GEOHAZARDS

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# Landslide risk in mountain areas

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**Abstract.** Landslide is a major geological hazard, which poses serious threat to human population and various infrastructures. Landslides occur very often together with other natural disasters such as earthquakes, floods or snow melting and volcanoes that play role of triggering mechanism for landslides. Mountainous areas are vulnerable to landslides and have also been affected by earthquakes. Mountainous and coastal areas are the most affected regions. Landslides cause huge damage in the world and kill many people each year. Paper is devoted to landslides research on the base of risk analysis, assessment, management and reduction concept. Landslide Risk Management is seen as a series of events leading to landslides risk reduction and avoiding. It includes landslides monitoring, landslide forecast, engineering works, slopes strengthen, insurance and others. Paper also considered India, China and Russia case studies including Kolka disaster on 20 September 2002 and other related disasters. Kazbek volcanic center is characterized by the complex interrelationship of various hazardous geological processes. Disasters of 2002 and 2014 caused by ice-rock fall govern importance of investigation of the area. The network recorded a collapse of the mass of ice and rocks in the region of the Devdorak glacier on May 17, 2014 and the movement of the formed stone-ice avalanche. In India, the Himalayas are prone to landslides, particularly n monsoon season, from months of June to October. Various types of landslides occur in Himalayas, including block slumping, debris flow, debris slide, rock fall, rotational slip and slump. Generally landslides are triggered by heavy or prolonged rainfall. Landslides cause severe damage to lives and property while also causing disruption in communication networks and movement of traffic.

**Keywords:** landslide, risk, risk management, risk assessment, risk reduction, monitoring

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## 1. Introduction

Landslide is a major geological hazard, which poses serious threat to human population and various infrastructures like highways, rail routes and civil structures like dams, buildings and others. The idea that landslide could occur is frightening people in every area prone to such phenomena. That is because the effects of landslides can be devastating, leaving thousands of people without home and threatening their lives.

Landslides occur very often together with other natural disasters such as earthquakes, floods or snow melting and volcanoes that play role of triggering mechanism for landslides.

Landslides are caused by different factors, but three of them are predominantly important. They are slope saturation with water, seismic activity and volcanic activity.

These phenomena often occur at the same time and in the same area.

Certain mountainous areas are vulnerable to landslides but have also been affected by earthquakes.

When an earthquake occurs, the risk for a landslide grows very high. Ground shaking allows water to infiltrate between ground layers. Then layers slide on one another. Ground shaking causes rock falls also.

Volcanic activity is the factor of the most devastating landslides. Lava melts snow and causes a deluge of rock, soil, ash, and water which rushes down on the slopes of the volcano. The deluge devastates everything during moving. Volcanic debris flows at great distances. They damage the structures in areas around the volcano. There were many cases when the eruption of a volcano triggered great landslides.

Mountainous and coastal areas are the most affected regions, but that does not mean that the other areas are safe.

Landslides cause huge damage in the world and kill many people every year. Casualties are caused by debris flow, rock slides and rock falls. It is necessary to understand and to know how landslides are formed and how they act for protection people and constructions from its destructive action. [Kutepov et al., 2002; Osipov et al., 2002; Svalova 2011].

The word “landslide” describes different processes that have as a result the movements of materials like soil, rock, earth, mud, debris, artificial fill, snow, ice, ash, combination of these materials and others.

When these materials start moving, they may be falling, toppling, sliding, spreading, flowing and others. According to the moving trajectory the landslides could be rotational or translational. There are some specific types of slides or mass movements as lahars, solifluction, avalanches, glaciers and others.

Landslides are associated with mountainous areas, but they also affect low relief areas. In this case the trigger factors could be failures determined by building or roadway excavations, collapse of mine piles, slope failures associated with quarries, lateral spreading landslides, river bluff failures and others.

Depending on the location and type of human activity, the landslide effect could be lessened. People should know hazard zones and avoid activities like digging in such areas.

For systematic analysis of landslide hazard it is fruitful to use the notion of risk.

Geological risk is a relatively new and not fully explored concept. [Corominas et al., 2014; Ragozin, 2003; Svalova, 2017].There are many definitions of geological risk. And often scientific study or scientific approach to the problem begins with a presentation of the author’s position and the choice of the definition of geological risk for the problem under consideration. One of the most common approach defines that risk is the expectation of the damage, or risk is the product of the probability of possible hazardous events on the damage produced by.

Vulnerability to landslides depends on location, frequency of landslide events, type of human activity in the area and other factors.

## 2. Landslides – natural risk phenomena with complex impact

The word “landslide” particularly represents only a type of movement that is slide. However it is generally used as a term to cover all the types of land movements including falls, creep, spreads, flows and other complex movements. A correct term to represent all these movements may be “mass movement.” However the term “landslide” has been accepted and is being used commonly around the world as a synonym of “mass movement.”

Sliding of huge debris, rocks and other material down the slope is considered as “Landslides.” Landslides occur along with earthquakes, floods and volcanic eruptions. Landslides are common in mountainous regions and steep slopes.

Landslides take place in different parts of the world. The biggest and the most active ones are connected with earthquakes and volcanoes near tectonic plates boundaries in collision and subduction zones and Pacific Ring of Fire.

The social impact of landslides is significant and it increases due to the expansion of human activity and settlements in areas of risk. The landslides often are triggered by

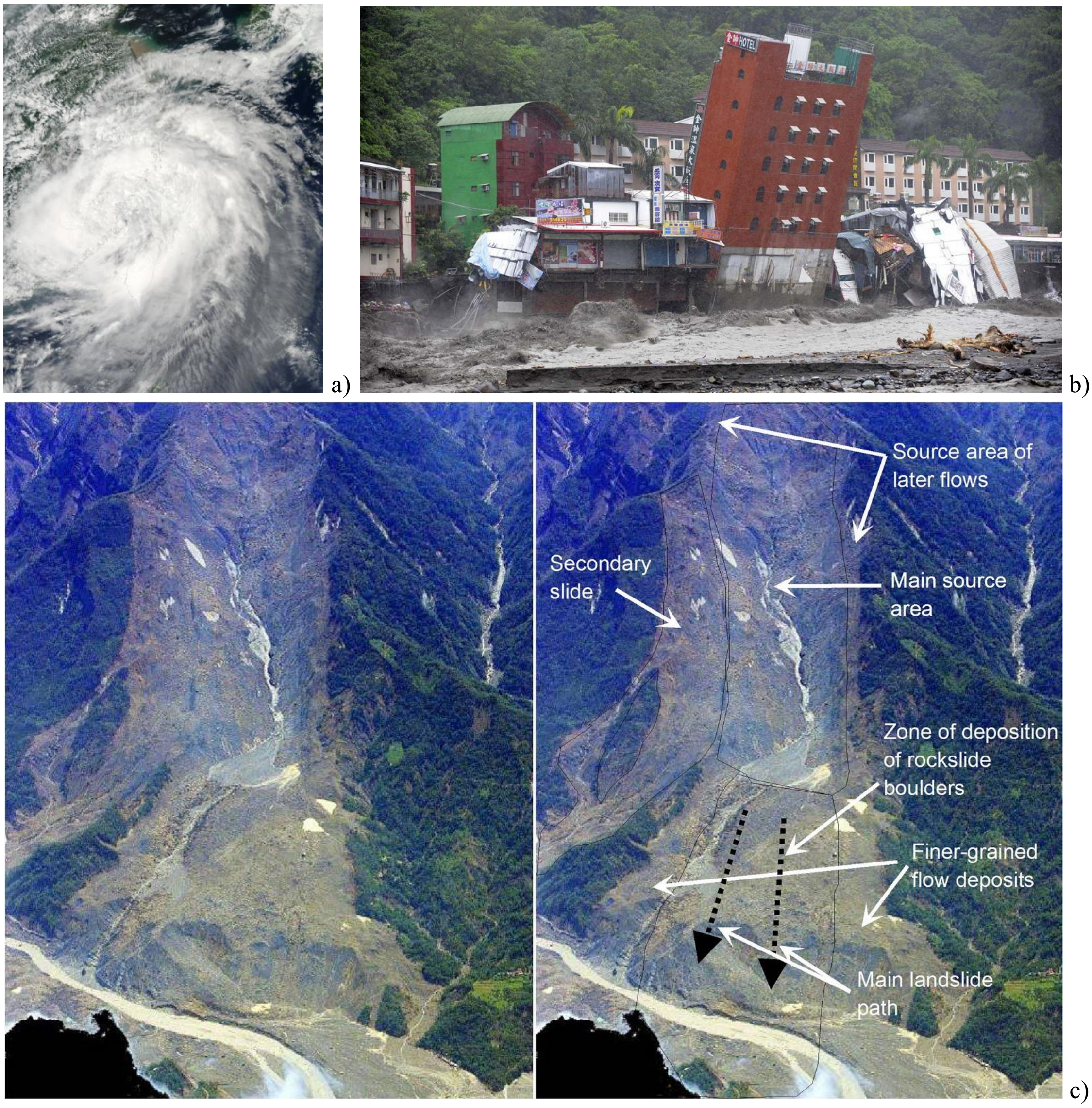


*Figure 1. a) Typhoon Morakot on August 9, 2009; b) Falling Hotel in Taiwan after Typhoon Morakot; c) Landslides in Taiwan’s Shiaolin after typhoon Morakot in 2009 (USGS)*

rainfalls and earthquakes. Landslides due to heavy rains occur in mountainous areas. So a 296.5 cm precipitation event due to Typhoon Morakot in 2009, the deadliest typhoon to impact Taiwan in recorded history, resulted in deep-seated landslides in Taiwan's Shiaolin (Figure 1).

Other cases of recent deep-seated landslides happened in 2011 in Kii Peninsula, Japan, and in 2013 in Uttarakhand, India.

Among significant factors determining slope instability are landscape modifications, such as changes in slope geometry, construction of infrastructure, terracing, slope excavations, loading, mining, disturbances to the equilibrium of slopes produced by vibrations, water linkage, land-use changes, deforestation and others.

Development of human activity in mountainous areas, urbanization, and lack of good territorial planning and management, together with earthquakes and significant rainfalls produce dangerous scenarios for landslide disasters.

There are many different classifications of landslides but the classic one is Varnes D.J. classification [Varnes, 1978] on the base of 5 types of movement (fall, topple, slide, spread and flow) and 3 types of material (rock, debris and earth) (Table 1).

Also there are complex movements changing their type during process and having some stages. It is necessary to stress the principal difference between fall and topple from one side and slide, spread and flow from another side, as first two occur with destruction of continuous medium and last three take place without separation from sliding surface as a rule. This difference is important for landslides modeling.

**Table 1. Landslides classification**

| Type of Movement Type of Material<br><br>Bedrock Debris Earth |
|---|
| Fall Rock fall Debris fall Earth fall<br><br>Topple Rock topple Debris topple Earth topple<br><br>Slide Rock slide Debris slide Earth slide<br><br>Spread Rock spread Debris spread Earth spread<br><br>Flow Rock flow Debris flow Earth flow |

Earth slide is the most typical landslide. Slide can be rotational and translational depending on the movement trajectory. Rotational slides arise in continuous media where sliding surface reflects stress state of the landslide body. Translational slides arise mostly in layered medium or if sliding surface already exists reflecting higher density of lower soils and rocks. Also there can be snow, ice, mud, soil, sand, silt, loess, clay, lava, ash, water and other materials in landslide body. And the names of gravitational processes and events can be avalanche, creep, slump, solifluction, lahar, glacier, iceberg and others. But all of them can be described on the base of the main table. So avalanche is snow slide. Lahars (Indonesian word) are dangerous mud flows of volcanic ash mixed with water generated by volcanic eruptions that travel far beyond the volcano. Solifluction is the movement of wet soil down a slope, especially where frozen subsoil acts as a barrier to the percolation of water. Solifluction is relatively rapid processes in periglacial regions and can result in the active development of slopes.

Mass movement can be with different velocity. One of possible scale is in Table 2 (after Cruden and Varnes [Cruden, Varnes, 1996].

**Table 2. Landslide velocity scale**

| Velocity class | Description | Typical velocity |
|---|---|---|
| 7 | Extremely rapid | 5 m/sec |
| 6 | Very rapid | 3 m/min |
| 5 | Rapid | 2 m/hour |
| 4 | Moderate | 15 m/month |
| 3 | Slow | 2 m/year |
| 2 | Very slow | 20 mm/year |
| 1 | Extremely slow | 2 mm/year |

Landslides risk assessment is an important step towards solving the problem of natural risk management and reduction. Due to the complexity and diversity of the problem the combination of probabilistic and deterministic approaches and expert estimates arises.

The probability of landslide process depends on the stability of the landslide slope, trigger mechanisms (precipitation, earthquakes), technological factors. The first step is studying the physical and mechanical sliding process at different conditions. Nevertheless, the landslide process mechanics is still not fully understood. Landslide prediction is not always possible. Even statistical frequency of landslides activation for a particular area varies very widely.

## 3. Landslide examples

### 3.1. Wenchuan Earthquake, Landslides and Debris Flow, China

On May 12, 2008, the Ms 8.0 Wenchuan earthquake occurred in the Longmen mountain fault belt. The destructive Wenchuan earthquake induced an unprecedented number of geo-hazards. In the past 6 rainy seasons, debris flows in Wenchuan earthquake stricken area occurred frequently, resulting in serious casualties and property losses. [Field trip guide …, 2014].

The old Beichuan town is located in the middle part of the Yingxiu-Beichuan fault belt, and at the center of one of two zones where seismic intensity was the highest at XI during Wenchuan earthquake. The old Beichuan town had a population of 20,000 before the earthquake

When the Wenchuan Earthquake hit China on May 12, 2008, no town was hit harder than Beichuan. Up to 80 percent of the city’s buildings were destroyed and more than half the population was killed. The survivors of the earthquake have been relocated at Yongchang Town, which is about 23 km away from the old town.

After the earthquake, the area was deemed too vulnerable to geo-hazards. So it was decided that the ruins would be left as a memorial park to all those who lost their lives, including the hundreds who still remain buried in the rubble (Figure 2).


a)


b)

*Figure 2. Old Beichuan town after earthquake on 12 May, 2008 (a) and debris flow on 24 September, 2008 (b). [Field trip guide ..., 2014].*

Two deathful landslides and one debris flow caused severe damages in Beichuan caused by the Wenchuan earthquake and rainstorm after the earthquake: the Wangjiayan landslide, the new Beichuan middle school landslide and Weijiagou debris flow.

Wangjiayan landslide is located at the western side of the old Beichuan town, about 10 minutes after the mainly shaking, the slope slides from 980m to 660m with a volume of $140 \cdot 10^4$ $m^3$ in less than 10 seconds. This process accompany with fast speed and huge noises, most of the town in this area were buried (Figure 3). Statistic data shows that the landslide damaged more than 20 high buildings, including hospital, kindergarten, primary school and market, caused about 1700 death.

The width of slide area is about 350-400m, the length is about 700 m, and the total slide area is about 0.2 $km^2$.

Beichuan middle school landslide (Figure 3) is located at south of the town, it's shape looks like a tongue, the bedrock in this area is limestone. Triggered by the Wenchuan earthquake, the slope was reactivated, buring parts of building in affected zone and causing fatalities. The main scarp is located at an elevation of 900m and the height difference is 280m between the main scarp and its toe. The bedrock mainly consists of thick limestone of upper Devonian and lower Carboniferous Periods. The length of landslide area is 440m, the width is 250-290 m, its total area is about 0.11 $km^2$.

The length of deposit zone is 440 m, depth of debris is 5-20m, the total volume of debris in deposit zone is about $50 \cdot 10^4$ $m^3$. The landslide caused 700 death, most of whom are school students. 95% of the debris from landslide are compose of large stone with size of 2.5 m × 3 m × 4 m, the largest diameter of stone is about 10 m.

The Daguangbao gigantic landslide is located on the Gaochuan village, Anxian County. It is the hugest landslide triggered by the Wenchuan 8.0 earthquake on May 12 of 2008. It is the hugest landslide not only in China, but also in the world in recent hundred years.

The landslide is located on the hanging wall of the seismogenic fault, the Yingxiu-Beichuan fault, nearly 7 km away from the thrusting part of the fault (Figure 3).

The source area of the Daguangbao landslide is about 2.4 km long and 1.2 km wide, while the deposition area is approximately 3.2 km long and 2.2 km wide. It covers an area of 7.8 $km^2$ and an estimated volume of 1.15-1.2 billion $m^3$. The sliding mass travelled about 4.5 km and blocked the Huangdongzi gully, forming a landslide dam nearly 600 m high. The head scarp is serrated and near vertical (70°–90°), with the maximum vertical


*Figure 3. Wangjiayan landslide. (a); New Beichuan Middle School landslide (b); The Daguangbao gigantic landslide (c) [Field trip guide …, 2014].*

height of 700 m. The sliding mass crossed the Huangdongzi gully and ran up the opposite slope with a height of more than 500 m, forming many thrust and anti-slope (uphill facing) scarps.

Seven years later after Wenchuan earthquake some parts of Wenchuan County were reconstructed and restorated.

## 3.2. Kolka Glacier collapse

On September 20, 2002, in the gorge of the Genaldon River (North Ossetia, Russia), the Kolka glacier collapsed, which completely destroyed several villages and killed more than 135 people, among them there was the famous Russian actor Sergei Bodrov's film crew of 42 people.

According to the official version of the incident, a huge block of ice broke off from the slope of Mount Jimara (4780 m). It fell on the Kolka glacier, as a result of which most of its ice-firn body slipped from the "bed" and moved along the ravine at a speed of more than 200 km/h, capturing rocks and mud masses. This stream completely covered the Karmadon gorge (Figures 4) [Kutepov et al., 2002; Osipov et al., 2002; Ragozin, 2003; Svalova, 2017].

Based on the instrumental records of the Geophysical Institute of the VSC RAS, the Geophysical Survey of the RAS and stations of the adjacent territory, kindly provided by

Georgian colleagues, a scenario was developed for the main stages of the Kolka glacier collapse process on September 20, 2002. It includes a distant earthquake, a precursor event, powerful vertical vibrations, in essence of unknown nature (large rock mass collapse, gas-dynamic explosion, hydraulic shock, etc.). Horizontal vibrations of the glacier body at the equilibrium position, beginning of glacier collapse, hit the side of the rocks near Maili glacier, glacier movement to the north and hit of "Karmadon gate", stoppage of the most ice-rock mass [Zaalishvili, Melkov, 2014].

An analysis of the earthquakes catalog showed that on September 20, 2002, before the catastrophic collapse of the Kolka glacier, there was an earthquake timed to this time. So, at 15: 43: 50.3 in the West Irian region (1.68° N, 134.23° E) an earthquake with a magnitude of Ms = 6.2 and a source depth of h = 33 km occurred. This distance a primary P-waves pass for about 13 minutes, and shear S-waves for about 26 minutes. It should be noted that the entry of the P-wave will occur in 15 h 56 m 50 s, and S-waves – 16 h 09 m 50 s. Immediately, comes under notice the good agreement between the times of the main phases of the waves and the stages of the glacier collapse.

Currently, a number of different versions of the causes of the incident have been proposed (landslide, gas-dynamic explosion, hydraulic shock, etc.). Although their study has a different scientific depth, but any complete from a scientific point of view, a reasonable and unambiguous version, unfortunately, is still missing. This implies expanding the evidence base.

Kazbek volcanic center is characterized by the complex interrelationship of various hazardous geological processes. Developed network recorded a collapse of the mass of ice and rocks in the region of the Devdorak glacier on May 17, 2014 and the movement of the formed stone-ice avalanche [Zaalishvili et al., 2018]. The separation zone is located on the eastern slope of Kazbek, in the feeding area of the right branch of the Devdorak glacier, at an altitude of 4400-4500 m. The collapse was spread to the right of the main Devdorak icefall and fell on the tongue of the glacier. Then there was a transformation of the collapse into an "avalanche-like flow" or "rock-ice avalanche". People died. The resulting obstruction blocked the mouth of the Terek River, which led to the formation of a ponded lake. The hazard of a failure which threatened Vladikavkaz remained until the moment when the River Terek filled the diversion tunnel and the water level began to decline [Zaalishvili et al., 2018].


a)


b)

*Figure 4. Kolka glacier: Common view (a); Mud-snow flux near 20 km (b)*

### 3.3 Landslides in India

In India, the Himalayas are prone to landslides, particularly n monsoon season, from months of June to October. Various types of landslides occur in Himalayas, including block slumping, debris flow, debris slide, rock fall, rotational slip and slump.

Generally landslides are triggered by heavy or prolonged rainfall. Landslides cause severe damage to lives and property while also causing disruption in communication networks and movement of traffic.

Every year, landslides in the Himalayan region kill people and cause damage to several villages leaving them unfit for habitation. Landslides create blockades in the road network and also in river system, which causes flood. The terraced farm fields that are destroyed by landslides, cannot be easily recovered or made productive again. Affected by landslides, the road network remains closed for long periods, hence, causing huge hardships to people inhabiting and dependent on the area for their basic supplies and provisions. Landslides disrupt water sources and chocked them by debris fall. Due to landslides, the river sediment load is increased considerably, which results in irregular courses of river and frequent breaching of banks also resulting in unexpected floods. The water channels are also affected due to disruption in previous channels, this leads to disturbance in water supply to dependent villagers for irrigation purposes. This then adversely affects agriculture production in the affected region.

Landslides in India are considered a major hazard in most hilly and mountains regions as well as in steep river banks and coastlines. The causes of landslides in India are not much different from the world, but there are some peculiarities. Important factors considered to be responsible for causing landslides are:

1) Slope instability due to removal of lateral and underlying support.

2) Indiscriminate chopping down of trees.

3) Slash and burn cultivation practices in hills

4) Road construction and mining activities.

5) With increasing population pressure, there is an increase in grazing activities, urbanization which reduces dense natural evergreen forest cover.

6) Due to these activities the ecological balance is disrupted, thereby resulting in loosening of the soil.

7) Under conditions of heavy rain, there is increased and substantial soil erosion and frequent landslides.

The major areas affected by landslides in India are divided mainly in following regions as landslide-prone areas in India. These are based on landslide hazard zonation:

1) The Western Himalayas (in states of Uttar Pradesh, Uttaranchal, Himachal Pradesh and Jammu & Kashmir)

2) The Eastern & North-eastern Himalayas (in states of West Bengal, Sikkim and Arunachal Pradesh)

3) The Naga-Arakkan Mountain belt (in states of Nagaland, Manipur, Mizoram and Tripura)

4) The Western Ghats region including Nilgiris (in states of Maharashtra, Goa, Karnataka, Kerala & Tamil Nadu)

5) The Plateau margins of the Peninsular India and Meghalaya plateau in North-east India.

The following map of landslide prone areas in India will be useful in remembering the areas mentioned above. (Fig. 5)

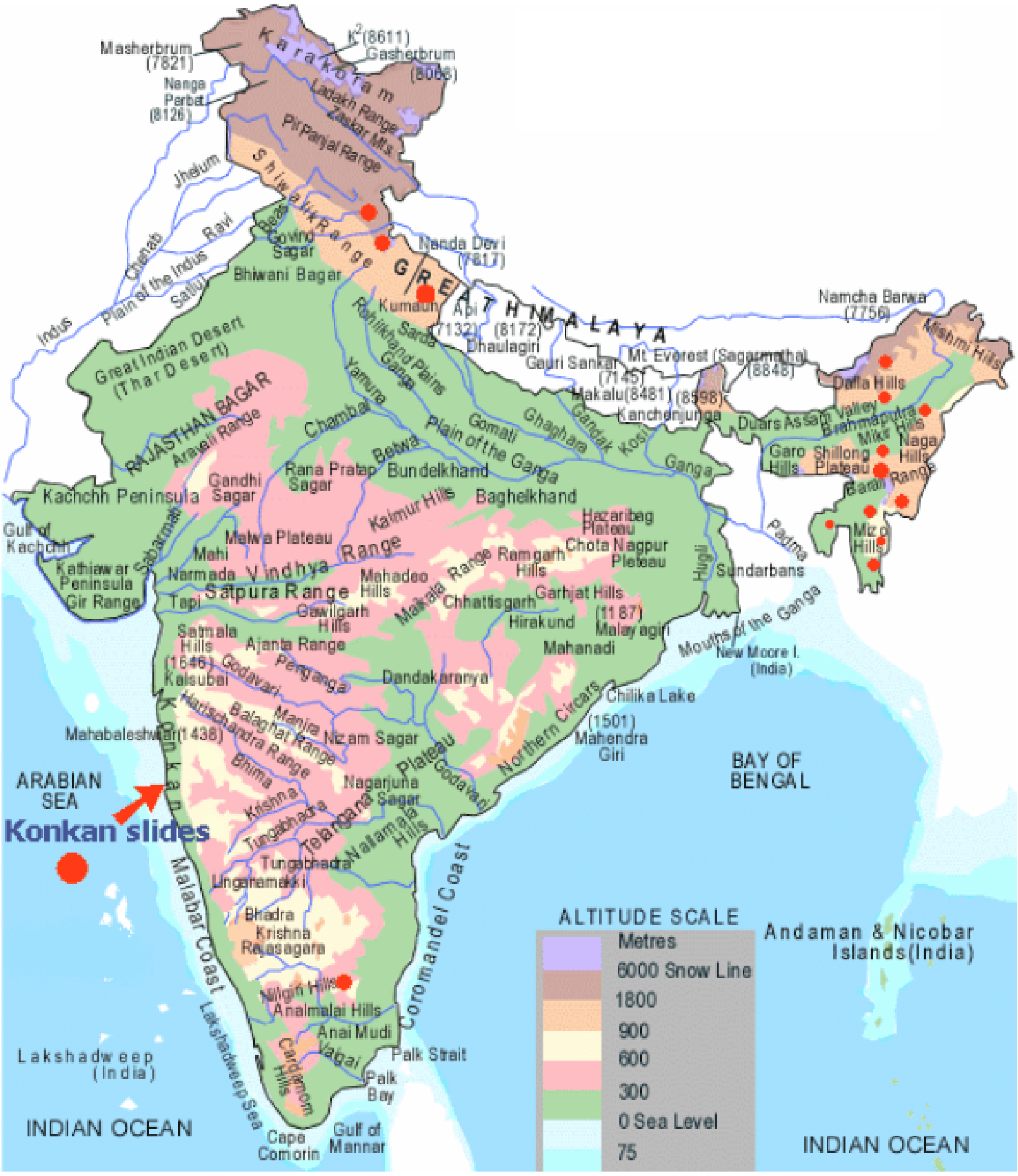


*Fig. 5. Landslide Hazard Zonation map of India. Areas prone to landslides*

The Nodal agency responsible for early warning of landslide disaster in India is – Geological Survey of India.

Mitigation steps for landslides in India are:

1) Excess water in catchments areas should be stored to reduce the effect of flash floods, this will also recharge the ground water level in areas prone to landslide in India.

2) The runoff collection ponds in the catchment areas must be dug to store water.

3) On community lands, fuel or fodder trees should be grown to increase forest cover to reduce landslide hazard in India.

Grazing should be restricted and better grass must be grown on the surface previously grazed to increase the hold on soil by plant roots. These grasses can be of some commercial importance so that economic returns encourage farmers in areas prone to landslide in India.

India suffers from landslides very much. The most dangerous places are in mountain areas, especially due to heavy rains and earthquakes.

*Fig. 6. A view of a major landslide after heavy rainfall in Shimla*

So a massive landslide near Shimla on the national highway near the state capital on 2 September 2017 buried at least six vehicles and parts of a temple. However, there were no reports of any casualty (Fig. 6).

A portion of the cliff opposite the temple near Bhattakufer caved in. Boulders rolled down and smashed six-seven vehicles parked along the highway

People who were stuck in houses below were rescued, 2-3 empty cars were under debris from landslide. The area has been witnessing heavy rainfall for the past three days.

Police have diverted traffic via Sanjauli, on Shimla's outskirts.

Also there are many landslide prone zones along the way to Himalaya (Fig. 7).

## 3.4. Multi-Hazards

Natural hazards such as floods, earthquakes, volcanic eruptions, and landslides can occur simultaneously, or these hazards can trigger the others. Landslides are often the result of earthquakes, floods, and volcanic activity and may in turn cause subsequent


*Figure 7. Landslides in India (Photos by V.B. Svalova)*

hazards; so an earthquake-induced landslide can cause a deadly tsunami. A volcanic eruption-induced or earthquake-induced landslide blocks the rivers. They cause water to back up behind the mass and flood the upstream area. If the dam fail, the impounded water will cause flooding downstream. Flooding can then add to coastal erosion and destabilization through undercutting of cliffs and banks. It is therefore necessary to examine all other possible natural hazards when evaluating an area's vulnerability to landslides (Figures 8).

A tsunami with a record run-up height occurred in Lituya Bay, Alaska. (Figure 8). An earthquake along the Fairweather Fault in the Alaska Panhandle loosened about 30.6 million cubic meters of rock high above the northeastern shore of Lituya Bay on the night of July 9, 1958. This mass of rock plunged from an altitude of 914 meters down into Gilbert Inlet.

The impact of masses generated tsunami that crashed against the southwest shoreline of Gilbert Inlet. The wave hit with such power that it swept completely over the spur of land that separates Gilbert Inlet from the main body of Lituya Bay. The wave continued down of Lituya Bay, over La Chaussee Spit and into the Gulf of Alaska. The waves removed all trees and vegetation from elevations as high as 524 meters above sea level. This is the highest wave that has ever been known.

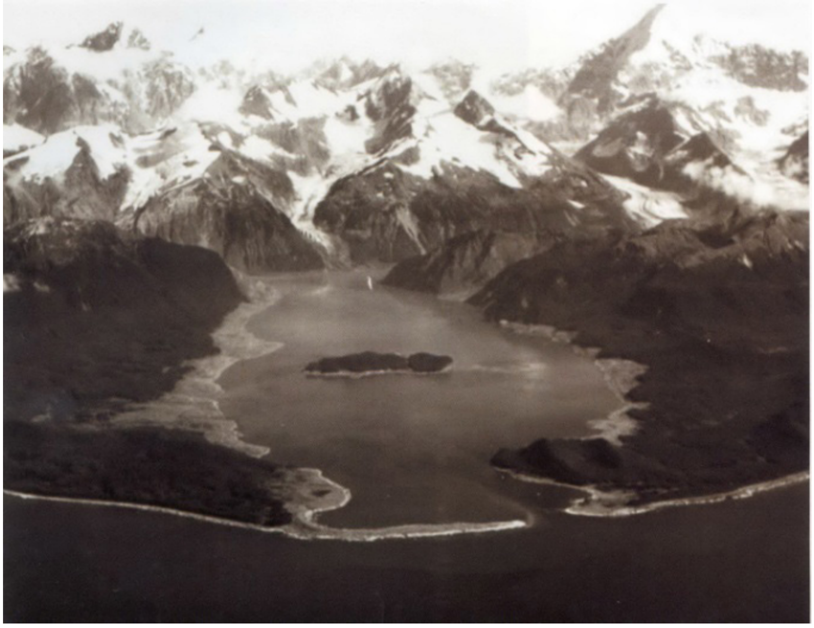

*Figure 8. Lituya Bay a few weeks after the 1958 tsunami. The areas of destroyed forest along the shorelines are clearly recognizable as the light areas rimming the bay (USGS).*

## 4. Risk Management Structure

Landslides risk assessment is an important step towards solving the problem of natural risk management and reduction. Due to the complexity and diversity of the problem the combination of probabilistic and deterministic approaches and expert estimates arises. [Svalova, 2014, 2016a, b; 2017; Wirtz et al., 2014].

The probability of landslide process depends on the stability of the landslide slope, trigger mechanisms (precipitation, earthquakes), technological factors. The first step is studying the physical and mechanical sliding process at different conditions. Nevertheless, the landslide process mechanics is still not fully understood. Landslide prediction is not always possible. Even statistical frequency of landslides activation for a particular area varies very widely.

**Natural risk** is a relatively new and not fully explored concept. There are many definitions of natural risk. If one of the main systematic approaches to hazards research is their classification so now also the concept of Risk **Management** can be considered as new step of science development and new basement for systematic hazards investigations.

Development of the **Risk** concept demands the promotion of the methods for **Risk Assessment** and calculation. It makes the theory of **Risk** the scientific discipline with good mathematical background. It is necessary to elaborate common approaches to the risk calculation for different types of natural hazards. The methods of seismic risk assessment as the most promoted ones must be spread to landslides, karst, suffusion, flooding, pollution and other types of natural hazards and risks and also to complex and multi-risk.

Arising from everyday life, gambling, finance, business and building the **Risk** concept became the subject for scientific research and basement for systematic investigations of natural and man-made hazards and disasters.

In common sense **Risk** is the potential of gaining or losing something of value. Values (such as physical health, social status, emotional well-being or financial wealth) can be gained or lost when taking risk resulting from a given action or inaction, foreseen or unforeseen. Risk can also be defined as the intentional interaction with uncertainty. Uncertainty is a potential, unpredictable, and uncontrollable outcome; risk is a consequence of action taken in spite of uncertainty. [Corominas et al., 2014].

**And in this sense t**he problem of **Landslide Risk Management** is seen as a series of events leading to landslides risk reduction and avoiding. It includes landslides monitoring, landslide forecast, engineering works, slopes strengthen, insurance and others [Corominas et al., 2014; Svalova, 2016c, 2017; 2018; Vranken et al., 2015]. Strictly speaking, geological risk management includes:

1) Hazard Identification;
2) Vulnerability evaluation;
3) Risk analysis;
4) Concept of acceptable risk;
5) Risk assessment;
6) Risk mapping;
7) Measures for risk reduction:
- legislative;
- organizational and administrative;
- economic, including insurance;
- engineering and technical;
- modeling;
- monitoring;
- information.

Summarizing systematic approach to natural hazards research on the base of the **Risk** concept it is possible to present the next steps and scheme to establish criteria for ranking risk posed by different types of natural or man-made hazards and disasters, to quantify the impact that hazardous event or process have on population, structures and to enhance strategies for risk reduction and avoiding (Figure 9).

According to the most common definition the Risk is the probability of the natural hazard event multiplied by the possible damage:

$$R = PxD, \tag{1}$$

where R – risk, P – probability, D – damage.

**Hazard Identification**
\+
**Vulnerability evaluation**

**Risk analysis**
\+
**Acceptable risk**

**Risk assessment**
\+
**Risk reduction**

**Risk management**

*Figure 9. Relationships between main items of Risk concept in strict form for systematic approaches to natural hazards and disasters research.*

For multi-risk assessment it is possible to use sum of risks of different hazards:

$$R = \sum R_i \tag{2}$$

For Risk Maps construction it is necessary to use the Natural Hazards maps and maps of possible damage. These maps can be of local, regional, federal (sub global) and global levels.

On the base of this approach different Risk maps and Natural Hazards maps can be constructed (Figure 10).

The total natural risk (In points determined by the intensity, frequency and destructive intensity of hazardous processes, the degree of protection and vulnerability of the facilities.

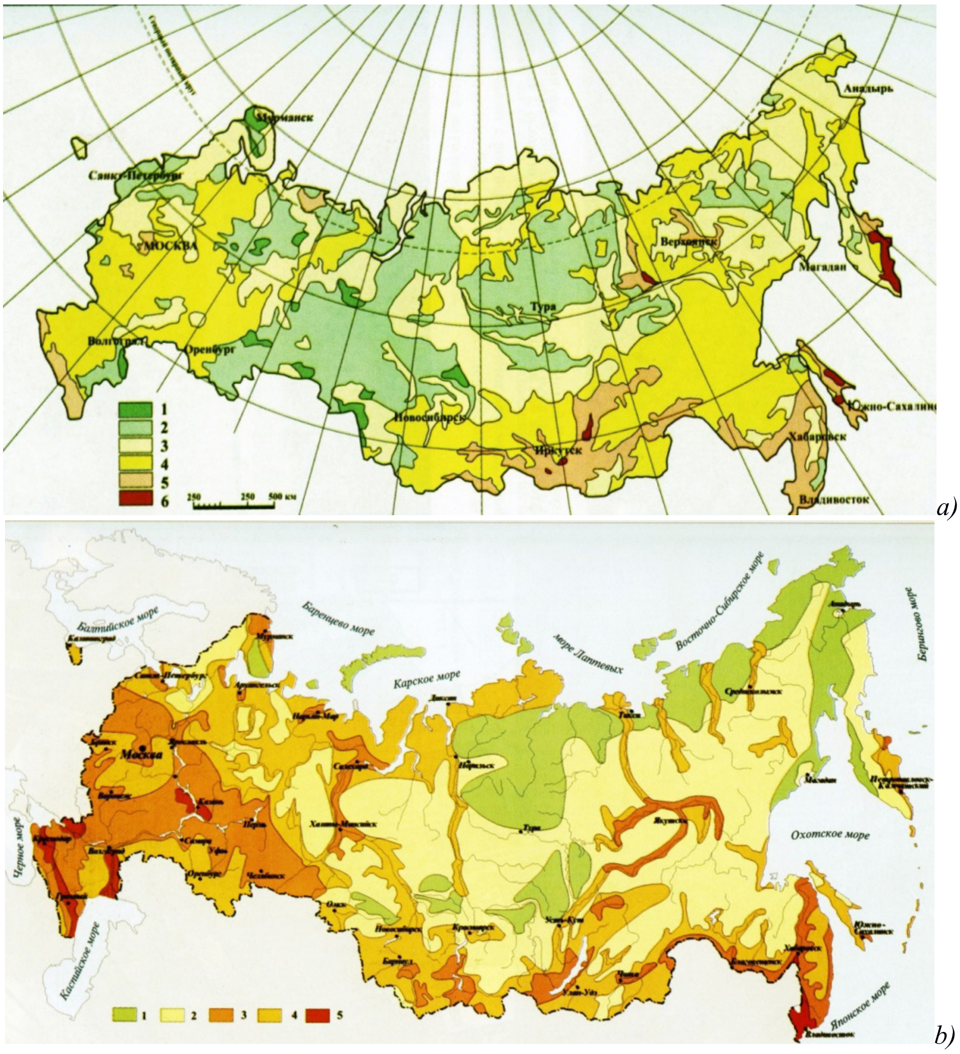


*Figure 10 a. Map of the natural economic risk of construction development and land use of the territory of the Russian Federation (A.L. Ragozin, O.V. Slinko, V.A. Pyrchenko et al. 1990). 1 point corresponds to the average annual damage of 1 million rubles per year (in 1990 prices) on an area of 20 thousand square km): 1 – very small (<2). 2 – small (10-2). 3 – medium (20-10). 4 – significant (80-20). 5 – large (200-80). 6 – huge (> 200).*

*b. Map of the Natural Disasters on the territory of Russia, caused by earthquakes, floods, cyclones, squalls, tornados, heavy rains, snowfalls, snowstorms, hail, snow avalanches and landslides (A.L. Shnyparkov). Frequency of occurrence (cases/year): 1 – <$10^{-5}$; 2-$10^{-5}$-$10^{-4}$; 3-$10^{-4}$-$10^{-3}$; 4-$10^{-3}$-$10^{-2}$, 5 -> $10^{-2}$.*

## 5. Discussion and conclusions

Systematic approach to the crises events research on the base of risk concept is a very fruitful and progressive method.

Local authorities must be ready for constant monitoring and technical-engineering works in such areas.

Life and work in areas of high natural risk demands knowledge, resources, equipment and willing to be ready for prognosis, forecast, people education and information. In case of crises events it is necessary to be ready for the consequences liquidation and the territories and objects reparation. The most important thing is to provide help to people. Sometimes people have to live in such dangerous places. It is necessary for people leaving under natural risk to understand and estimate this risk and to know how to overcome it and how to act in case of crises events. It is necessary to elect and appoint responsible people with good knowledge and special education for managerial posts. The local governments are responsible to establish rules meant to reduce the effects of possible landslides. Land-use regulations are required in landslide prone areas. The absence of such policies and dangerous human activities are the main factors that lead to landslides. No matter if landslide is caused by huge rainfall, seismic activity or volcanic eruption. The damage from event can be disastrous. Thousands of people may lose their houses and could lose their lives. It is important for local authorities to know which areas are prone to landslides and take appropriate measures in order to reduce vulnerability to such hazards. The effects on people and buildings can be lessened if hazardous areas are avoided or if activities in such areas are restricted. Local governments are responsible for land-use regulations for landslide risk reduction. It is possible to reduce exposure to hazards on the base of people education using the past history of disaster events. Departments of local governments must help a lot with their advice and activity. People can also benefit from the professional services of engineering geologists, civil engineers, or geotechnical engineers. Due to the huge losses that landslides imply, their prevention is very important for all the people living in the area of hazard. Preventing a landslide from causing material damage and human losses should be a main goal of local authorities.

Risk management concept is a good instrument for systematic approach to the problems decision.

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# Оползневый риск в горных районах

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**Аннотация.** Оползни являются одним из опаснейших геологических процессов, создающих угрозу для населения и различных объектов инфраструктуры. Оползни часто сопровождают другие стихийные бедствия, такие как землетрясения, наводнения, таяние снега и вулканические процессы, которые играют роль механизма запуска оползней. Горные районы, пострадавшие от землетрясений также уязвимы для оползней. Горные и прибрежные районы являются наиболее пострадавшими регионами. Во всем мире оползни наносят колоссальный ущерб и влекут за собой человеческие жертвы. Статья посвящена исследованию оползней на основе концепции анализа, оценки, управления и снижения рисков. Управление рисками рассматривается как серия мероприятий, ведущих к снижению и предотвращению риска оползней. Они включают в себя мониторинг оползней, прогноз оползней, инженерные работы, укрепление склонов, страхование и др. Рассмотрены примеры исследований Индии, Китая и России, включая Колкинскую катастрофу 20 сентября 2002 года и другие связанные с ней катастрофы. Казбекский вулканический центр характеризуется сложной взаимосвязью различных опасных геологических процессов. Бедствия 2002 и 2014 гг., вызванные падением ледяных скал, определяют важность исследования местности. Сеть зафиксировала обвал массы льда и камней в районе ледника Девдорак 17 мая 2014 года и движение образовавшейся ледово-каменной лавины. В Индии Гималаи подвержены оползням, особенно в сезон муссонов, с июня по октябрь. В Гималаях встречаются различные типы оползней, в том числе оползни блоков, обломки, оползни, обвалы, проскальзывание и спад. Обычно сход оползней вызван сильными или продолжительными осадками. Оползни наносят серьезный социальный ущерб, вызывают сбои в различных сетях и движении транспорта.

**Ключевые слова:** оползень, риск, управление риском, оценка риска, снижение риска, мониторинг

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