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ASSESSMENT OF A MUDFLOW HAZARD ON THE BLACK SEA COAST OF CAUCASUS AND IN THE ADJACENT MOUNTAINOUS AREAS

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ABSTRACT

Assessment of a mudflow hazard in the current period of unstable climate and possible extreme situations is especially important for the Caucasian Black Sea coast. Here mudflows constantly threaten to economic and tourist's objects and happen due to the mass construction of different structures, including their probable appearance during preparation of XXII Olympic Winter Games of 2014 in Sochi. The hazard assessment of mudflows is made through analyzing their activity and the degree to which they affect the territory. Data on the mudflow activity in the past and present time are extrapolated for the period up to 2015 basing on analysis of the basic changing factors of their formation: meteorological and anthropogenic ones in the interaction with geological conditions. High mudflows activity is expected in the nearest years both on the territory where they were known earlier and also in the areas under intensive development. The highest hazard is possible in 2011 - 2012.

***Key words**: mudflow, XXII Olympic Winter Games, atmospheric circulation*

INTRODUCTION

Assessment of a mudflow hazard in the current period of unstable climate and possible extreme situations is especially important for the Caucasian Black Sea coast. Here mudflows constantly threaten to economic and tourist's objects and happen due to the mass construction of different structures, including their probable appearance during preparation of XXII Olympic Winter Games of 2014 in Sochi. The risk of mudflows is especially probable in the Mzymta River Basin.

METHODS AND DATA

As an initial informational data in the assessment of a mudflow hazard, there were taken the data on mudflows in the region under study, information on air temperature and precipitation amounts from the Russian Hydrometeorological Center and History of alternation of elementary circulation mechanisms (abbreviated as ECM) in the atmosphere of the Northern Hemisphere according to the Classification by B.L. Dzerdzeevskii (Dzerdzeevskii, 1962; Kononova, 2010).

CONTENT OF INVESTIGATIONS

The basic characteristics which are used to assess the hazard of mudflows include intensity of mudflow process on a given territory, sizes of simultaneously formed mudflow cones, discharges and velocities of mudflows and activity of their manifestations. Here, under activity of a mud-flowing process one understands the frequency of mudflows or duration of a period between mudflows (UNEP/UNESCO,1988; Natural hazards of Russia, 2002).

Mudflow activity changes in time and is subjected to cyclic variations of different duration depending on the factors causing development of mudflows. Just the activity of mudflows directly depends on weather

extremes, and just this activity represents a hazard of mudflows in a particular basin or region during the current epoch (Lin & Lee, 2006; Ma *et alii*, 2006; Kononova & Malneva, 2007).

At the present time the territory under investigation is characterized by a slight hazard of mudflows. Predominantly the mudflows, here, has a capacity of not more than 10,000 m^3 and a low frequency (once per 15 - 30 years). In the highlands the mudflow frequency is higher - once per 8 - 15 years. The generating sources of the most hazardous mudflows are located in the belts of high and medium-height mountains. The capacity of mudflows can change from a few tens and hundreds m^3 to 100,000 m^3 and more. Activity of mudflows is closely connected with the regime of precipitation.

Depending on the factors that cause formation of mudflows, the following mudflow-hazardous regions can be distinguished on the territory under investigation:

Mud-flows that are being formed on small watercourses and ravines flowing directly into the Black Sea. Their activity is especially high in the area of Novorossiysk City where predominantly water-stony mudflows are formed due to intensive rainfalls, and hard fragmental streams considerably - due to dumps from cement quarries. The slopes are composed of Upper-Cretaceous flysch and loose sediments of 2-3 m and sometimes to 10 m thick. Mudflows along these watercourses often damaged railways (in 1946, 1950, 1953 and 1958, as well as in 2009, 2010), causing interruptions in train traffic, sometimes for 10 days! In the area stretching from Tuapse to Adler, the mudflows are formed mainly in landslide-generating sites. The character of generating mudflows is usually erosive due to washing-out of accumulated sediments in stream channels (UNEP/UNESCO, 1988).

Mudflows in high- and medium-height areas of the Main Caucasian Ridge, which are formed due to washing-out of loose fragmental rock material coming into the channels of temporary and small water streams in the form of mud avalanches, slides and debris. In the alpine zone a great role in formation of hard material flows belongs to ancient moraine.

Until 1950s of XX century recoding of mudflow manifestations in the above-mentioned regions actually was not fulfilled with the exception of the most hazardous territories, i.e. the cities of Novorossiysk and Tuapse. Presently data on the number of the past mudflows are not sufficient as well. In 1970s the workers from VSEGINGEO have carried out the engineering-geological investigations of the Black Sea coast and the adjacent mountainous territory. As a result of these investigations a special map was compiled showing the watercourses in the areas of Novorossiysk and Tuapse and some watercourses in the highland zone of the Mzymta River Basin as mudflow-hazardous ones. Dense forests of the highland and medium-height zones and small-scaled investigations (1:200,000) made it impossible to characterize the mudflow streams of the given territory in more details, but it was noted that no high intensity of them was observed. According to the data obtained during the investigations of the last years, only in the Krasnaya Polyana area 40 mudflow-hazardous streams were registered with 37 among them located in the Mzymta River basin (mainly from the northern slope of Aibga Ridge) and 3 streams - in the basin of Psou River (the southern slope of Aibga Ridge).

It is noted that the most hazardous mudflows are formed in high mountains and medium-height lands along watercourses that cut circus moraines or along channels filled with slide material in the zone of clayey shale and argillites (streamlet Galion - 2, Vodopadnaya, Tobias, Sulimovsky and others). Due to steep slopes of channels, the floods in small mudflow-hazardous basins need little time to reach overflowing onto flat surfaces and are characterized by sharp rises and drawdowns of levels and high water discharges.

As it follows from comparison of data of the investigations, during the recent years the mudflow hazard on the investigated territory grew, which was caused, to a considerable degree, by the increased intensity of anthropogenic impacts and in particular by deforestation and, as a result, the related erosion on the slopes. Such a tendency is observed generally in Caucasus during the last decades.

An increase in intensity and activity of the mudflow process is considerably connected with the geological conditions of the given territory and is observed in the areas composed by metamorphic, terrigenic and flysch rocks of different ages, especially of Lower- and Middle-Jurassic period. The strength of clayey and aspid slates, occurred in the upstream of Mzymta River, highly changes depending on the wetting degree. Of attention is the slight ductility of argil-

lites, clayey shale, aleurolites to weathering processes, especially in areas of tectonic crushing. In many cases rocks are soaked and swollen or become even fluent. On clayey shale such a zone with highly soaking heavy loams with inclusion of rock debris can have a thickness of 1 to 5 m. Typical to such rocks is a decrease in resistance to shearing and development of a sliding process, including in sites of originating mudflows. Simultaneously with this is lower resistance to erosive wash-out. It is natural that in the zone of the Lower-Jurassic, Eocene-Oligocene clayey rocks that are low-stable to denudation, and loamy slope formations of different genesis, there are formed mud-stony streams different by thickness and density.

Investigations of the conditions of forming mudflows on the Black Sea coast of Caucasus and in the adjacent mountainous areas have established that the basic factor increasing their activity is the degree and regime of territory wetting.

Analysis of all the known cases of mudflow formation makes it possible to note that a close linkage exists between precipitation and mudflows in the given region, especially in lowlands. Thus, in the area of Tuapse and Novorossiysk the daily precipitation amount during mudflows exceeds, as a rule, 100 mm. Sources of hard stony streams here are small-sized landslides, detrital cones of ravines, covers of alluvial sediments at slope foots, as well as sediments from the channels washed out by floor erosion. The high mudflow hazard of the Tuapse region is evidenced by the sad events occurred in the beginning of August 1991, which covered the mountains and the coast in the area of Tuapse-Sochi and distributed over the northern macro-slope up to Maikop City. At night from July 31 to August 1 a heavy rainfall happened in these areas. The rainfall caused a high water in the rivers and activated mudflows. The similar tragedy occurred here in October 2010.

In the area of Novorossiysk the catastrophic manifestation of mudflows in August 2002 was also caused by anomalous precipitation. The center of catastrophic events was in the area of Novorossiysk City. Heavy rains covered the entire Krasnodar Region and caused mud streams. The precipitation amounts in those days are presented in Table 1.

Thus, on some days (5 and 8 August in Novorossiysk and August 6-8 in Anapa) daily precipitation sums exceeded the long-term monthly average sum.

The above-indicated precipitation amounts are, indeed, sufficiently high. However in July in the same area the rainfall has also been heavy (Novorosiysk, 23 July - 42.4 mm, 24 July - 89.9 mm), but no information was about floods and mudflows. The first significant manifestation of mudflows happened on August 6, the next rains fell on the territory when it was already prepared for activation of exogenic processes by the weather of the previous period, therefore they caused mass mudflows and activation of landslides in the surface sediments.

Settlement	Date	Daily precipitation sums (mm).	Long-term period average monthly precipitation sums (mm)
Novorossiysk	5	69,0	45
	6	12,8	
	7	8,0	
	8	58,2	
Anapa	5	24,6	34
	6	62,4	
	7	61,9	
	8	55,5	

Tab. 1 - Daily precipitation sums in August 2002

It is known that in the north-western part of the Black Sea coast the most mudflow-hazardous in the sliding and erosive-sliding sites were the years with an increased humidity - 1960, 1962, 1967, 1970, etc. In these years the meteorological stations of Anapa and Novorossiysk recorded an increase of days with heavy rainfalls. In the area of Tuapse and Novorossiysk the daily precipitation amount exceeded 100 mm in all the cases of mudflows. As we have established, in this part of Caucasus the daily maximum precipitation is highest in those years when the monthly and annual precipitation amounts considerably exceed the long-term period average precipitation sums.

It should be noted that the multi-year course of the annual precipitation on the Black Sea coast and in the adjacent territory of North Caucasus (Sochi, Krasnaya Polyana) differs slightly. The multi-year courses of precipitation in seasons of the year at some meteorological stations have generally also much common.

In the multi-year course of annual precipitation amounts there are seen the extreme years when precipitation much exceeds the norm (1924, 1932, 1937, 1939, 1940, 1953, 1955, 1958, 1967, 1977, 1988-1989, 2002). The territory under investigation is character-

ized by a high homogeneity of the multi-year regime of precipitation. This is confirmed by the high correlation coefficients between the rows of annual precipitation at different meteorological points. These coefficients are equal to: Achishkho-Krasnaya Polyana-0.89; Achishkho-Goitkh-0.76; Sochi-Krasnaya Polyana-0.89. However, according to the values of heat- and moisture provision, the regime of meteorological factors, which determine activity of exogenic geological processes, in highlands and medium-height areas will significantly differ from those located on the coast and in the piedmont areas both between years with extreme precipitation values and by the sum of precipitation.

Formation of mudflows on the investigated territory depends not only on absolute values of air temperature and precipitation amount, but also on the character of weather in general which can be quantitatively expressed by a number of days with one or other macro-circulation processes in the Northern Hemisphere (Dzerdzeevskii, 1962).

For analysis of circulation conditions it is reasonable to use the Classification of elementary circulation mechanisms (abbreviated as ECM) of the Northern Hemisphere, developed by B.L. Dzerdzeevskii jointly with his. graduates The information on the Classification can be found on the website *www.atmospheric-circulation.ru*. The entire variety of circulation processes on the Hemisphere is represented in this Classification by 41 elementary circulation mechanisms (ECM). For each ECM a scheme of cyclones movement and stationing of anticyclones is given providing the possibility to imagine vividly a manifestation of each ECM in any region of the Hemisphere.

The History of alternation of ECM is compiled since 1899 till the present time, where for each day the appropriate ECM is indicated. By means of comparing the time of mudflow activation with the Calendar of ECM alternation it was determined at which ECM that kind of weather is formed which causes activation of mudflows in different sites of their origination.

In the erosion sites, these are the ECM that cause intensive destruction of rocks due to frequent changes of their wetting state into drying and freezing into thawing, as well as intensive run-off of weathering products and wash-out of channel sediments.

In the sliding sites for the formation of mudflows, of importance are amounts of precipitation and such a regime of its fall-out, at which destruction of stability of slopes occurs. Here, mudflows are connected, first of all, with those macro-circulation processes, at which the probability of rainfalls is not less than 60%, and with those which bring intensive precipitation with a 10% provision, most often - heavy rains.

It is established that the most dangerous weather for any sites of mudflow origination on the given territory is connected with those ECM-mechanisms, at which the Mediterranean cyclones outcrop to the Black Sea coast of Caucasus. The unstable weather, brought by these ECM, form favorable conditions for alternate wetting-drying of easily breakable rocks in mudflow-generating sites and accumulation of loose detrital rock materials; intensive rainfalls cause run-off of crushed rock materials and formation of liquid mudflows. For the basin of Mzymta River and the adjacent areas of the Krasnodar Region the same ECMs are dangerous. The dynamic schemes of them are shown in Figg.1 and 2.

As activation of mudflows needs abundant rainfalls, then through analyzing the linkage of daily precipitation sums, recorded at meteorological stations of Sochi, Krasnaya Polyana, Novorossiysk and Tuapse, with the elementary circulation mechanisms, those ECMs were distinguished, at which precipitation falls out not less than in 60% of cases of manifesting the given ECM and amounts in total to not less than 50% of the monthly precipitation in a concrete month. These turned out to be ECMs 12a and 13 s. It can be seen from the schemes of Figures. 1 and 2 that at these mechanisms North Caucasus expects coming

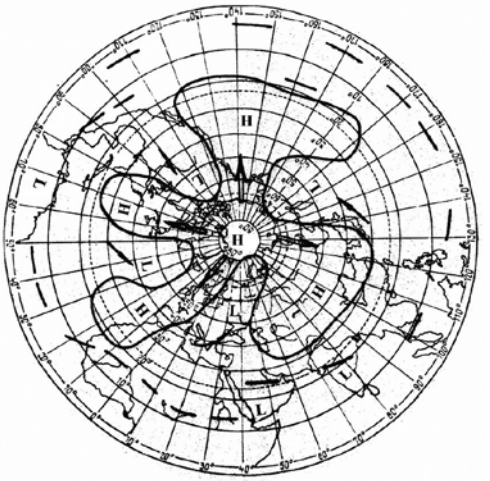

Fig. 1 - Dynamic scheme of ECM 12a:. Letters 'H' and 'L' denote correspondingly high atmosphere pressure (anticyclone) and low one (cyclone)

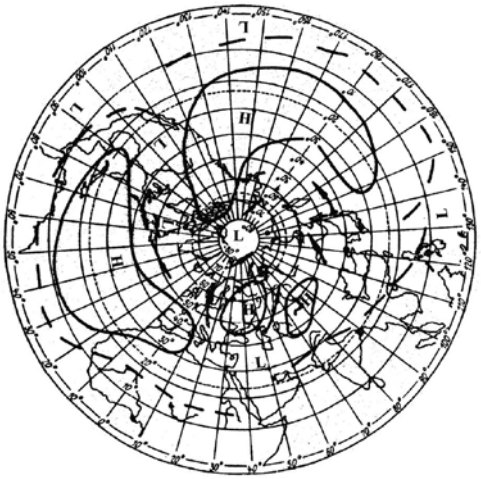

Fig. 2 - Dynamic scheme of ECM 13s:. Letters 'H' and 'L' denote correspondingly high atmosphere pressure (anticyclone) and low one (cyclone)

of Mediterranean cyclones.

The total annual duration of these ECM (Figure. 3) according to the data of 2009 significantly exceeds the average one for 1899 - 2009. The tendency of last changes shows a curve 3 (10-year smoothing). It is seen that the total annual duration of precipitation forming ECM for the Black Sea coast in the modern period is the highest of all time since 1899. This gives the grounds to suppose that in the nearest 10 - 15 years the risk of mudflows in this region will remain high.

The above-described statements allow us to pass to the assessment of mudflow activity using the data of the above-indicated fast-changing factors causing the development of mudflows. Here, it should be noted that assessment of mudflow activity for the nearest decade on the regional level represents only the assessment of probability of appearance of a mudflow-hazardous situation. The given assessment requires yearly specification.

For all the factors determining the activity of mudflows in the given region the time rows are compiled. Analysis of the time rows gives the possibility with sufficient substantiation to predict the degree of mudflow-hazardous situations in the zones of low-height mountains, medium-height and high mountains of the territory under investigation. Knowledge of the cyclic character of mudflows helps the mathematical model's extrapolation process:

$$x(t) = \eta(t) + z(t) + e(t)$$

where the components $\eta(e)$ and $z(t)$ are regular, and $e(t)$

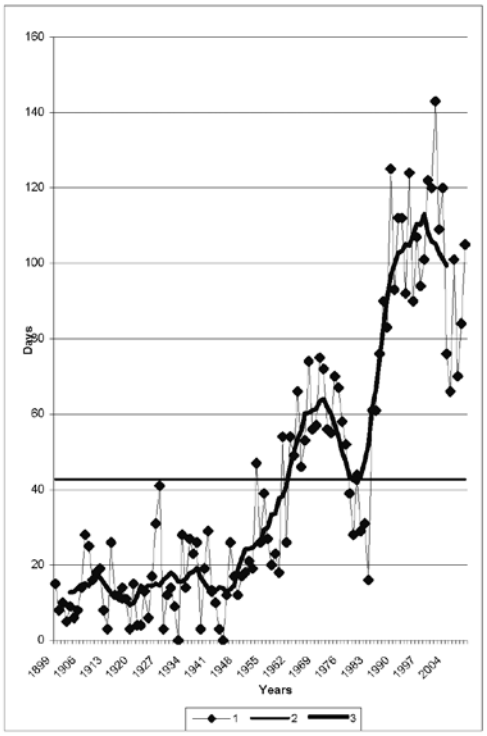

Fig. 3 - Total annual duration of ECM 12a and 13s. 1 - annual duration, 2 - average for 1899 - 2009, 3 - annual duration smoothed by a sliding 10-years

is casual. Implementation of this model by means of the program MAPR makes it possible to fulfill extrapolation for the fourth part of the time row. Accuracy of the predictive assessment with 60%-provision is within the standard deviation, with 90%-provision is within twice standard deviation.

Using the above-mentioned program and with the aid of statistical criteria one finds a trend and cycles in the time rows, determines parameters of the functions which describe regular changes; and as a result, by regular and casual components of the initial time row the predictive values are produced.

The obtained results give the possibility to compare the time rows of different mudflow-forming factors. The degree of mudflow activity in concrete years depends on the force with which the factors influence the mudflow process. The activity is considered strong when mudflows cover over 60% of mudflow streams within a territory under study; medium activity - when mudflows cover 30 to 60% of streams, and weak - when less than 30% of territory.

On the basis of extrapolation of the basic chang-

ing factors of mudflow formation in the Mzymta River basin and the adjacent territory of the Krasnodar Region it is possible to assess the mudflow-hazardous situation for the nearest ten years. Thus, in the nearest years the amount of precipitation on the Caucasian Black Sea coast and in the adjacent mountainous areas will remain sufficiently high, especially in the area of low mountains. A considerable increase in precipitation is possible in 2012. In this year the precipitation increase is expected in January and February, which may lead to development of a sliding process in this area and, hence, to activation of mudflow origination. In summer when heavy rainfalls are possible at ECM 13s, an increase of precipitation is also possible in 2012. The above-proposed high duration of ECM 12a in spring and 13s in summer and extreme character of weather at these ECM confirm the truth of the statistical predictions.

Prediction of mudflows for this region was made first in 1975. Increase in mudflow activity was expected in the years of 1981-1982, 1987-1988 and 1992-1993. The prediction proved to be correct. The proposed high activity of mudflows in 2002 proved also to be correct.

The natural conditions of mudflow formation on the territory under study are considerably disturbed by anthropogenic activities, the intensity of which is presently increasing fast. All this considerably affects the geological environment. Many types of economic development of the territory cause watering of soils, a rise of shallow groundwater level, soaking of rocks and decrease of their strength properties, which on the given territory are not so high, as it was shown above. When the natural and anthropogenic factors act jointly, the hazard of mudflows in the above-discussed rock complexes will be especially high.

Taking into account the construction of Olympic objects, activity of formation of stony streams will considerably increase and, with anomalous wetting, can lead to formation of mudflows with a capacity of to 200,000 m^3.

The hazard of mudflow formation is explained by the fact that even small mudflows formed, for example, in water streams on the slope of Aibga Ridge and so on, can be added with active landslides developed on the left- and right-hand shores of Mzymta River. As a result, Mzymta can be dammed by the formed catastrophic mudflow. Therefore, a special attention should be given to assessment of the present-day activity of landslides of different genetic types, and to their possible manifestations as sources of a hard component of mudflows.

Attention should be paid also to other areas with a high intensity of landslides in the basin of Mzymta River, with which manifestations of large-sized mudflows can be connected, in particular, the basin of Medoveevka River. Also, a very dangerous area is the basin of Kepshi River, characterized by an extremely high risk of mudflows. There are known mudflows here, which are connected with landslide-originating sites. With activation of a landslide, formation of a catastrophic mud flow of a capacity of to 300,000 m^3 is possible.

CONCLUSIONS

1. In the nearest years one should expect a high increase of mudflow hazard on the Black Sea coast and in the adjacent mountainous areas due to increasing intensity and activity of mudflow process as a result of natural and anthropogenic factors.
2. According to analysis of the conditions for development of mudflows and factors that cause them, the next increase of mudflow activity is expected in 2011-2012.
3. With a considerable increase in mudflow hazard, the mudflows in the given area can be formed in places where they never happened. The expected increasing anthropogenic load connected with the Olympic Games of 2014, the total impact of natural and anthropogenic factors can be especially high. Many economic objects can be damaged even by small mudflows. Thus, for some certain objects, for example, oil- and gas pipelines, highways even the mudflows of low capacity will be dangerous. They can interrupt the traffic for a long time and cause a large material damage.
4. To prevent possible catastrophic events is impossible, but negative consequences of them can be minimized to conduct systematic monitoring of hazardous exogenic geological processes.

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