INFLUENCES OF NATURAL AND MAN - MADE HAZARDS ON ROAD NETWORK AND ELEMENTS OF RISK MANAGEMENT STRATEGY

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Natural and man-made hazards are causing in average yearly damage of more than 40 billion US dollars worldwide. Among them, landslides and floods are the most frequent. In order to improve management of such hazards, many studies focus on the different topics related to qualitative and quantitative flood and landslide risk assessment from global to national scales.

With aim to underline again the importance of these hazards for Macedonian road infrastructure, here we are presenting some analyses, connected with influences of floods and landslides to the Macedonian trunk road network. The analyses are mainly based on own experiences for several case histories in the country. Authors believe that these findings can help in improvement of legislative in line with the flood and landslide risk management strategies to be developed on national scale.

Keywords: Floods, landslides, road infrastructure, risk management, legislation

1. INTRODUCTION

It is well known that the conditions for rational and successful design of infrastructure facilities, as well as their exploitation and maintenance, are highly dependent on the impacts of different geohazards. Among them, the most significant are the impacts of landslides and floods, as they annually cause damages in the amount of over $ 40 billion or an equivalent of over 40,000 human lives [1].

Such phenomena, as elsewhere, are also of great importance to our country. Moreover, due to the complex geological-tectonic, geomorphologic, climatic and other conditions, parts of the territory of the Republic of Macedonia belong into the category of terrains with natural predispositions for development of instabilities. So far, there have been a number of floods and over 300 landslides that have directly or indirectly endangered the infrastructure. Variety of damages were caused: disruption of road and railway traffic, damage to and demolition of individual and collective residential buildings, damage and interruptions to water, utility, gas, telecommunication and electrical installations, destruction of natural terrain and agricultural arable land, endangering entire settlements etc. In some cases, even human lives were lost.

It is characteristic that at present, directly or indirectly, to a certain degree of risk are exposed more and more routes from the national road network, with frequent traffic interruptions and redirections. In our country, the economic losses from these adverse events are measured in tens of millions of Euros annually. Due to urgency, in such cases, additional costs may arise due to the necessity for urgent design and execution of extensive remedial measures, such as retaining structures, anchor structures, installation of protective meshes, drainage systems and other remediation measures. The constant and necessary monitoring of these unstable phenomena also entails "permanent" costs.

In this context, beside presentation of the impacts of these hazards on infrastructure, one of the aims of this paper is to provide guidance on addressing these aspects with specific proposals for improving the legislation and developing a floods and landslides risk management strategy on national level.

2. OVERVIEW OF ACHIEVEMENTS IN THE FIELD OF IMPACT OF NATURAL AND MAN-MADE HAZARDS ON INFRASTRUCTURE

Considering the importance of this problem, a large number of papers, designs, conferences and more have been prepared on worldwide and national level. Specifically, for the issues addressed in this paper, of great importance are the papers dealing with classification and definition of landslide types, laboratory and field investigations of rock and soil materials, methods for stability assessment, impacts of groundwater and earthquakes on the occurrence of instabilities, methods for formation of landslides cadastre, methods for vulnerability, hazard and risk mapping, methods of mathematical statistics, various analytical and numerical procedures, etc. Details can be found in Peshevski, 2015 [12].

Therefore, in this paper will be mentioned some of the more important papers.

For example, there are over 200 different landslides classifications, but the actual ones in worldwide use are those of Varnes D.J. (1978); IAEG (1990); Cruden D.M. (1991), Hungr O. et al. (2014) and others [12]. The concepts for determining the stability of the slopes and the measures for their stabilization have been elaborated at different times and by different authors, Fellenius W. (1927), (1936); Taylor D.W. (1937); Janbu N. (1954), (1968), (1973); Bishop A.W. & Morgernstern N.R. (1960); Morgerstern N.R. & Price V.E. (1965); Spencer E. (1967); Skempton A.W. & Hutchinson, J.N. (1969); Corps of Engineers (1970), (1982); Chowdhury R.N. & Xu, D.W. (1994); Bishop A.W., (1955). Methodologies for stability assessment of slopes build of solid rock masses have been developed by Hoek E. Bray J.W., & Boyd J.M. (1973); Sarma S.K. & Bhave M.V. (1974); Hoek E. & Bray J. (1977), Goodman E. (1976), (1980). Formation of databases and statistical analysis of landslides have been developed by Malamud et al. (2004); Guzzetti F. et al. (2012); Eeckhaut M.V.D & Hervas H. [12]. At the moment, for preparation of maps and cadastres for instabilities, the most actual are the data by Eeckhaut M.V.D & Hervas H. (2012); Guzzetti F. et al. (2012) [12]. In terms of landslide hazard and risk assessment and zoning, the papers by Varnes D.J. (1984); Westen Van C.J. (2004); Cascini L. et al. (2005); AGS (2007); Fell R. et al. (2008); Gokceoglu, C., & Sezer, E., (2009), and others [2], are considered especially important.

It is important to be mentioned that scientific and expert meetings on this topic are regularly organized worldwide, such as World Landslide Forums (2008, 2011, 2014 and 2017), regional symposia and workshops being organized by the International Consortium for Landslides-ICL.

Here, in the past, several methodologies and procedures dealing with some of these aspects have been developed. The first landslide database was established at the time of the Former Yugoslav Federation in 1960-1970. During this period, the Basic Geological Map of the Republic of Macedonia (BGM) was prepared in scale of 1:100000 and all observed landslides were applied on it. In the period 1990-2012 several landslide data collection programs have been developed, which have been relatively successful. There are also numerous significant papers related to this topic in Macedonia. Details can be found in the references [8], [9], [10], [11] and [12].

The following projects are important on internationaland national level [1], [2], [3], [4], [5], [6], [7] and [8]:

- SafeLand
- Horizon 2020 Transport Advisory Group – TAG;
- FEHRL Vision 2025 for Road Transport in Europe;
- Sendai Framework for Disaster Risk Reduction (2015-2030);
- UNDP- implemented EU Recovery Program to support Macedonia recovery efforts after 2015-floods;
- European Union Program for overcoming the consequences of floods, reconstruction and rehabilitation of transport and water supply infrastructure after the floods in 2015;
- Technical assistance for designing of climate resistant constructions, Manual for the needs of Public Enterprise for State Roads in Macedonia (2019) and others.

Particularly noteworthy is the SafeLand international research project (FP7) supported by the European Commission that was implemented in the period 2009-2012. The project involved 27 institutions from 13 European countries and was coordinated by the Norwegian Geotechnical Institute (NGI). Another important project also funded by the European Commission and JRC is INSPIRE (Infrastructure for Spatial Information in Europe) launched in May 2007, where a special thematic working group on natural risk zoning has been set up. This group considers the landslides as a natural hazard and gives recommendations for further activities in this field to EU Member States [2].

In this context, and bearing in mind the significance of this problem, this paper presents some examples of drastic impacts of floods and landslides on Macedonian roads [9], [10], [11], [12]. The analyzes are presented mainly on the basis of the authors' experiences, and are in context of the recommendations of the Study concerning the construction of so-called "climate" resistant structures. This Study is prepared for the needs of the Public Enterprise for State Roads - PESR [8]. One of the goals of this study, among other things, is to integrate the data on landslides, floods and other hazards into the so-called system RAMS (Road Asset Management System) introduced for the purposes of road management under the authority of PESR.Another purpose of the Study is to provide comprehensive recommendations to all involved in the design of road infrastructure in our country, to take them into account in the projects and the expected effects of climate changes.

It is worth to mention a few significant conferences specifically devoted to the problem of the influence of natural and man-made hazards. Here are just a few examples: 16th European Danube Geotechnical Conference: "Geotechnical Hazard and Risks, Experiences and Practices" held in the Republic of Macedonia in June 2018 [1], "Seventh International Conference on Debris-Flow Hazards Mitigation" in Golden, Colorado 2019, ResyLab 4 - Sarajevo 2019 and many more.

3. BASICS OF METHODOLOGIES FOR HAZARD AND RISK ASSESSMENT OF NATURAL AND MAN-MADE HAZARDS ON THE INFRASTRUCTURE

In the world practice, it is generally known that any analysis dealing with natural and man-made hazards should be based on an analysis of susceptibility, hazard and definition of the risk of their occurrence.

Landslide susceptibility zoning covers the classification, size (volume) and spatial distribution of existing and potential landslides in one area. Susceptibility zoning usually involves the formation of cadastre of landslides that have occurred in the past, together with an assessment of areas with potential for future landslides, but without estimating the frequency (annual probability) of landslides occurrence.

Landslide hazard zoning can be performed by taking into account the results of the susceptibility mapping and estimating the frequency of the potential landslides. It should consider all the landslides that may affect the analyzed area, including the landslides above that can reach the area, and landslides below it that can move regressively (retrograde) therein.

Landslide risk zoning can be done by taking into account the results of hazard mapping, assessing the potential for harm to people (annual probability of loss of life), to property (annual value of lost property), and aspects of endangering the environment.

In order to generally illustrate the core of the preceding paragraphs, the following figures show some recent cartographic examples for definition of landslide susceptibility, hazards and risks, also prepared for the needs of PESR. Some of these maps have been adapted for different rainfall scenarios according to some forecasts of climate scenarios developed worldwide [8], and are based on the knowledge gathered trough the landslide database from the past 50 years. In general the following analysis sequence is applied *(Figure 1):*

1. Defining the landslide susceptibility
2. Defining the basic level of hazard
3. Defining design hazard for a certain period.

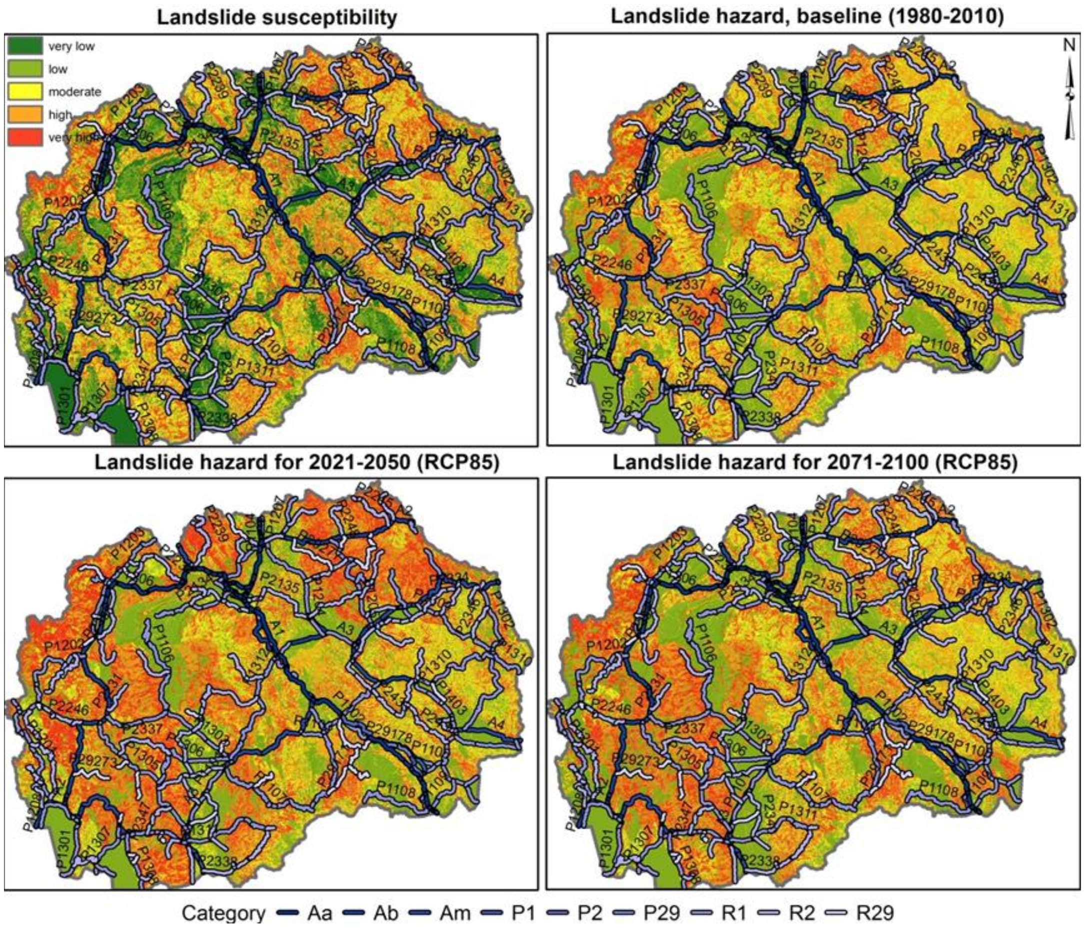

Figure 1. Presentation of models for defining landslide susceptibility and hazard of the Macedonian road infrastructure for certain periods [8]

The essence of preparing such models for forecast of the landslide hazard (LH) is, besides the impacts of lithological settings (L), slope inclination (S), land cover (LC) and earthquake impact (E), to define also the effect of the rainfalls (R) by changing their influence based on certain climate scenarios and introducing a rainfall impact factor (RF). This factor is normalized to a value of 0 - 1. For certain scenarios for the periods 2021-2050 and 2071-2100, using the worst case scenario for RCP85 emissions, the following formulas are obtained:

LH = 0.3 x L + 0.175 x (S + LC + E_100 years return period + R) (1)

For rainfalls scenarios the following factors are adopted: RF1 = 90th percentiles of rain x expected annual amount for 2021-2050 and RF2 = 90th percentiles of rain x expected annual amount for 2071-2100. Thus, the prognosis of the landslide hazard is based on the following formulas:

LH1 = 0.3 x L + 0.175 x (S + LC + E_100+ (1+RF1) * R) (2)

LH2 = 0.3 x L + 0.175 x (S + LC + E_100 + (1+RF2) * R) (3)

An example of prognosis of the hazard, vulnerability and risks of the roads in Polog region is shown in Figure 2.

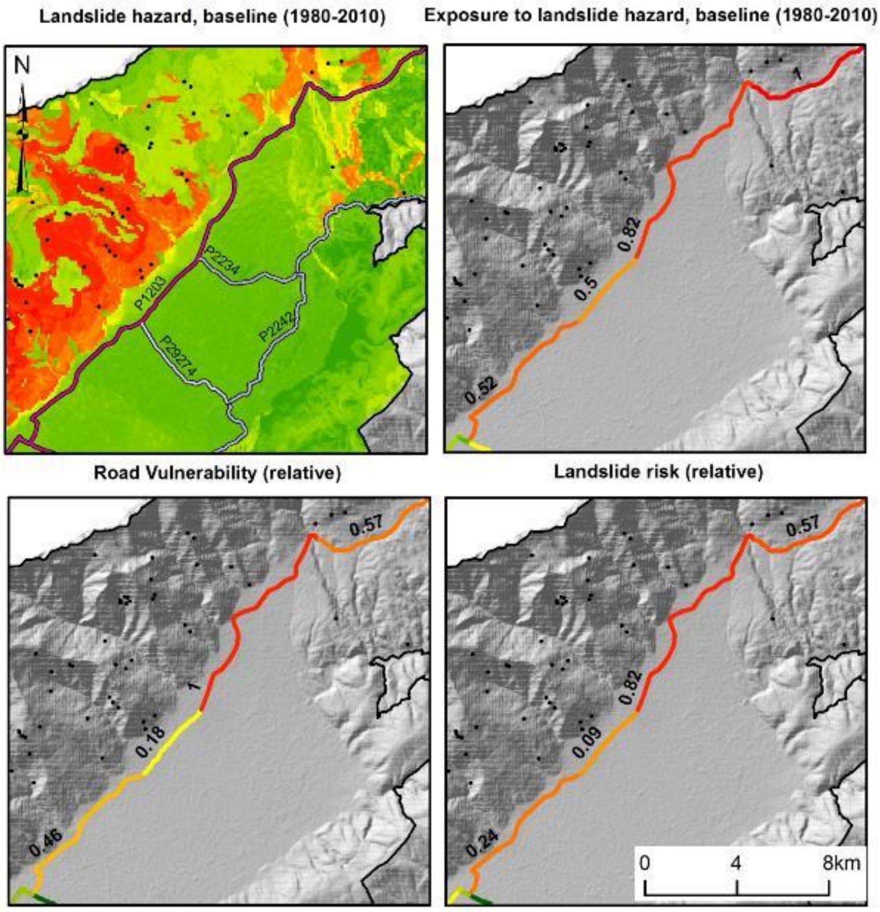

Figure 2. Presentation of models for defining landslide susceptibility and hazard, vulnerability of the road and landslide risk of the road infrastructure in Polog region for certain periods [8

Of course, these models can be subject to discussion and eventual changes, as some of the input factors are not fully predictable, but they can certainly be helpful in defining the current state of the infrastructure and certain forecasts that will help to manage the risks in the future. Successful realization of this aspect of course requires a general state management strategy.

4. SOME EXAMPLES FOR DAMAGE OF THE INFRASTRUCTURE

Every year, the landslides and floods in the Republic of Macedonia cause losses that are measured in millions of Euros. Most of these funds are usually spent on rehabilitation and cleaning of roads and railways. This is confirmed by the fact that 60% of the registered landslides have obstructed or blocked the traffic on the highways, regional and local roads. In order to get impression where the largest number of landslides is registered in our country, Figure 3 shows a cadastral map of unstable phenomena.

Statistics show that about 70% of the landslides are triggered by the effects of intense or prolonged rainfalls, which in turn are the cause of floods.

The usual period for floods in the country is November – January, and they are caused by the outflow of the major rivers Vardar, Crna Reka, Treska, Strumica and Bregalnica. To illustrate some of the effects, it will be mentioned that the floods in 2004 affected 26 municipalities with an estimated damage of about 15 million Euros. The floods in January and February 2015 affected 43 of 80 municipalities in the Republic of Macedonia (Mogila, Zrnovci, Petrovec, Novaci, Bosilevo, Demir Kapija, Strumica, Vinica, Radovish, Bitola). This has caused enormous damages to roads, bridges, culverts, irrigation canals and systems, industrial facilities, schools and individual dwellings. The floods in August 3, 2015, and the landslides triggered by them, caused the loss of 6 people and a lot of damage to the municipal and state infrastructure in the north western region Polog. The total estimated damage from these floods is 21.5 million Euros. The occurrence of

intense rainfall in the night between August 6 and August 7, 2016 is very indicative, as a result of which the Northern bypass of the city of Skopje was affected, with a tragic loss of 23 human lives and an estimated damage of over 30 million Euros. According to official data from the Hydro Meteorological Institute, rainfall of 92.9 mm/m^2 fell during a few hours, which is considered as an event with a return period of 1000 years.

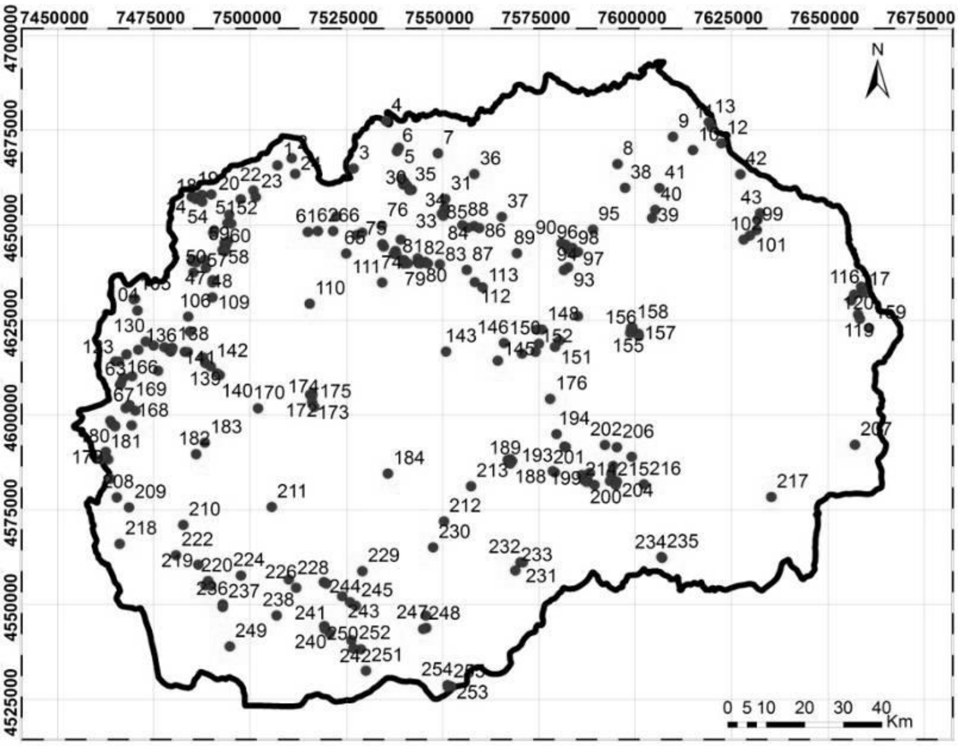

Figure 3. Cadastre of occurred landslides on the territory of R. Macedonia, for the period 1970-2015 [12]

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Having in mind these numbers, according to data from the Centre for Research on the Epidemiology of Disasters (CRED), between 2015 and 2016, Macedonia is among the 10 countries most affected by the impacts of floods and landslides. For example, according to the economic damages suffered or the mortality, our country ranks 6th in 2016 (1.06/100,000) by mortality, then 3rd in 2016 (0.55% of GDP) and 8th in 2015 (0.85% of GDP) according to occurred damage.

An illustration of the damage caused by landslides and floods is given in the following figures (Figure 4). The figures are undertaken from the authors' personal archive, colleagues in the profession and daily newspapers.

A) Rockfall on the road Istibanja – Makedonska Kamenica (2015 year)

B) Mudflow on the road Tetovo - Jazince triggered by flash flood of Poroj river (2017 year)

C) Landslide on national road Bitola-Resen (2010 year)

D) Total deformation of the pavement of the northern bypass of the city of Skopje, due to the flood in 2016

E) Snow and debris avalanche on the road Mavrovo-Debar (2010 year)

F) Rockfall on the road Kochani-Shtip (2013 year)

G) Landslide on the road Resen – Greece Border, place Markova Noga, in 2017

H) Rockfall on the road Veles-Gradsko in 2013

Figure 4. Some examples of impacts from occurred landslides, rock falls and floods on the road infrastructure [most examples are from authors' archive]

In order to see the value of the costs to be spent on remediation of some of the cases shown, Table 1 shows some data by design bill of quantities or by already finalized remediation.

Table 1. Some examples for remediation costs for landslides and rockfalls (reference – design documentation)

Location	Costs for remediation (EUR)
Road R-2433, Resen – Greece Border, place Markova noga	1.700.000,00
Veles, road R-1102, km 49+300	894.000,00
Kratovo, road R-1205, km 18+125	305.000,00
Kratovo, road R-1205, km 18+165	850.000,00
Road for the ski center Kozuv R-1105, seven landslides	3.500.000,00
Bitola bypass	600.000,00

All this is a sufficient alarm, in the near future, to adopt a certain integrated Hazard and Risk Management Strategy for the environment, in order to prevent a great part of the problems and not to act after the disaster.

5. BASIC ELEMENTS IN THE RISK MANAGEMENT STRATEGY

It should be noted that there is no unique procedure in the world capable of estimating the land-sliding potential for each individual type of landslide and the expected displacement of the material, but the risk management scheme shown in Figure 5is considered suitable.

The particular steps in the risk management scheme should be all performed consistently, in order to achieve the final goal. As it can be seen from the figure 5 the risk management strategies predict continuous monitoring, review of input data and drawing conclusions for future studies. The process of landslide hazard and risk assessment is therefore repetitive, with average period of repetition (in developed countries) from 5 to 10 years.

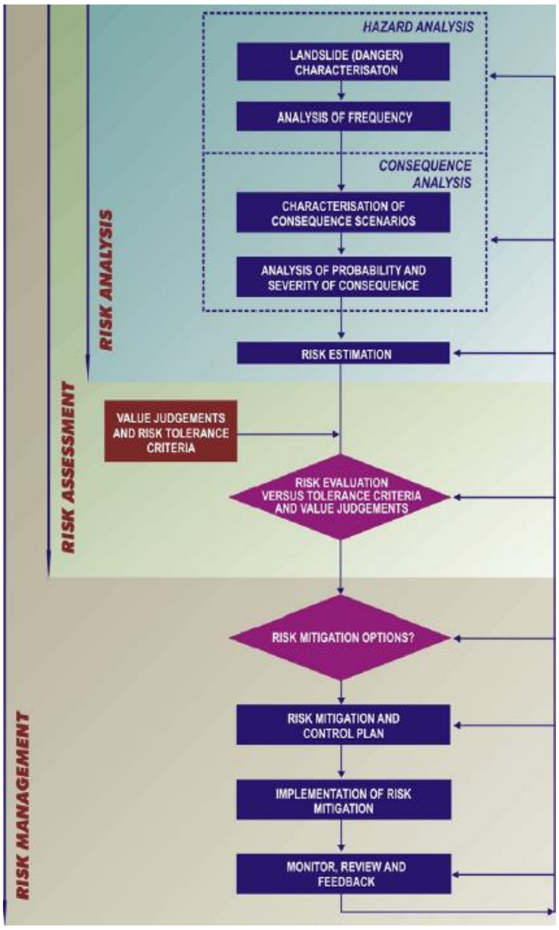

Figure 5. General scheme for landslide risk management according to Fell R. et al. Engineering Geology, vol. 102, (12)

The quality of the input data for landslide hazard and risk assessment is essential to the reliability of the results. Quality data enables the preparation of precise hazard and risk models, which is the basis for making the right decisions in terms of spatial planning and development of the country's infrastructure. Figure 6 below shows the general structure of the proposed national body for landslides where specific teams will work on various aspects related to landslides, such as: teams for technical documentation collection, teams for field mapping and investigation, teams for data bank preparation and maintenance and teams for preparation of landslide hazard and risk maps.

The ultimate goal of all activities of this body (institution) is: to propose appropriate construction methods depending on the landslide susceptibility of a certain area, to propose protection and remediation measures in endangered areas, cooperation with the Ministry of Environment and Physical Planning and Ministry of Transport and Communications. All these aspects contribute for proper development of the infrastructure, both at regional and local level. This set-up also requires a quite number of changes to the legislation, in particular the Law on Construction and the Law on Public Procurement, where the natural disaster management is scarce, and legislation itself in such cases is often a limiting factor in overcoming the consequences, if any challenge appears.

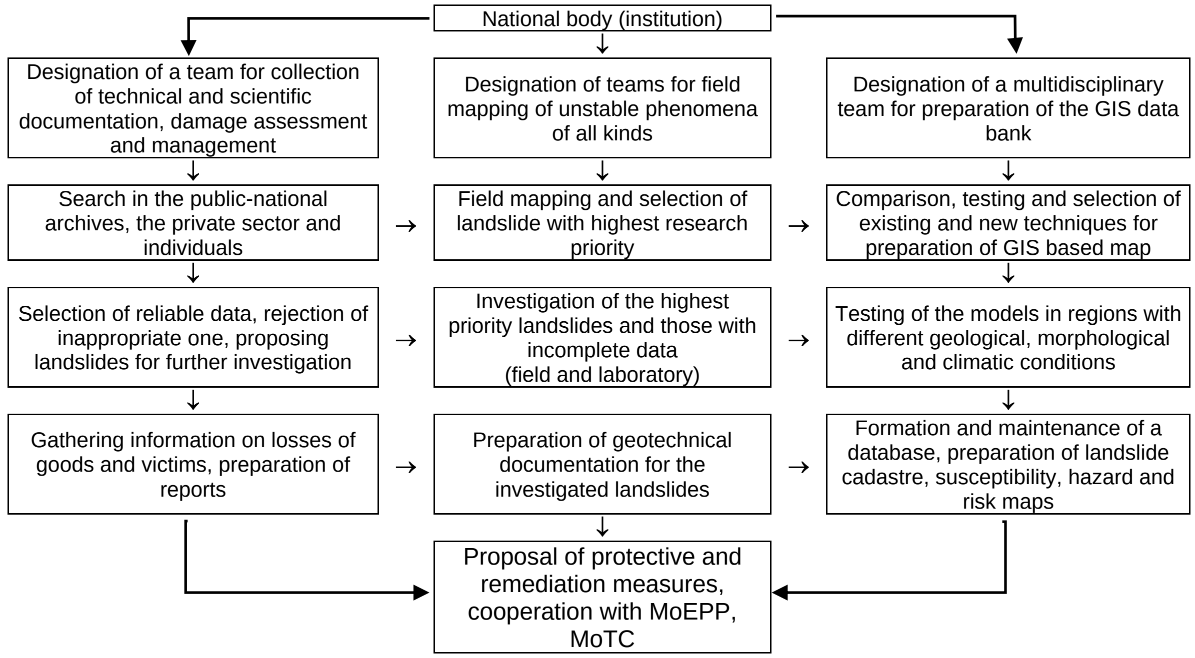

Figure 6. Strategic plan for establishing a landslide database in the Republic of Macedonia

6. CONCLUSION

From the realized work and all the conducted analyses, it is clear that there are many activities in this scientific and practical field that have yet to be planned and implemented. Here the priority steps would be: adapting the legislation in line with the positive experiences from around the world to enable it to deal successfully with the risks from the natural and man-made hazards; defining the developer and holder of the proposed GIS database, selection of appropriate landslide susceptibility/hazard and risk assessment methods following the example of the latest study prepared for the necessities of PESR, preparation of hazard and risk zone maps and their inclusion in the legislation on construction and environmental protection, preparation of recommendations for citizens and construction companies on how to reduce the vulnerability of already constructed structures in areas of high flood and landslide hazard, defining areas that restrict or prohibit the construction of buildings of different categories and more. All of these activities can be performed at national level, or for certain priority regions. Since landslides and floods are considered as main hazards to roads in the country, the hazard/risk management strategy should be focused around them.

For the realization of the proposed activities, it is necessary to involve more experts from the fields of geology, geotechnics, climatology, hydrology, agriculture and forestry, spatial planning etc., but above all, state assistance and coordination of a number of institutions that in one way or another have points in common with these problems.

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