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THE IMPACT OF AVALANCHE HAZARD ON RECREATIONAL ACTIVITIES IN THE ILE ALATAU, KAZAKHSTAN

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Abstract: The aim of this study is to investigate the impact of avalanche hazards on recreational activities in the Ile Alatau Mountains. The study utilizes data on avalanches and the resulting damage from 1950 to 2025, collected by snow-avalanche stations of Hydro-meteo Service (Kazhydromet), the Institute of Geography and Water Security, and the Kazakhstan Mudflow Protection Service (Kazselezashchita). The Ile Alatau Mountains, part of the Northern Tien Shan, are characterized by high avalanche hazard and a significant level of recreational development. This results in casualties among tourists, destruction of tourist infrastructure, road blockages, and downtime of recreational facilities. Indicators of avalanche activity exhibit high interannual variability and a strongly positive skew. In the 270 km² study area, 50 to 220 avalanches occur annually. The average avalanche volume is 15,000 m³, while the maximum volume reaches 350,000 m³. Total annual avalanche volumes range from 30,000 to 1,500,000 m³. During the observation period, 97 avalanche incidents involving people were recorded, affecting 169 individuals, with 74 fatalities. 90% of the victims were tourists, mountaineers, or skiers. The number of accidents is weakly correlated with overall avalanche activity. However, material damage to tourism infrastructure is more pronounced during winters with the highest avalanche activity, namely 1965/66, 1986/87, 2022/23, and 2023/24. Avalanche safety in recreational areas is ensured through avalanche monitoring and warnings, preventive avalanche release, and to a limited extent, protective structures.

Keywords: snow avalanches, avalanche hazard, mountain tourism, avalanche incidents, Northern Tien Shan

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INTRODUCTION

Snow avalanches are hazardous natural processes typical of mountainous regions where winter recreational activities are possible. They pose a natural threat as defined by the United Nations Office for Disaster Risk Reduction – a natural process or phenomenon that may cause loss of life, injury, property damage, loss of livelihoods or services, social and economic disruption, or environmental damage. Snow avalanches can cause significant material damage and human casualties. In Alpine countries of Europe, people have dealt with avalanches since ancient times. One of the most tragic years was 1951, when more than 100 people died in avalanches in Switzerland and Austria (Badoux, 2016). In the late 19th and early 20th centuries, during the "Gold Rush," avalanches significantly hindered the work of miners and prospectors in North America. In 1874, over 60 miners were killed in an avalanche in the town of Alta, and in 1910, a train was buried by an avalanche, killing over 100 people (Davis, 1998). During the industrial development of the Soviet Union, avalanches heavily impacted mining operations. In 1935, 89 miners were killed and 44 werw injured in an avalanche in the Khibiny Mountains. Another 22 miners died there in 1937 (Timofeev, 2017). Today, deaths of local residents or miners due to avalanches are rare.

However, due to the widespread growth of winter tourism, the main avalanche victims are mountaineers, tourists, and skiers. On average, 250 people die in avalanches worldwide annually. In Switzerland alone, an average of 23 people die in avalanches each year (Schweizer et al., 2015). Fatalities have also been recorded in popular tourist mountain regions of Canada and the USA (Vontobel, 2013; Jamieson, 2011; Haegeli, 2011; http://www.whiterisk.ch; Hohlrieder, 2007; McIntosh, 2018).

A group of specialists from Moscow State University and the Swiss Institute for Snow and Avalanche Research developed methods for assessing avalanche hazards during mountain development (Myagkov, 1995; Troshkina & Voitkovsky, 1987; Rodionova et al., 2019; Korovina et al., 2021; Margreth, 2007; Margreth, 2014). There is a classification for areas by avalanche exposure level: construction is prohibited in zones with annual avalanches, while areas with a 30-year recurrence interval must have avalanche protection measures (http://www.slf.ch). Recommendations for assessing the effectiveness of warnings about hazardous hydrometeorological phenomena were provided by the Russian

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Hydrometeorological Service (Kutval, 2007) and the World Meteorological Organization (Fleming, 2015). Analyzing avalanche incidents and developing protection methods is crucial for all countries engaged in tourism and recreation. In 1942, the Institute for Snow and Avalanche Research "SLF" was established in Davos, Switzerland, accumulating significant experience over the decades (Haegeli, 2011). The institute covers meteorological and snow surveys, avalanche hazard mapping, forecasting, and avalanche dynamics modeling (http://www.slf.ch) Similar studies are conducted by the Colorado Institute of Arctic Research in collaboration with the North American Avalanche Association. Avalanche protection is also relevant in tourist regions of Austria, France, and Russia (Vedenin, 2016).

In the Republic of Kazakhstan, 10% of the territory is exposed to avalanche hazard, mainly mountainous regions in the south, southeast, and east of the country. Given the country's large size, all regions have different climatic conditions (Seversky, 2021; Seversky et al., 2000). Avalanches result in casualties and material damage. The state has to spend significant resources on eliminating the consequences (https://www.gov.kz/memleket/entities/emer/press/article/1?lang=ru).

In recent years, tourism and the ski industry have grown rapidly. Many recreational sites are among the most popular in the former Soviet Union (https://stat.gov.kz/ru/industries/business-statistics/stat-tourism/dynamic-tables/). The tourist flow in the Almaty mountain cluster of the Ile Alatau reaches 3.4 million visitors per year or 9,500 people per day. In 2023, tourism generated $158 million annually or $433,000 daily (https://stat.gov.kz/ru/industries/business-statistics/stat-tourism/dynamic-tables/). The state plans to attract significant investment in this industry, leading to a growing number of visitors and consequently, a growing number of avalanche-related accidents.

The aim of this work is to assess avalanche hazards and their impact on recreational development in the Ile Alatau ridge. It provides data on avalanche characteristics, consequences, and safety measures, considering the prospects for winter recreation.

STUDY AREA

The Ile Alatau Mountains are the northernmost ridge of the Tien Shan range. They stretch 190 km in an east-west direction along 43° N from 76°05′ to 78°20′ E. The main watershed in the central part of the ridge rises to elevations of 4300-4500 m above sea level. The highest point is Talgar Peak, with an elevation of 4979 m. The northern slope of the ridge, 30-33 km wide, descends in several steps toward the intermountain depression of the Ili River. It is dissected by the valleys of the Turgen, Yesik, Talgar, Kishi Almaty, Ulken Almaty, Kargaly, Aksai, Kaskelen, Shamalgan, and Uzynkargaly rivers. The foothills lie at around 1000 m a.s.l. The southern slope of the Ile Alatau descends steeply toward the valleys of the Chon-Kemin and Shelek rivers, which separate it from the Kungey Alatau range. At the foot of the Ile Alatau lies the largest city in Kazakhstan – Almaty, with a population of about 2.5 million. Located nearby, in the basins of the Ulken Almaty, Kishi Almaty, and Kotyrbulak rivers, the Almaty Mountain Cluster is, which includes the ski resorts of Shymbulak, Pioneer, Oi-Karagai, Maralsai, and Akbulak, the high-mountain Medeu skating rink, and the Tuyuksu mountaineering camp. Numerous hiking trails and mountaineering routes also originate in this area (Figure 1).

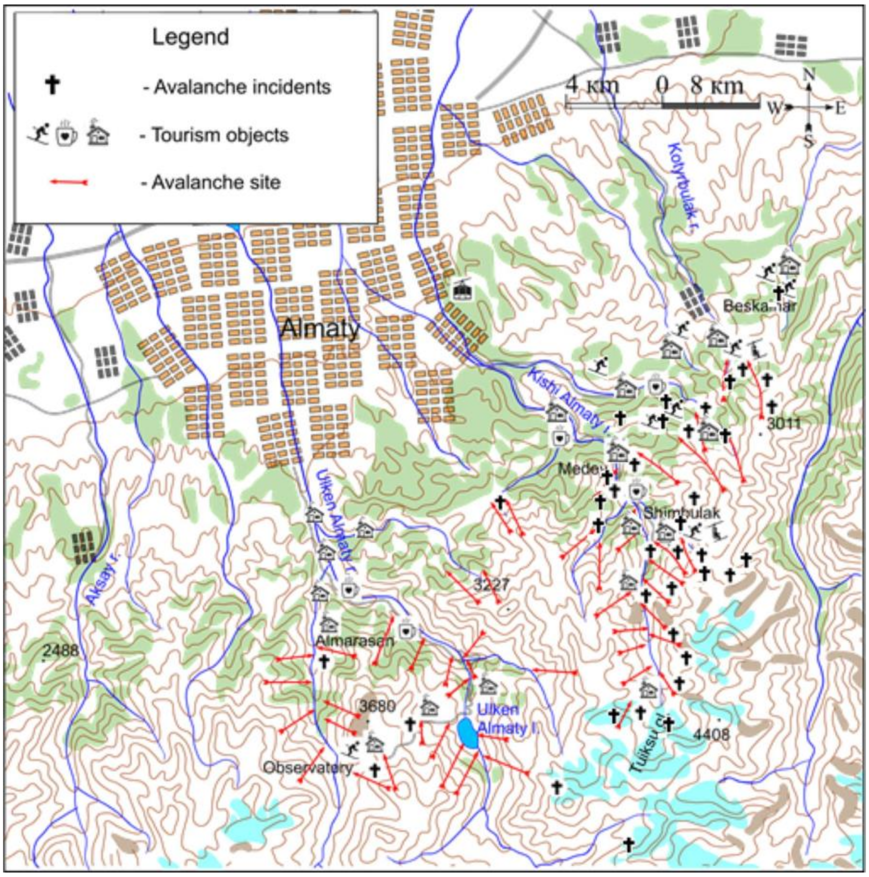

Figure 1. Map of the Almaty Tourist Cluster (Source: Author's development)

The largest ski resort is Shymbulak, recognized as the best among ski resorts in Central Asia. It attracts about 2 million visitors annually. Daily visitor numbers range from 2,000 to 5,000. The ski slopes are situated at elevations between 2300 and 3200 m. The skiing season lasts from November to April. A key advantage that draws skiers from neighboring countries is its proximity – only 10 km from Almaty allowing tourists to reach the summit of the ski trail from a comfortable hotel within an hour. Popular hiking and skiing routes through gorges and to the peaks of the Ile Alatau begin from the upper station of the Shymbulak cable car. Other ski resorts are significantly smaller in terms of size and capacity. By 2030, it is planned to unite all ski resorts of the Almaty cluster into a single network of cableways. As a result, the total length of the trails will increase to 120 km, and the total capacity will reach 22,000 skiers per day. Annual visitation is projected to reach 5 million people. Ski resorts are the core of the Almaty Mountain Cluster. The core area covers 90 km². On some days, up to 3,000 skiers may be present, which equates to 33 people per km². The area outside the ski resorts is used for hiking, ski touring, freeriding, and mountaineering. This area extends up to elevations of 4000 m. The total area of the cluster is approximately 400 km². Visitor density is much lower here – up to 500 people per day (1.2 people/km²). However, unlike ski resort visitors, they are exposed to a much greater avalanche risk as they are in unprotected areas.

MATERIALS AND METHODS

This study uses long-term observational data on weather and avalanches in the Almaty Mountain Cluster, collected by the State Hydrometeorological Service of Kazakhstan (Kazhydromet) and the Institute of Geography and Water Security (IGWS). Since 1966, two integrated weather and avalanche observation stations of Kazhydromet have been operating in the area: Shymbulak and Big Almaty Lake. The Shymbulak station is located in the Kishi Almaty River basin at an altitude of 2195 m, while the Big Almaty Lake station is situated in the Ulken Almaty River basin, 11 km from the Shymbulak station, at an altitude of 2506 m. Weather observations at these stations are conducted according to the standards of the World Meteorological Organization (WMO, 2009). Weather data are available on the Kazhydromet website: https://www.kazhydromet.kz/ru. Data on tourist flows were obtained from the Bureau of National Statistics website (https://stat.gov.kz/ru/industries/business-statistics/stat-tourism/dynamic-tables/).

In Kazakhstan, a network of observation points conducts regular observations of snow avalanches. All information is entered into an archive (Guidelines, 2006). Avalanche observations include information on the number of avalanches, timing and causes of release, type and volume of avalanches, and damage caused. Avalanche volume is determined by measuring the volume of snow deposits. Avalanches exceeding 10,000 m³ are measured using geodetic methods. Since 2020, aerial surveys using drones have been employed for measuring large avalanche volumes. Avalanches smaller than 10,000 m³ are visually estimated. Sources of data on avalanche incidents include reviews of hazardous hydrometeorological events published in the Kazhydromet scientific journal (https://journal.kazhydromet.kz/index.php/kazgidro/search/index) as well as literature (Seversky, 2021; Kondrashov, 1991). Operational reports and summaries of emergencies were taken from information websites (https://www.gov.kz/memleket/entities/emer/press/article/1?lang=ru; http://www.zakon.kz; https://mountain.kz/ru).

Statistical characteristics of long-term data series on snow cover and avalanches (such as long-term mean, standard deviation, coefficient of variation, and maximum values with various return periods) were calculated using the Statistica software (StatSoft Russia, http://www.statsoft.ru). All cases where avalanches resulted in fatalities or material damage were classified as avalanche incidents. All individuals caught in avalanches, both deceased and survivors, were considered victims.

RESULTS AND DISCUSSION

Avalanche Hazard

The avalanche-prone season in the Ile Alatau lasts from November to May, with avalanches occurring year-round in the glacial zone (Kondrashov, 1991; Seversky et al., 2000; Kolesnikov, 2005). In winter months, avalanches are triggered by snowfalls; in spring, by thawing and mixed precipitation. During winter, under subzero temperatures, dry snow avalanches prevail. March is the most avalanche-prone month and is also when the largest wet-snow avalanches occur.

Over the observation period since 1966, more than 4,000 avalanches have been recorded in the Almaty Mountain Cluster. Over half (60%) of the avalanches had volumes ranging from 50 to 1000 m³. Avalanches smaller than 50 m³ are not registered, as they usually stop on slopes and do not pose threats to infrastructure. However, they are highly dangerous for hikers and skiers, especially freeriders. Avalanches with volumes of 1000-2000 m³ (13%) and 2000-3000 m³ (6%) are fairly common. In total, avalanches with volumes up to 10,000 m³ account for 93% of all avalanches. The recurrence of larger avalanches drops sharply: 4% of avalanches are 10,000-20,000 m³, 1% are 20,000–30,000 m³. Catastrophic avalanches exceeding 30,000 m³ are very rare (less than 3%). Avalanches exceeding 100,000 m³ were recorded only a few times – just 0.3% of all cases. The maximum recorded avalanche volume was 350,000 m³.

Snow-rich winters with high avalanche activity occur approximately once every five years. The most extreme years in terms of avalanche quantity and volume were 1965/66, 1986/87, 2022/23, and 2023/24.

Table 1 presents statistical characteristics of annual avalanche activity over the long-term period. Key avalanche activity indicators are maximum avalanche volume, total avalanche volume, and the number of avalanches. They are strongly dependent on winter snowiness, indicated by the maximum annual snow depth. This parameter’s distribution is close to normal, with a mean of 106 cm and a standard deviation of 23 cm (coefficient of variation: 0.22). Other avalanche activity indicators exhibit positive skewness, particularly for avalanche volumes (coefficient of variation: 1.1). Therefore, while snow depth with a 50-year return period exceeds the long-term mean by a factor of 1.6, the number of avalanches increases by a factor of 2.3, maximum avalanche volume by 4.1, and total avalanche volume by 4.9.

Table 1. Long-term characteristics of snowiness and avalanche activity in the Almaty Mountain Cluster (1966-2025) (Source: Author's development)

Index	Mean	Standard deviation	Variation coefficient	Maximum with the return period. years		
				10	50	100
Maximum snow depth, cm	106	23	0.22	137	171	185
Maximum avalanche volume, 10^3 m^3	67	75	1.1	176	273	314
Total avalanche volume, 10^3 m^3	336	380	1.1	928	1652	1821
Number of avalanches	92	54	0.59	154	212	236

Table 2. Major avalanche incidents in the Ile Alatau (Source: Author's development)

Date	Location	Cause	Consequences
March 10–15, 1966	Basins of the Turgen, Ulken and Kishi Almaty, and Kotyrbulak Rivers	Spontaneous mass avalanches; abnormal snowfall	Destruction of Tuyuksu alpine camp, Edelweiss tourist camp, water intakes, power lines; 1 fatality
April 9, 1972	Devil's Gorge, the Kishi Almaty River	Human-triggered avalanche; intense thaw, unstable snowpack	9 climbers killed, 8 injured
January 31, 1980	Chkalov Peak, the Kishi Almaty River	Human-triggered; strong blizzard in the highlands	7 climbers killed during climbing Chkalov Peak
December 1986	Sovetov Peak, the Ulken Almaty River	Human-triggered	6 tourists killed during climbing Sovetov Peak
April 12, 2023	Basins of the Turgen, Ulken and Kishi Almaty, and Kotyrbulak Rivers	Spontaneous mass avalanches; abnormal snowfall	Destruction of buildings at Pioneer tourist camp; roads blocked

Avalanche Incidents

From 1950 to 2025, 97 avalanche incidents were recorded in the Ile Alatau (Table 2, Figure 2). A total of 169 people were caught in avalanches, of whom 74 died and 95 were injured. The survival rate was 44%, consistent with global statistics (URL: http://www.whiterisk.ch; Vedenin, 2016).

a b c d

Figure 2. Examples of avalanche incidents in the Ile Alatau: a) Damage to Pioneer tourist camp, March 2024; b) Search for a climber's body, November 1990; c) Avalanche-blocked road, April 2022; d) Evacuation of a skier's body, March 2009 (Source: Authors)

The long-term trend in avalanche incidents shows a peak in the 1960s-1980s (Figure 3). A decline occurred in the 1990s due to reduced resort visitation during the economic crisis. Since the early 2000s, the number of incidents has increased, driven by a rise in extreme mountain recreation. The linear trend shows a general increase; the coefficient of determination (R^2 = 0.1794) indicates that the trend explains 18% of the total variance. The absolute number of accidents continues to rise.

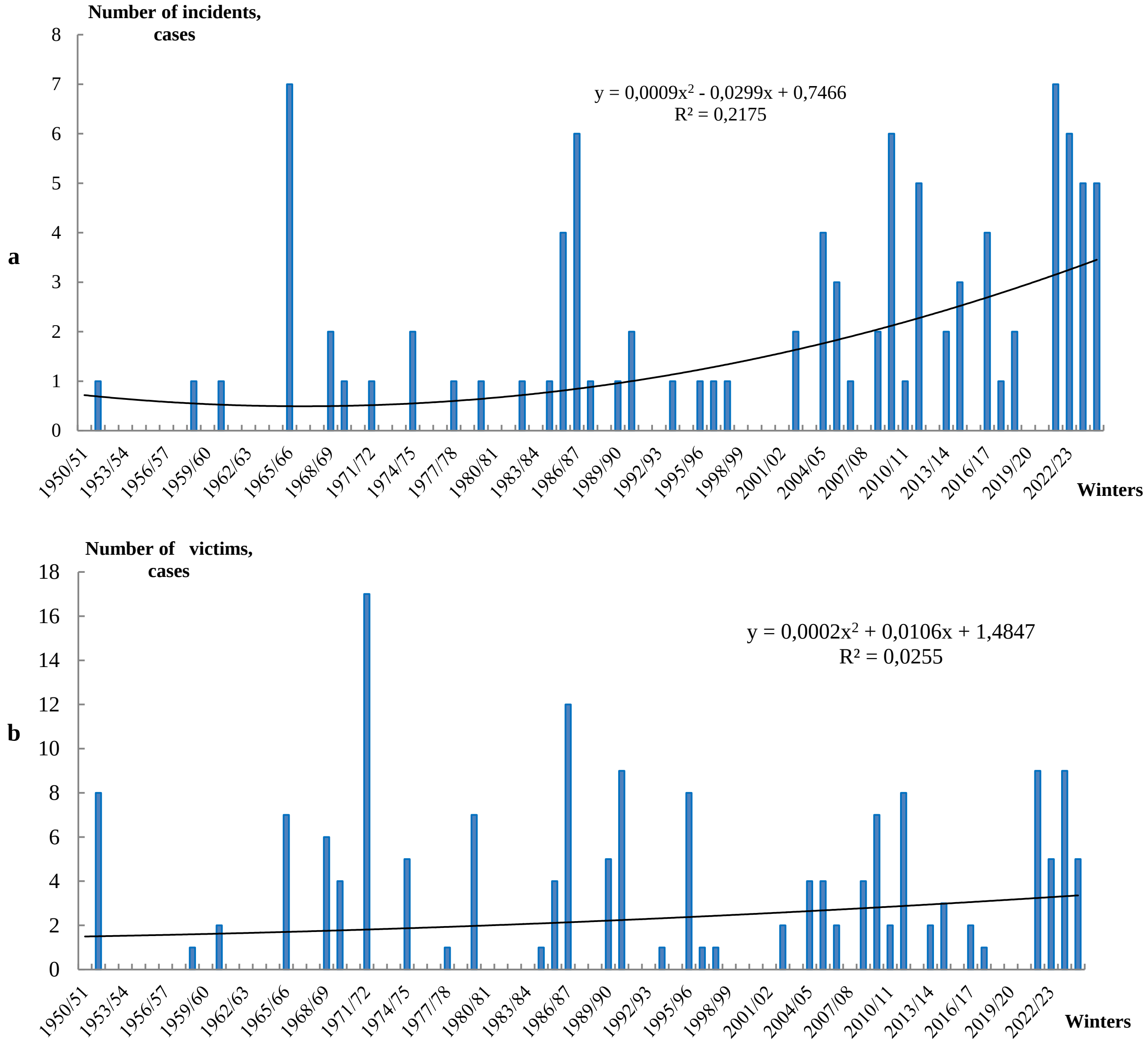

Figure 3. Long-term changes in: a) number of avalanche incidents, cases; b) number of avalanche victims, cases (Source: Author's development)

Table 3 presents data on the distribution of fatalities and survivors across different time periods. It can be concluded that in the early 21st century, the number of fatalities decreased while the number of survivors increased compared to the 20th century. This is due to several factors. First, during the Soviet era, controlled mass tourism and large groups were common. Tourists and climbers were accommodated at large state-run recreational and mountaineering centers. As a result, accidents in such groups tended to be large-scale. In the 21st century, after the collapse of the USSR, large state recreation centers and organized groups disappeared. Instead, many small private tourist and ski resorts emerged, along with independent, unsupervised tourists. However, their total number has become significantly greater. Consequently, the ratio of fatalities to survivors has shifted. Nevertheless, the overall number of incidents and victims has increased. An additional factor influencing avalanche safety has been the development of avalanche services and communication technologies. Methods for assessing avalanche danger and disseminating warnings to tourists through television and the internet have been improved.

Table 3. Average number of avalanche incidents with victims in different periods (Source: Author's development)

Period	Incidents	Fatalities	Survivors	Survival Rate (%)
1950-2025	1.29	0.99	1.27	56
1966-1996	1.06	1.52	1.29	46
1997-2025	2.1	0.69	1.76	72

Only 10% of avalanche victims were professionals (e.g., hydrometeorological service staff, emergency personnel, ski resort workers) (Figure 4a). The remaining 90% were tourists, climbers, and skiers. Recently, more victims have been freeriders and ski tourers. Most accidents (65%) were caused by human-triggered avalanches (Figure 4b). Large spontaneous avalanches typically result in property damage (19%). Some accidents occurred during preventive avalanche releases or due to spontaneous avalanches (16%).

The Ile Alatau accounts for 82% of avalanche incidents in Kazakhstan since 1950 (Figure 4c), mainly due to the popularity of its tourist attractions near Almaty such as Medeu ice rink, Shymbulak mountain skiing resort, and Big Almaty Lake.

There is a distinct seasonality: most incidents occurred in March and April, coinciding with maximum snow accumulation in the Northern Hemisphere. March alone accounts for 43% of all avalanche emergencies (Figure 4d).

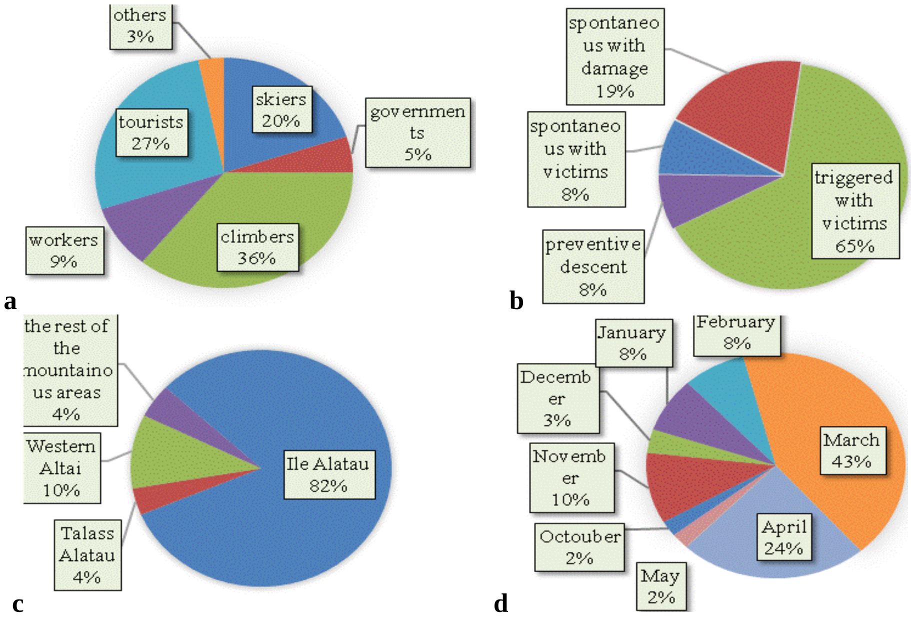

Figure 4. Distribution of avalanche incidents by: a) Type of recreationist; b) Cause of avalanche; c) Mountain region; d) Month (Source: Author's development)

The presence of avalanche-prone areas limits or complicates both the construction of recreational facilities and the use of the territory for skiing and other forms of recreational activity. Developing avalanche-prone areas requires additional expenditures related to hazard assessment and mapping, facility design, avalanche control, and the maintenance of rescue services. Moreover, the closure of recreational facilities, roads, and tourist routes during periods of high avalanche hazard results in financial losses for tourism companies and dissatisfaction among visitors.

A day of downtime of the Almaty tourism cluster facilities costs a loss of profit of $ 433 thousand (URL: https://stat.gov.kz/ru/industries/business-statistics/stat-tourism/dynamic-tables/).

In Switzerland and other Alpine countries, experts also note losses due to the closure of ski resorts during the avalanche danger period (Schweizer, 2020; Techel, 2017). At the Shymbulak ski resort, which has an avalanche control service, such downtime occurs 1 to 3 times per winter season. Other ski resorts without such a service are forced to shut down due to avalanche danger for 7 to 10 days. During periods of avalanche hazard, local authorities set up police checkpoints on tourist trails and roads passing through hazardous zones to restrict access. These restrictions can last up to 15 days. Such measures often provoke numerous negative reactions on social media.

Protective Measures

Ensuring avalanche safety requires the implementation of protective measures, which include: avalanche hazard assessment and hazard mapping; avalanche danger forecasting and warnings; avalanche hazard control (preventive avalanche releases); the organization of rescue services; and the construction of protective structures.

Avalanche Hazard Assessment and Mapping. When planning the development of recreational infrastructure, such as constructing new hotels, ski lifts, or preparing slopes, it is essential to first conduct avalanche hazard assessment and create hazard maps. In the Ile Alatau, such work is carried out by the Institute of Geography and Water Security, which includes a specialized Laboratory of Natural Hazards. These maps include historical records of snow avalanches observed during the monitoring period (Kondrashov, 1991; URL: https://journal.kazhydromet.kz/index.php/kazgidro/search/index).

An example of a hazard map for the Kotyrbulak Gorge, which hosts the “Pioneer” ski resort, is shown in Figure 5. The resort was damaged by snow avalanches in 1966, 1980, 2003, 2023, and 2024. The greatest threat to infrastructure is posed by long-travel avalanches during snow-rich winters. These caused the most damage. Under such extreme conditions, the resort ceases operation. The maps delineate four levels of avalanche hazard:

1) Small avalanches (less than 1,000 m³) occur less than once in 10 years;
2) Large avalanches (over 100,000 m³) occur less than once in 10 years;
3) Small avalanches (less than 1,000 m³) occur annually;
4) Medium avalanches (10,000 to 100,000 m³) occur annually.

With plans to expand recreation in new areas of the Ile Alatau, there is an urgent need to produce avalanche hazard maps for these territories. Importantly, these maps should be completed before the design and construction of recreational infrastructure and the development of tourism zones.

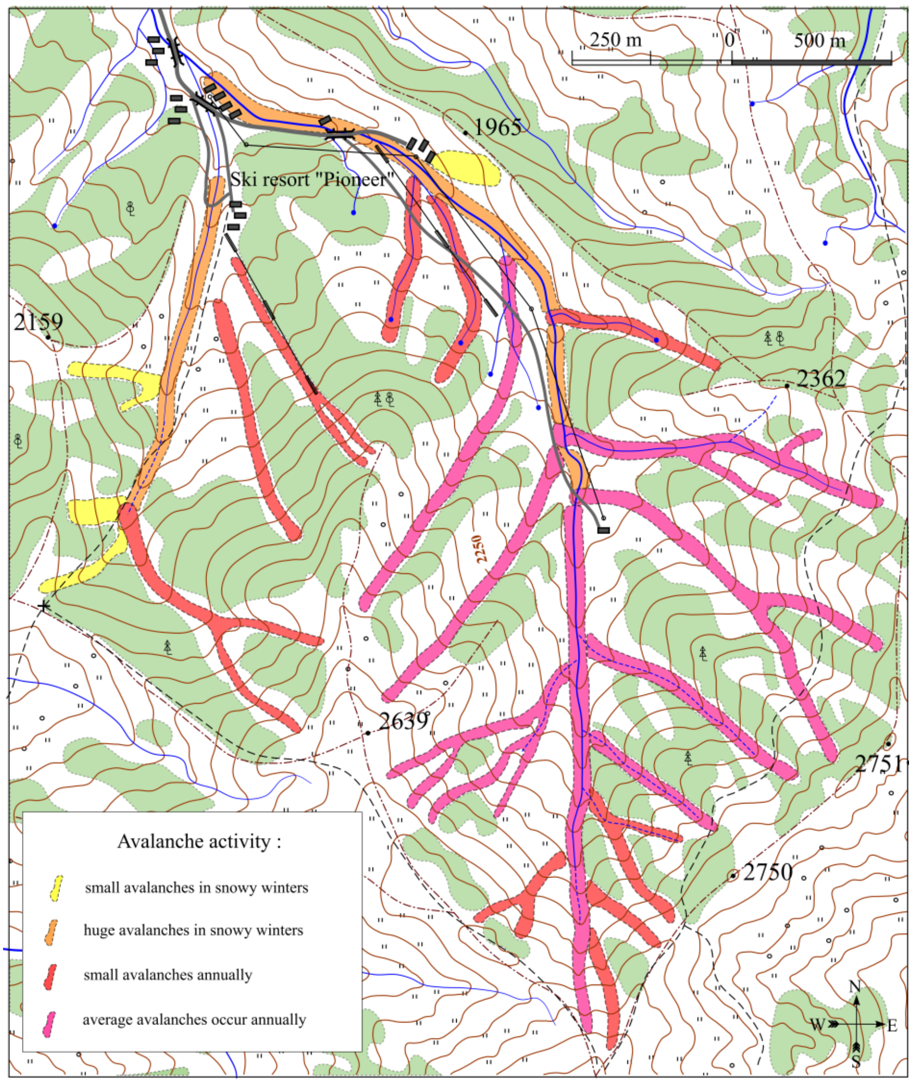

Figure 5. Avalanche hazard map of the “Pioneer” ski resort (Source: Author's development)

Avalanche Hazard Forecasting and Warnings. Avalanche forecasts in the Ile Alatau are provided by the State Hydrometeorological Service based on observations at the “Shymbulak” and “Big Almaty Lake” snow-avalanche stations, located at 2195 m and 2506 m a.s.l., respectively. Public warnings are issued by local branches of the Ministry for Emergency Situations, based on these forecasts.

Forecasts are issued one day in advance in categorical form: “Snow avalanches expected in the Ile Alatau.” No probability or hazard level is specified.

The general accuracy of avalanche forecasts is 75–85% (Kondrashov, 1991; Practical Guide, 2005). In spring, accuracy drops to 60–70%. Nonetheless, warning coverage exceeds 95% due to forecasters erring on the side of caution.

Based on avalanche hazard forecasts produced at avalanche observation stations, the Hydrometeorological Service issues storm warnings to government agencies, and the Almaty City Department for Emergency Situations informs the public of the avalanche threat, recommending that people refrain from mountain hikes. If these recommendations were strictly followed, the mountains would be closed to tourists for 30 to 40 days each winter. As a result, mountain enthusiasts have gradually stopped paying attention to such warnings.

To improve public awareness of avalanche hazard, the Institute of Geography and Water Security began publishing a regional avalanche bulletin in 2029, drawing on the experience of European and North American avalanche services. The avalanche hazard level was assessed using a five-level scale proposed by the Swiss Institute for Snow and Avalanche Research, adapted to conditions in the Ile Alatau (EAWS, 2021; Morgan, 2023). The avalanche forecast was enhanced through the use of artificial neural networks trained on a dataset of weather and avalanche activity dating back to 2005 (Blagovechshenskiy, 2023). The quality of the avalanche forecast reached 75–90%. A key distinction of Kazakhstan’s avalanche bulletin, compared to those in other countries, is the inclusion of a detailed map of avalanche-prone areas, allowing tourists to choose safe routes even under overall high hazard conditions. The avalanche bulletin quickly became highly valued by the mountain community and earned a strong reputation. Each issue of the bulletin receives 2,000 to 3,000 views.

In light of the planned expansion of the ski resort network, the Institute of Geography and Water Security developed a project for an automated avalanche hazard monitoring system for the Almaty tourist cluster. The system includes 35 automatic weather stations to be installed in avalanche formation zones. These stations will transmit real-time data to the forecast center, including precipitation, wind direction and speed, snow depth and temperature, and solar radiation intensity. The data will be processed using artificial intelligence software. Implementing this system will significantly improve the quality and spatial resolution of avalanche forecasts.

Avalanche Control. Avalanche control consists of the artificial release of avalanches. At Shymbulak ski resort, this is done using a French-manufactured Avalancher pneumatic cannon. Controlled slopes for avalanche mitigation cover 12.8 hectares. The decision to carry out a release is made by the resort's rescue service chief, after consulting with avalanche station specialists. Over the course of a winter season, three to five releases are conducted, depending on weather and snowpack conditions. Other artificial release systems such as Gazex and DaisyBell have proven ineffective in the Ile Alatau.

In avalanche-prone areas affecting roads, preventive avalanche releases are carried out by the Ministry for Emergency Situations using explosives in the avalanche release zone. Charges are manually placed, which makes the method labor-intensive and dangerous. Only one site can be cleared per day. Ensuring safety across the entire area takes several days during which spontaneous avalanches may occur, or snow conditions may change such that explosives no longer trigger releases. There have been cases of fatalities due to premature avalanches.

Rescue Service. At ski resorts, avalanche rescues are handled by the resort's rescue services. Outside resort areas, rescue operations are conducted by Ministry for Emergency Situations teams. Specially trained dogs are used to search for people buried in avalanches. Helicopters are used when needed to transport rescuers and evacuate victims. During winter, rescue stations are set up along popular tourist routes, staffed by rapid-response teams on snowmobiles. In difficult situations, additional personnel and equipment are dispatched from the city's central rescue base. Volunteers (often skiers and mountaineers) also participate in rescue efforts. All of these services work in close coordination.

Raising awareness of avalanche safety rules and training tourists, skiers, and climbers in rescue techniques is of great importance, as survival chances depend on whether a buried person is located and dug out by the companions. Specialists from the Institute of Geography and Water Security, along with experienced internationally certified instructors, conduct lectures and practical courses on avalanche hazard assessment, victim search techniques, and first aid. For ski touring and freeriding, carrying an avalanche transceiver, probe, and shovel is mandatory.

Protective Structures. The most reliable method of ensuring avalanche safety is the use of protective structures, but it is also the most expensive. Thus, they are used only for critical infrastructure. In the Ile Alatau, snow-retaining fences and nets have been installed to protect key sites, including Medeu high-mountain skating rink, the upper station of the Left Talgar cable car at Shymbulak, and the Medeu–Shymbulak mountain road. A total of 15.3 hectares of avalanche-prone slopes are equipped with such structures. Expanding protective infrastructure remains an urgent task, especially given the prospects for developing new recreation areas.

CONCLUSIONS

Snow avalanches have a major impact on the development of recreational activities in mountainous regions. They destroy facilities, block roads, and kill or injure tourists, skiers, and climbers. Avalanches also increase the cost of building and maintaining infrastructure, require protective measures, and cause economic losses due to resort closures.

Even small avalanches with volumes of several hundred cubic meters can pose serious danger to people.

Most avalanche-related accidents involving humans occur at moderate or considerable hazard levels and in avalanches smaller than 1,000 m^3. Infrastructure damage, on the other hand, occurs at high or extreme hazard levels during avalanches exceeding 10,000 m^3.

Avalanche hazard assessment and detailed mapping of hazardous zones must be carried out in the early stages of recreational planning in mountainous areas. These assessments should be based on long-term observational data on weather, snowpack, and avalanche events. Modeling may be used only after models are calibrated for local conditions.

Avalanche safety measures must include: forecasting and warning of avalanche danger, avalanche control (preventive releases), rescue service organization, tourist education in avalanche safety, and construction of protective structures.

Monitoring of avalanche formation and activity should use automated stations placed in avalanche formation zones. Promising approaches to avalanche forecasting include machine learning, neural networks, and artificial intelligence. The hazard level in forecasts should follow a multi-level scale adapted to local conditions. Public warnings must be timely and specific. The preferred format is an avalanche bulletin with a hazard zone map, distributed via social media.

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