APPROACHES TO A MULTI-HAZARD RISK ANALYSIS FOR SELECTED NATURAL AND TECHNOLOGICAL HAZARDS

Róbert Jelínek[1] - Maureen Wood[1] - Peter Pauditš[2]

SUMMARY

This paper briefly summarises the findings from the Joint Research Centre survey on general practices for mapping in eleven (11) new Member States: Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia for eight (8) major natural and technological hazards such as floods, forest fires, storms, landslides, earthquakes, industrial installations, transport of dangerous goods and contaminated lands. The current situation regarding overall risk mapping indicates that in the new Member States there is significant diversity and incompatibility between different mapping practices across hazards and countries, and sometimes even between regions within countries. The second part of the paper describes selected concepts of a multi-hazard and risk analysis in order to identify the most effective way of working towards harmonized or comparable map coverage across the different risk sectors.

1. INTRODUCTION

Through modern computational systems, maps of areas at risk from different hazards become valuable information and communication tools. They are useful in variety of purposes ranging from identifying affected areas at risk, land use planning or crisis event management for a preparation of emergency response plans. However, as pointed by [1] the existence of variety maps developed by different approaches can result in significant differences in outcome for the same situation when considered separately by different practitioners. Likewise, some of the natural hazards, such as floods, earthquakes, forest fires or windstorms can have cross-border implications. Therefore having a common or harmonised mapping standard at least in the European level is highly appreciated and clearly required.

In 2003 the Joint Research Centre performed a survey in eleven (11) new Member States: Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia to examine the existing mapping situation for selected natural and technological hazards such as earthquakes, industrial installations, landslides, transport of dangerous goods, floods, contaminated lands, storms, pipelines, forest fires and oil-shale mining. The overall results of the survey responses are summarized in [2]. While the results con-

[1] Róbert Jelínek & Maureen Wood, European Commission Joint Research Centre, Institute for the Protection and the Security of the Citizen, Traceability, Risk and Vulnerability Assessment, Via E. Fermi 1, 210 20 Ispra, Italy
[2] Peter Pauditš, State Geological Institute of Dionyz Stur, Mlynská dolina 1, 817 04 Bratislava 11, Slovakia

cerning selected priority hazards such as floods, landslides, earthquakes and industrial hazards are outlined in separate reports [3], [4], [5] and [6], respectively. One of the interesting finding of the survey was a strong interest in risk mapping, and most probably multi-hazard risk mapping, although such new techniques are generally not yet being implemented in these countries. This situation implies an opportunity for collaboration on methodology development and potentially harmonized implementation through a pilot project. The pilot project mainly focuses on the multi-hazard and risk assessment of selected hazards, on the basis of different experiences carried out in selected European sites such as the North Bulgarian Black sea cost, the area between Hlohovec and Sereď in Slovakia and the Frýdek-Místek county area in the Czech Republic. The topic regarding the particular pilot sites is beyond the scope of this paper. The emphasis is on methodological approaches to a multi-hazard and risk.

Modern approaches of risk assessment are based on three equal parts: risk analysis, risk evaluation and risk management. Within this study, only the risk analysis is considered. Traditionally the risk analyses have been carried out separately for a specific natural process such as floods, landslides, earthquakes or man-made events. Recognizing that there are often several interpretations for common terms associated with hazards, risks and mapping practices, the following definitions were included to facilitate a common understanding of these terms.

The term “risk” is still confused by the term “hazard” by many scientists. The hazard is defined as the probability of occurrence of a potentially damaging phenomenon within a specified period of time, within a given area and a given magnitude. The distribution of hazards in a particular country or region can be measured and expressed in a map in a number of different ways and using different representation techniques. In this paper, the term “hazard map” is used in a broad non-technical sense meaning for all kinds of maps illustrating the probability or location of a specific hazardous event. The risk is defined as the product of the frequency/probability with which a hazardous event occurs, and the consequence of that event. In case of natural hazards, this traditional concept of risk is extended to new components, such as vulnerability and natural hazard phenomena. Estimating risk is an uncertain science because it involves forecasting future events whose time and location of occurrence may be largely unknown. Therefore this uncertainty is mathematically captured in terms of probability. The risk map is a map that portrays levels of risk across a geographic area. The vulnerability means the degree of loss to a given element or set of elements at risk resulting from a occurrence of a natural phenomenon of a given magnitude. It can be expressed on a scale from 0 (no damage) to 1 (total loss).

A relationship between the three basic components of risk can be explained in a form of a triangle, as shown in Figure 1. The total risk may be decreased by reducing the size of any one or more of the three contributing variables such as the hazard, the elements exposed and/or their vulnerability. And the following general expression can be used to define risk:

Risk = Hazard x Vulnerability x Elements at Risk (Exposure)

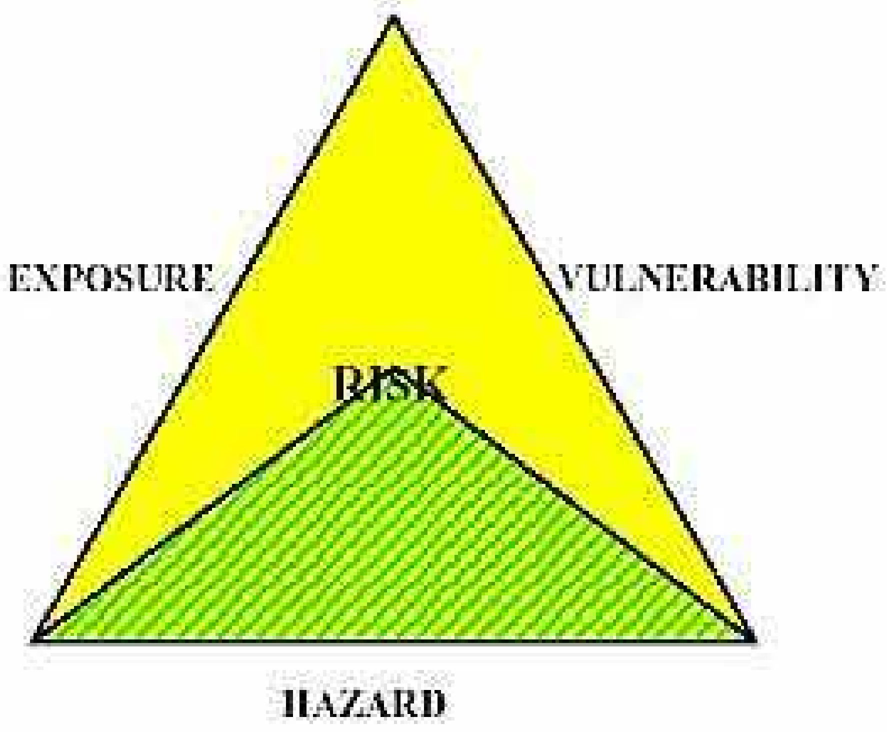

Figure 1: Risk, hazard, exposure and vulnerability relationship according to the Geo-science Australia

2. GENERAL RESULTS OF THE JRC RISK MAPPING SURVEY

The questionnaire [7] encompassed nine separate sections: eight sections devoted to a particular section and one section on general hazard and risk mapping practices. Each of the eight sections focusing on a particular hazard, was constructed in a similar manner. In essence, the questionnaire aimed to identify state-of-the-art mapping practices, priorities, and similarities and differences in mapping practices for each hazard. The data identity and availability based on the questionnaire encompassing more than 35 questions grouped into six categories: hazard maps, hazard data, elements at risk to the hazard, vulnerability maps and risk maps. Questions within sections were then individualized for each type of hazard.

To obtain knowledge about the availability of existing hazard, vulnerability and risk maps in each surveyed country, Table 1 (on the next page) was prepared. The questionnaire results indicate that a variety of hazard maps exist in all of the surveyed countries:

- Flood hazard maps usually portray potentially or frequently inundated areas.
- Only two countries indicated having sufficient information to define a national map locating the presence of hazards associated with transportation of dangerous goods.
- A majority of the countries have official hazard maps that cover industrial installations, or at least have inventory maps of hazardous installations in the SPIRS database.
- Seven countries noted having sufficient information for defining a national forest fire hazard map.

- Two countries indicated having sufficient information for defining a national contaminated land hazard map.
- Storm hazard maps are currently not available in any of the surveyed countries.
- Two types of earthquake hazard maps, intensity maps and acceleration maps, are available in the surveyed countries.
- Landslide hazards maps are usually represented by landslide inventory maps.

Only a few countries have begun significant work relating to vulnerability and that, by and large, most remain open to looking at different approaches and methodologies. Most notably, vulnerability maps are not common in the surveyed countries. Moreover, there are only a few examples of vulnerability assessments available, specifically for floods (in one country only) and landslides (in two countries). However, three countries indicated that they have an official classification system identifying types of objects considered potentially vulnerable to transport of dangerous goods and contaminated lands. As part of this question, respondents were also asked to indicate how various categories of typically vulnerable objects are prioritized for risk management in their countries. Humans as individuals, humans as social targets and infrastructures are generally the most vulnerable elements at risk related to all surveyed natural and technological hazards. The other elements are ecology and natural resources.

Risk maps are currently available only for industrial installations (four countries). However, the majority of the respondents expressed their intention to create risk maps within the next few years for various hazards. Even so, there are limited numbers of methodologies developed for natural hazard and risk mapping at European level. Therefore, not surprisingly, responses indicated that any assistance or collaborative work in this area would be helpful.

Table 1: Basic characteristics of hazard, vulnerability and risk maps between countries and across hazards

Hazards (# of Countries Responding)	**Hazard Maps**	**Vulnerability and Elements at Risk**	**Risk Maps**
Floods (10 countries)	4 countries have official flood hazard maps 1 country has maps of the flood plain areas 2 countries have flood maps connected with dams	1 country has official flood vulnerability maps Humans as individuals and humans as social targets were cited as the most vulnerable elements	None of the surveyed countries have flood risk maps
Transport of Dangerous Goods (9 countries)	2 countries claim to have official hazard maps for transportation of dangerous goods 2 other countries reporting having some hazard maps, but not at an official level	2 countries have an official classification system for vulnerability Ecology, humans as social targets, humans as individuals, and natural resources were cited as the most vulnerable elements	There are no risk maps for transportation of dangerous goods in any of the surveyed countries
Industrial Installations (11 countries)	7 countries have maps that cover industrial hazards	Vulnerability maps are not available, even though elements at risk and the extension of possible effects can be identified in most countries. Humans as individuals, humans as social targets, and infrastructures were cited as the most vulnerable elements	4 countries have industrial risk maps
Forest Fires (9 countries)	There are many hazard maps in the PECO countries related to forest fires. Almost all of them contain the typical parameters for describing forest fire hazards	No country has developed any kind of vulnerability map for forest fires Ecology, natural resources, and infrastructures were cited as the most vulnerable elements	No country reported having any risk maps for forest fires
Contaminated Lands (6 countries)	2 countries have official contaminated lands hazard maps 2 countries have national databases of contaminated sites	2 countries have an official vulnerability classification for assessing risk Humans as individuals, humans as social targets, infrastructure, natural resources, and ecology were the most vulnerable elements	None of the surveyed countries have risk maps of contaminated lands
Storms (8 countries)	No storm hazard maps, neither official nor unofficial, are available in the majority of the surveyed countries	None of the surveyed countries have official storm vulnerability maps Humans and infrastructure are the elements with the highest potential risk	None of the surveyed countries have storm risk maps but most of them are planning to prepare such maps in future
Earthquakes (6 countries)	5 countries have their own national hazard maps usually used for applying seismic design codes and rules in appropriate areas.	No seismic vulnerability maps are currently being developed (minor exceptions) Infrastructures and humans as individuals are cited as the elements with the highest potential vulnerability	No seismic risk maps are prepared (with some minor exceptions)
Landslides (6 countries)	4 countries have official landslide hazards maps 5 countries have landslide inventory maps of various scales	2 countries have official landslide vulnerability maps Infrastructure and ecology are cited as having the highest potential vulnerability	None of the surveyed countries have official landslide risk maps

3. METHODS FOR A MULTI-HAZARD AND RISK ANALYSIS

Methodology for identification of single risk and its components is one of the issues most studied in the literature. In recent years, variety of guidelines, standards or documents on risk management has been developed worldwide, as for example [8], [9] or [10]. The importance of this issue can be also illustrated on variety of the projects founded by the EU Framework Programmes such as ARAMIS, ARMONIA, ESPON, IMIRILAND, IRASMOS, LessLoss, TEMRAP or TIGRA. Many of the conceptual approaches for natural risk assessment have been developed or derived from existing "generic" risk management standards. A good example of this approach can be finding from Australia and New Zealand, where multi-hazard risk assessment of different natural hazards is consistent with the general risk management process outlined in AS/NZS 4030 Risk management.

Since natural hazards are not isolated events, the risk assessment should not focus on a singular process but on multiple processes. Likewise as demonstrated by [11] that separate investigations of single processes only might lead to a misjudgement of the general risks for these areas, hence a multi-hazard and risk assessment is clearly required.

A literature review on existing methodologies for the multi-hazard and risk analyses has been carried out in order to identify the most effective way of working towards harmonized or comparable map coverage across the different risk sectors. Likewise, knowing about the strengths or weaknesses of different approaches, their applicability or limitations is an important issue. The following paragraphs describe conceptual frameworks for selected multi-hazard and risk analyses only. Therefore, the individual components of risk such as the hazard, vulnerability and elements at risk are not analyzed in depth.

The National Oceanic and Atmospheric Administration (NOAA) [12] developed guidelines that illustrate various steps for assessing community risk and vulnerability including the following analyses: hazard identification, critical facilities, societal, economic, and environmental vulnerability and mitigation opportunities. The hazards identified for the analyses are prioritize based on factors such as probability, magnitude, or potential impact areas according to the scoring system developed for New Hanover County:

Total score = (Frequency + Area Impact) x Potential Damage Magnitude

The frequency, area impact, and potential damage magnitude values are defined by a scale of numbers ranging from 1 to 5, where 1=low and 5=high. Using a GIS, the seven risk consideration areas are combined and the scores are added together to create summary scores for every location in the county. These summary scores are used to develop a summary risk area map based on overlay techniques.

The multi-hazard and risk study considering snow avalanches, debris flows and rock falls carried out in the village Bíldudalur in NW-Iceland demonstrates importance of the multi approach, because this gives better overview of the investigated area and has higher significance for planning effective countermeasures than single approach [11]. As can be seen in Figure 2, at first the risk posed by each hazard is calculated than the resulted single process risk maps are combined to multi-hazard risk maps.

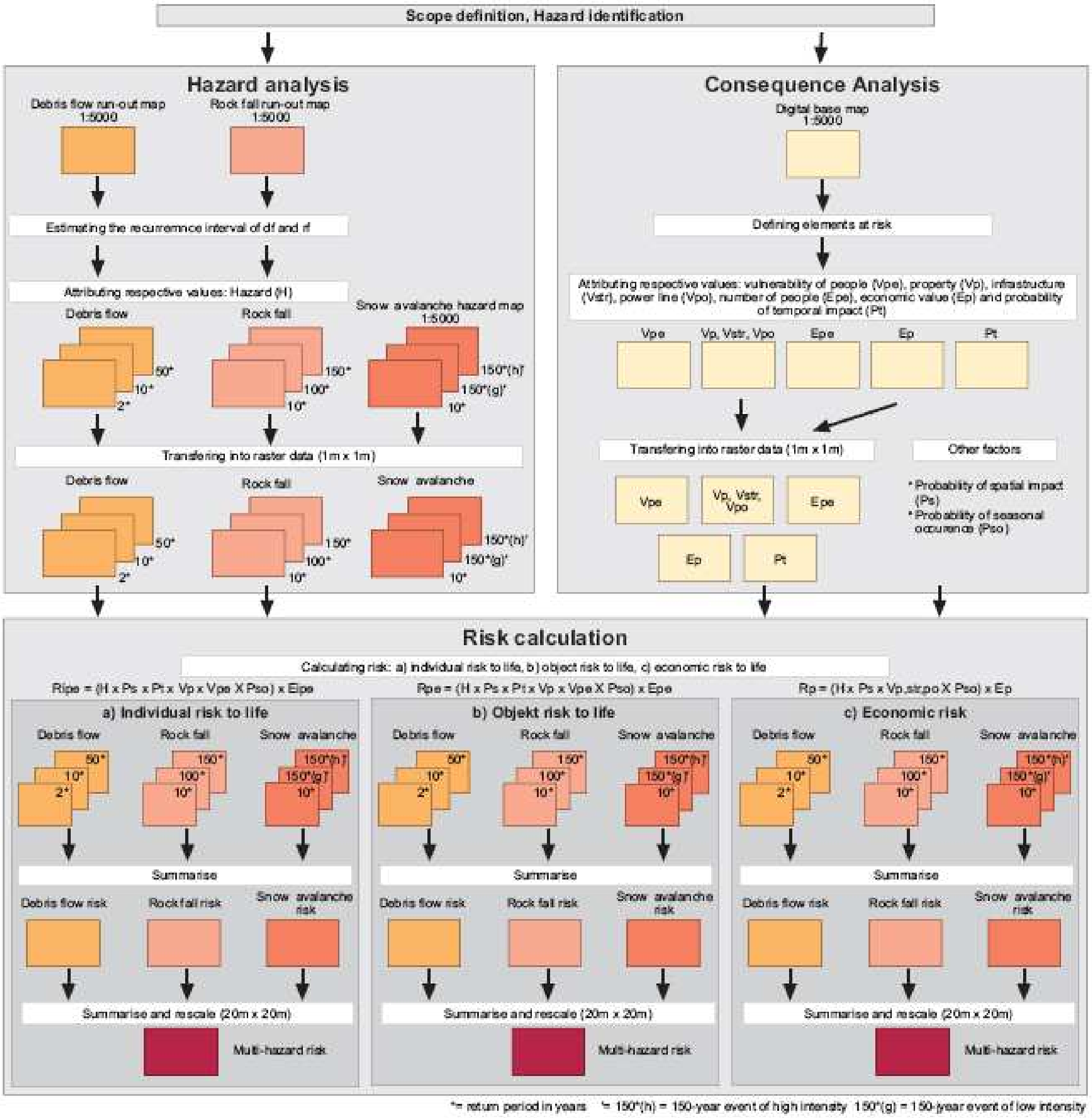

Figure 2: Methodological concept of multi-hazard analysis according to [11]

The problems of the approaches mentioned above arise when risk of several hazards with different probabilities of occurrence for the same area must be combined and therefore the simple summarizing or overlapping techniques cannot be used. As illustrated by the results of the TIGRA and TEMRAP projects, the economic indexes reporting the expected economic losses resulting from each individual procedure applied to single hazard can be used to define a multi-hazard risk assessment.

A multi-risk analysis considering storms, floods and earthquakes was performed for the city of Cologne, Germany [13]. The investigated hazards were compared by risk curves showing the exceedence probability of the estimated losses, as illustrated in Figure 3.

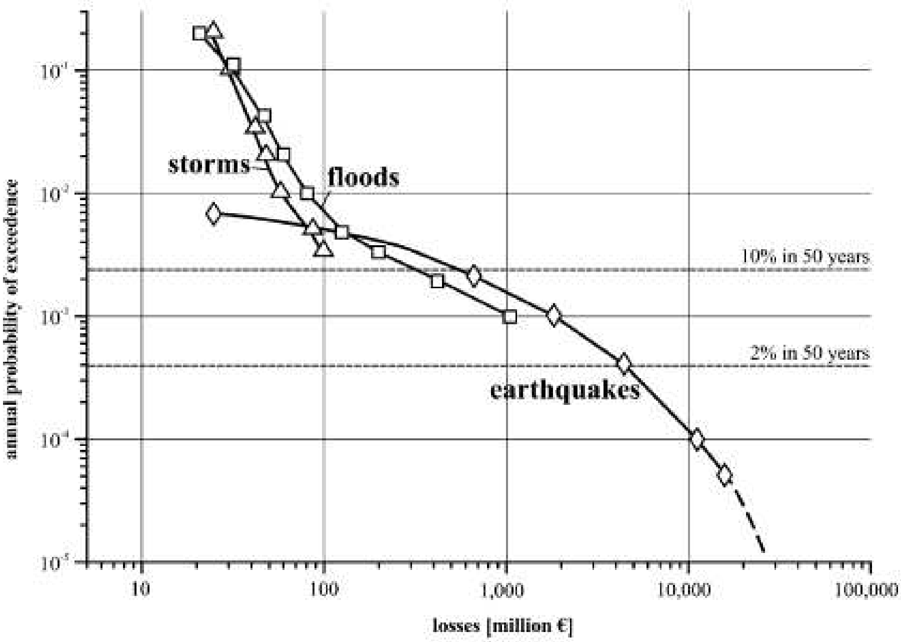

Figure 3: Risk curves for the storms, floods and earthquakes in the city of Cologne [13]

This case study demonstrated that combined consideration of risk curves provides the base for comparison and interpretation of different types of hazards within one area.

A similar example of a risk approach using a damage indicator was provided by [14]. The total risk across all hazards has been compared using the single risk indicator based on the building damage. That is, the level of the building damage can be used to rank risks from various natural hazards (when considered against its probability of occurrence). The building damage can also be used to estimate risk in absolute terms, although such estimates will be incomplete. Other potential direct and indirect costs to the community, for example from casualties or from business interruption, are also important sources of risk. However, the damage to buildings may be the largest component of direct damage from natural hazard disasters [14].

A holistic evaluation of risk for a multi-hazard evaluation based on Cardana's model was applied in a seismic risk evaluation for the cities of Bogota (Colombia) and Barcelona (Spain) [15]. The risk in a holistic perspective is a function of the potential physical damage and an impact factor. According to this procedure, a physical risk index is obtained for each unit of analysis from existing loss scenarios. The total risk index is obtained by factoring the former index by an impact factor or aggravating coefficient, based on variables associated with the socioeconomic conditions of each unit of analysis. The theoretical framework for this approach is illustrated in Figure 4.

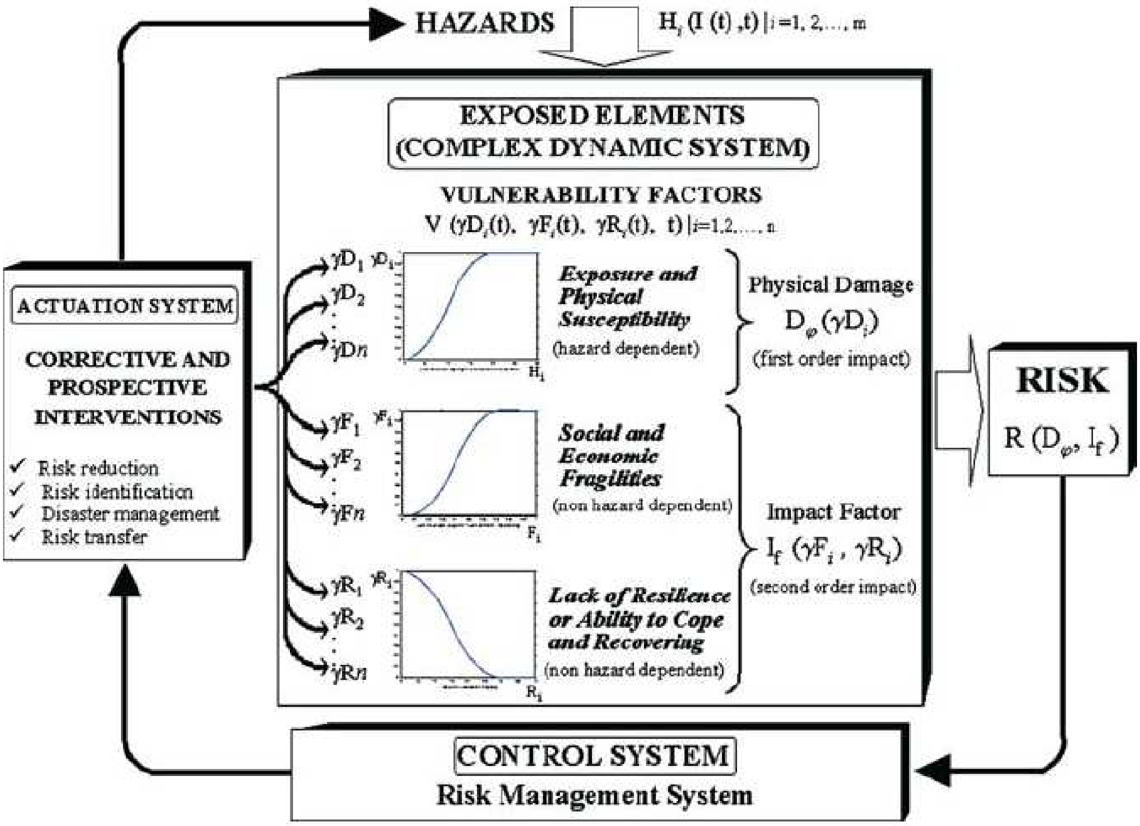

Figure 4: Theoretical framework and model for holistic approach of disaster risk [15]

A methodological approach for the definition of multi-risks maps at regional level considering an integrated indicator based on aggregated damage was applied in two regions in Italy: Piedmont [16] and Lombardy [17]. The different risks related to a specific type of damage such as population, buildings, infrastructures or environment are integrated by socio-politics weights in order to obtain aggregated risk indicators (social, economic, environmental risk, etc.).

4. CONCLUSIONS

The analysis of the JRC survey on the existing hazard and risk mapping situation showed the followings:

- The majority of countries have hazard maps (in a broad sense) available for the investigated hazards. However, these maps are typically prepared for a single hazard.
- Vulnerability maps are not common in the surveyed countries; however in many countries vulnerable objects are classified.
- Currently, no risk maps are available for the selected natural hazards in the surveyed countries.

The initial results of the review on the methods for the multi-hazard and risk revealed the following key findings:

- The risk expressed as a product of three components, hazard, vulnerability and elements at risk is widely accepted in natural hazards and is also frequently used in the multi-risk approach.
- Whenever is possible, the multi-risk analysis including all relevant hazard types within a region should be applied rather than the single approach. The multi-level approach gives a better overview of the investigated area and has a higher significance for planning effective countermeasures.
- It is not possible to define a multi-risk approach simply by overlapping or summing of the individual risk procedure. This is in correspondence with a holistic concept for the multi-risk approaches. The simple overlapping of individual risk maps can be performed just for the hazards within the same range of the probabilities.
- Usual process for a multi-risk analysis involves two basic steps: at first, the risk posed by each hazard is calculated, than the resulted single process risk maps are combine or integrate to the multi-risk maps.
- The integration of different hazards with different probabilities can be carried out by means of the economic indexes, frequently a damage that summaries the contribution of individual risk procedures is used.

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