that occur on the earth, in its uppermost layers. They either simplify or complicate the underlying relief. Synergism in exogenous processes can consist in simultaneous occurrence of landslides, mudflows and floods in appropriate conditions. The studies, to a certain extent, indicated the synergy in the behavior of the above mentioned phenomena. The research hypothesis implies the adaptation of the synergistic approach to the study of exogenous processes.

1. Introduction

Exogenous phenomena are known to encompass geological processes that occur on the earth, in its uppermost layers. They either simplify or complicate the underlying relief.

Landslides are among the most common exogenous processes that usually occur on slopes. Their intensity is largely determined by the properties of rocks that compose the crust of a particular territory. In areas composed of permeable soils, erosion processes are practically undeveloped or relatively weak, and the slopes remain steep due to the fact that surface runoff passes beneath the surface. Given that impermeable water-resistant soils (usually clay) lie in the bottom of a slope, certain favorable conditions can provoke landslide processes and their activation.

In recent years, a number of scientific articles have been devoted to landslide processes alone on the territory of the Chechen Republic [1, 2, 5]. The paper focuses on the synergetic aspects in the behavior of these phenomena in the territory.

Synergetics as an independent interdisciplinary field exploring natural phenomena and processes based on the principles of self-organized systems arose in the late 60s of the 21st century, when the German physicist G. Haken first introduced this term [10]. Translated from Greek, it means ‘a joint, coordinated action, and involves the interaction of various elements of the system’. All processes in nature occur in closed or open systems. In closed systems, processes tend to be based on increasing
entropy and establishing balance between them. Synergetics deals exactly with the processes and phenomena in open systems that occur due to the intense exchange of energy and matter with the environment under nonequilibrium conditions. In open complex systems under nonequilibrium conditions, according to I. Prigogine, the effects arise leading not to an increase in entropy, but to a synergistic behavior of system elements, which contributes to a multiple increase in the intensity of processes and phenomena [7]. Exogenous processes – landslides, debris flows, floods and others – can also be attributed to such processes.

Synergism associated with exogenous processes may consist in simultaneous manifestations of landslides, mudflows and floods in appropriate conditions. The material for a mudflow can be the lithomass from a landslide site. The synergistic nature of natural phenomena, in particular exogenous and endogenous processes, involves triggering a number of other dangerous processes by one phenomenon. For example, an earthquake or prolonged rainfall can cause the simultaneous occurrence of floods, debris flows, landslides and earth flows. The simultaneous behavior of different exogenous processes is also due to the community of factors that lie behind their occurrence and development.

The basic reasons for mudflows and landslides are:
1. Precipitation (rains, showers) provoking excess saturation of mountain slopes. In particular, debris flows are caused by rains and showers – 85 %, snow – 6 %, etc.
2. Degree of slopes – the minimum slope of a mudflow is 10–15°, the maximum is 80°.
3. Man-induced factors including unsystematic deforestation on mountain slopes, land and soil cover degradation by unregulated grazing, plowing and watering of soils on slopes, etc.
4. Unpredictable behavior of landslides and mudflows.

The paper [3] provides some examples of synergism when mudflows and landslides happen simultaneously in the same or nearby areas on the territory of Kabardino-Balkaria (sections along the right bank of the Cardon River, a left tributary of the Karasu River, etc.). The mechanism of synergetic manifestation of dangerous natural processes is described. Heavy rains lead to a rise in the water level in rivers and, consequently, to the caving of banks (composed of easily eroded rocks – usually clay). This contributes to the sliding of coastal areas (mudflow material) and the formation of mudflows. In other words, synergism follows the scheme: showers – floods – landslides – mudflows.

2. Methods and materials

The study is based on the methods of a systematic approach to generalizing the materials available. The main research method is a comprehensive analysis of these manifestations of landslide and mudflow processes. The basis of the study was reserve and archival materials as well as published literary sources on the topic under study (domestic and foreign).

3. Results

Synergism between exogenous processes occurring in the Chechen Republic can be most characteristic of the Black Mountains region, within the uplifts of clastic rocks (mainly clay). Under the conditions of dissected topography and significant amount of precipitation infiltrating the soil, these rocks become intolerant to the formation of landslide-mudflow and other processes. Landslides in the Black Mountains are developed on the northern slopes, continuously stretching for 15–25 km. They become increasingly active on the slopes of mountain river valleys, where mudflows can also occur.

To a large extent, landslide processes are widespread in the eastern and southeastern parts of the Black Mountains, where landslides occasionally become more intense in springs and autumns characterized by increased atmospheric precipitation and snowmelt in the mountains.

This territory is known as one of the active landslide zones in the Chechen Republic. A wide scope and active occurrence of landslides is determined here by particular geological features and intensity of ongoing tectonic movements of the earth’s crust. Clay rocks – predominantly of Sarmatian stage – are widespread in the region along with a monoclinic structure complicated by a number of anticlines – Nozhay-Yurtovskaya, North-Nozhay-Yurtovskaya, Sayasanovskaya, Benoyskaya, North-Benoyskaya, etc. In terms of lithology and stratigraphy, the region is characterized by the Upper Cretaceous,
Paleogene-Neogene and Quaternary layers composed of carbonate and clastic rocks that are exposed at the earth’s surface. In the south of the region (Planiduk, Dyurin Lam ridges and others), Upper Cretaceous rocks and foraminiferous layers, composed of strong limestones and colorful marls, respectively, are exposed. In the region of the Mehkdetten-Kort and Amir-Kort mountains, nearby the settlements of Baytarki, Mazhgar, Tatay-Otar and others, the Chokrak layers that are mainly sandstones with rare clay bands are exposed at the surface. The Lower and Middle Sarmatian deposits forming a narrow arch-like strip can be traced from the border of the Chechen Republic and the Republic of Dagestan in the east to the village of Sayasan and further west [5]. The settlements of Dattakh, Chechel-Khee, Zandak-Ara, Khochi-Ara, Sayasan, just south of Engenoy and others are located over this strip. The same deposits are also developed near the villages of Benoy and Alkhan-Otar. Their sections can be observed along the numerous small rivers and gullies – B. Yaryksu, M. Yaryksu, Doku-Ein, Yaman-Su, Erzumbere-Ein, Sheren-Ein and others (Fig. 1).

Figure 1. Sarmatian clay uplift in the area of intense landslides

Lower and Middle Sarmatian deposits are lithologically represented by dark gray, bluish-gray, partially layered and gault clay. A thick mass of Upper Sarmatian rocks is exposed to the north of the described deposits. In the upper part it is composed of dark gray clays with fine-grained yellow-gray sandstone bonds, and in the lower part it is composed of dark gray clays with a thickness of more than 300 m. The villages of Gilyany, Zandak, Rogun-Kazha, Ayti-Mokhk, etc. are located in the area where upper Sarmatian sediments are exposed at the surface. Thus, the relationship between the landslide manifestation and geological composition (lithology) can be clearly traced here. Their intense manifestations are mainly attributed to the central zone of the region that is composed of Sarmatian clay deposits (the location of the settlements of Zandak, Gilyany, Sayasan, Engenoy, Chechel-Khee, etc.). In the southern part, Chokrak sand layers and Upper Cretaceous carbonates are exposed at the surface, while in the northern part – Quaternary Akchagyl-Absheron layers represented by sand-siltstone rocks. All the above rocks fall within the so-called easily permeable group. Landslide processes are practically absent or slightly manifested here.

Since the 60s of the last century, landslide processes have been repeatedly intensified in the study area. In the spring of 1963, landslides occurred within a limited area, namely in the central part of the village of Chechel-Khee. In a matter of minutes, almost all the households in the central part of the village were completely or partially destroyed. About half of the villagers were resettled in the plains of the republic, mainly in the village of Engel-Yurt of Gudermessky district. In April 1989, intense landslides expanded to immediately affect three districts of the republic, including Nozhay-Yurtovsky where dozens of settlements – Engenoy, Sayasan, Benoy, Chechel-Khee, Khochi-Ara and many others were damaged or destroyed. On the whole, in the Chechen-Ingush Republic, landslides struck more than 80 large and small settlements on an area of 2.5 thousand km², destroyed more than 60 km of roads, and about 100 km of power lines. As of 01.07.89, the Council of Ministers of the Republic reported a direct damage to amount to 334 million rubles [2]. According to experts, landslide processes were mainly
triggered by the solid and liquid precipitation in quantities many times higher than the long-term average.

In 1993, devastating landslides occurred in the area of Gilyany village, resulting in half of the villagers to be resettled in the village of Kobe of Shelkovskoy district, where they were allocated plots for the construction of houses.

At the end of 2003, landslides became more intense in the area of Zandak village. As a result, over 50 houses were completely or partially destroyed, a gas pipeline up to 2 km long, power lines up to 1 km and roads up to 150 m were damaged. The landslide zone amounted to 8 thousand m².

Thus, despite a long-term experience in prospecting and exploration of landslide processes, once occurring in the above region, they cause significant material damage and further problems regarding the development of the infrastructure of settlements and the whole region. In this regard, the improvement of existing and the development of new methods to combat landslides remain very relevant. The generalized solution to this problem does not seem possible, since in each case it is necessary to take into account the features of this area. The following measures to prevent landslides are proposed in the scientific literature:

- organization of engineering and geological research and regular monitoring of landslide processes;
- surface and groundwater piracy and drainage through drainage systems and upland ditches with a view to dewatering a landslide zone;
- measures aimed at increasing the strength of slope soils, including silicification, freezing, cementation, etc.;
- measures to keep landslide masses by driving piles in a checkerboard pattern;
- planting of trees and shrubs with well-developed turf to create a closed vegetation cover in order to reduce the intensity of landslide processes.

Each of the above measures requires a separate analysis and consideration. Subject to the location and origin of landslides, certain measures may be even more effective. There are some examples of effective measures taken to combat landslides. Thus, over the past decades in Khochi-Ara of Nozhay-Yurtovsky district, numerous landslides have occasionally occurred on a few-hectare mountainside. The intensity of these processes increased significantly in the aftermath of a series of rash actions initiated by the officials of the collective farm named after M.I. Kalinin. In the mid-80s of the last century, they launched a grandiose project to grow alfalfa on the slopes. Bulldozers began to uproot trees and shrubs. To utilize agricultural machinery for planting and harvesting alfalfa, the slopes were leveled. Meanwhile, the natural system of water drainage from under the ground, created by storm flows for a long time, was completely destroyed. This system consisted of small streams that flowed together, forming larger rivers. In summer they dried up, but in fall and spring they intensively whirled away the underground water. Of course, it cannot be argued that this factor was crucial wherever landslides were, but in this particular area it was the destruction of the described system, deforestation and uprooting of forests that were decisive in the outbreak of landslide processes. Obviously, the restoration of the destroyed system in a natural way would require tens and hundreds of years, if this is possible in principle. In this regard, instead of the destroyed drainage system, the authors designed a new one. It goes without saying that each particular area requires careful study, analysis and individual decision making. In the above case study, a road went up the slope. The road had served as a central channel for precipitation water flowing down. The drainage procedure included the following activities. A trench 1–1.5 m deep was dug across the slope of the mountain at an angle of 20–25. The bottom and bottom wall were covered with a polyethylene film that normally contributes to the drainage of water along a drainage ditch. A special drainage pipe was put on the film and padded with gravel on top. The whole system was wrapped in special material and covered up with earth (Fig. 3). Five years after the launch of the system, landslide processes in this particular area almost stopped.
The Chechen Republic is generally divided into mudflow vulnerable areas of different categories in terms of mudflow intensity [4–6].

**Mudflow vulnerable areas of category I.** The category includes basins with large mudflow sites of mainly dispersed mudflow genesis. The length of the sites exceeds 3 km, the flood basin is over 10 km², and the volumes of mudflows are more than 1 million m³.

The territory comprises 4 sites orographically confined to Greater Caucasus and North Jurassic Depression.

Debris flows of rain genesis and suspended streams (turning into debris flows as they move in the main channels) are formed in the mudflow basins of the Maistykhi, Kerigo, Khacharoy-Ekhk, Heldikhoy-Ekhk (tributaries of the Argun River) and Kenkhi (a tributary of the Sharo-Argun River).

**Mudflow vulnerable areas of category II.** The category includes basins with mudflow medium-sized sites including mudflow trenches, catchments and dispersed mudflow sites. The length of the sites is 1–3 km, the flood basin is 2–10 km², and the volume of mudflows is 0.2–1.0 km³.

The territory comprises two such areas. The first, most extensive area orographically confined to Greater Caucasus, extends from the Sharo-Argun to Khrebet Vegilam. The second region, orographically located within the North Jurassic Depression between Skalistyy Khrebet and Peredovoy Khrebet, is confined to the mudflow basins of the Varanda and Verderyk (tributaries of the Argun River).

Debris flows are mostly formed here. Suspended streams flow in the main riverbeds. The saturation of mudflows is rain. In the area of Greater Caucasus, replenishments are likely to happen due to the melting of glaciers and ice cellars.

In general, the southern part of the Chechen Republic, where the described regions are located, is characterized by rather high mudflow activity.

**Mudflow vulnerable areas of category III.** The category includes basins with small mudflow sites. The length of the sites does not exceed 1 km, the flood basis is up to 2 km², and the volume of mudflows is less than 0.2 million m³.

The sites are distributed locally. Suspended streams of rain genesis are mainly formed within the limits of Skalisty Khrebet and Pastbishny Khrebet and the Shato Basin. The occurrence of mudflows in the described regions may be associated with intense snowmelt (Fig. 3).
Mudflow vulnerable areas of category III. The category includes areas confined to Pastbischny Khrebet and Lesnoy Khrebet. The sites have a small extension; mudflows are rarely formed and not intensive.

This area includes the main sites where the above and other landslides occur in the Chechen Republic (Fig. 4) [1].

Mudflows here are impeded by the strong drainage of the territory, due to the karstification of limestones, and forestry slopes.

Once caused by heavy rain falls, light suspended streams are formed in places with significant slopes of the riverbeds, and loose material or clay, easily eroded rocks. Mudflows are possible when associated with anthropogenic activities in the areas of logging and construction.

Due to the poor study of the mudflow basins, there is almost no information about the mudflow hazard and the frequency of mudflows.

4. Conclusion
Natural phenomena are usually divided into processes that appear in closed and open systems. The former ultimately lead to an equilibrium state, developing in the direction of increasing entropy, while the latter, on the contrary, develop in the direction of decreasing entropy, leading to the formation of new self-organizing systems at instability periods. The landslide-mudflow processes occurring in
complex open systems and exchanging with the environment can be attributed to the latter. Due to the influx of outside energy, instability increases, the former structure is destroyed and a new one appears [10]. Synergism of landslide-mudflow processes in the territory under consideration consists in the simultaneous and joint manifestation, thereby making them more devastating. The behavior of mudflow and landslide processes in mountainous Chechnya is quite massive. Communications between settlements, inter-settlement and inter-district roads are subject to danger. Once occurring, mudflows and landslides cause great damage to the landscapes and infrastructure of mountainous areas. Further research of data and other exogenous processes in the context of synergism is of great practical and theoretical importance.

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