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Natural Hazards Estimation and Mapping in the Dzungar Alatau Range (Kazakhstan)

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Introduction

Mountain areas are the territories characterized by heightened natural risk. The number of nature catastrophes accompanied with human victims and a material damage is disproportionate here [1]. Despite of increase in expenses at protection all over the world steady growth of accidents and damage is recently observed. Annually on protection against natural dangers it is spent about 2 % of the gross world product. At growth rate of the gross world product of 3,5 % in year, growth of damage from nature hazards is about 10 % one year. In 20-30 years the gain of losses from nature hazards will exceed a gain of the gross world product [3].

In Switzerland each year only from avalanches 50 people are lost on the average, or about 1 person per 100000 inhabitants. In the Zailiyakiy Alatau range in Kazakhstan avalanches kill annually 1 person per 10000, constantly staying in mountains. In settlements in foothills of the Dzungar Alatau range victims of mudflows become on the average 1 person on 10000 inhabitants. According to the international standards the acceptable natural risk is only one human life loss per 1 million inhabitants. As we see natural risk in mountain areas of Kazakhstan considerably exceeds the acceptable level. Now mountain areas of Kazakhstan are poorly populated. Therefore the average annual damage from natural hazards is insignificant. However at 1963 in the Zailiyskiy Alatau and at 1959 in the Dzungar Alatau, the number of natural accident victims counted some tens person. In connection with development of mountain territories, especially with development of tourism, the number of visitors of dangerous areas will grow, and that will lead to increase in amount of victims.

One of the most effective methods of damage reduction is estimation and mapping of the natural hazards risk with determination of people and objects defeat probability. In territories where the level of natural risk exceeds the acceptable limit, development can be conducted only in a combination to protective actions. Cost of these actions is necessary for including in expenses for development of area.

1. Research area description

The Dzungar Alatau range is located in a southeast part of Kazakhstan. Border with China passes along its crest. The northern and western slopes of the range with the area of 22500 км^2 belong of to Kazakhstan. The ridge extend lengthways 45^o N on distance of 300 km. The height of watersheds reaches 4400 m a.s.l. The height of foothill plains is 600 – 800 m a.s.l. Five natural zones are allocated in a high-altitude structure of the range: low-mountainous steppe, middle mountainous forest, middle-mountainous meadow, high-mountainous stony, and high-mountainous glacial [2].

The low-mountainous steppe zone occupies the lower parts of the Dzungar Alatau range from 600 – 800 up to 1200 – 1400 m on the area of 7580 км^2. Slopes are covered by grassy steppe vegetation, bushes and a deciduous birch-aspen forest. Valleys have a narrow V-shaped cross-section. Valleys depth is 200 – 400 m.

The middle-mountainous forest zone is located in the altitude limits from 1200 – 1400 up to 2200 – 2400 m. The area of this zone is 2800 км2. Valleys are narrow V-shaped, with depth of 600 – 800 m. Northern, northwest and northeast slopes are covered by a coniferous fir forest. The rest slopes are meadow. The timberline height is 2400 m a.s.l.

The middle-mountainous meadow zone is located above the middle-mountainous forest zone up to heights 2800 - 3000 m. Grassy slopes here prevail; there are juniper bushes somewhere. Valleys are narrow V-shaped. Valleys depth is 800 – 1000 m. The zone area is of 7300 км^2.

The high-mountainous stony zone is located in limits from 2800 – 3000 up to 3200 – 3400 m a.s.l. Slopes are covered by stones. There is a lot of rocky outcrops, and a few of alpine meadows glades. It is a zone of distribution of former glaciers, therefore valleys look like trough with the wide bottoms filled by moraines. Valleys depth is 400 – 600 m. Permafrost grounds are widely distributed in this zone. The zone area is of 3200 км^2.

The high-mountainous glacial zone occupies the highest parts of watersheds above 3200 – 3400 m a.s.l. Glaciers, firn fields, moraines, glacier lakes exist at this zone. Depth of valleys is 600 – 800 m. The valley bottoms are wide. Slopes are abrupt, rocky, and stony.

Areas with a leveled relief are widespread at watersheds and intermountain depressions of the Dzungar Alatau range. The area with the leveled relief makes about 30 % of the Dzungar Alatau.

Depending on altitude, relief characteristics, and a slope surface conditions 247 kinds of landscapes were distinguished at the Dzungar Alatau. They are grouped in 67 landscape types. Each landscape type corresponds the certain composition of natural dangerous processes, their spatial distribution, occurrence frequency, and, finally, a level of natural risk.

2. Natural hazards in the Dzungar Alatau

The most widespread natural hazards in the Dzungar Alatau are snow avalanches, mudflows, rockfalls, stonefalls and landslides. From these dangerous processes avalanches have the maximal distribution on the area and are most frequently occurrence [5]. Avalanche danger exist at all territories located above 1500 m a.s.l., except leveled watersheds and intermountain depressions hollows. At the most areas avalanches occur each winter. The avalanche dangerous period lasts from December until April, and in a high-mountainous glacial zone – the year round. Avalanche volumes are usually from 10000 up to 100000 m^3. The maximal volumes of avalanches exceed one million m^3. In usual years avalanches hit from 30 up to 50 % of slopes and valley bottoms. In the extreme years, repeating each 10 years, avalanching gets catastrophic character, and avalanches hit about 75 % of the area. The majority of avalanche events are connected with snowfalls. For avalanche descend it is enough, that the height of an old snow was more than 30 cm, and the new snow height – more than 10 cm. On leeward slopes of east orientation, avalanche activity is higher for the account of snowdrift than carry of a snow by prevailing western winds.

Dry avalanches prevail in number, but wet avalanches are the biggest. Spatial distribution of an avalanche activity is determined by distribution of a snow cover height and a snowfall intensity. The most snowy territories are located at the western slope of the Dzungar Alatau range, open towards the western atmospheric streams. In this part of the range the sum of winter precipitation usually exceeds 500 mm, and the height of a snow cover at the end of winter reaches two and more meters. These areas are most dangerous. The northern and southern slopes of the range are drier. The snow height here is 1 – 1,5 m, and the sum of winter precipitation is 200 – 250 mm. These areas are characterized by moderate avalanche activity. The least snowy are the eastern slope of the Dzungar Alatau where for the winter precipitation drops out less than 200 mm, and the snow height does not exceed one meter. Avalanche activity in these areas is weak.

The mudflow danger takes place at all high-altitude zones of the Dzungar Alatau range. Mudflow traces exist practically in all river valleys. Mudflow events repeat about 1 time in 10 years. Catastrophic events, traveled more than 20 km with volume more than 1 million m^3, are observed about 1 time in 100 years. Mudflows connected with rains and spring snowmelting prevail in number. For mudflow formation it is enough a 40 mm rain [4]. The most destructive mudflows events had occurred on April, 8, 1959 in area of the Tekeli town. Plentiful rain with 76 mm of precipitation was accompanied by intensive snowmelt. The air temperature was 14 ^oC. Mudflow discharges were from 20 up to 250 m^3/s. In Tekeli town many houses were destroyed. The number of victims was 89 people.

The most destructive mudflows are glacial ones. They are connected with outbreaks of moraine lakes near glacier terminus. An example such event is mudflow on the Sarkand river on September, 9, 1982 [4]. the mudflow was formed after outbreak of lake at height of 3220 m. The initial volume of the water weight was 1250 m^3. Moving downwards on an abrupt channel, cut onto moraine, the water stream was enriched with stones and clay. Mudflow discharge reached 1000 – 1300 m^3/s. The mudflow traveled on the Sarkand valley 25 km and stopped on foothill plain at height of 800 m н.у.м. The mudflow deposit volume was about 2 million m^3.

Stonefalls are the falling of separate stones down abrupt rocky slopes. Rockfalls occur mainly in the summer and are characterized by often frequency. A share of rockfalls dangerous slopes increases with absolute height and reaches a maximum in a high-mountainous stony zone where this share reaches 40 %.

Rockfalls are the most destructive natural dangerous processes. Its volumes can reach several hundred million m^3. Big rockfalls are usually produced by strong earthquakes. The Dzungar Alatau range is located in seismically active zone with possible magnitude more M=8. Two Dzasylkol rockfalls in the Aganakty river valley have volume 100 – 120 million m^3. Another big rockfall is located in the Khorgos river valley. The age of these rockfalls was estimated by experts in 2 – 7 thousand years. Rockfalls form frequently a dam at the bottom of a valley, and lakes are filled above them. Lake outbursts can generate catastrophic mudflows. In total in it is revealed More than 20 big ancient rockfalls with volume more than 100 thousand m^3 number at the Dzungar Alatau range. The most of big rockfalls are located at the middle-mountainous zone where the relief dissection is maximum.

Landslides at the Dzungar Alatau range have the limited distribution and are located at the low-mountainous zone, where clay depositions are widespread. Small landslides with volume of tens m^3 are marked in the western Dzungar Alatau at the altitudes 800 – 1200 m. They occur usually during heavy rains and frequently are an initial stage of mudflow formation. Frequency of landslides is about 1 time in 10 years. The extensive landslides areas are located at the

bottom of the Kolpakov intermountain depression in the northeast part of the Dzungar Alatau range. Landslides can hit up to 50 % of dangerous areas.

3. Natural hazards in different landscapes

Presence of natural hazards, their types, scale, and frequency in many respects are determined by such characteristics of a terrain, as: altitude, grounds, relief dissection, and vegetation. The certain combinations of these characteristics form landscape types. In the Dzungar Alatau 67 types of landscapes were distinguished. They were combined into 13 groups according to an altitude zone and a type of vegetation.

For definition of features of dangerous natural processes in each type of landscapes key sites with the area near 100 км^2 everyone have been chosen. Maps of natural hazard distribution at the key sites with scale 1:25000 have been made by interpretation of aerial photos. Some from these maps are shown on Fig .

High-mountainous glacial landscapes

These landscapes are located at the watershed areas above 3200 m a.s.l. Ice surfaces occupy 80 % of the area, rocks - 5 %, and stones – 15 %. Valleys have the trough-shape profile with wide bottom of 300-500 m. The slopes height is 400 – 600 m, and somewhere reaches 800 – 1000 m. Slope steepness is 35-45 degrees. The valley bottoms are filled by glaciers and moraines. The glacier terminuses end at height of 3300-3350 m. Lakes with water volume up to 20000 m^3 there are between glaciers and moraine dams. Avalanches, mudflows, stone falls, and slush flows are widespread at these landscapes.

Snow avalanches descend at ice and stone slopes and at rocky gullies. They occur annually and all year around. Avalanches volumes are 1-5 thousand m^3. 15 Avalanche hit area is 25 %. The avalanche risk is also equal to 25 %.
Mudflows are formed during thawing of a seasonal snow cover in the spring or at thawing of glacial ice in the summer. Increase of charges in channels on a surface of moraines results in their washout and formation small, Mudflows with volume up to 1-thousand m^3 and travel length up to 1 km repeat almost annually. The greatest danger represents outbursts of glacier lakes. They produce powerful mudflows with hundred thousand m^3, which pass downwards on a valley up to 5 km. These mudflows occur each 10 years. The mudflow risk is less than 10 % as the most part of territory is occupied with glaciers.

Slush flows with volume tens m^3 form on flat surfaces of glacial terminuses and moraine fields during spring snowmelt. They do not usually represent any danger.
Rocky outcrops and beneath them are a source of a stone fall danger. The area of these sites accounts 10 %. The risk produced by stone falls also exceeds 10 %.
As a whole the natural risk at the glacier and rocky-glacier landscapes is within the limits of 25-35 %. Except of the written dangerous processes a number of adverse natural processes: thermocarse, soilfluction, and snowdrift are widespread at these landscapes.

High-mountainous rock-stony landscapes

High-mountainous rock-stony landscapes border from below glacial landscapes. It is a zone of distribution of the ancient glaciers, located in high-altitude limits from 2800 – 3000 up to 3200

– 3400 m a.s.l. The width of the valley bottoms are up to 400 – 600 m. The valleys are filled by ancient moraine stone depositions. uneven-age moraines.

Slope surfaces are stony with small fragments of a grass. Rock outcrops occupy about 5 % of the area. The steepness of valley slopes is 30-35 degree. The slope height is 300 – 400 m in average and 600 – 800 m in maximum.

Mudflows and avalanches are the most widespread natural hazards at these landscapes. Avalanche sites occupy 30-50 % of the area. Slope avalanches with volume 1 – 5 thousand m^3 prevail. Avalanches occur annually. The avalanche risk is about 25-30 %.

Slopes with stone fall danger occupy about 50 % of the area of the landscape. These sites coincide often with avalanche dangerous sites. As a whole the natural risk in the high-mountain stony landscapes lies in the limits of 25-50 %. Other adverse phenomena are soilfluction, permafrost, and snowdrift.

Middle-mountainous meadow landscapes with deep valleys

Middle-mountainous meadow landscapes are located at altitudes 2400 –3000 m a.s.l. The valley depth is 400 – 600 m. The valley are narrow V-shaped with steep (30 – 35 degree) grassy slopes. The basic danger is represented with snow avalanches are the main natural hazard here. Avalanche volumes reach hundreds thousand m^3. They occur annually. Avalanches make the territory inaccessible in a winter season. Avalanche risk is more than 50 %.

Except avalanches the rainfall mudflows hit valley bottoms with frequency 1 time in 10 years. The mudflow volumes are tens thousand m^3. The mudflow risk less is about 10 %. The natural risk is equal as a whole of 50 - 75 %. Frozen grounds there are at the northern slopes.

Middle-mountainous meadow landscapes with a hilly relief

Terrains with a hilly relief are widespread at watersheds of the middle-mountain zone. Low ranges of hills arise above planes. The height of hills is 50 – 100 m. The slope steepness is 15 – 20 degree. This territory is characterized by low avalanche danger. The portion of the avalanche sites doesn't exceed 0.1. Avalanches occur annually, but their volumes are 100 - 500 m^3. The avalanche risk is 1 %.
There are no another natural hazards needed taking into account here.

Middle-mountainous coniferous forest landscapes with deep valleys

Middle-mountainous conifer forest landscapes occupy the range slopes between 1300 – 2400 v a.s.l. Valleys are narrow V-shaped. Valley slopes are steep (30 – 35 ^{o}). Slope height is 800 – 1000 m. Fir forest covers northern slopes. Meadow and bush are widespread the rest. The dense fir forest obstacle avalanche formation, but big avalanches originated above the forest line penetrate to the fir forest zone. These avalanches hit annually about 30 % of area.

Large mudflows move through these territories from high to low mountains. They repeat 1 time in 50 – 100 years. The mudflow risk is 1 – 5 %.

Catastrophic rockfalls occur with probability 0.001 per year. They concern with heavy earthquake. Volume of the rockfalls deposition can reach more than 100 million m^3, and a deposition depth can exceed 100 – 200 m. Rockfalls are the most destructive natural

phenomena, but they are also the rarest ones. So, they introduce an insignificant part into the natural risk value.

As a whole the natural risk in such landscapes riches 35 %, mainly due to avalanche risk.

Low-mountainous deciduous forest landscapes

These landscapes are located at the altitudes between 1000 – 1500 m a.s.l. Valleys are narrow, V-shaped. Valley depths are 200 – 400 m. Slope steepness is 30 – 35 ^{o}. Slope surfaces are covered by steppe with shrubs.

In these landscapes landslides and mudflows represent the main natural hazards. Mudflows form during rain falls. They have volume up to several thousand m^3 and repeat one time in 10 years and hit about 0.1 areas. The mudflow risk is near 1 %.
Landslide volumes are 1 – 10 thousand m^3; frequency is 1 time in 10 year. Landslides hit about 10 % of areas. The landslide risk is about 1 %.

Snow avalanches are a significant danger at territories with deep valleys. There is a low snow cover and avalanches descend only at snowy winters (1 time in 5 year). Avalanche volumes reach 10 thousand m^3. Areas hit by avalanches are 50 – 75 %. Avalanche risk is 10 - 15 %.

4. A natural risk map

The result of determination of integral natural risk at key sites was used for to establish the Table of natural risk at landscape types. A natural risk map was developed using the landscape map and this table. The scale of the map is 1:200000. Territories with six level of a natural risk (from less than 0.1 % to more than 50 %) are shown on the map.

Table. A natural risk at various landscapes

Landscape categories				Risk, %				Total risk, %	Main hazards*
Type	Relief	Valleys shape	Valleys depth	Avalan-ches	Stone falls	Mud-flows	Land-slides		
High-mountain rock-glacial landscapes									
Glacial	Steep-slope	U	<250	10-25	1-10	1-10	0	10-25	AMS
			250-500	10-25	1-10	1-10	0	10-25	AMS
			> 500	25-50	1-10	1-10	0	25-50	AMS
Rock-glacial	Steep-slope	U	<250	10-25	1-10	1-10	0	10-25	AMS
			250-500	10-25	10-25	1-10	0	10-25	SAM
			> 500	25-50	10-25	1-10	0	25-50	SAM
High-mountain rock-stony landscapes									

Stony	Pene-plain	U	<100	0,1-1	<0.1	<0.1	0	0,1-1	ASM
	Steep-slope	U	<250	10-25	1-10	10-25	0	10-25	MAS
			250-500	10-25	1-10	10-25	0	10-25	MAS
			> 500	25-50	1-10	10-25	0	25-50	AMS
Rocky каменистое	Pene-plain	U	<100	0,1-1	<0.1	<0.1	0	0,1-1	ASM
	Steep-slope	U	<250	10-25	10-25	10-25	0	10-25	MAS
			250-500	10-25	10-25	10-25	0	10-25	MSA
			> 500	25-50	25-50	10-25	0	25-50	SMA
Middle-mountain meadow and rock-meadow landscapes									
Meadowy	Pene-plain	U	<100	0,1-1	0,1-1	0,1-1	0	0,1-1	AMS
	Steep-slope	V	<250	10-25	1-10	1-10	0	10-25	AMS
			250-500	25-50	1-10	1-10	0,1-1	25-50	AMS
			> 500	50-75	1-10	10-25	0,1-1	50-75	AMS
		U	<250	10-25	1-10	1-10	0	10-25	AMS
			250-500	10-25	1-10	1-10	0,1-1	10-25	AMS
			> 500	25-50	1-10	10-25	0,1-1	25-50	AMS
Rock-meadowy	Pene-plain	U	<100	0,1-1	0,1-1	0,1-1	0	0,1-1	AMS
	Steep-slope	V	<250	10-25	10-25	1-10	0.1-1	10-25	AMS
			250-500	25-50	10-25	1-10	1-10	25-50	AMS
			> 500	50-75	10-25	10-25	1-10	50-75	SAM
		U	<250	10-25	10-25	1-10	0,1-1	10-25	ASM
			250-500	10-25	10-25	1-10	1-10	10-25	ASM
			> 500	25-50	10-25	10-25	1-10	25-50	SAM
Middle-mountain forest-meadow landscapes									

Forest-meadowy	Pene-plain	U	<100	0,1-1	0,1-1	0,1-1	0	0,1-1	AMS
	Steep-slope	V	<250	1-10	1-10	1-10	0	1-10	AMS
			250-500	10-25	1-10	1-10	0,1-1	10-25	AMS
			> 500	25-50	1-10	1-10	0,1-1	25-50	AMS
		U	<250	1-10	1-10	1-10	0	1-10	AMS
			250-500	10-25	1-10	1-10	0,1-1	10-25	AMS
			> 500	10-25	1-10	1-10	0,1-1	10-25	AMS
Rockyo-leso-lugovые	Pene-plain	U	<100	0,1-1	0,1-1	0,1-1	0	0,1-1	AMS
	Steep-slope	V	<250	1-10	10-25	1-10	0,1-1	10-25	SAM
			250-500	10-25	10-25	1-10	1-10	10-25	SAM
			> 500	25-50	25-50	1-10	1-10	25-50	ASM
		U	<250	1-10	10-25	1-10	0,1-1	10-25	SAM
			250-500	10-25	10-25	1-10	1-10	10-25	SAM
			> 500	10-25	10-25	1-10	1-10	25-50	ASM
Low-mountain and depression landscapes									
Deciduous foresty	Pene-plain	U	<100	<0.1	<0.1	<0.1	0	<0.1	MSA
	Steep-slope	V	<250	1-10	1-10	1-10	0	1-10	MSA
			250-500	1-10	1-10	1-10	0,1-1	1-10	MSA
			> 500	1-10	1-10	1-10	0,1-1	1-10	MSA
		U	<250	1-10	1-10	1-10	0	1-10	MSA
			250-500	1-10	1-10	1-10	0,1-1	1-10	MSA
			> 500	1-10	1-10	1-10	0,1-1	1-10	MSA
Bush and steppe	Pene-plain	U	<100	<0.1	<0.1	<0.1	0	<0.1	MSA
	Steep-slope	V	<250	10-25	1-10	1-10	0	10-25	MSA
			250-500	10-25	1-10	1-10	0,1-1	10-25	AMS
			> 500	10-25	1-10	1-10	0,1-1	10-25	AMS
		U	<250	10-25	1-10	1-10	0	10-25	AMS
			250-500	10-25	1-10	1-10	0,1-1	10-25	AMS
			> 500	10-25	1-10	1-10	0,1-1	10-25	AMS

Rocky	Pene-plain	U	<100	<0.1	<0.1	<0.1	0	<0.1	SMA
	Steep-slope	V	<250	10-25	25-50	1-10	0,1-1	25-50	SMA
			250-500	10-25	25-50	1-10	1-10	25-50	SMA
			> 500	10-25	25-50	1-10	1-10	25-50	SMA
		U	<250	10-25	10-25	1-10	0,1-1	10-25	SMA
			250-500	10-25	10-25	1-10	1-10	10-25	SMA
			> 500	10-25	10-25	1-10	1-10	10-25	SMA
Clay ground	Pene-plain	U	<100	0,1-1	<0.1	1-10	1-10	0.1-1	MAK
	Steep-slope	U	<250	1-10	0.1-1	10-25	10-25	10-25	MLA
			250-500	1-10	0.1-1	10-25	10-25	25-50	MLA

*Dangerous processes: A – avalanches, M – mudflows, S – stonefalls, L - landslides.

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