Chapter 9

Landslide Risk Management for Urbanized Territories

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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 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. The problem is investigated on the examples of Moscow and Taiwan.

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

1. Introduction

The problem of landslide risk management is seen as a series of events leading to landslides risk reduction. **Natural risk** is a relatively new and not fully explored concept. There are many definitions of natural risk. Often a scientific study or a scientific approach to the problem begins with a presentation of the author's position and the choice of the definition of natural risk for the problem. This individualistic approach is difficult to avoid. Spores are carried out so far. For example, if there is a risk without material damage to people or not.

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 a new step of science development and a 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 a 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 multirisk.

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 possibility to gain or lose something (life, health, property, money, environment, etc.). Risk situation can rise at meeting with uncertainty resulting from action or inaction. Risk is a consequence of unpredictable outcome.

In **risk-analysis** science**, risk** is considered as a measure of the probability of damage to life, health, property, money, or the environment. Risk is defined as the probability of the natural hazard event multiplied by the damage from possible consequences.

According to Corominas et al. [1]:

Risk analysis is the use of available information for hazard identification and vulnerability evaluation.

Vulnerability is the degree of loss of a given element or set of elements exposed to the occurrence of a natural or man-made hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss).

Risk assessment is considered as the process of making decision on whether existing risk is acceptable or nonacceptable and implies the risk analysis and risk evaluation processes.

Sometimes, risk assessment is considered as risk calculation on the basis of selected parameters and establishment of ranking risk criteria.

Acceptable risk is defined by the level of human and property loss that can be tolerated by an individual or community. The probability of acceptable risk is very small. The concept of acceptable risk arises from the understanding that absolute safety is an unachievable purpose.

Risk management is considered as the complete process of risk assessment and risk reduction.

Risk reduction implies some methods and measures, as legislative, organizing, economic, engineering, information and others.

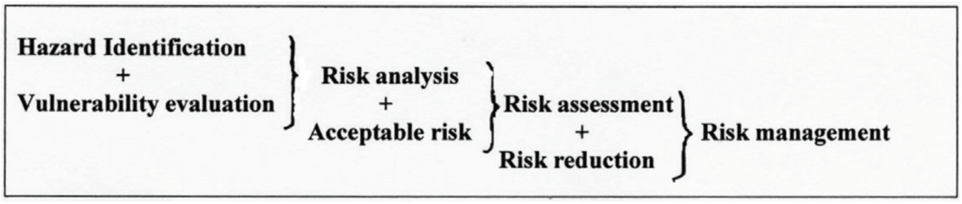
Sometimes in narrow sense, **risk management** is considered as measures for risk reduction.

In this sense, the 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.

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 (**Table 1**).

Risk management
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

Table 1. Risk management structure.



Relationships between main items of risk concept for systematic approaches to natural hazards and disasters research.

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

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

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

For multirisk 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.

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

Landslides occur very often during other major natural disasters such as earthquakes, floods and volcanoes.

The word “landslide” 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” or “mass wastage.” However, the term “landslide” has been accepted and is being used commonly around the world as a synonym of “mass wastage.”

Some main aspects of landslides risk management are considered.

2. Landslides risk assessment and mapping

Geological risk mapping is an important step toward solving the problem of natural risk management [1, 2]. 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.

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

2.1. Study area

Landslide processes in Moscow are well investigated [3–21]. Landslides cover approximately 3% of the city, where there are 15 deep and a lot of small landslides, and the landslide hazard is mapped. Last 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 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 completely solvable task. Gradation is possible as in the three degrees of danger (high, medium, low) as in five ones (very high, high, medium, low, not dangerous), depending on the detail of the task.

The most expensive land and buildings in Moscow are located in the city center, where there are also the oldest historic buildings, the most vulnerable to natural hazards, and the most expensive new ground and underground construction, subway lines, complex traffic, and technical communications of high density. 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 Vorobyovy 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 of the highest landslide risk in the territory of Moscow.

The methodology for risk evaluation and mapping is suggested in the following paragraph.

2.2. Methodology for landslide risk mapping

For the automated analysis of the factual material and the risk maps construction, it is needed to find the intersection of the landslide hazard map and integrated map of possible damage i.e. 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 be damage to land, to buildings, to transport, to communications, to people and others:

$$R\,i = P\,i\ \sum j\,D\,ij \tag{3}$$

Maps of landslide hazard are necessary calibrated from 0 to 1, to reflect the probability of landslide events ($0 \leq P \leq 1$). 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 - low, 0.5 - average 0.75 - high and 1—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 means no damage, 1 is middle, and 2 is high damage. The parameters here are, for example, (1) cost of land, (2) cost of housing, (3) density of buildings, (4) population density, (5) density of roads and communications. The higher the value (the value of land, housing, etc.), the greater is 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.

$$D\,i\ = \sum j\,D\,ij,\ \ j = 1 - 5,\ \ D\,ij\ = (0, 1, 2),\ \ 0 \leq D\,i \leq 10, 0 \leq R\,i\ \leq 10. \tag{4}$$

After defeating 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 a 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 places of high landslide risk are Andronievskaya embankment (**Figures 1** and **2**), Nikolo-Yamskaya embankment (**Figure 3**), Kotelnicheskaya embankment (**Figure 4**), and Samotechnaya street (**Figure 5**) in the center of Moscow.

The places of the highest landslide risk are Vorobiovy Mountains (Hills) (**Figures 6** and **7**) and Kremlin Hill (**Figures 8** and **9**). They are shown as white circles in the map of geological danger in Moscow (**Figure 10**).

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

Figure 1. Andronievskaya embankment with Svjato-Andronikov monastery.

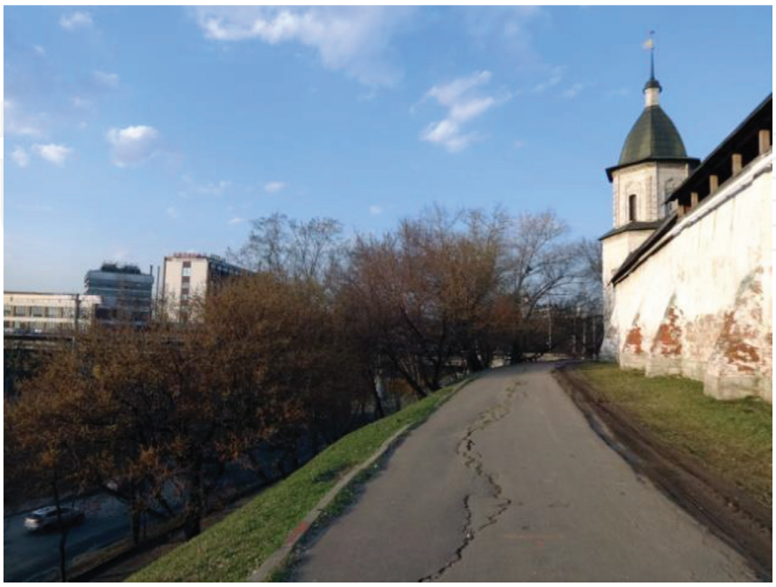


Figure 2. Cracks near Svjato-Andronikov monastery.

Figure 3. Nikolo-Yamskaya embankment.

Figure 4. Kotelnicheskaya embankment.

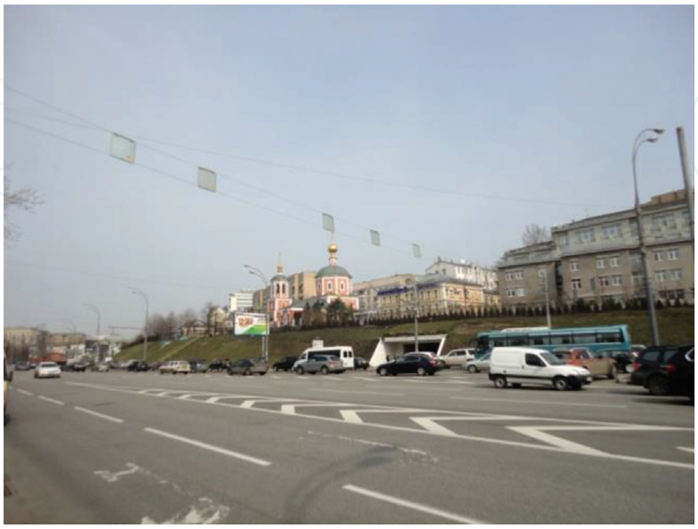


Figure 5. Samotechnaya street.

Figure 6. Vorobyovy Mountains with Moscow State University, ski-jumps and metro-bridge.

Figure 7. Vorobyovy mountains with building of Presidium Russian Academy of Sciences (RAS), Andreevsky monastery and new living houses.

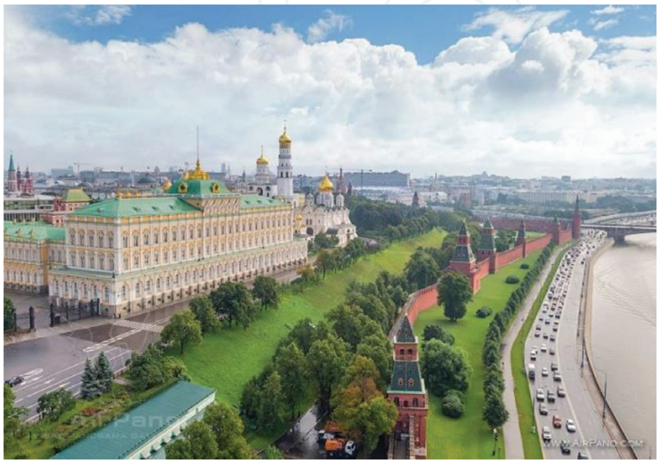


Figure 8. Kremlin embankment.

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Figure 9. Center of Moscow with Kremlin Hill and Moscow River.

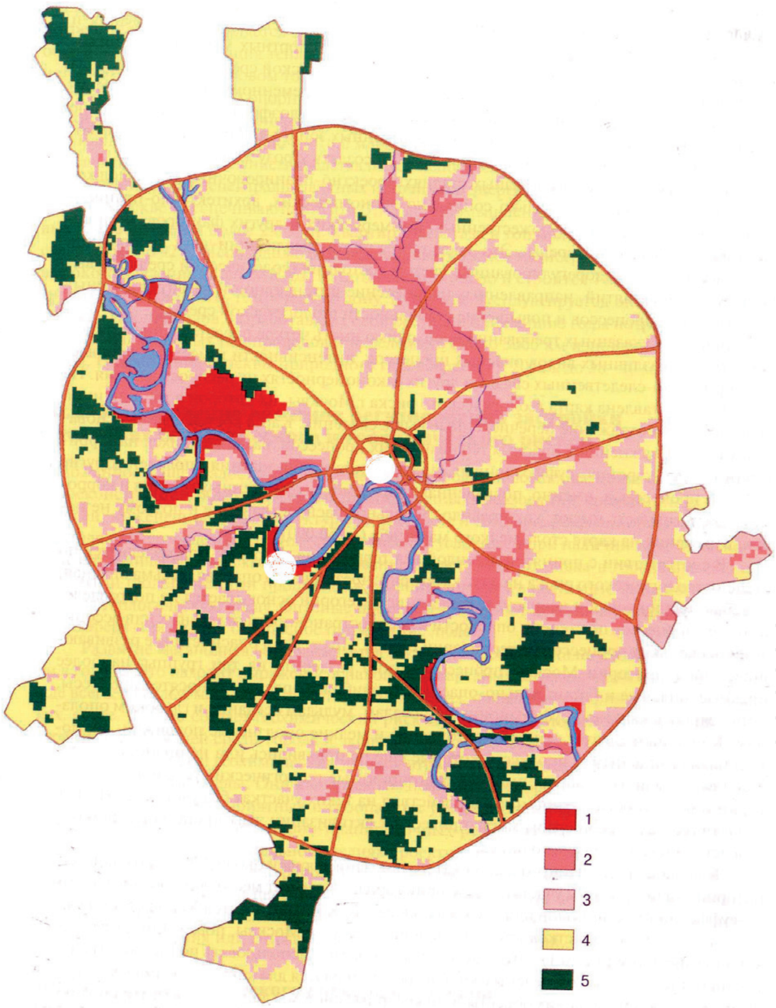

Figure 10. Map of geological danger in Moscow. Landslides, karst, underflooding (Osipov et al. [3]). Landslides are near rivers in semidark (red and pink); 1—very high danger, 2—high, 3—middle, 4—low, 5—no; white circles—risk “hot spots”; Kremlin Hill (center) and Vorobyovy mountains (southwest).

Figure 11. Cosmic photo of Moscow at night.

importance of the object, the density of underground utilities and others) give a great contribution to the high risk assessment.

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

As an additional fact, it is interesting to use night cosmic and aero photos of Moscow that reflect the density of communications and possible damage (**Figure 11**).

3. Monitoring organization for debris flow: a case study of Taiwan

Taiwan is located on the edge of Eurasian Sea Plate and Philippine Sea Plate. The maximum length and the average width of Taiwan is about 395 and 144 km, respectively. The total area is about 36,000 km^2. The mountains in Taiwan are high and steep, and the terrain is highly variable, as well as the elevations. (Taiwan's highest point is Yu Shan, also called Jade Mountain, which is at 3952 m). In Taiwan, the plains are narrow, which is only occupied with one-third of Taiwan. Earthquakes occur frequently in Taiwan. The rainy season in Taiwan is caused by rainfall along a persistent stationary front between spring and summer; and typhoons are influencing Taiwan mostly in the summer and autumn. The annual average rainfall is more than 2500 mm.

There is abundant rainfall in Taiwan. Variable rainfall duration and intensity lead to floods and debris flow disasters [22–30] (**Figure 12**).

Since the 1999 Chi-Chi earthquake (ML = 7.3) occurred (earthquake 921), the frequency of the disasters, which are caused by landslides, complex landslides, debris flows and soil erosion, has increased more than before.

The 921 earthquake (ML = 7.3) took place in central Taiwan on September 21, 1999. A 195-ha slopeland was devastated by a gigantic rock avalanche, called the Chiu-Fen-Erh-Shan (Chiufengershan) landslide, near the Nankang village of Kouhsing in Nantou County during the earthquake; the slid materials blocked the confluence of two streams leading to the formation of two landslide dams (**Figures 13** and **14**).

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Figure 12. Landslide after rain in 2010, Taiwan.

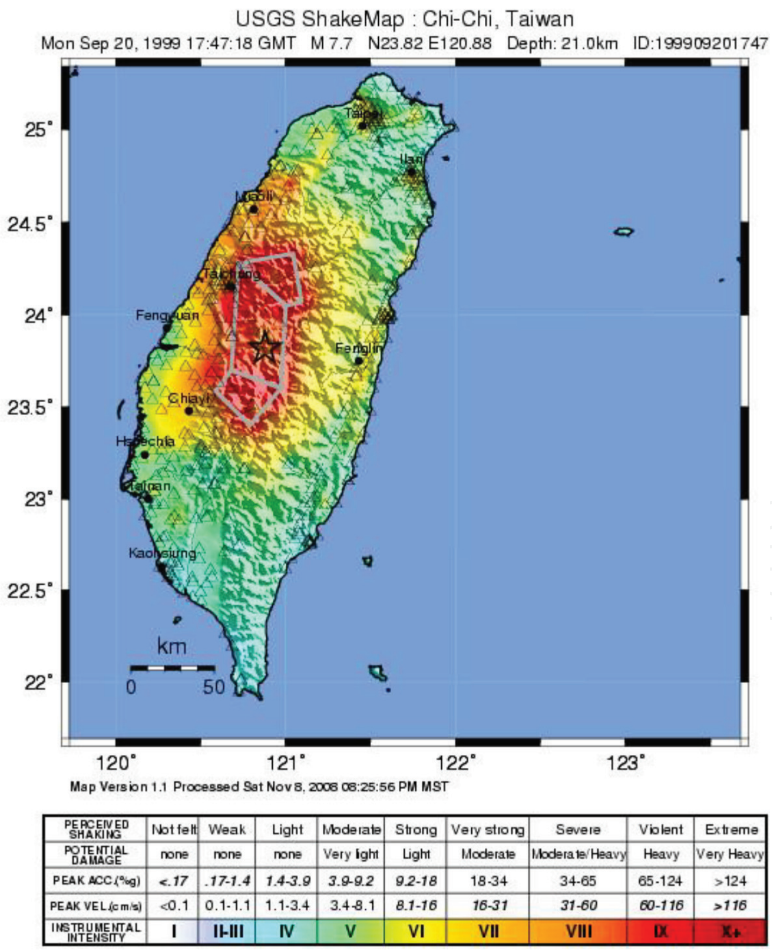

Figure 13. USGS ShakeMap for the 921 earthquake.

Further monitoring and hydrology studies on landslide area became necessary for landslide management. Thus, a project for monitoring the Chiu-Fen-Erh-Shan landslide began in 2003. It includes:

1. landslide dams water-level monitoring;

2. post-failure behavior simulation;

Figure 14. Chiufengershan landslide after 921 earthquake in Taiwan.

Figure 15. The equipment at the Fengqiu Debris Flow Monitoring Station include one rain gauge, two CCD cameras, two geophones, four wire sensors and one water-level meter.

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3. morphological fluctuation using light detection and ranging (LiDAR); and
4. long-term monitoring using photogrammetry images.

Figure 16. The equipment at the Shang'an Debris Flow Monitoring Sstation includes one rain gauge, one CCD camera, one geophone, two wire sensors and one water-level meter.

Figure 17. The equipment at the Songhe Debris Flow Monitoring Station includes one rain gauge, two CCD cameras, two geophones and eight wire sensors.

The post-failure behavior and impact area of Chiu-Fen-Erh-Shan slope along the inferred sliding surface were investigated by using the method of discontinuous deformation analysis (DDA).

In order to prevent life and economic losses due to landslide, complex landslide, debris flows and soil erosion, the Soil and Water Conservation Bureau (SWCB) has aimed at debris flow disaster management and early warning operations and begun the construction of debris flow monitoring station and Formosa Emergency Management Action System (FEMA) since 2000. Satellite imagery, geographic information, high-end communications and sophisticated monitoring technologies have been implemented and integrated in the system. (**Figures 15–17**). SWCB is keen on the international exchanges for debris flow disaster prevention.

4. Engineering and technical methods: debris flow management

4.1. Source management

To reduce the amount of sediment material, source management is very important. Different engineering methods are utilized according to the terrain and its recent history.

Large amounts of water is one of the main factors that cause debris flows, so excess water must be eliminated to the fullest extent possible. This can be done using inbuilt drainage pipes in stream beds or in slopes to divert groundwater.

Runoff with a thick deposition layer can easily induce debris flow. Often, rocks are set in stream beds to capture sediment from the water and prevent further sediment from being lifted, reducing the risk of debris flows.

Cleaning unstable depositions in and around streams such as rocks and logs as well as overhanging braches prevents the obstruction of a debris flow, which can cause the debris to build up and then burst, creating a more dangerous situation.

4.2. Transportation stage management

Engineering and re-vegetation can lower the velocity of debris during the transportation stage of debris flow, and thus to reduce the damage caused by debris flow.

The velocity of debris flow is closely related to the slope degree. In order to lower the velocity, check dams or submerged dams are used to increase the roughness of the streambed. This allows accumulation of sediments, making the slope gentler, decreasing the velocity of debris flow.

Debris flows contain a lot of water that allows it to move fluidly. If the water and sediments are separated, the debris flow will slow down. Check dams can reduce the velocity of debris flow while horizontal grates allow sediment and water to be separated, stopping the debris flow (**Figure 18**).

Figure 18. The debris flow dehydration.

In order to prevent the accumulation of debris in valleys, check dam are used to accumulate sediments more efficiently.

4.3. Deposition stage management

When the debris flow comes to flat areas, the accumulation of sediments often causes riverbed siltation, elevating the riverbed. It is necessary to dispose of this sediment effectively.

The velocity of debris flow will slow when it reaches a gentler slope. Check dams are set in broad, flat terrain to form deposition areas, adjusting the slope and stabilizing the streambed.

Using debris or concrete cofferdams to form deposition areas allows safe debris accumulation. They are often located on flat, broad areas such as alluvial fans, usually about 30–40 m wide and located close to valleys.

Setting forest buffer zones in outlets help stop debris flow and contribute to debris accumulation.

If the outlet is not wide enough for debris flow accumulation, diversion dams or artificial channels are used to lead debris flow to a safer place to discharge.

5. Conclusions

Risk management is an important way to risk reduction. The main aspects of landslides risk management could be considered as landslides risk assessment and mapping, landslides monitoring and engineering methods for slope strengthen, water discharge and rational land use.

The problems of risk assessment, monitoring and engineering methods for risk reduction as parts of risk management concept are considered and analyzed.

Methodology for landslide risk assessment and mapping at urban areas is elaborated. The construction of landslide risk map in the territory of Moscow is suggested. Engineering-technical methods for landslide risk reduction are considered for Taiwan landslide areas.

The case studies for Moscow and Taiwan are presented.

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