N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224-5278
Volume 1, Number 427 (2018), 34 – 40

UDC 624.131

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ASSESSMENT AND MAPPING OF LANDSLIDE RISK IN THE TERRITORY OF ALMATY CITY

Abstract. The problem of assessing landslide risk is very urgent for the city of Almaty and its environs. Many landslide areas are built up by residential buildings or are actively used in economic activities. The landslide hazard and the territory development maps were used to assess landslide risk. The landslide hazard map was compiled based on the results of surveys of landslides' traces and the data on seismogenic landslides of 1887. In Almaty region, landslide risk is largely due to a seismogenic factor. Three degrees of hazard were distinguished on the map of landslide hazard: a significant one, a moderate one and a low one. The criteria for identifying a degree of hazard were the data on volumes of landslides and the proportion of landslide areas. The map of the territory dacha development was divided into territories with urban development, with dacha development, territories adjacent to built-up areas, uninhabited territories used for recreation, and uninhabited territories rarely visited by people. Assessment of landslide risk, meaning a possibility of landslides causing damage of a certain severity, was done by combining the maps of landslide hazard and the territory development. There were identified areas with a significant, a moderate and a low risk on the landslide risk map. Territories with a significant risk include all landslide areas with a permanent population and territories with a high degree of landslide hazard, adjacent to populated areas. A significant damage from landslides is quite possible in these territories. It is necessary to carry out engineering anti-landslide measures here. Areas with a moderate and a low landslide hazards that adjoin to populated areas or are used for recreation are characterized by a moderate risk. Probability of damage from landslides is small here. In such territories, it is sufficient to create a warning system. A low risk is observed in areas rarely visited by people, and in areas with a low landslide hazard, used for recreation. In such areas, anti-landslide measures are not applied.

Key words: landslides, rock falls, landslide risk, assessment and mapping.

Introduction. The largest megalopolis of Kazakhstan, the city of Almaty, with a population of more than 1.7 million people is located at the foot of the Ile Alatau Ridge. The southern part of the city occupies a low-mountain zone where loess-like loams are widespread. The low-mountain zone, adjacent to the city's territory, is used for dachas and as a recreation area. In recent years, cottages are being actively built here.

The territories formed by loess-like loams are characterized by a significant degree of landslide hazard. Typically, landslides are formed in spring and early summer, when an annual maximum of precipitation is recorded in the Ile Alatau [1]. Recently, landslide activity has increased as a result of human activities like cutting and overloading of slopes during construction of roads and houses, wetting of slopes by domestic sewage and as a result of water pipe breaks.

The Ile Alatau Ridge is distinguished by its high seismic activity. Here earthquakes of up to 9-10 points are possible. Such earthquakes occurred here in 1887 and 1911 [2]. There is a very high probability of mass formation of seismogenic landslides, as it occurred on May 28, 1887.

Therefore, the task of assessing and mapping of landslide risk is very urgent for the city of Almaty and its environs. As it is known, risk is a product of damage from any dangerous phenomenon by probability of such a phenomenon [3]. In our case, we are considering the risk caused by landslides that is landslide risk. In conditions of a great uncertainty of the components of landslide risk, when it is impos-

sible to accurately calculate a level of the risk in quantitative indicators, we must resort to risk assessment by qualitative categories [4, 5]. In this paper, we used three grades of risk level: an unacceptable, acceptable and negligible. A level of risk is considered unacceptable when a possibility of landslides is high and they are likely to cause significant damage and human casualties. In this case, engineering protection measures are necessary. An acceptable level of risk means that there is a significant possibility of landslides, which can cause an insignificant damage. In such conditions it is enough to organize proper land use and establish a warning system. The risk is considered negligible when both a probability of landslides and damage from them are insignificant. In this case, no protective measures are taken.

To assess landslide risk in Almaty, the data on volume and distribution of landslides obtained in the course of field surveys and on literary data were used. A potential damage was determined by presence of a permanent or temporary population, facilities and infrastructure in the given territory.

Seismogenic landslides in Almaty regions. A very valuable material on landslides and rock falls is stated in a book by I. Mushketov, published in 1890 [6, 7]. An earthquake with a magnitude of 7.3 occurred early in the morning on May 28, 1887. The maximum force in the epicenter was more than 9-10 points [2]. In total, 332 people became victims of the earthquake. 154 people of those died in the mountains under rock falls and landslides.

Large and continuous destructions begin from the Belbulak and Koturbulak Valleys, stretching almost an uninterrupted path to the west of the Kaskelen Valley. The length of the greatest damage path is 35 km. In the transverse direction it is 20 km. The lower boundary passes at the foot of the Ridge at an altitude of 900-1 200 m above sea level, the upper boundary is at 2 400-2700 m above sea level. The largest and almost continuous damages can be traced to an altitude of 1 500-1800 m. The entire area of damage occupies 2 000 km^2, but the area of continuous damage is 175 km^2. The total volume of displaced rocks on the northern slope of the Ile Alatau is 440 million m^3.

The eyewitnesses testify that all the landslides and rock falls occurred simultaneously, as they were from one blow. At the same time, the earth "was exploding and throwing up large blocks", and "liquid mud was flying out" from some cracks. Mud slides immediately flowed from all the ravines. At first, they were flowing swiftly, but then very slowly, so that the largest ones passed not more than 300 m per a day. Motion of some of the mud slides continued for several days.

In the course of their advancing from the slopes to the valley, the mud slides dammed stream channels and formed temporary lakes. Breakthrough of these lakes, which took place in 1-3 days, was rather rough in some places. The largest landslides and rock falls occurred on the site from the Shirokaya Shchel to the Aksai. At present, this territory is a part of Almaty.

In the Pryamaya Shchel the mud slides begin at an altitude of more than 1800 m, and stretch almost continuously for 10 km. The main mud slide occupies almost the entire valley of the Pryamaya Shchel. There are only 2 km left to reach the foot of the mountains. The main mud slide length is about 7 km, the width is from 100 to 500 m, the thickness is from 30 to 60 m, in some places it is even 70 m, and the volume is 84 million m^3. The total volume of landslides in the Pryamaya Shchel Valley is 126 million m^3.

In the Shirokaya Shchel, the total volume of landslides is 1.5 million m^3. In the Kishi Almaty Valley, the volume of displaced rocks is 12 million m^3. The volume of all the displacements between the Ulken and Kishi Almaty Gorges is 6 million m^3.

Destructions in the Ulken Almaty Valley begin at an altitude of 850 m. Opposite to the Teresbutak outfall on the left side of the Ulken Almaty, there is a granite rock fall in the side gorge of the Koksheka. It differs from other rock falls with its white color. The length of the rock fall is 4 km, the width is 200 m, the thickness is 30 m, and the volume is 24 million m^3.

A huge rock fall that is above the Teresbutak amazes with its size. It emerged from the left inflow that is the Prokhodnaya Shchel. This rock fall overwhelmed a house of a forester with his entire family, as well as several yurts with 39 shepherds and many cattle. The thickness of the rock fall sediments is 60 m. It filled the Ulken Almaty Valley with 300 m in width and 3 km in length. Its volume is 54 million m^3.

Between the Ulken Almaty and Jamanbulak, mud slides are numerous, but they do not reach the bottom of the mountains. Their volume is 6 million m^3.

There is a mud slide in the Jamanbulak that filled not only the entire valley, but also went beyond the mountains. The stream of thick mud was moving very slowly, and after leaving the mountains, continued to crawl for 4 days. It spread widely along the foothill plain along the both banks of the outfall, filled the

plain that separated the Jamanbulak from the neighboring Karagaily River, and spread over a wide area between the Jamanbulak and Oijaylyau. The length of this huge mud slide is 4 km in the mountains, and almost 2.5 km on the plain, the volume is 30 million m^3.

The next western mud slide in Tastybulak Gorge is much smaller. Its length is 1500 m beyond the Gorge, and 3 000 m in the Gorge. Its greatest width at the end is 250 m, the average one is 70 m, the thickness is 20 m, and the volume is 6.5 million m^3.

In the Aksai Valley, traces of destruction are numerous and reach the greatest development at an altitude of 1 650 m. The first landslides appear on the left slope of the Aksai just 1 km from the beginning of the Gorge. The first major landslide is on the right slope at 2 km from the beginning of the Gorge. Its thickness is up to 20 m, and the volume is 200 thousand m^3. Less than 0.5 km above there is a continuous heap formed by several landslides that have filled the entire Aksai Valley. The thickness of the deposits is 40-50 m, in some places it is up to 70-80 m, and the volume is 25 mln m^3.

At an altitude of 1 400 m, mud flows terminate and are replaced by a stone granite rock fall, that differs sharply from dark-colored mud flows with its white color. The rock fall began at the top of Akzhar and occupies the entire width of the Aksay Valley, and has the length of 500 m. The thickness of the granite heap in the Akzhar Gorge is more than 100 m. The volume of the rock fall is 40 million m^3. All the landslides above Akzhar have a total volume of 6 million m^3. Up to 60 people died in the Aksay Valley.

Landslides and rock falls dammed the Aksai Valley in several places and formed temporary lakes, so that there was no water in Aksay until 11 pm on May 28. At night the dams were broken. The formed mud flow passed more than 15 km along the foothill plain and blocked the road between Verny and Kaskelen at the length of 8 km.

Landslide risk assessment and mapping. To assess landslide risk, two maps were compiled: the landslide hazard map and the territory development map.

The landslide hazard map at a scale of 1:25 000 (figure 1) was compiled based on a survey of landslide trails, most of which occurred during the Verny Earthquake of 1887 [16, 17]. The map is made for the territory of the southern part of Almaty City and a low-mountain zone of the Ile Alatau, adjacent to the city. The map shows landslide areas with a significant, moderate and low level of landslide hazard.

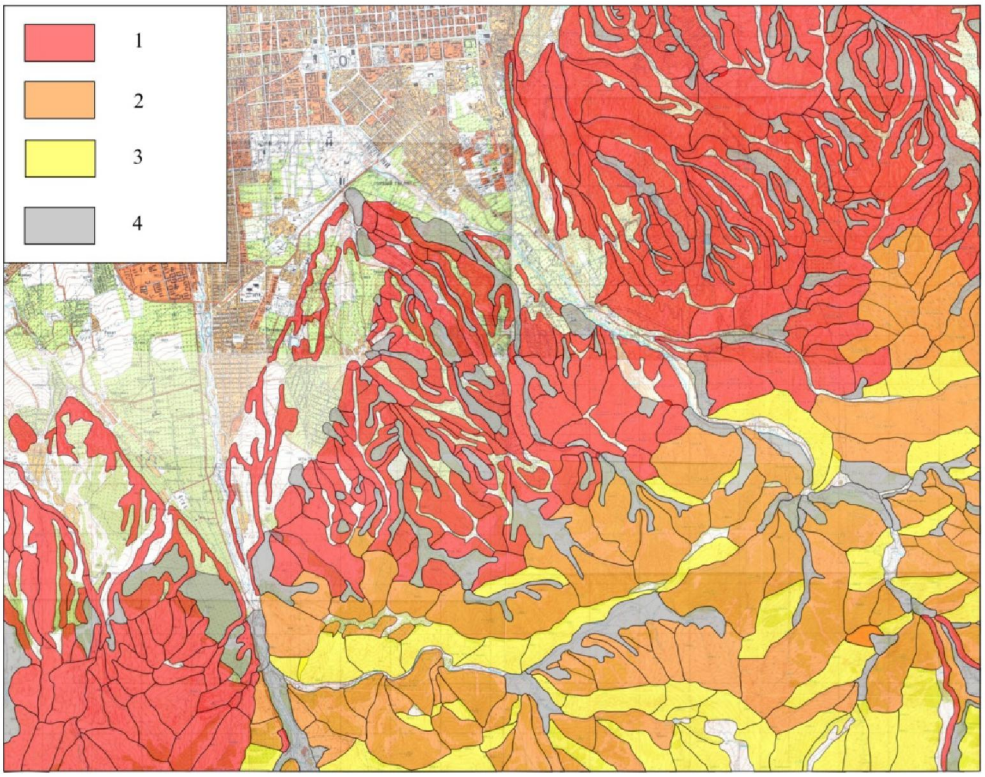

Figure 1 – The map of landslide hazard of Almaty region.
The level of landslide hazard: 1 – significant, 2 – moderate, 3 – low, 4 – deposits of old landslides

Territories with a significant degree of landslide hazard occupy the foothill zone that is the so-called "benches". Loess-like soils with the sickness of up to 50 m are common here. A characteristic feature of these soils is loss of strength when moistened. Therefore, it is very likely that landslides may be formed here after strong and prolonged rains, as it occurred in 2003 and in 2016. In recent times, occurrence of anthropogenic landslides has increased after water leakages from damaged water pipelines. If a strong earthquake occurs in a rainy period, landslide formation will have a massive and catastrophic character, as it occurred in 1887. Landslides volumes reach hundreds of thousands of cubic meters in these territories, and more than 50% of the area is subject to landslide hazard.

In the southern part of Almaty, areas with a significant degree of landslide hazard are stretched in narrow lines along slopes of erosion cuts that fan out from the tops of debris cones of the Kishi Almaty, Ulken Almaty and Kargaly Rivers.

Above benches, in a low-mountain zone of the Ile Alatau (at an altitude of 1000-2000 m above sea level), bed-rock slopes are covered with a thick saddle cover of deluvial crushed loams. The northern exposure slopes are distinguished by an increased thickness of the deluvial cover. The degree of landslide hazard in these territories can be characterized as a moderate one. The cutting depth of the soil does not exceed 2-3 meters. Volumes of landslides without seismic influences do not exceed 10 thousand m^3. However, more than 50 % of the slope area of the northern exposure is subject to landslide hazard. With an unfavorable combination of circumstances (heavy rains and a strong earthquake), landslides may cover large areas, and landslides volumes may exceed 100 thousand m^3. Such landslides were observed in 1887 in the basins of the Pryamukha, Kamenka, Oijaylyau, and Tastybulak Rivers.

In a middle zone of the Ile Alatau, above 2 000 m, the thickness of a deluvial cover on the slopes is 1-2 m, which prevents formation of large landslides. This zone is characterized by small mud flows with a volume of less than 1 thousand m3, which occurred after heavy rains. Landslide hazard affects less than 20 % of the slope area. In this zone there is a hazard of rock falls. With strong earthquakes, sizes of rock falls may reach catastrophic volumes of several tens of millions of m^3, such as the rock fall in the Prokhodnaya River Valley or Akzhar Rock Fall in the Aksay River Valley. However, such cases are very rare. Therefore, in general, landslide hazard can be considered low in this zone.

On the territories development map, five types of development are identified (figure 2). The main criterion of division is the population density and the nature of its location.

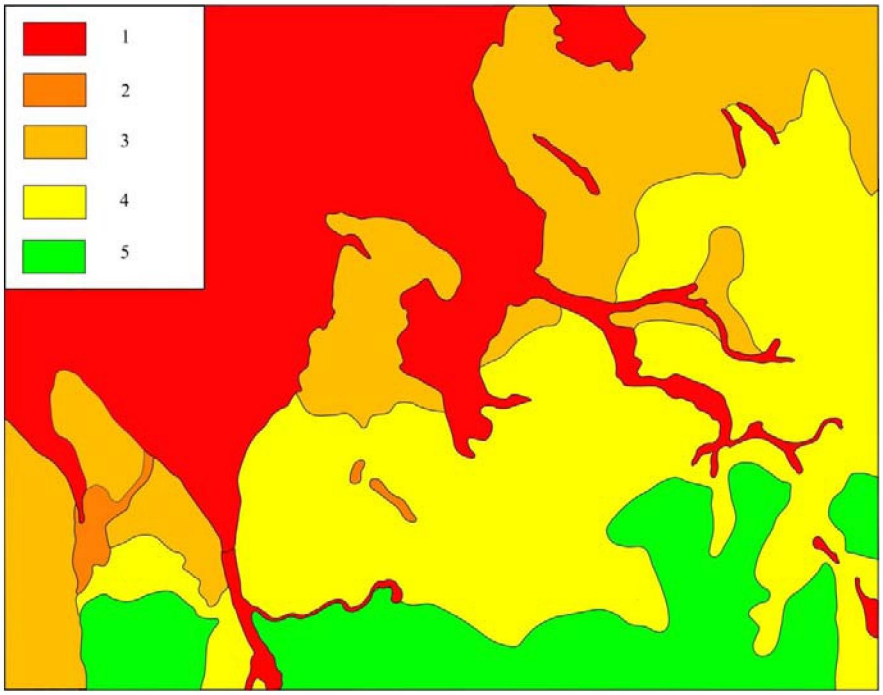

Figure 2 – The map of the territory development.

The type of the territory development: 1 – urban development with a permanent population, 2 – dacha development with a temporary population, 3 – territories adjacent to built-up areas, 4 – uninhabited territories used for recreation, 5 – uninhabited territories rarely visited by people

In territories with urban buildings, density of the population permanently staying on this territory exceeds 10 thousand people/km^2. Therefore, any landslide occurring here will inevitably lead to death of people. In the areas with dachas, people stay not all the time, depending on the season and time of a day. The average density of the population here is less than 1 thousand people/km^2. Therefore, probability of people falling under an action of landslides is several times less than in territories with urban buildings, but still quite high.

Among built-up areas and in their neighborhood there are plots with no houses, but which are used for various purposes by the population. In these territories there are no more than 100 people per 1 km^2 at the same time.

In the immediate vicinity of the city, especially along the valleys of the Kishi Almaty, Ulken Almaty and Aksay, there are territories used for recreation. In these territories, there may be a large gathering of people on weekends. If a landslide occurs this period of time, human sacrifices will be inevitable.

In the upper reaches of mountain valleys in hard-to-reach areas visited by individual lovers of extreme sports, possibility of falling under landslides for people is minimal and close to negligible.

Combination of the landslide hazard map and the territory development map made it possible to assess a level of landslide risk in Almaty region (Figure 3). The whole territory was divided into three zones: 1) a zone with a significant landslide risk, 2) a zone with a moderate landslide risk, 3) and a zone with a low landslide risk (table, figure 3).

The Level of Landslide Risk, Depending on the Degree of Landslide Hazard and Type of the Territory Development

Type of the Development	Degree of Landslide Hazard		
	Significant	Moderate	Low
Urban Development	Significant	Significant	Significant
Dacha Development	Significant	Significant	Significant
Territories Adjacent to Built-up Areas	Significant	Moderate	Moderate
Uninhabited Territories Frequently Visited by People	Moderate	Moderate	Low
Uninhabited Territories Rarely Visited by People	Low	Low	Low

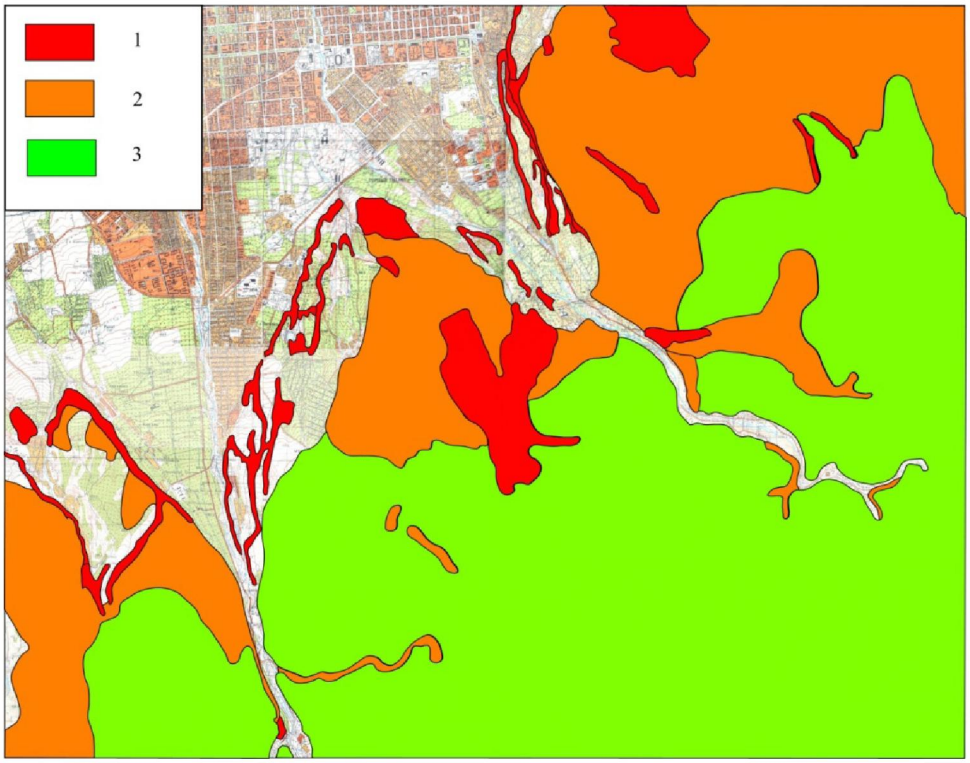

Figure 3 – The map of seismogenic landslide risk.
Risk level: 1 – significant, 2 – moderate, 3 – low

A zone of a significant landslide risk includes territories with a permanent population, where there is a hazard of even small landslides. These are urban territories and dacha sites.

A zone with a moderate risk includes territories with a significant landslide hazard without a permanent presence of people. They are a low mountain zone of the Ile Alatau, adjoining to Almaty from the south.

Low risk zones include territories with a low landslide hazard, rarely visited by people.

Acknowledgement. The research was carried out with financial support of the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan within the framework of grant financing of fundamental scientific research for 2018-2020.

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АЛМАТЫ ҚАЛАСЫ АУМАҒЫНДА ЖЫЛЖЫМА ҚАТЕРІН БАҒАЛАУ ЖӘНЕ КАРТОГРАФИЯЛАУ

Аннотация. Алматы қаласы мен оның маңайында жылжыма қатерін бағалау мәселесі өте маңызды. Көптеген жылжыма қауіпі бар аймақтарға тұрғын үйлер салынған немесе шаруашылық әрекетінде өте белсенді қолданыста. Жылжыма қатерін бағалау үшін аумақтың игерілуі және жылжыма қауіпі карталары қолданылды. Жылжыма қауіпі картасы бұрын болған жылжыма орындарын зерттеу арқылы және 1887 жылғы сейсмогендік жылжымалар туралы мәліметтер негізінде құрастырылды. Алматы маңы аймағында жылжыма қатерінің болуы біршама сейсмогенді факторларға негізделген. Жылжыма қауіпі картасында үш қауіп деңгейі көрсетілген: жоғары, орташа және төмен. Жылжыма көлемі мен жылжыма қауіпі бар учаскелердің ауданы туралы мәліметтер қауіп деңгейін бөлудің белгісі ретінде қолданылды. Аумақтың игерілуі картасында аумақтар қала құрылысы бар жерлер, саяжай құрылысы, құрылыс салынған жерге жақын аумақтар, халық қоныстанбаған аумақтар, адамдар аз баратын жерлер деп бөлінді. Белгілі бір деңгейде жылжыма әсерінен мүмкін болатын шығын ретінде жылжыма қатерін бағалау, жылжыма қауіпі мен аумақтың игерілу картасын біріктіру арқылы жүзеге асырылды.

Жылжыма қатері картасында жоғары, орташа және төмен қатерлі аумақтар бөлінді. Жоғары қатерлі жылжымалы аумақтарға жылжыма қауіпі бар тұрақты халық қоныстанған және елді мекендерге жақын орналасқан жылжыма қауіпі өте жоғары аумақтар жатқызылды. Бұл аумақтарда жылжыма болған жағдайда мүмкін болатын шығын көлемі өте жоғары. Оларға жылжымаға қарсы инженерлік шаралар жасау қажет. Орташа қатерлі деп елді мекендерге жақын орналасқан немесе рекреациялық мақсаттарда қолданылатын орташа және әлсіз жылжыма қауіпі бар аумақтар сипатталады. Мұндағы жылжымадан болатын шығын аса көп емес. Бұл аумақтарда ескерту жүйесін құру жеткілікті. Төмен деңгейлі қатер адамдар аз жүретін және әлсіз жылжыма қауіпі бар рекреация мақсатында қолданылатын аумақтарда байқалады. Бұл аумақтарда жылжымаға қарсы шаралар жасалмайды.

Түйін сөздер: жылжымалар, опырылмалар, жылжыма қатері, бағалау және картографиялау.

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ОЦЕНКА И КАРТОГРАФИРОВАНИЕ ОПОЛЗНЕВОГО РИСКА НА ТЕРРИТОРИИ ГОРОДА АЛМАТЫ

Аннотация. Для города Алматы и его окрестностей проблема оценки оползневого риска является очень актуальной. Многие оползнеопасные участки застроены жилыми домами или активно используются в хозяйственной деятельности Для оценки оползневого риска использовались карты оползневой опасности и освоенности территории. Карта оползневой опасности составлялась по результатам обследований следов сошедших оползней и данным о сейсмогенных оползнях 1887 г. В Приалматинском регионе оползневой риск в значительной мере обусловлен сейсмогенным фактором. На карте оползневой опасности выделялись три степени опасности: сильная, средняя и слабая. Критериями для выделения степени опасности служили данные об объемах оползней и доле оползнеопасных участков. На карте освоенности территории выделялись территории с городской застройкой, с дачной застройкой, территории, прилегающие к застроенным, ненаселенные территории, используемой под рекреацию, ненаселенные территории, редко посещаемые людьми. Оценка оползневого риска, как вероятности нанесения оползнями ущерба определенной тяжести, производилась путем совмещения карты оползневой опасности и освоенности территории. На карте оползневого риска были выделены территории с высоким, умеренным и низким риском. К территориям с высоким риском отнесены все оползнеопасные территории с постоянным населением и территории с сильной степенью оползневой опасности, прилегающие к населенным территориям. На этих территориях очень высока вероятность значительного ущерба от схода оползней. На них необходимо осуществлять инженерные противооползневые мероприятия. Умеренным риском характеризуются территории со средней и слабой оползневой опасности, которые прилегают к населенным территориям либо используются под рекреацию. Здесь вероятность ущерба от оползней небольшая. На таких территориях достаточно создать систему предупреждения. Низкий риск отмечается на территориях, редко посещаемых людьми, и на территориях со слабой оползневой опасностю,, используемых под рекреацию. На таких территориях противооползневые мероприятия не применяются.

Ключевые слова: оползни, обвалы, оползневой риск, оценка и картографирование.

Сведения об авторах:

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