RISK MAPPING METHODOLOGY FOR ENVIRONMENTAL HAZARDS

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Abstract
During the last decade the interest of society toward natural destructive processes increasing considerably. These processes constitute a giant mechanism of destruction witch cause a huge damage and often take people's lives. The risk management is a modus operandi of the society faced against disaster. Multyrisk (complex risk) is important part of the risk and disaster management processes, which take into account all types of potentially damaging phenomenon.
The recent research is focused on the complex risk analysis. The main aim is to obtain multyrisk (complex) maps for several hazards for the Northeast Bulgaria. Clear identification of the different hazards has been done, their consequences, elements at risk, exposure and their vulnerability as well as the analysis of the triggered secondary events investigated.
For the first time risk perception conception is taken into account and involved in risk assessment.

Keywords*: complex risk analysis and assessment, risk perception*

INTRODUCTION

In the present report a risk mapping methodology for environmental hazards is presented. Most popular European and world practices for risk assessment are incorporated. The main topic of the report is to present an enhanced complex method for risk (multyrisk) assessment for natural hazard which incorporates most useful applications and practices of several developed and applied useful practices – the IADB, WB, UNISDR, etc.

The new developed and adapted methodology is applied to several areas using real data. The main aim is to obtain risk levels for several hazards for the Northeast Bulgaria. Clear identification of the different hazards has been done, their consequences, elements at risk, exposure and their vulnerability as well as the analysis of the triggered secondary events investigated. For the first time risk perception conception is taken into account and involved in risk assessment.

THE „NATURE“ OF RISK - COMMON CONSIDERATIONS

The risk assessment (analysis) of natural hazards is a disaster preparedness activity including pre-disaster risk reduction phase of the risk management process. Risk analysis is a base for decision making and the main tool for the risk management and scenarios development about the risk reduction.

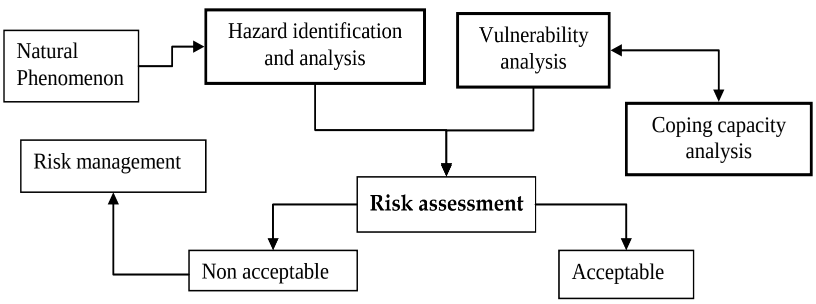


Figure 1. Risk assessment (UN,2004)

UN terms and definition are accepted and approved among risk management specialists. According that, risk assessment includes three main activities shown on figure 1: vulnerability, hazard and coping capacity assessment.

Risk – the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disruption or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions. The term *risk* refers to the expected losses from a given hazard to a given element at risk, over a specified future time period. The first definition is given by (Blaikie et al. 1994)

Risk = Hazard potential x Vulnerability
Or
Risk = Hazard x Vulnerability / Coping capacity (UNISDR, 2002; UNDP, 2004)

It must be mention that these are not algebraic equations and only show the interactions between risk, hazard and vulnerability.

Hazard potential is characterized by its probability (frequency) and intensity (magnitude or severity).

Vulnerability – the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards.

Vulnerability is determined by the potential of a community to react and withstand a disaster, e.g. its emergency facilities, disaster organization structure, education rate, early warning system, etc (coping capacity).

The *coping capacity* expresses the suitability of the society to "stand against disaster" and is described by the interaction of technical, organization, social and economic factors.

Table 1. Relationship between vulnerability and coping capacity (Frantzova, 2007)

Vulnerability/coping capacity	Very low	Low	Medium	High	Very high
Very high	Very high	Very high	High	Medium	Medium/low
High	High	High	Medium/low	Low	Low
Medium	Medium	Medium	Medium/low	Low	Low
Low	Low	Low	Very low	Very low	Very low
Very low	Very low	Very low	Very low	Very low	Very low

Risk can be expressed by physical exposure which describes the people faced with hazards. Exposure represents the number of people exposed per year to a particular hazard. Usually, physical exposure is expressed by the frequency and severity multiplied by exposed population (UNDP, 2004):

$$\text{Risk} = \text{PhExp x Vul}$$

In additional physical exposures describes not only people, but also building and facilities, infrastructures, economic activity etc. located in hazardous areas and exposed to a particular hazard.

Multi-risk or complex risk is the total risk obtained for all hazardous (disastrous) phenomena peculiar to certain area. The main basis of the multirisk concept is the assumption that most hazards are not hazards per se and triggered by other hazards (UNDP, 2004):

$$Milty - Risk = \sum Risk_{\text{floods}} + \sum Risk_{\text{eartquackes}} + \sum Risk_{vilcano} + ... + \sum Risk_{n-hazards}$$

Risk assessment

Hazards assessment

Hazard assessment and the hazard analysis is the process of estimation, for selected areas, the probabilities of the occurrence of potentially damaging phenomenon of given magnitudes (severity) within a specified period of time. Hazard assessment involves analysis of formal and informal historical records, and scientific interpretation of all existing and available data and information related to the particular hazards. Hazard is usually expressed by probability of occurrence for the given period of time. (UNDP/DMTP, 1992; Reed, 1997).

Different natural hazards are examined in different time scale, because of different return period. For instance – geological hazards (earthquake, vocalic eruption, tsunami) usually are presented within 1000 year time scale, while floods, storms, landslides could be assessed for about 20,30,50 or 100-year time scale, because they occurred more frequent. The severity of natural hazards is measured for a specific location applying hazard specific scales (e.g. the Richter magnitude for earthquakes, Beaufort wind strength, The Saffir-Simpson Hurricane Scale, Fujita scale for tornado intensity, etc.). Frequently hazard assessment includes as well as the secondary effects, due to the main hazard event's realization. The results are most common presented as maps.

Vulnerability assessment

The consequences of a potentially damaging phenomenon may be computed as (WMO,1999):

$$K = \sum_{i=1}^{n_0} v_i k_i$$

where K is the total consequences summed over all people or objects affected, n_o is the number of elements (people or objects) at risk, v_i is the vulnerability of the i- th element to a given potentially damaging phenomenon, and k_i is the extreme consequence to the i-th element from a given potentially damaging phenomenon.

Vulnerability has the follow aspects: economic, social, environmental, physical and demographic.

Economical aspects of vulnerability

According to the (UNISDR, 1992), vulnerability is defined as the degree of loss resulting from a potentially damaging phenomenon. As is stated above, these losses may include lives lost, persons injured, property damage and disruption of economic activity. In the estimation of the actual or expected losses, three categories of damages (losses) are considered: direct, indirect and due to the secondary effects (A.L.Vetere Arellano at all, 2003). Direct damages (losses) are linked directly to disaster and include property damage, injuries and loss of life, whereas indirect damages refer to the disruption of economic activity. The secondary effects are the short – and long-term impacts of a disaster to the overall economy and socio-economic conditions (Vetere Arellano at all, 2003).

Social vulnerability

The social dimension of vulnerability acknowledges the vulnerability of people, and the emphasis is on the *coping capacity* of different social groups. Many sociologists identify vulnerable groups as "children", "female-mistress", "elders and disabled". Blaikie et al. (1994) argue that the most vulnerable groups of people are those, who find it hardest to reconstruct their livelihood after a disaster. He describes as a rule – "the poor suffer more from hazards than the rich". The time dimension is relevant, since reconstruction in poor areas can take longer time, which affects the economy and livelihood of the area. The idea that "poor are more vulnerable" is widely spread and well adopted – the risk analyzers used GDP per capita like comparative measure for poverty and people vulnerability.

However, the social science community has widely acknowledged some major factors that influence social vulnerability: lack of access to resources (including information); limited access to political power and representation; social capital (including social networks); beliefs and customs; building stock and age; frail and physically limited individuals; type and density of infrastructure and lifelines, risk reception, physiological and physical recovery from last disaster, etc. (ESPON, 2003).

Environmental aspects of vulnerability

Environmental aspects of vulnerability show in which extent the natural environmental may be affected by particular hazards and/or in which extent the natural hazards can be exacerbated by the present environmental condition.

Usually environmental vulnerability is not included in risk assessment since there is no general agreement on how best to define environmental properties, or how to calculate corresponding indicators (ESPON, 2002).

Currently are defined the following environmental indicators. Part of them may be included in risk assessment of natural hazards: EVI (Environmental Vulnerability Index) – consist of 50 indicators for environmental and developed by South Pacific Applied Geoscience Commission (SOPAC), UNEP (United Nations Environment Programme -

UNEP) and their partners; and EEA Core Set of Indicators (Indicators about Europe's environment- CSI) developed by European Environment Agency.

Physical (constructional) vulnerability

Physical vulnerability is a measure for buildings and infrastructure resistance. It is dependent of constructional feature, location, influencing force and many other factors. Physical vulnerability is usually not easy to assess. There are different aspects and assessment methodologies applied by the different specialists to assess the vulnerability. There is not a unified methodology about the vulnerability assessment as a homogeneous method.

Demographic vulnerability

Demographic vulnerability includes main demographic feature like population growth, people density, etc. It needs frequent update of the data to the reliable assessment.

Coping capacity assessment

Vulnerability and capacity are closely linked and can in fact not be separated since an increase of capacity means at the same time a decrease of vulnerability. Measures that reduce the vulnerability also reduce the disaster risk. While Vulnerability focuses on the underlying factors of a community's vulnerability (inherent weaknesses, structural factors etc.), the coping capacity are measures of prevention, mitigation, preparation, response and rehabilitation and reconstruction. They reflect all policies, systems, kinds of public and private investment on community level that help to prevent disaster, mitigate their effects, prepare society to cope with extreme events and assist victims to recover (Wisner 2000). In this way coping capacity point to the risk reducing potential of a community, which is directly addressable (IADB/GTZ, 2003).

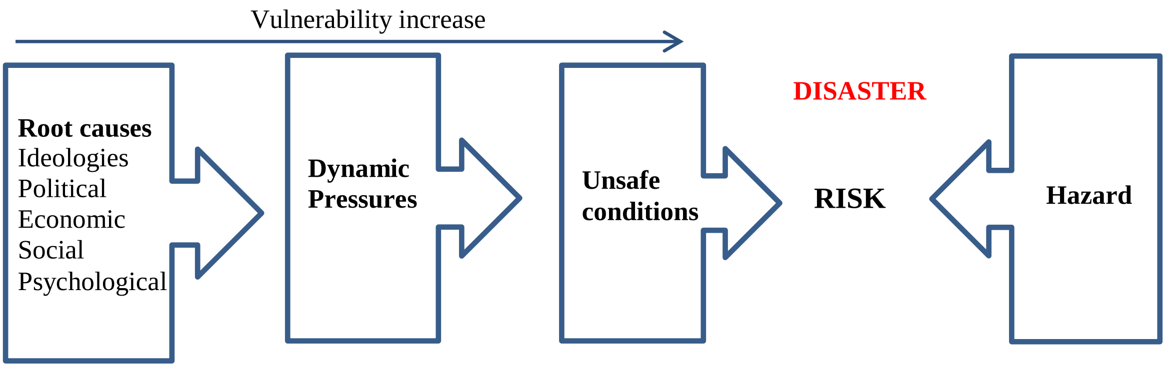


Figure 2. The „nature" of risk – disaster as interception between natural event and human activities (Blackie at all,1994)

RISK ASSESSMENT METHODOLOGY

There are many models and methods for disaster and damage assessment caused by particular natural hazards. Each methods or model for his own specific features. The differences in models very often lead to some disadvantages like: different results, different scenarios with various initial and final data and results, incompatibility, inappropriateness, etc. That's why during the last years the efforts are directed to search complex methods including all factors and parameters concerning risk assessment and analysis.

Basic methods and methodologies about the risk and multi-risk assessment are developed by:

- United nations programs – ISDR, UNDP;
- Inter-American Development Bank and Deutsche Gesellschaft für Technische Zusammenarbeit GmbH (GTZ);
- World Bank;
- ESPON 3.1.3. Project - The spatial effects and management of natural and technological hazards in general and in relation to climate change;

- “Natural hazards” FP5 Project - Joint Research Centre (JRC), Institute for Environment and Sustainability (IES).

The IADB methodology has been chosen for the purpose of the risk assessment and analysis. IABD uses four risk factors (IADB/GTZ, 2003): hazards, exposure, vulnerability and coping capacity. The methodology is described in detail in Frantzova, 2013.

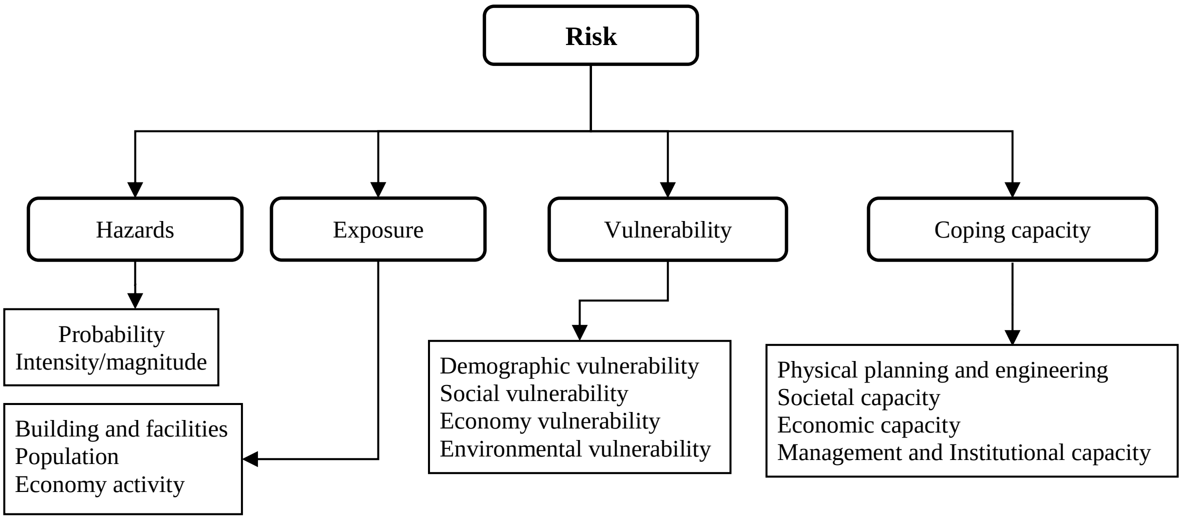


Figure 3. IADB methodology

The main components (called risk factors) values are determined as follows:

$$H = w_{(H1)} \text{ x } H_1 + w_{(H2)} \text{ x } H_2 + w_{(H3)} \text{ x } H_3 + \ldots + w_{(Hn)} \text{ x } Hn$$

$$E = w_{(E1)} \text{ x } E_1 + w_{(E2)} \text{ x } E_2 + w_{(E3)} \text{ x } E_3 + ... + w_{(En)} \text{ x } En$$

$$V = w_{(V1)} \text{ x } V_1 + w_{(V2)} \text{ x } V_2 + w_{(V3)} \text{ x } V_3 + ... + w_{(Vn)} \text{ x } Vn$$

$$C = w_{(C1)} \text{ x } C_1 + w_{(C2)} \text{ x } C_2 + w_{(C3)} \text{ x } C_3 + ... + w_{(Cn)} \text{ x } Cn$$

where H, E, V and C are the values of the Hazard, Exposure, Vulnerability and Capacity & Measures, respectively; H_1,H_2…E_1,E_2…V_1, V_2….C_1,C_2….refer to the scaled values of the indicators; and w_i are the weights. A total sum of the weighting coefficients must be equal to 100.

The risk profile for the given selected area is expressed as:

$$R = (wH + wE + wV) - wC$$

where R is the overall risk index, H, E, V and C are the factors value of the hazard, exposure, vulnerability and coping capacity, respectively and wi is the weighting coefficient.

The new developed and adapted methodology for risk and multi-risk assessment includes:

- Risk perception as a part of the risk assessment.

This is an attempt to quantify psychological factor as a source of increasing risk and vulnerability. Considering the models and research (presented in Frantzova,2013) risk perception can be accepted as a root cause related to the risk management. Therefore, the inclusion in the risk assessment is imperative. The psychological variable "It won’t happen to me" (fig.2) is associated with personal decisions. But the analogous psychological factors are the base of the human behavior and decisions. Risk perception as a key factor could be the main reason for maximizes vulnerability or its reduction respectively.

Thereby, the risk profile for the given selected area is expressed as:

$$R = wH+wE+wV+wRP-wC$$

where H, E, V and C are the values of the Hazard, Exposure, Vulnerability, Coping Capacity and Risk Perception, respectively; H_1,H_2…E_1,E_2…V_1, V_2….C_1,C_2….refer to the scaled values of the indicators; and w_i are the weights. A total sum of the weighting coefficients must be equal to 100.

The main feature of the methodology is the assumption that the coefficient w is not equal to the five factors; it is assumed that various factors have varying weight and contribute in changing magnitude for the assessment of the risk levels. The values of weighting coefficients are defined similar as it is presumed that all risk factors contribute equally to the increasing or reducing of given risk. For the time being there are no scientific studies or technical methods which are able to defined whether the factor "hazard" is more important than the factor "vulnerability" or “copping capacity”. The risk factors are closely related to environment and the areas to be considered and thus their impact can range from minimum to maximum.

Thus, we can accept the "risk perception" as the one of the core factors with the highest „weight" in the establishment of the risk profile for the given phenomenon. The statement „It won’t happen to me” lead to „I won’t take any measures because it merely won’t happen to me."

- The total number of indicators used to assess the risk profiles are over 70, including climate change.
- Five classification characteristics associated with risk perception are included as indicators for hazard assessment.

These evaluation elements are derived from risk perception research. They have already been proposed as criteria for risk evaluation procedures in a number of countries such as Denmark, the Netherlands and Switzerland (WBGU, 1996). The following are particularly important:

Location - Spatial distribution of damage or of damage potential

Persistency - Temporal scope of damage or damage potential

Irreversibility - Non-restorability of the state that prevailed prior to occurrence of damage. In the environmental context, this is primarily a matter of the restorability of processes of dynamic change (such as reforestation or water treatment), not of the individual restoration of an original state (such as preserving an individual tree or extirpating non-native plant and animal species).

Delay effect - The possibility that there is large latency between the cause and its consequential damage. Latency can be of physical (low reaction speed), chemical or biological nature (such as in many forms of cancer or mutagenic changes). It can also result from a long chain of variables (such as cessation of the Gulf Stream due to climatic changes).

Mobilization potential (refusal of acceptance) - The violation of individual, social or cultural interests and values that leads to a corresponding reaction on the part of those affected. Such reactions can include open protest, the withdrawal of trust in decision makers, covert acts of sabotage or other forms of resistance. Psychosomatic consequences can also be included in this category.

- Global Change Syndromes, specific to particular natural hazards for selected areas.

Global Change Syndromes are described in detail in WBGU, 1996.

“Utilization” Syndromes

1. Overcultivation of marginal land: Sahel Syndrome
2. Overexploitation of natural ecosystems: Overexploitation Syndrome
3. Environmental degradation through abandonment of traditional agricultural practices: Rural Exodus Syndrome
4. Non-sustainable agro-industrial use of soils and bodies of water: Dust Bowl Syndrome

5. Environmental degradation through depletion of non-renewable resources: Katanga Syndrome

6. Development and destruction of nature for recreational ends: Mass Tourism Syndrome

7. Environmental destruction through war and military action: Scorched Earth Syndrome “Development” Syndromes

8. Environmental damage of natural landscapes as a result of large-scale projects: Aral Sea Syndrome

9. Environmental degradation through the introduction of inappropriate farming methods:

Green Revolution Syndrome

10. Disregard for environmental standards in the course of rapid economic growth: Asian Tigers

Syndrome

11. Environmental degradation through uncontrolled urban growth: Favela Syndrome

12. Destruction of landscapes through planned expansion of urban infrastructures: Urban Sprawl Syndrome

13. Singular anthropogenic environmental disasters with long-term impacts: Major Accident Syndrome

“Sink” Syndromes

14. Environmental degradation through largescale diffusion of long-lived substances: Smokestack Syndrome

15. Environmental degradation through controlled and uncontrolled disposal of waste: Waste Dumping Syndrome

16. Local contamination of environmental assets at industrial locations: Contaminated Land Syndrome

The new developed and adapted methodology for risk and multi-risk assessment is applied for the Northern Bulgarian Black Sea coast for geophysical hazards.

The risk profile is expressed as:

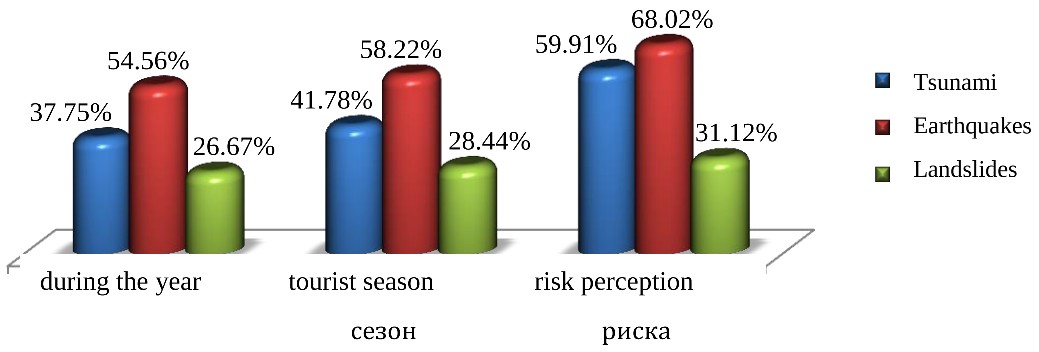
$$R = 0.27*H+0.23*E+0.23*V+0.27*RP-0.28*CC$$

where H, E, V, C and RP are the values of the Hazard, Exposure, Vulnerability, Capacity & Measures and Risk Perception respectively; H1,H2…E1,E2…V1, V2….C1,C2….refer to the scaled values of the indicators; and wi are the weights.

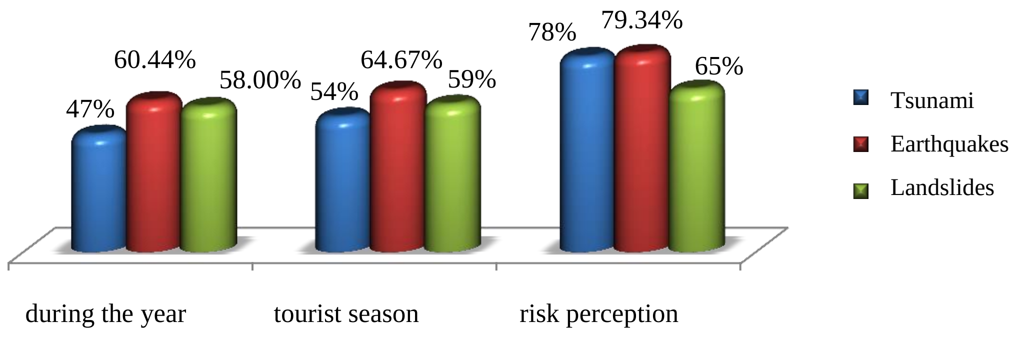
Results

For clearly presentation and visualization, the selected area is divided into three regions (AoI): from the border with Romania ($43^0$44'N, $28^0$34'E) to the cape Kaliakra ($43^0$21'N, $28^0$28' E); from the cape Kaliakra to the Kranevo resort ($43^0$20' N, $28^0$03' E), and from Kranevo resort to Varna town ($43^0$13' N, 27^0 55' E). Risk profiles for each of the regions (Region 1, Region 2 and Region 3) are presented in the graphs. Risk profiles have been calculated for the summer time (tourist season), outside the tourist season and including concept of risk perception.

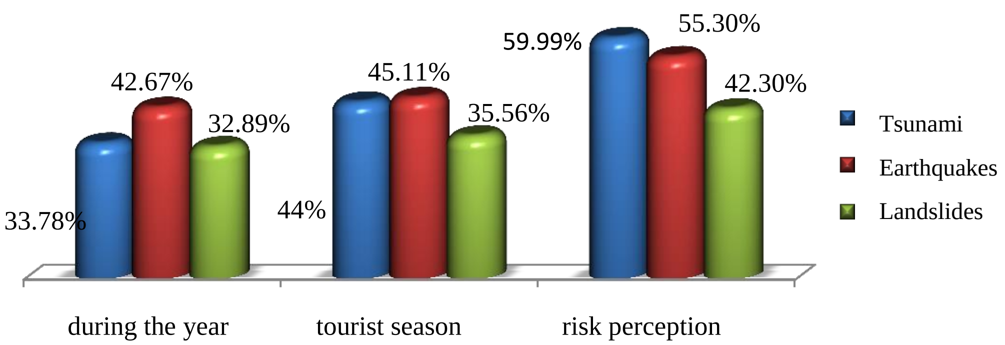
Comparative risk profiles



Risk profiles – AoI 1 ($43^0$44' N, $28^0$34' E - $43^0$21' N,$28^0$28' E)



Risk profiles - AoI 2 ($43^0$21' N, $28^0$28' E - $43^0$20' N, $28^0$03' E)



Risk profiles – AoI 3 ($43^0$20' N, $28^0$03' E - $43^0$13' N, 27^0 55' E)

The presented charts show a significant increase in the risk levels because of risk perception. Risk levels are mapped by GIS and presented in the attached map for the AoI 2.

The results indicated that regional risk profiles of the selected areas rises to very high - about 80% when concept of risk perception is taking into account.

According to the classification, presented in the paper „Classifications and typology of the natural and triggered technological risks according to the GDP and probability of occurrence" geophysical risk is located in the prohibited area because of extremely levels. In the prohibited area, the expected consequences are so severe that risk reduction is unconditional. In extreme cases, the proper response here is an immediate ban or moratorium (WBGU, 1998).

CONCLUSION: WHY IS THE RISK PERCEPTION SO IMPORTANT?

The study of risk perception arose out of the observation that experts and people often disagreed about the risky various technologies and natural hazards. Three major families of theory have been developed: psychology approaches (heuristics and cognitive), anthropology/sociology approaches (cultural theory) and interdisciplinary approaches (social amplification of risk framework).The earliest psychometric research was done by psychologists Daniel Kahneman and Amos Tversky, who performed a series of gambling experiments to see how people evaluated probabilities. Their major finding was that people use a number of heuristics to evaluate information.

Research within the psychometric paradigm turned to focus on the roles of affect, emotion, believes, etc, in influencing risk perception. Melissa Finucane and Paul Slovic have been the key researchers here. Daniel Kahneman known for his work on the psychology of judgment and decision-making, as well as behavioral economics, for which he was awarded the 2002 Nobel Memorial Prize in Economic Sciences (shared with Vernon L. Smith).

Meanwhile, many different methods, methodologies and techniques have been developed to predict with the highest accuracy relative frequencies and magnitude of natural events and possible damage.

Risk perception, by contrast is based largely on personal experience, mediated information, intuitive estimations, cultural evolution, etc. As studies of risk perception have shown that people associate risks not only with physical damage, but also violations of social and cultural values (Fischhoff et al., 1978; Covello, 1983; Slovic, 1987; Brehmer, 1987; Gould et al., 1988; Renn, 1989; Drottz-Sjöberg, 1991; Pidgeon et al., 1992; Jungermann and Slovic, 1993; Rohrmann, 1995). The technical-scientific risk perspective has largely excluded this dimension of risk, restricting itself essentially to damage to property, health and the environment (WBGU,1998). It was only psychological and sociological risk research that then created a basis for sufficiently characterizing and largely explaining societal risk experience. Besides underscoring non-physical risk dimensions, perception research has also shown that people base their evaluations of risks on a series of contextual risk properties in addition to the probability and severity of damage.

On the basis of the knowledge of non-physical dimensions and contextual risk properties we can understand the human behavior against natural events and threats. What a society defines or recognize to perceive as risk is thus not necessarily in any direct relation to the magnitude of risk as defined by the two components of probability of occurrence and extent of damage. (Slovak, 2000; Slovak, 2002; Fischoff at all,2000; Renn 1998).

It is very important for several reasons that a proactive and rationally structured risk policy addresses the issue of risk perception. For one thing, the behavior of people is guided by their perceptions and not by scientific risk models. The perception of risk is not independent of the „objective“ risk. Over the long run, only those risk perceptions will prevail that tally with the experience of real damage. However, in rare cases, imagined risks can generate precisely those symptoms that are in principle caused by the damage potentials of the risk sources in question. Psychosomatic reactions are frequently the consequences of risk perceptions (Aurand and Hazard, 1992).

Secondly, in addition to severity and probability people also act on other risk properties that not only reflect their personal preferences but should also be integrated in a rational risk policy on the basis of normative considerations (Renn, 1998). Whether a potential damage is irreversible or not, or whether it may impact upon other people or upon future generations, are dimensions that are usually excluded from classic risk assessments.

Thirdly, most people are not indifferent to distributional patterns of damage over time and space. The risk assessment process is based by definition on relative frequencies, necessarily meaning that averages are formed over space and time. However, in the perception of most people it is by no means the same thing whether a source of risk damages 1,000 people at one blow or continuously damages 1,000 people over a certain period (Jungermann and Slovic, 1993).

Moreover, people also link concepts of social equity and justice to distributional patterns. In most cultures, an asymmetrical distribution of benefits and risks requires a particular social justification. Whether a risk is viewed as fair or acceptable depends less upon the magnitude of the risk than upon an individual or cultural standard of equity. Classic risk assessments do not inform us on this point (WBGU,1998).

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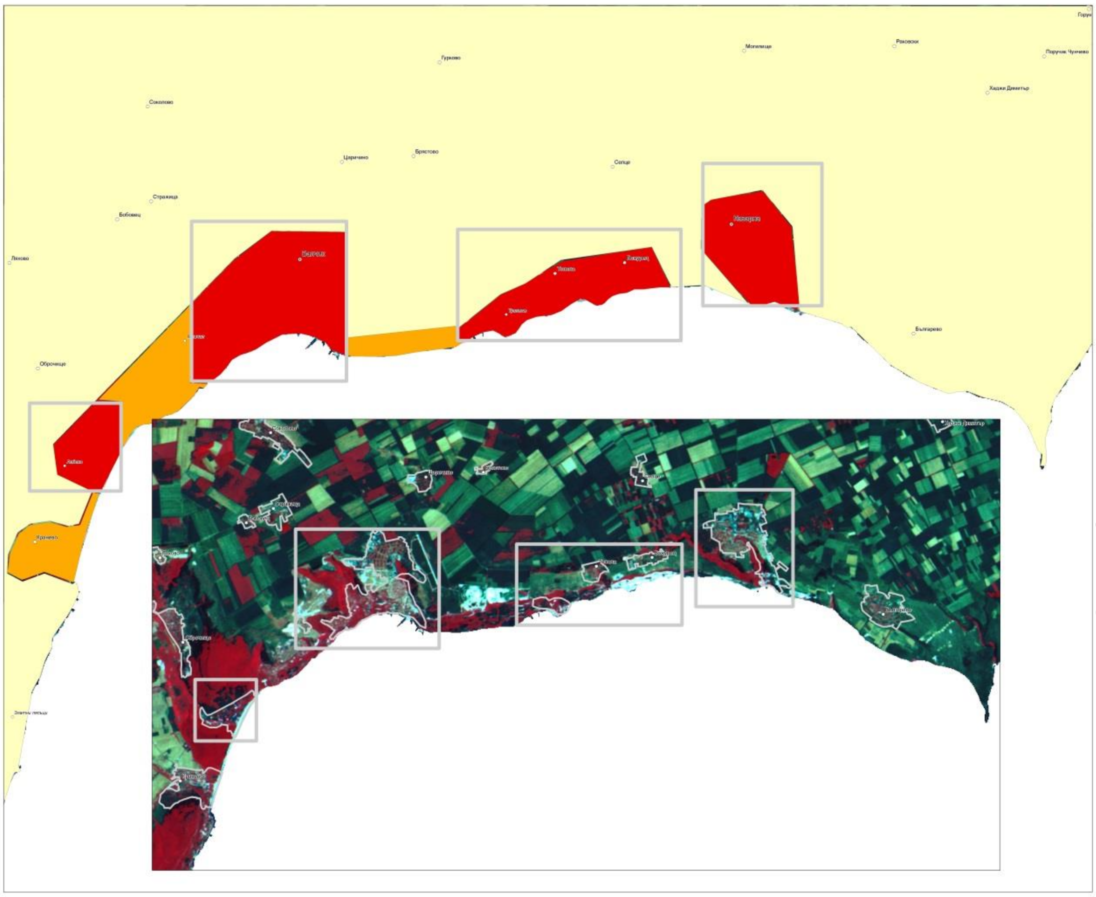
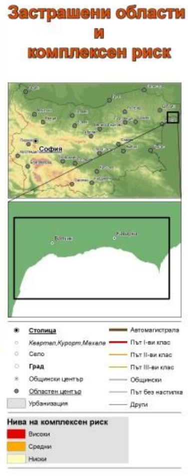

Complex risk map cape Kaliakra - Kranevo resort ($43^0$20' N, $28^0$03' E)