Chapter 13

Landslide Risk Management and Crises Events

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Additional information is available at the end of the chapter

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Abstract

The problem of geological and landslide risk management is seen as a series of events leading to risk reduction, including risk analysis, risk assessment, risk mapping, vulnerability evaluation, concept of acceptable risk, monitoring organization, engineering-technical methods, insurance, and others. Some examples of crises events are presented and investigated.

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

1. Introduction

Natural disasters always caused fear and horror in people. The greatest horror is caused by earthquakes, volcanic eruptions, and tsunamis that are unpredictable and catastrophic in its consequences. The most unpredictable are earthquakes. Active volcanoes are constantly monitored, giving the possibility of anticipating a possible eruption. Tsunamis also have a number of predictive features, which makes it possible to mitigate the consequences of their onset.

Often unexpected for a person are snow avalanches and giant landslides and debris flows. Giant landslides and debris flows are often caused by prolonged torrential rains or earthquakes. The task of preserving the cultural heritage can be considered theoretically solvable. A practical solution will require only correct and timely engineering decisions and material costs, and the role of science is very great here.

Landslide is a major geological hazard, which poses serious threat to human population and various infrastructures such as highways, rail routes, and civil structures such as dams, buildings, and others [1–21].

The idea that landslide could occur is frightening people in every area prone to such phenomena. This is because the effects of landslides can be devastating, leaving thousands of people without home and threatening their lives.

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 each year. Casualties are caused by rockslides, rockfalls, and debris falls. In order to know this phenomenon better, and eventually protect themselves from its destructive action, people should be aware of how landslides are formed and how they act.

The word "landslide" describes different processes that result in the movement 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, 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 not only with mountainous areas, but also they 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 [22–31]. 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 approaches defines that risk is the expectation of damage, or risk is the product of the probability of possible hazardous events on the damage produced.

The problem of landslide risk management is considered as measures leading to landslides risk reduction. It includes landslides monitoring, mapping, landslide forecast, engineering works, slopes strengthen, insurance, and others. Strictly speaking, geological risk management includes:

1. Hazard identification;
2. Vulnerability evaluation;
3. Risk analysis;
4. Concept of acceptable risk;

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5. Risk assessment;
6. Risk mapping;
7. Measures for risk reduction;
8. legislative;
9. organizational and administrative;
10. economic, including insurance;
11. engineering and technical;
12. modeling;
13. monitoring; and
14. information.

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

2. Natural hazards and disasters: hazard identification

Natural hazards are potentially damaging physical events and phenomena, which may cause the loss of life; injury or human life disruption; property damage; social, economic, and political disruption; or environmental degradation.

Natural hazards can be divided into different groups: geological, hydro-meteorological, climatological, outer space, and biological hazards.

Natural hazards can be single, multiple, regional, and global in space. Each natural hazard is characterized by its location, intensity, and probability.

A disaster is a serious disruption of the normal functioning of a society causing widespread human, material, economic, or environmental losses.

For the last 35 years, the frequency of the disasters associated with natural hazard events has been steadily increasing. An average number of 405 events per year was registered by Munich Re in 1980–1989, 650 events in the 1990s, 780 events during the period 2000–2009, and more than 800 events in 2010 [32]. **Figure 1(a–f)** shows that total number of disasters increase, but the number of geological disasters has not changed much for the last 30 years when compared to the number of hydro-meteorological and climatological events. Victims and economic damage increase drastically.

Earthquakes, volcano eruptions, tsunamis, crust, suffusion, coast erosion, and landslides belong to geological hazards.

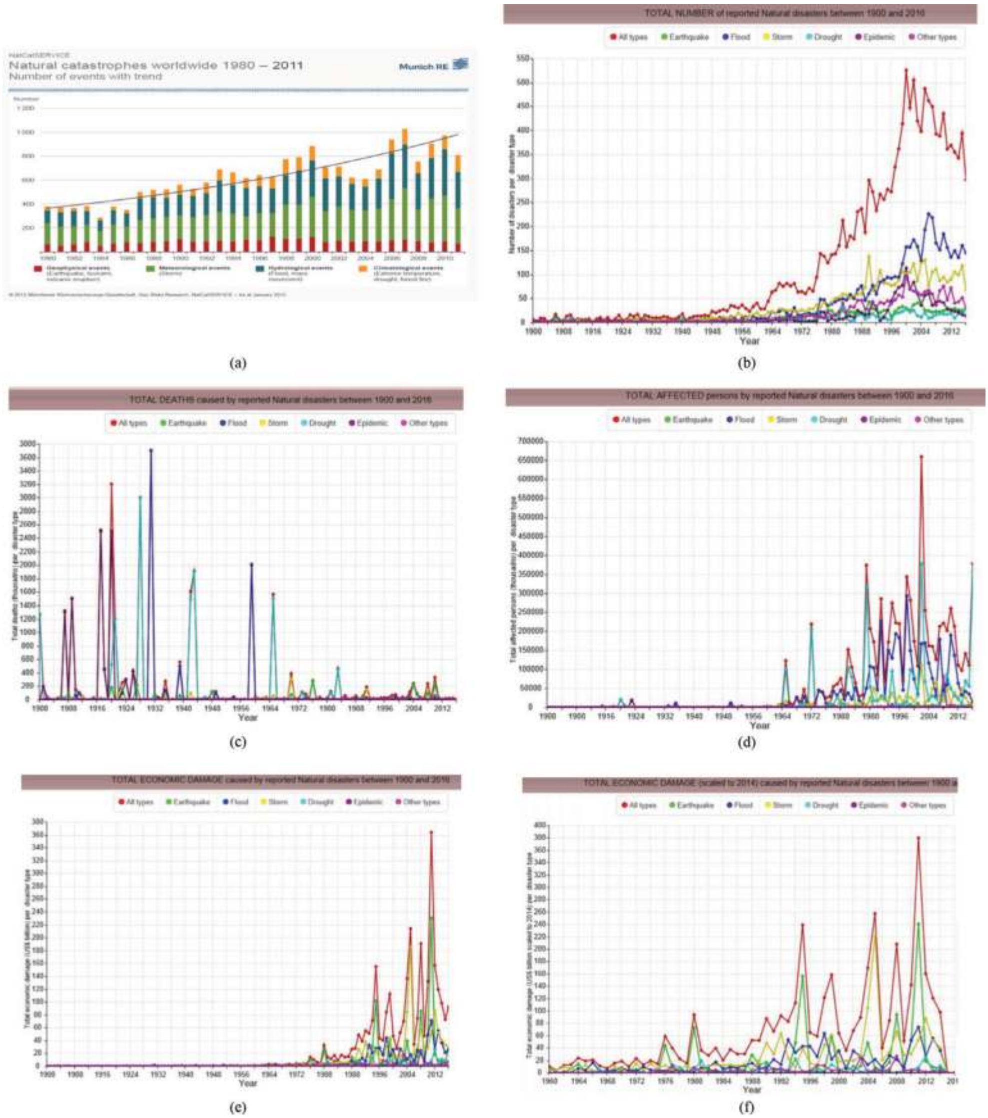

Figure 1. (a) Annual number of disasters associated with natural events from 1980 to 2013 1: red represents the geological events; 2: green represents the meteorological events; 3: blue represents the hydrological events; and 4: orange represents the climatological events (NatCatSERVICE, Munich re, 2014). (b) Total number of natural disasters, 1900–2016. http://emdat.be/. (c) Total deaths caused by natural disasters, 1900–2016. http://emdat.be/. (d) Total affected persons by natural disasters, 1900–2016. http://emdat.be/. (e) Total economic damage caused by natural disasters, 1900–2016. http://emdat.be/. (f). Total economic damage (scaled to 2014) by natural disasters, 1960–2016. http://emdat.be/.

Hydro-meteorological and climatological hazards are the most frequent causes of the disaster events among all natural hazards (**Figure 1**). The most common meteorological hazards are heavy rains, storms, hurricanes, droughts, tropical cyclones, rainstorm floods, heat waves, and low temperature disasters. Moreover, meteorological hazards include lightning, tornadoes, dust storms, hail, frost, fog, and haze [32]. Adverse impacts from weather and climate extremes can be considered meteorological disasters when they produce widespread damage and cause severe alterations in the normal functioning of communities or societies.

3. Risk assessments

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

$$R = P \times D, \tag{1}$$

where R—risk, P—probability, and D—damage.

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

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

For the risk map 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.

Areas of such crises events must be places of the highest risk at the natural risk maps of the territories.

3.1. Landslides risk assessment and mapping

Geological risk mapping is an important step toward solving the problem of natural risk management. 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), and technological factors. The first step is studying the physical and mechanical sliding process at different conditions. Nevertheless, the landslide process mechanics are still not fully understood. Landslide prediction is not always possible. Even statistical frequency of landslides activation for a particular area varies very widely.

As an example to be considered is the approach to the construction of the landslide risk map in the territory of Moscow.

Landslide processes in Moscow are well investigated. Landslides cover about 3% of the city, where there are 15 deep and a lot of small landslides, and the landslide hazard is mapped. In the last few years in Moscow, there is a significant activation of landslide processes. To assess the landslide hazard, the height of the slope, the landslide body volume, mass velocity, rock properties, topography of the surrounding area, the range of possible promotion of landslide masses, hydrogeological conditions, and trigger mechanisms have to be taken into account. Selection of taxons' (special areas) varying degrees of landslide hazard in the city is a completely solvable task. Gradation is possible as in the three degrees of danger (high, medium, and low) as in the five ones (very high, high, medium, low, and not dangerous), depending on the details of the task.

The most expensive land and buildings in Moscow are located in the city center, where the oldest historic buildings, buildings that are most vulnerable to natural hazards, and the most expensive new ground and underground constructions, subway lines, complex traffic, and technical communications of high density are present. There is an increased density of population. We can assume that the closer to the center of Moscow, the greater the potential damage from possible landslide process.

Hazardous industrial production brought to Moscow's periphery. But the protected zone of Moscow on the Vorobiovy Hills and in Kolomenskoye also has high cultural value, and the potential damage there is highly evaluated. Therefore, a first approximation map of landslide risk in Moscow may be an overlay of landslide hazard maps and population density, building density, land prices, density of roads, and infrastructure maps. Areas with the highest degree of landslide hazard and the highest damage are the areas with the highest landslide risk in the territory of Moscow [31].

For the automated analysis of the factual material and the risk map construction, it is necessary to find the intersection of the landslide hazard map and integrated map of possible damage, that is, for each i-th fragment Ri of risk map to find the product of probability Pi of landslide event to the amount of different j-th possible damages from landslides, that could result in the damage to land, to buildings, to transport, to communications, to people, and others:

$$R_i = P_i \sum_j D_{ij}. \quad (3)$$

It is necessary to calibrate maps of landslide hazard from 0 to 1 to reflect the probability of landslide events ($0 \le P \le 1$). Thus, gradation, for example, is possible on a scale of (0; 0.25; 0.5; 0.75; 1), where 0 corresponds to no danger of landslides, 0.25 corresponds to low, 0.5corresponds to average, 0.75corresponds to high, and 1corresponds to a very high probability of the landslide process. This assessment is an expert in nature. In principle, it is possible to construct the landslide hazard maps as the intersection of maps of factual material, such as map of relief contrast, rock strength, slope stability, speed of motion of the surface, the density of rainfall, seismicity, and so on. Of course, this will require additional research and evaluation.

For a comprehensive assessment of the damage in each region, it is suggested to calibrate the possible damage of each option on a three-point system (0, 1, 2), where 0 corresponds no damage, 1corresponds to middle, and 2 corresponds to high damage. The parameters here are: (1) cost of land, (2) cost of housing, (3) density of buildings, (4) population density, and (5) density of roads and communications. The higher the value (the value of land, housing, etc.), the greater the damage in case of a hazardous event.

Then, the possible damage to five parameters for each element varies from 0 to 10.

The risk also in each element ranges from 0 to 10. This is the risk in relative terms (high-low), on a 10-point scale.

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$$D_i = \sum_j D_{ij},\ j = 1\text{–}5,\ D_{ij} = (0, 1, 2),\ 0 \le D_i \le 10,\ 0 \le R_i \le 10. \quad (4)$$

After dividing the map of the area into squares and calculating the risk for each square, you can get a map of the area at risk on the 10-point scale.

On the basis of preliminary expert estimates, it will be the areas in the vicinity of Moscow River and Yauza River, as well as in the areas of contrasting relief along riverbeds of paleorivers in the city center.

The areas of highest landslide risk are Vorobiovy Mountains (Hills) and Kremlin Hill. (**Figure 2**).

They are shown as white circles in the map of geological danger in Moscow. (**Figure 3**).

These areas may be considered as "hot spots" on the risk map. Even though in some of these areas, the population density is not so high, the other components (cost of land, the historical importance of the object, the density of underground utilities, and others) have contributed greatly to the high-risk assessment [31].

(a) (b) (c)

Figure 2. (a) Vorobievy Mountains with Moscow State University, ski jumps, and metro bridge. (b) Vorobievy Mountains with building of Presidium Russian Academy of Sciences (RAS), Andreevsky monastery, and new living houses. (c) Kremlin embankment.

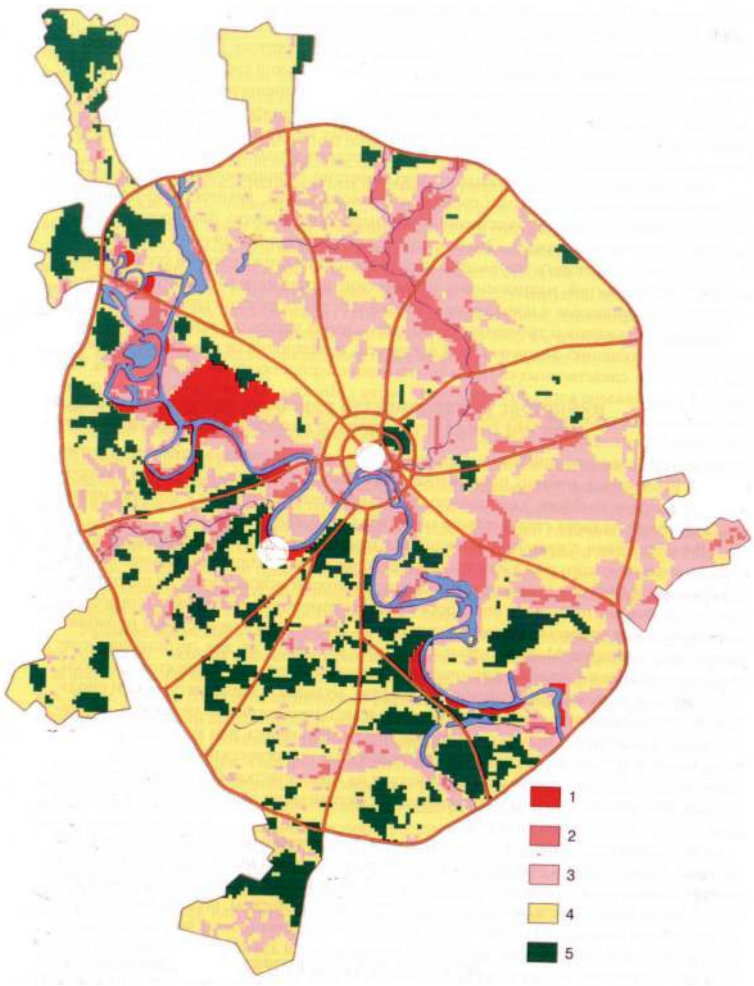

Figure 3. Map of geological danger in Moscow. Landslides, karst, and underflooding. (Osipov V.I., Kutepon V.M., Mironov O.K.) [1]. Landslides are near rivers in semi-dark (red and pink). 1: Very high danger, 2: High, 3: Middle, 4: Low, 5: No. white circles: Risk "hot spots." Kremlin hill (center) and Vorobiovy Mountains (south-west).

These areas must be measured for risk management and reduction at the first line. It means monitoring organization, slope strength, ban on extra buildings and activity.

4. Risk management and reduction: engineering and technical methods

When studying landslides, risk reduction is one of the most important aspects to be considered while discussing engineering and technical methods that are used to strengthen slopes

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and rational land use. The most well-known method for slope stabilization is the changing of slope surface (reducing the height of the slope, correction of the slope profile) and reinforcing constructions and water discharge when undertaking building construction. Different protective methods are widely used (**Figures 4–6**).

4a)

4b)

Figure 4. (a and b) Technogenic landscapes in China.

5a) 5b)

Figure 5. (a and b) Strength of slopes and defense constructions along the roads in China.

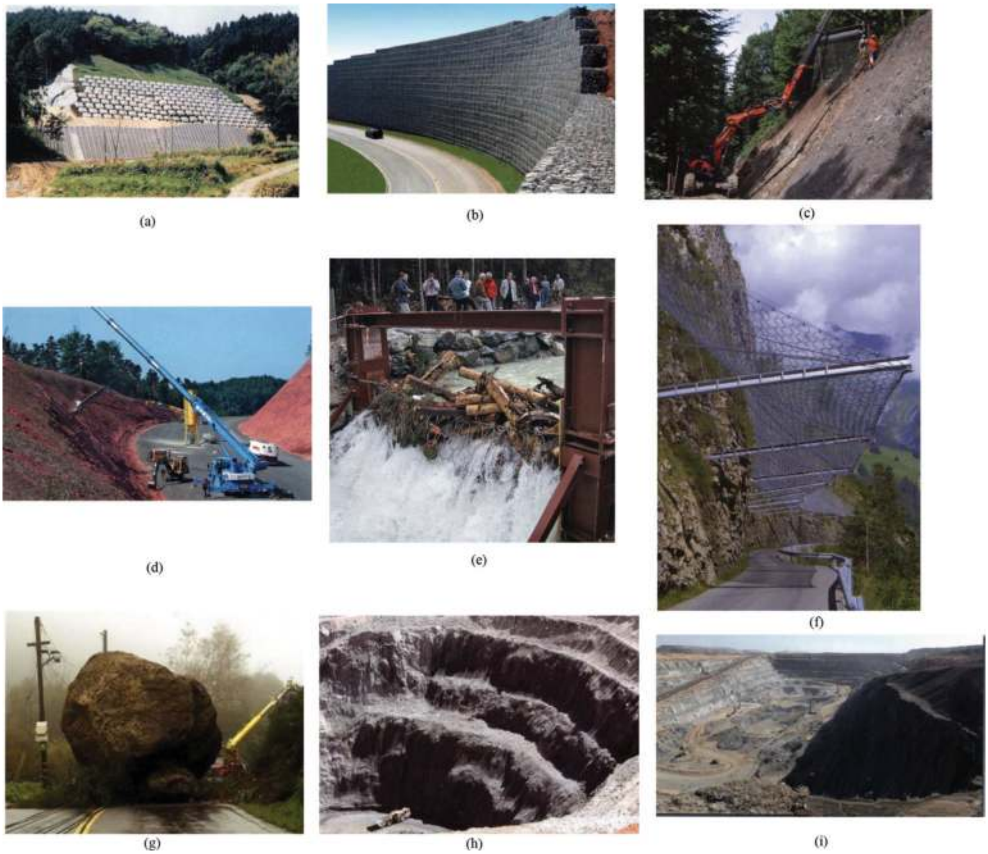

Figure 6. (a) Anchor construction—Japan. (b) Strengthen wall—Switzerland. (c) Slope defense by flexible metallic net—Switzerland. (d). Slope protection by flexible metallic net—Switzerland. (e). Barrier for retaining debris flow—Switzerland. (f) Ring metallic net protection above road against rockfall—Switzerland. (g) Big stone on the road. It is possible to make it fall down, to break, or to reinforce by cement on the slope of the road. (h) Rock slope surface stabilization and rockfall hazard mitigation using coated double-twist rockfall mesh. Australia. Mining company Barrick (Australia Pacific) Ltd., 2010. (i) Rockfall mitigation drapery using double-twist rockfall mesh—South Africa. Mining company Anglo-platinum, 2009.

5. Case studies for landslide-prone slopes protection

Sometimes destructions after landslides or earthquake are so huge that it is more acceptable to leave the place of fatal event than reconstruct buildings or strengthen slopes. There are examples in Bulgaria, Italy, and the USA where innovative decisions for slope strengthening and construction repair are suggested.

5.1. Landslide in Cavallerizzo town, Italy

In Italy, the town of Cavallerizzo was closed after a big landslide was reported on March 7, 2005. It was impossible to visit the town (**Figure 7**) even in 2008 and was visible only from a distance. All roads to the town were blocked.

(a) (b)

Figure 7. (a) Big landslide in Cavallerizzo town, Italy, on March 7,2005. (b) Cavallerizzo town in 2008.

Scientists warned the authorities on the dangers of landslide, but they waited till the last moment before evacuating the people. They were fortunate as no one was killed during the landslides.

5.2. Ancona, Italy

On December 13, 1982, the city of Ancona in Italy experienced a huge landslide. The landslide in Ancona took place after a long period of precipitation. The 1982 event began without warning, lasted only a few hours, and affected the whole area simultaneously within a maximum width of 2 km near the coastline involving a volume of about 180 million cubic meters. Some buildings were damaged. A total of 3000 people were evacuated.

After the major landslide, the Ancona administration came out with the "Living with Landslide" policy. An Early Warning System and Emergency Plan was put into place in 2009. Stabilization was unacceptable because of the high cost and impact to the environment. This system offers the best safety measures for the people living in Ancona.

The Early Warning System consists of an integrated and continuous monitoring system aimed at controlling both superficial and deep displacements over the whole area. The surface monitoring is based on 34 geodetic GPS, 8 automatic robotic stations, 230 reflector point and later control with 8 high-precision inclinometric sensors for the stability control of the main station. The complex network of instruments installed makes the Ancona landslide one of the best monitored stations in the world (**Figure 8**).

Many amazing towns in Italy need well-organized monitoring and constant attention to landslide risk (**Figure 9**).

5.3. Road repair in Bulgaria

When there is no option left, it is necessary to repair the mountain roads after a landslide event. So, in Bulgaria, an engineering decision was suggested and fulfilled under the research, conduction, and control of Dr. Kiril Angelov, Bulgaria (**Figure 10**).

(a)

(b)

Figure 8. (a) Geological field trip to Ancona, Orvieto and Civita di Bagnoregio. (b) Presentation of monitoring system.

5.4. The collapse of the highway in California after the rain

On November 21, 2011, after a heavy rainfall, part of the coastal road to San Pedro, California, collapsed (**Figure 11**). During the incident, no one was injured. Monitoring of soil movement began in the spring, when cracks appeared near the White Point Nature Preserve. The highway was gradually lowered from June and the track was closed in September.

The coast of the Palos Verdes Peninsula has been subject to landslides due to unstable rocks that are prone to shifts toward the ocean.

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Figure 9. Civita di Bagnoregio.

(a)

(b)

(c)

Figure 10. (a) Road breakage; (b) stage of repair; (c) ready road.


(a) (b)

Figure 11. (a) The collapse of the highway in California and (b) view from airplane.

There was no danger to surrounding houses as the landslide was far from the nearest buildings. The Paseo del Mar section of the road, 300 meters long, was closed and fenced.

The authorities in Los Angeles came out and said that the section of the road that collapsed could not be repaired and hence a new route of the scenic road would be built elsewhere.

5.5. USA: Bingham Canyon Open Pit Copper Mine

The largest nonvolcanic landslide in North America occurred in the world's largest mine.

At 9:30 pm, on April 10, 2013, a landslide occurred at the mine.

The largest man-made mining site in the world is the Bingham Canyon Mine, located in the State of Utah, USA. Here, ore is extracted for more than 110 years. In Bingham Canyon, a quarter of the country's copper is mined.

Such volumes for so much time have led to the formation of a giant crater about 970 m wide and about 4 km long. With the growth of the "pit," the operators-controllers ascertained the fact that the walls of the mine were becoming increasingly unstable. Then, seismic sensors were installed. In early 2013, there was a danger of a collapse of the northeastern "wall."

Fortunately, even before two destructive landslide waves, evacuation was carried out. The duration of each avalanche was approximately 1.5 min. The volume of the landslide was more than 65 million cubic meters.

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The power of the landslide was so great that seismologists recorded it, like an earthquake at 2.5 on the Richter scale.

Since 1966, mine is listed in the National Historic Monuments Register under the name of Bingham Canyon Open Pit Copper Mine (**Figure 12**).

Figure 12. Bingham Canyon Open Pit Copper Mine at landslide and before (last).

6. Cultural and natural heritage at landslide risk

There are many historical and beautiful natural objects and places under landslide risk in the world. It is possible to classify them into some types. But every object of natural and cultural heritage is unique. Suggested types could be, for example:

1. Temple on the top,

2. Churches on the high bank of the river,

3. Town in the mountains,

4. Waterfall in the mountains,

5. Volcanoes,

6. Islands,

7. Sculptures in the mountains,

8. Hot springs in the mountains,

9. Others.

Natural disasters always remain a grandiose natural force, which is impossible to combat directly, but it is only necessary to study and to adapt to it.

6.1. Crisis event, Malta

The **Azure Window** was a 28-m-tall limestone natural arch on the island of Gozo in Malta. It was one of Malta's major tourist attractions. The arch is featured in a number of international films and other media representations [33].

The formation was anchored on the east end by the seaside cliff, arching over open water, to be anchored to a freestanding pillar in the sea to the west of the cliff. It was created when two limestone sea caves collapsed.

Following years of natural erosion causing parts of the arch to fall into the sea, the arch and freestanding pillar collapsed completely during a storm on March 8, 2017 (**Figure 13**).

Everybody understood that one day the arch can be destroyed. Local authorities, government of Malta, and UNESCO knew about it. But nothing was done. Enough engineering measures were not provided. Only it was forbidden for people to go upstairs and to visit the top of the arch.

We thus lost an amazing object of cultural and natural heritage.

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Figure 13. Azure Window before and after.

7. 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. Good examples of monitoring organization and engineering works are demonstrated and suggested in some different areas. But sometimes people do not pay enough attention to the problems. Sometimes, it is necessary to evaluate whether to undertake reconstruction of the object after crises event or to change the place for another similar construction or living as in the case of Cavallerizzo (**Figure 7**), Bulgaria (**Figure 10**), or USA (**Figure 11**). The best way is to forecast crises events and provide protective measures in advance. Bingham event (**Figure 12**) could be avoided and protected as in Australia (**Figure 6h**) and South Africa (**Figure 6i**).

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 of the territories, and object 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 such risks 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 a landslide event can be disastrous. Thousands of people may lose their houses or 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 basis of educating people using the past history of disaster events. Departments of local governments must assist 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 caused by landslides, their prevention is very important for all the people living in hazardous areas. Preventing a landslide from causing material damage and human losses should be the main goal of local authorities.

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

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