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Short Communication

Statistical Analysis of Hydrological Drivers of Landslide Inducing Factors Using Weights of Evidence Approach on Kerch Peninsula

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Abstract

Article is devoted to statistical analysis of the influence of the surface water of Kerch Peninsula on landslides. We chose a distance from water as indicator that can be express the impact of surface water on landslides. The territory of the peninsula was divided into 5 classes according to the degree of distance. Thus, according to the results of the study, it was found that the greatest impact on landslides is observed at a distance of up to 500 m. On the other hand, it is noted that there is no effect of surface water on landslides at a distance over 2 km.

Keywords: Landslides, GIS, surface waters, Kerch Peninsula, statistical analysis

Introduction

The Kerch peninsula, nowadays, is an important link in the transport and logistics chain of the Russian Federation and is having rapid development in connection with the construction of the Crimean bridge, the development of the road transport network and coastal infrastructure (Krivoguz, 2020). The main natural features of the peninsula are complex geological structure, high seismic activity, arid climate, and a high level of erosive dissection (Krivoguz and Bespalova, 2017; Krivoguz and Bespalova, 2020). One of the most characteristic problems for the Kerch peninsula has always been the activity of landslides. This problem appears in the transformation of existing landscapes and ecosystems, and also leads to serious economic and social damage. Being complex, landslides can significantly affect not only the functioning of the urbanized environment, but also lead to significant loss of life. Saturation of the slope with water is the main cause of the landslide's occurrence (Bathurst, et al., 2007; Margielewski and Urban, 2000). Saturation can occur in the form of intense rainfall, snowmelt, changes in groundwater levels, as well as changes in water surface levels along coastlines in lakes, reservoirs, canals and rivers. Some types of landslides and floods are closely related, because both of these phenomena occur due to heavy rainfall, increased runoff, and water saturation of the soil (Krivoguz and Bespalova, 2017;. Krivoguz and Burtnik, 2018). In fact, these two phenomena often occur simultaneously in the same territory. On the other hand, landslides can also lead to flooding during the collapse of massive parts of the slope that overlap waterways, which leads to an increase in the volume of accumulated water. If the dam, formed in this way, does not collapse due to physical or other factors, then the area will be flooded downstream (Dahal and Hasegawa, 2008). The occurrence of landslides is incorrectly associated only with the activity of groundwater. They are a complex process that occurs under the influence of large number of factors, including levels of underground water. In some cases, one of the main reasons for their occurring is the intensive washing of the coast with a river (landslides in Volga region) or the sea (landslides in the Crimea), as a result of which the steepness of the slope and its stress state increase, which upsets the balance (Ayalew, et al., 2014). Groundwater, moving to drainage areas, creates a certain hydrodynamic pressure near the exit to the surface of the slope. This is especially true when the aquifer is hydraulically connected to the river. The recession of water in the river is relatively quick, while the decrease in groundwater level is relatively slow. It turns out, as it were, a gap between the levels of groundwater and river water, which creates additional hydrodynamic pressure. As a result, the slope of the aquifer can be squeezed out, followed by the creep of the rocks of the upper part of the slope. In this regard, in a number of cases, landslides are intensified after the flood.

Hydrological characteristics of study area

The surface watercourses of the Kerch Peninsula are represented by rivers and streams. Due to their low water availability, they are not used enough in agriculture and industry; they are poorly studied due to the lack of interest in them. The low water levels of the surface watercourses of the peninsula is caused by an insignificant level of precipitation, the average annual value of which is about 400 mm. The water regime of rivers here is practically not studied. Also, they are characterized by floods in the winter-spring period. Surface runoff in the summer is provided mainly due to the emergence of springs to the surface.

The main source of water for the rivers of the peninsula is a small amount of atmospheric precipitation. However, in some years, short-term floods in summer are more intensive then in winter and spring. Mostly they occur in June-July, and pass within a few hours.

Table 1 - Main morphometric characteristics of biggest rivers on Kerch peninsula.

Name	Catchment area, km^2	River lenght, km	Tributary rivers amount, pcs / length, km	Weighted average slope of the river, ‰ ‰	Weighted average slope gradient, ‰	Average length of slope, km	Averaged height of river, m
Melek-Chesme	85,0	18,5	4/22,35	8,9	3,5	1,02	50,0
Katerlez	45,66	9,5	9/53,18	9,45	6,4	0,4	50,0
Bulganak	23,87	8,4	5/8,4	13,4	7,0	0,8	37,0

Autumn-winter floods are weak, sometimes they occur in December - January. The average intensity of raised water levels in rivers in the spring is 0.1 ... 0.2 m / day, the maximum is 0.5 m / day, which is most often observed in the spring (March - April), or at the beginning of summer (June). In some cases, some floods were recorded in July-August (Krivoguz and Bespalova, 2018; Krivoguz and Bespalova, 2020).

Materials and methods

Landslides can be mathematically described as the sum of the contribution of factors acting on it (weighting factors). Thus, the contribution of factors that have a positive effect and actually lead to the occurrence of landslides will be in the range from 0 to ∞, while the contribution of factors that have a restraining effect on them will be in the range from -∞ to 0.

From a mathematical point of view, in this case, it is necessary to separate the border, at which there is a transition from an unstable state to a stable state and vice versa. Since when calculating its indicators, the stability of the territory can vary from -∞ to +∞, then the boundary of this transition can be considered as 0 (Denis Krivoguz & Bespalova, 2020).

Hydrological factors determine the processes of water erosion and suffusion. These include:

- surface and underground waters and their spatial proximity to landslides, their depth;
- spatial and qualitative variations in the composition of the soil solution.

The river network, its density and proximity, determines the potential level and volume of water impact on the slopes.

The spatial analysis of resistance to landslides is when analyzing factors for a given number of grid cells $N\{D\}$ containing event D and the total number of grid cells $N\{T\}$, the prior probability is expressed by formula 1:

$$PD = \frac{ND}{NT} \quad (1)$$

Assuming that the binary predictor of the influencing factor B occupies $N\{B\}$ grid cells, and if a certain number of known occurring of landslides are within the cells of this factor, that is, $N\{D \cap B\}$, then the preference for occurrence, given the possibility of the presence of a predictor factor and the absence of an influencing factor, can be expressed by formulas 2 and 3

$$P\{D|B\} = \frac{P\{D \cap B\}}{P\{B\}} = P\{D\}\frac{P\{B|D\}}{P\{B\}} \quad (2)$$

$$P\{D|\bar{B}\} = \frac{P\{D \cap \bar{B}\}}{P\{\bar{B}\}} = P\{D\}\frac{P\{\bar{B}|D\}}{P\{\bar{B}\}} \quad (3)$$

The posterior probability of occurrence determines the presence or absence of a factor and is denoted by $P\{D \mid B\}$ and $P\{D \mid \bar{B}\}$, respectively. $P\{D \mid B\}$ and $P\{D \mid \bar{B}\}$ denote the posterior probabilities of finding the grid cells of factor B in the grid cells of event D (C. Van Westen, 1997; C. J. van Westen, Castellanos, & Kuriakose, 2008).

Weighting factors for binary factors are determined by formulas 4 and 5:

$$W^{+} = \log_e \frac{P\{B|D\}}{P\{B|\bar{D}\}} \quad (4)$$

$$W^{-} = \log_e \frac{P\{\bar{B}|D\}}{P\{\bar{B}|\bar{D}\}} \quad (5)$$

Where W^{+} and W^{-} - are the weights of the absence or presence of factors influencing the landslides, respectively. Using the weights of evidence method in a GIS, weights can be calculated using formulas 6 and 7:

$$W_i^{+} = \log_e \left(\frac{\frac{N_{pix1}}{N_{pix1}+N_{pix2}}}{\frac{N_{pix3}}{N_{pix3}+N_{pix4}}} \right) \quad (6)$$

$$W_i^{-} = \log_e \left(\frac{\frac{N_{pix2}}{N_{pix1}+N_{pix2}}}{\frac{N_{pix4}}{N_{pix3}+N_{pix4}}} \right) \quad (7)$$

where, N_{pix1} is the presence of the landslides inside the factor grid, N_{pix2} is the presence of the landslides outside the factor grid, N_{pix3} is the absence of the landslides inside the factor grid, N_{pix4} is the absence of the landslides outside the factor grid.

Results

One of the most important characteristics affecting the occurrence of landslides is the distance from surface watercourses. It is the distance at which each point in the study area is distant from the surface watercourse.

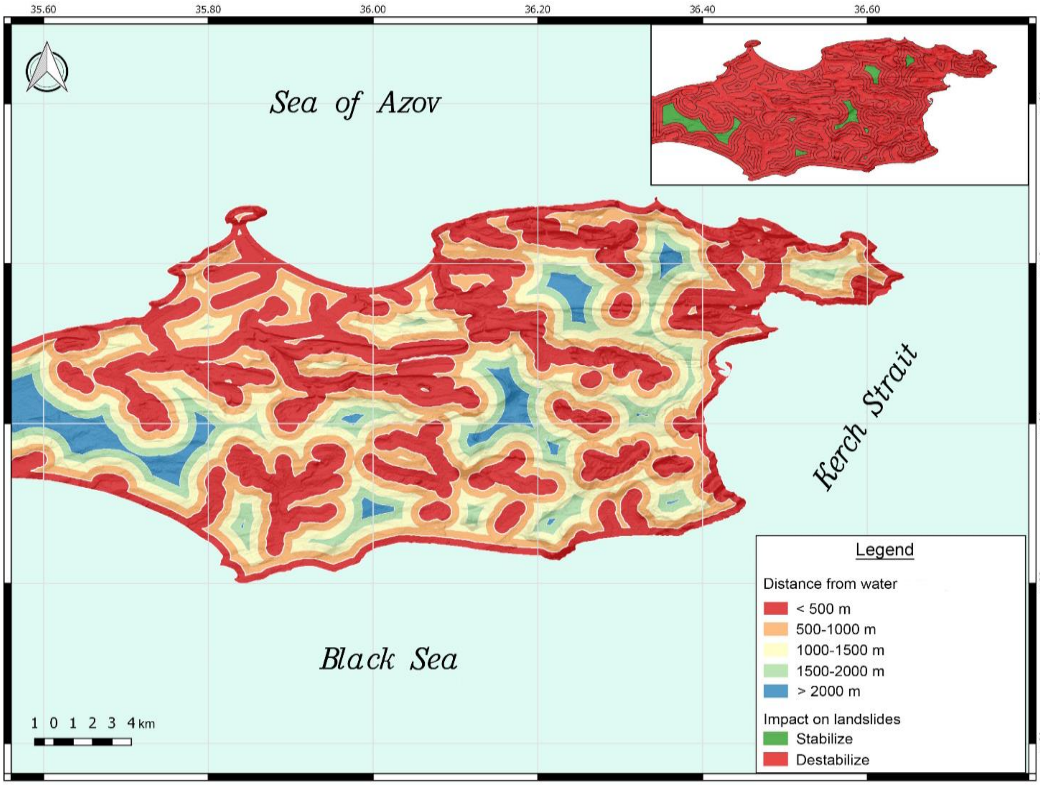

Figure 1 - Spatial distribution of distance from watercourses classes on the Kerch peninsula

According to the level of distance from the watercourse, the territory can be divided into several classes:

- very slightly distant (0-500 m)
- slightly distant (500-1000 m)
- distant (1000-1500)
- highly distant (1500-2000 m)
- very distant (more than 2000 m)

This factor significantly affects the level of landslides occurring. For example, the first two zones are territories with the most active processes of changing the composition and properties of the underlying surface.

Table 2 - Distribution of class distribution areas, according to level of distance from surface watercourses on Kerch peninsula

Class	Type	Area, km^2
1	very slightly distant	736,3948
2	slightly distant	629,636
3	distant	525,7279
4	highly distant	409,4954
5	very distant	617,5648

Thus, the biggest part of the territory is occupied by very slightly distant and slightly distant areas (Table 2). Their total area is about 1350 km^2. This is achieved mainly due to the fact that research area is a peninsula and it is almost completely surrounded by water, where the abrasive activity of the sea affects the coastal slopes. On the other hand, the surface watercourses of the peninsula are insignificant and territories located outside the coastal zone are slightly susceptible to water erosion processes (Table 2).
The contribution to landslides occurring of each class is described in table 3.

Table 3 - Contribution to landslides occurring of each class on Kerch peninsula

Class	Type	Value of impact on landslides
1	very slightly distant	0,3518
2	slightly distant	0,059
3	distant	0,0191
4	highly distant	0,0118
5	very distant	-0,6196

Discussion and Conclusion

Thus, the pattern of reduction in exposure depending on the distance with respect to the surface water body is visible. So, the greatest impact on landslides is caused by water bodies located at a distance of no more than 500 meters from them. With an increase in the distance up to 2 km, the effect of the hydrological environment is practically reduced to zero. Based on the obtained results, since the index of influence on landslides does not exceed 1, it can be concluded that the hydrological environment does not make any determinative effect on the formation and occurring of landslides on Kerch peninsula.

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