Decision-Support System for Spatially Distributed Multi-Hazard Risk Analysis

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Abstract

The paper dwells on a dynamic spatially distributed model of multi-hazard risk analysis for critical infrastructure elements, which is meant to assess risk indecision-support systems. Multi-hazard risk is centered around a model of the socio-economic system, hazard dynamics model, a model of the dynamic vulnerability of critical infrastructure elements, and a model of multi-hazard risk assessment. The hazard dynamics model represents the knowledge about the dynamics of hazards, their interactions and cascading effects using plausible event-tree networks with the events having both temporal and spatial reference. Multi-hazard risk analysis model allows assessing integrated dynamic spatially distributed multi-hazard risk in decision-support systems dealing with a threat, vulnerability, damage, cascading and domino effects. The risk scenarios within the decision-support system can describe multi-hazard risk as a multitude of spatially distributed dynamic processes influenced by a various range of drivers. The practical use of the proposed model is also considered.

Keywords

Decision-support system, risk assessment, critical infrastructure, multi-hazard risk, risk scenario, cascading effect, domino effect, event.

1. Introduction

Imagine our world being impeccable, without any disasters, losses and risks – it is hardly possible, isn't it? Unfortunately, natural disasters are quite ubiquitous, and the forests, sabulous and marine areas, such as rivers, lakes or coasts are no exception. For instance, sandy or arenaceous areas suffer from erosion, which can provoke landslides or coastal fade; rivers and lakes may be prone to shallowing and drying out, and constructing dams on rivers cause coastal erosion and wildfires that make slopes and cliffs more susceptible to floods, sinkage, landslides, mudflows and so on. The global increase in a temperature is nowadays at its best: the climate changes, invoking a plethora of threats, disasters and catastrophes all over the world and without any lowering of greenhouse gasses, before next century the Earth atmosphere may reach and exceed about 5 ºC! Climate altering makes the weather conditions more complex depending on the concrete region and country. Global warming has gotten the potential to deplete our conditions even worse than we think. The unexpected world pandemic breakout already gave us a lesson on how to react to challenges quickly and effectively. Bearing this in mind, it is high time we commenced counteracting, but now two nefarious issues.

According to many studies, [1, 2] risk signifies the probability or likelihood of detrimental consequences, such as injuries of inhabitants, real estate or environmental damage due to the human (anthropogenic) factors and vulnerable conditions. Risks by their nature are single, sequential, or

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combined. Each hazard is characterized by its probability, intensity, frequency, location, duration, area of action, rate of onset, spatial variance, and time interval.

The difference between risk and danger is noticeable. Risk is a likelihood, high or low, that someone or something is harmed by danger showing how serious the damage can be. The danger is something that can harm objects, exposed to risk [3]. In this paper, we are talking about the risk of certain natural phenomena and threats.

The multi-risk term is often used to refer to all relevant hazards that are possible in a certain area of interest, while in the scientific context it often refers to more than one hazard. When a threat becomes a reality or when it materializes, the risk becomes a catastrophe.

In our research multi-hazard risk shows up as a process, resulting from a set of hazards, vulnerabilities, and inadequate capacity of measures to reduce the adverse effect [3]. Let us take an example of some coastal area where floods may occur: a certain danger is present, but the risk exists only if there are vulnerable objects in the danger zone, i.e., there is a risk that danger may lead to considerable outcomes in the future when danger materializes, floods occur, causing loss and catastrophe [1, 4]. However, the flood is not itself considered a catastrophe when it occurs in unpopulated areas and does not bring significant consequences until it takes place in dwelled regions and causes damage, loss, or destruction.

We consider risks originating from the influence of hazards on critical infrastructure elements. Critical infrastructure (CI) is defined as a large-scale distributed socio-technical system which contains some critical asserts, provides services to the society, and is essential for its proper functioning. The critical infrastructure consists of the sectors that determine its multi-layer architecture. The functioning of each sector can be connected with some hazards posed sector-specific risks to some critical assets. Given the fact that the hazards posed risk are distributed in space and time, and the existence of the sectors determine the multi-layer structure of CI, the integrated inter-sectoral risk assessment should be multi-dimensional, dynamic, spatially distributed. The additional factor of risk is climate change that acts as a threat multiplier, exacerbating current problems of, for example, mass migration and maintenance of reliable supply chains.

The paper concerns with developing a model of space-distributed dynamic multi-hazard threats and risks on different timescales and with different detail of space.

2. Related works

For the time being, there are a variety of methods and approaches to research and assess the risks of emergencies timely, depending on the region of the potential risk and local conditions. For example, [4] provides a quantitative and semi-quantitative assessment of fire danger, risk of earthquakes, volcanic eruptions, landslides, rock falls, strong winds (hurricanes), floods, tsunamis and more. Scientists and researchers all over the world conduct research, analyzing the different degrees of risk and likelihood of threats. Some of the best known are the following: Sven Fuchs, Joern Birkmann and Thomas Glade, who study the assessment of vulnerability due to natural risk [5, 6]; Philip J. Ward, Veit Blauhut, Nadia Bloemendaal [7, 8] study the threats of natural disasters worldwide; in turn, Johann Goldammer, Ioannis Mitsopoulos, Giorgos Mallinis and Martine Woolf [9, 10, 11] are working on assessing the risk of wildfires. Significant progress in risk analysis was also achieved by C.J. van Westen, Stefan Greiving, D. Alkema, M.C.J. Damen, N. Kerle and N.C. Kingma [12, 13, 14]. Their research concerns procedures for collecting, analyzing, and evaluating spatial information to assess risks from natural and man-made hazards (such as geological, hydrometeorological, environmental and technological hazards).

When risk analysis and identification are performed in a joint process, we say that we are doing a risk assessment, that is, risk assessment is a general process of risk analysis and identification. Risk assessment is always a proactive approach in the sense that it deals exclusively with possible accidents. This is the opposite of accident investigation, which is a reactive approach that seeks to determine the causes and circumstances of accidents that have already occurred.

The risk analysis can be qualitative or quantitative, depending on its purpose [3]. Qualitative risk analysis is when the probabilities and consequences are determined only qualitatively. Quantitative risk analysis gives numerical estimates for probabilities and consequences, sometimes together with the associated uncertainties.

The risk quantification method is suitable for evaluating several alternatives for risk reduction by comparative risk analysis both before and after implementation with subsequent low-cost analysis. Event tree analysis is the best approach for determining complex event chains and related probabilities or likelihoods [3].

Qualitative risk assessment methods are useful as an initial screening process to identify hazards and risks. They are also used when the expected level of risk does not justify the time and effort to collect the vast amount of data needed to qualify the risks, and when the ability to obtain numerical data is limited.

Nevertheless, there are some more risk-assessment approaches and one of them is called "risk matrix". It is a diagram to analyze the risk itself, its stage, starting from minor risk probability ending with the threat of catastrophic predictions (Table 1). The risk matrix depicts risks in a diagram - they are divided depending on their likelihood or the extent of damage, knowing that risk is the gap in the outcome of taking an option.

In terms of quantity, the level of risk can be assessed as a product of the likelihood that an accident happens by the potential loss. Hence, the risk matrix approach can be useful when either the likelihood of a hazard or potential damage cannot be estimated with sufficient accuracy [15].

Table 1
The risk matrix

	Negligible	Marginal	Critical	Catastrophic
Certain	High	High	Extreme	Extreme
Likely	Moderate	High	High	Extreme
Possible	Low	Moderate	High	Extreme
Unlikely	Low	Low	Moderate	Extreme
Rare	Low	Low	Moderate	High

The approach based in the risk matrix is often the most practical as a basis for spatial planning, where the effect of risk mitigation methods can be seen as a change of risk classes. The static representation of risk is the main disadvantage of this approach.

We propose to consider risk as a spatially distributed process using event trees with the nodes referenced to spatial locations.

3. Available risk-and-threat detection information systems

In general, risk analysis requires a repetitive procedure to be performed for each hazard scenario (different hazard types and return periods) in combination with the risk elements, and then for each possible alternative. This requires the use of automated procedures using geographic information systems (GIS). We can assess risk to some extent using conventional GIS systems, although it is preferable to use specific software. The best public damage assessment initiative to date is HAZUS, established by FEMA (Federal Emergency Management Agency) in conjunction with the National Institute of Civil Engineering.

The first version of HAZUS was released in 1997 with a focus on seismic damage assessment and was extended to high-risk losses in 2004, including losses from floods and winds. HAZUS was intended as a software tool for ArcGIS. Currently, hazard models of numerous types such as earthquakes, hurricanes, tsunamis, coastal surges, and floods can be implemented and maintained in Hazus.

Many GIS specialists, emergency managers and response planners use FEMA's Hazus program to estimate damage, to depict the detrimental effect of disasters and to define effective strategies of countering them.

Hazus system classifies risks scenarios as:

1. An impairment of private or state buildings and critical infrastructure.
2. Community influence (wounded households, shelter requirements, and dwellers exposed to hurricanes, floods, earthquakes, or landslides).
3. Economic damage, such as unemployment and refurbishing costs thereafter.

There are three stages of the risk assessment. Initially, the risk exposure must be evaluated for target areas. Secondly, the intensity level should be estimated for the exposed area. It can describe the hazard, which affect the exposed area.

At the last stage, Hazus evaluates the hazard-specific potential losses in the exposed area of the with respect to structural, economic, and others type of damage. Despite that Hazus was originally developed in the U.S., there are many countries over the world such as Australia, Canada, Singapore, which emergency combating services adopted Hazus as well [16].

As for stand-alone software modules for risk assessment with various hazards, which do not work as part of existing GIS, there is an application of probabilistic risk assessments called computer-assisted pest risk analysis (CAPRA) supported by the World Bank. Its methodology focuses on developing probabilistic risk assessment modules for earthquakes, hurricanes, floods, volcanic hazards and the risks of disasters caused by them, such as tsunamis, floods, storms and landslides.

It is worth saying that such open-source web modules for risk assessment are currently being developed by the Global Earthquake Initiative (GEM) to become the standard for earthquake loss assessment tool [3].

Another web module has gotten a name SimpleRisk. It is a fully integrated governance, risk management, and compliance (GRC) platform to meet all risk management and compliance prerequisites. It serves such functionality that is comprehensive enough to be utilized by some of the largest organizations on the planet while presenting a user interface that is both simple and intuitive [17].

4. Underlying models

The approach to multi-risk analysis offered in this paper is founded on the models:

- a model of the socio-economic system (SES) representing both people, CI, and ecosystem.
- hazard dynamics model representing the knowledge about spatially distributed multi-hazard scenarios to evaluate the potential direct and indirect effects.
- model of the dynamic vulnerability of CI elements of various classes affected by a combination of multi-hazards to provide a reliable estimation of the systemic vulnerability of different CI sectors exposed to multi-hazard risk.
- the model of assessing multi-hazard risks.

Multi-hazardous threats and risk assessments allow identifying vulnerable areas, infrastructures, and target objects at risk, imposed by multi-hazards. They can be represented by spatially distributed assessments having a dynamic nature with respect to the threatened elements of the critical infrastructure. as well as present and future risks.

All the above-stated models are based on a five-layer space model (Fig. 1) containing the following layers:

- geographic coordinate system.
- grid of isometric square cells.
- set of non-overlapping space objects (geotaxons).
- territory’s administrative structure.
- areas with homogeneous danger, threat, and risk characteristics.

Technical and socio-economic infrastructures, environment, and people interact with each other within the considered territory. Their interactions and interdependencies cause to the formation of a complex dynamic system namely socio-economic system (SES).

The activity of people within SES is based on some important entities, which are spatially distributed over the territory. Such elements constitute a dynamic system, which represents technical and socio-economic infrastructure (TSI). Some its elements that are vitally essential for people constitute, in other turn, a critical infrastructure (CI). Obviously, CI is a part of TSI. However, in the present time, there are a large number of hazards threatening CI facilities and CI in general such as natural disasters, man-made accidents, crime and terrorist threats, etc. CI facilities exposed by such hazards can be disrupted, destroyed or damaged. Clearly, such situations impact negatively on TSI and, consequently, on SES as a whole.

The territory usually contains a kind of network consisting not only of buildings and roads but also of other TSI elements and people. Some of these elements usually provide other elements with food, energy, services, and so on. The authors consider the model of the socio-economic system as a network of such networks. The model of SES hierarchically organizes its own subsystems. It usually consists of infrastructures, which contains some elements that consume air, water, and other kinds of natural resources. The SES model can adequately describe a wide range of elements. It can also define many kinds of relations between them.

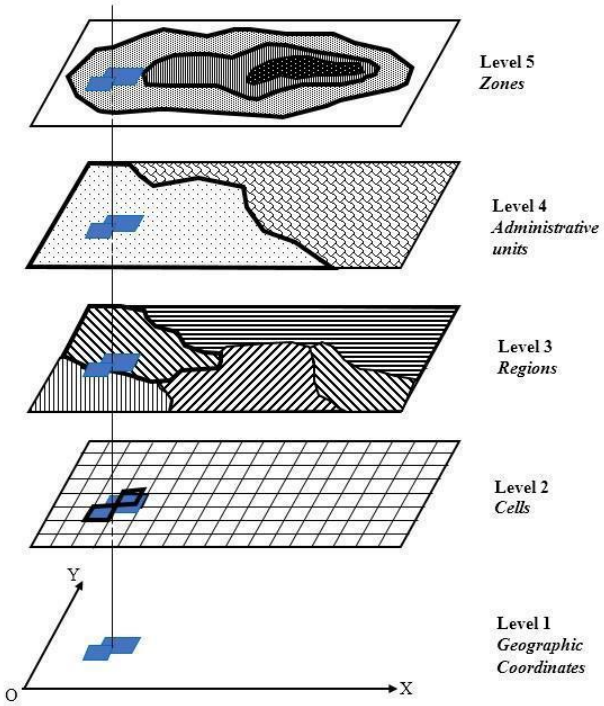

Figure 1: The spatial model

The SES model is defined over the spatial model, which describes the considered territory. The spatial model is GIS-based. Therefore, all objects of the socio-economic system are spatially referenced (Fig. 2).

Each element of the SES is considered as an object that has its own state described by a set of observed parameters. Each change of some parameter of the object state that causes a state change is considered as an event.

Accordingly, the next important model is the hazard dynamics model, which is based on the above-mentioned interpretation of events. We propose to represent the knowledge about the hazards, their interactions and dynamics using plausible event-tree networks (PETN). PETN represents the cell’s transition from state to state. Since such transitions have temporal and spatial dimensions, events can be both geo- and time- referenced. Therefore, PETN can adequately represent cascading effects of hazards. Target objects are also geo- referenced within the SES model, and the cell is smallest spatial part of the object. Thus, each object can be described by a set of underlying cells. Therefore, if a certain cell changes its state, the state of the correspondent overlying object should be also changed.

There are various short, mid, and long-term processes (respectively, meteorological, migration, climate change) impact TSI elements. TSI elements can also be influenced by people activity. The vulnerability of TSI elements is a dynamic property because of their interactions. Clearly, if some TSI elements are exposed to hazardous processes, decision-makers should protect them.

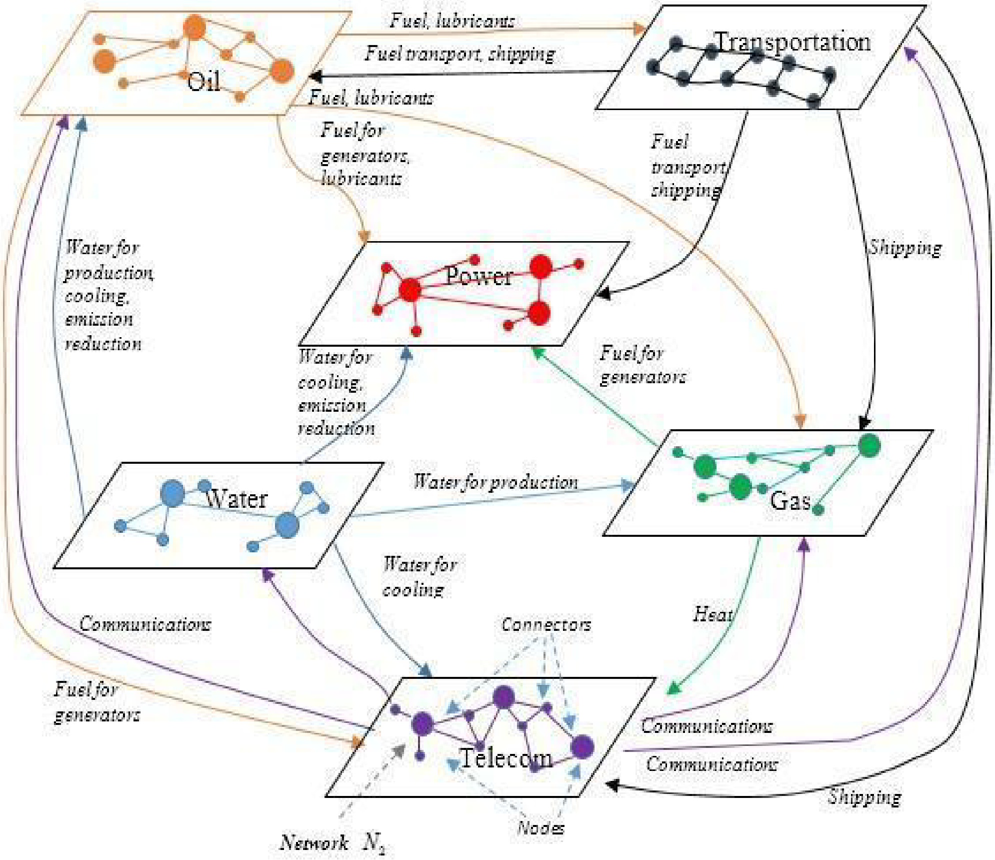

Figure 2: The model of infrastructures

Since decision-makers need to minimize risk to the target objects, they are interested to consider the values of these objects in dynamics. That is why, we must describe the property of vulnerability of various types of target objects as dynamic property.

The property of vulnerability is cumulative with respect to accumulation both positive and negative effects and recoveries. Consequently, the possibility of recovery function can also be considered as well as vulnerability accumulation property.

Within the frame of our research, the risk is related to CI objects having a geographical reference. The whole area of interest is characterized by a spatially distributed dynamic multi-risk assessment.

The authors' risk analysis approach is going to refine existing probabilistic approaches, which consider big areas (most commonly region-specific or country-specific) and large time (hundreds of years). The authors hope that their approach can improve the quality of the risk analysis by reducing its dependence on statistical samples.

Since events related to hazardous processes are mostly rare, such approaches are ungrounded while information about events is usually ambiguous, imprecise, incomplete, and inconsistent. We propose to represent a risk as a combination of the plausibility of hazard occurrence, intensity, and potential damage, to extend the definition of risk by adding a new component called threat, which describes spatiotemporal relation between active hazards and SES elements, and assess the possibility of threat and risk for each target object or area using soft rough-fuzzy sets.

The proposed combination of the interrelated spatial model, SES model, and the hazard dynamics model can be scaled both spatially and temporally. This makes it possible to consider the ongoing hazardous processes at a various spatial and time scales from the geotaxon level up to the region or country level. It allows different classes of stakeholders to enhance their understanding of the relationships and interactions of multiple hazards. This applies to cascading and compound hazards as well. Moreover, various types of societal, environmental, and other changes that drive hazardous processes over the considered territory, can be also well-understood by stakeholders. To reduce the risk, the decision-maker can select and introduce suitable coping capacities to protect important elements of the TSI.

Thus, the proposed multi-hazard risk model is dynamic and spatially distributed. It can then be applied to determine whether the newly introduced coping capacities have noticeably reduced the risk.

5. Event-based multi-hazard model

We propose to represent the multi-hazard model using an event tree. A sequence of consecutive events can be visualized as a branch of the tree. It usually represents “cause” – “effect” relationships. Such a tree allows analyzing multi-risks considering all possible types of relations between hazards such as compound hazards, cascades, spill-over effects, etc. [18].

The nodes of the event tree can be juxtaposed with the hazards. The arcs of the event tree reflect the causation of one hazard by another [18]. Such representation of a multi-hazard model will be called the representation on the macro-level.

At the micro-level, each node of the event tree reflects the hazard behavior, so its sub-tree can properly detail the macro-level (Fig. 3). Thus, at the second level of the spatial model the detailed sub-tree represents the model describing the spreading of the hazard over the grid of cells.

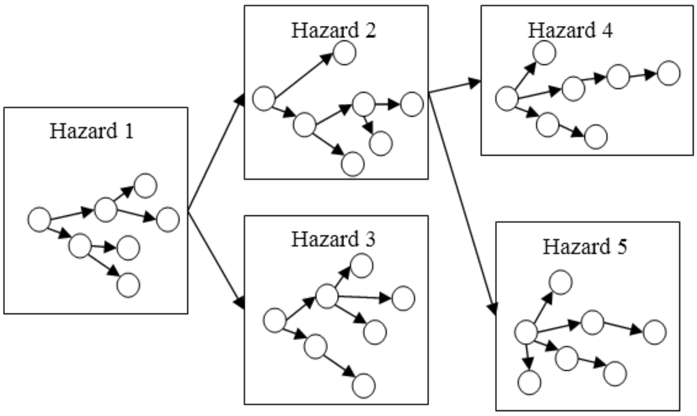

Figure 3: Macro and micro levels of multi-hazard model

Each cell can be described by a subset of attributes $w_t^{O_i} = \{a_{ij},...a_{im}\}$. Therefore, the cell’s state can be defined by $w_t^{O_i}$ at the time t. Of course, a certain cell can be treated as an entire object O_i.

Thus, modelling the behavior of hazard on the micro-level comes down to modelling the change of cells’ states. Let’s assume that when changing the state of the cell it goes through a sequence of ordered qualitatively different classes of states. Each class of cell’s states is characterized by specific laws of the state’s change. At the moment of state transition, the law of cell state’s behavior changes.

Cells’ state changes continuously, but a change of state’s class occurs discretely. Suppose $W = \{W_0,...W_F\}$ is a set of classes of the object’s states. If a value of a certain attribute $a_k \subseteq A_D$ of the object O_i changes at the time t, the corresponding state will also change. In some cases, it leads to a change of state class. We call this change an event and denoted it by ψ. Thus, we obtain $\psi : w_t^{O_i} \to w_{t+1}^{O_i}$, where $w_t^{O_i} \in W_j$, $w_{t+1}^{O_i} \in W_k$, $W_j, W_k \in W$, and $W_j \neq W_k$.

There can be a certain sequence of states’ classes that each object should pass through during the hazard. Let’s take as a case a cell modelling a part of a forest area under fire conditions. For such cell we can distinguish the following classes of states:

- heating forest fuel up to a burning temperature.
- pyrolysis of forest fuel by heat.
- starting to ignite.
- process of burning.
- attenuation.

Accordingly, hazard dynamics can be modelled as the transition of cell sate classes. It’s suggested to render such dynamics using event trees.

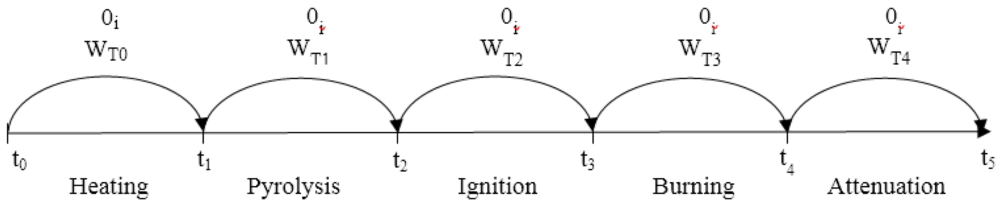

Figure 4: The sequence example of the class states

In this connection, for each class of hazards (such as fires, overflows, etc.) we propose to build a template of hazard dynamics in the form of multilevel plausible event tree (PET), which describes the relationships between all possible cell state classes in the form of transition from one class to another. Expanding the tree structure to multilevel one allows taking into account the influences of conditions of the external environment (for example, climate change) on the possibilities of transitions from one state class to another represented by tree arcs. The template must be flexible to be able to be adapted to any cell size and any external environment conditions.

Figure 5 shows the PETN template for modelling the hazard of a certain class, which consists of two levels. The PETN mainly represents sequences of cell state transitions with respect to the time and spatial locations. However, there are a wide range of relations (spatial, temporal, causal, etc.) between events and objects, which can also be adequately represented by PETN.

A significant advantage of PETN in comparison with other known approaches is that PETN can reference events both spatially and temporally. Thereby, PETN provide a dynamic model of the spatially distributed hazardous processes, which maps the events adequately.

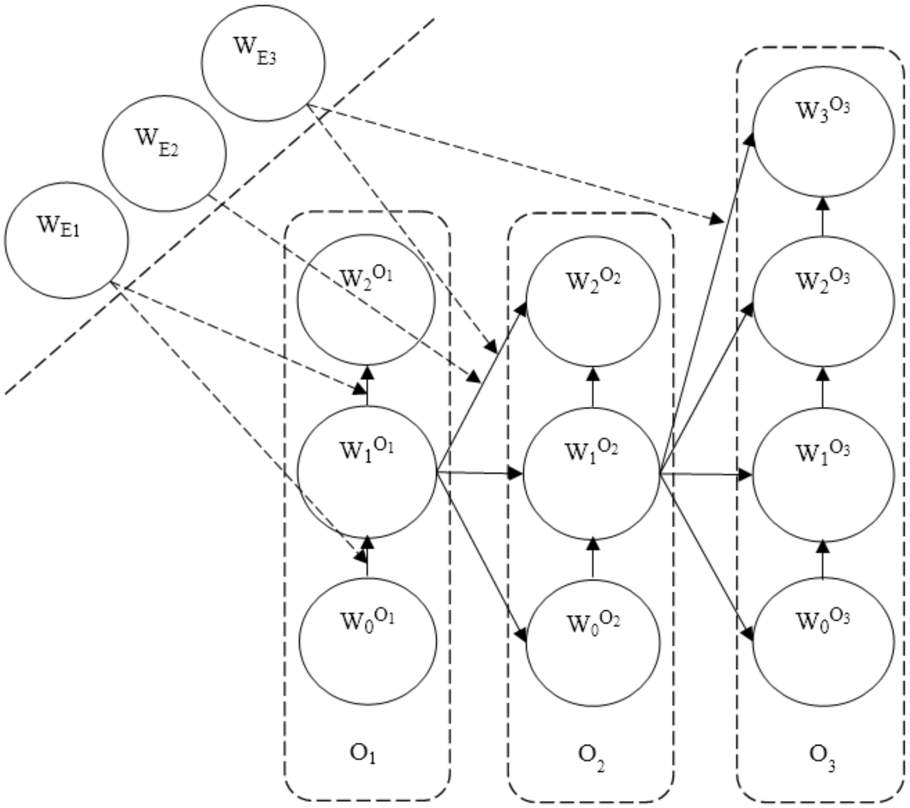

Figure 5: The network template for dynamics’ modelling of the destructive process

Since evaluation of observed parameters can often be incomplete and unreliable, PETN allow assessing the likelihood of events. The likelihood can be expressed by probability, possibility, fuzzy, or rough measures and their combinations. Such measures express a plausibility of the cell's transition from state to another state.

Another important advantage is that PETN can unite likelihood measures with time moments and spatial locations in one frame. As a result, PETN describes events independently on the uncertainty conditions, and provide more adequate representation of dynamic processes than other well-known approaches such as possibilistic or probabilistic.

PETN allows representing the multi-hazards' dynamics within territories of different types as plausibility of cell states' transitions and thereby ensures alternative scenarios to model of the situation dynamics.

The proposed PETN model is novel and applicable for the modelling of multitudes of interacting spatially distributed hazardous processes evolving in space and time. This applies well to disasters influenced by climatic or meteorological drivers, and natural disasters. Such disasters can dynamically interact causing cascading and composing effects. They often expose TSI objects to danger and risk.

6. The model of spatially distributed multi-hazard risk

There are several components of risk with respect to the target object such as object's vulnerability, potential damage, disaster intensity, and the current object state. Thus, risk $R_i(t)$ for each CI object O_i will be a combination of above-mentioned components at the time t.

Disturbing events within SES usually produce threats to the TSI elements. Such threats can be described by a certain plausibility measure that indicate a violation rate with respect to the common behavior of the SES. They reflect that the system is disturbed by the event of a certain type at a given location and in a specific time.

Vulnerability can be defined based on the nature of the object, which can usually be considered as the TSI element. From this point of view, vulnerability estimations can be defined differently for each particular type of disturbing events.

The vulnerability of an object to certain disturbing events determines the plausibility that these events will cause damages to this object if they occur at a specific location.

Consequence refers to the damages (deaths, injured, losses, etc.) caused by the disturbance succeeds. Disturbing events impact both people and SES. That is why danger, threat, and risk assessment are certain (and different) aspects of the same practical problem, namely the problem of assessing the chances of adverse events of an uncertain nature and its negative consequences.

As a result, multi-risk assessments in the conditions of multi-hazard is $\left\{R_i(t) \middle| \forall o_i \in O^*(t)\right\}$ at the time t. Clearly, these assessments are spatially distributed, dynamic, and can be an integrated measure of risk with respect to the target objects and their capabilities. Such integrated risk assessment allows decision makers to determine basic scenarios to overcome emerging threats using a set of already existing facilities to protect CI objects.

7. Examples of specific issues in Ukraine that need to be addressed

7.1. The issue of shallowing the Dnipro river

Global warming leads to snowless winters, which in turn cause a decrease in floodwaters, shallowing the rivers and lakes and thus they desiccate. Moreover, anthropogenic factors also create problems. For instance, such an anthropogenic factor as illegal sand mining leads to the Dnipro River shallowing: the soil moves towards the formed voids, the pits are tightened, but the river channel changes (see figure 6).

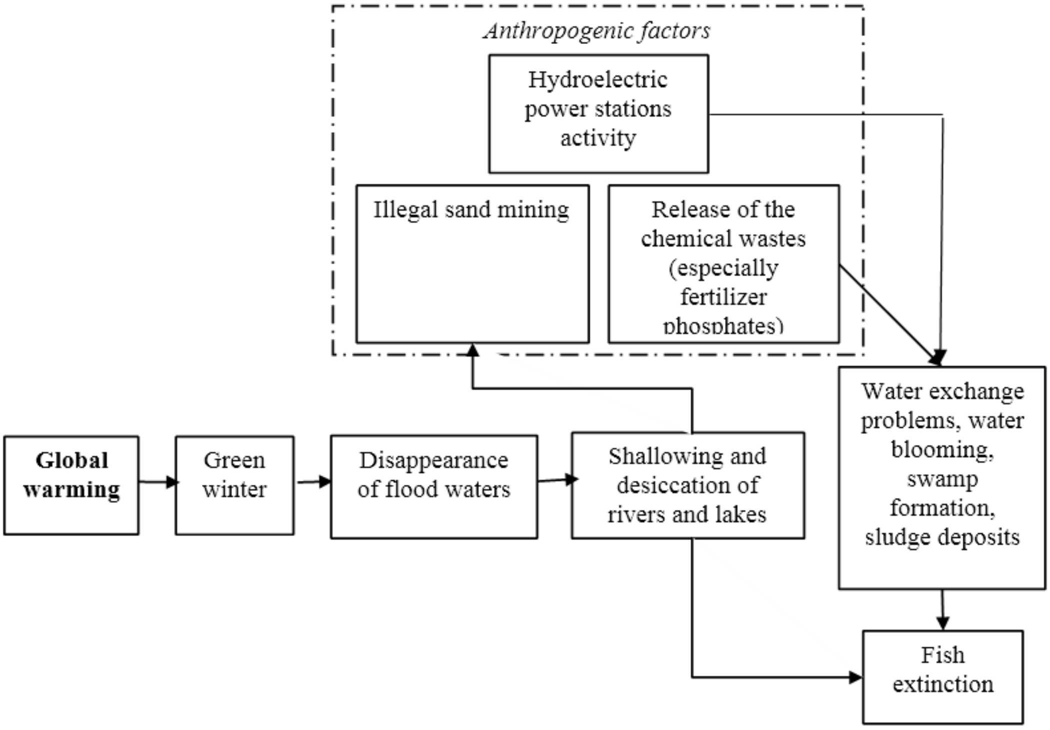

Figure 6: The event tree of river shallowing factors

The next set of issues is tightly associated with industrial, agricultural and domestic wastewater. Phosphates, which enter the Dnipro in unlimited quantities, become the main cause of water bloom. The decomposition products of algae absorb oxygen and evolve into an ideal breeding ground for bacteria and lack of oxygen result in fish extinction.

The normal existence of fish is hindered by obstacles that stand in the way of their migration, which is caused by a change in the chemical composition of the water caused by an increase in its temperature due to a slowdown in its flow due to the corresponding influence of hydroelectric power plants built on the river.

7.2. The deforestation issues

Here is the example of artificial coniferous forests planted around the Lower Dnipro Sands (Oleshky Sands) in the Kherson region, in Southern Ukraine. Those sands sometimes are qualified as a semi-desert. Sands are surrounded by dense coniferous forests planted to prevent dunes from moving. Despite the relatively small areas of the steppes, they are composed mainly of sand, so they often experience sandstorms.

The first reason leading to deforestation is global warming. Another reason is the increasing frequency of forest fires, the scale of which can already be regarded as a global disaster. In addition, forests are prone to insect infestations, which are destroying them at an increasing rate. A completely different reason is that the underground level of water is falling more and more, causing the forests to dry out, which leads to the desolation of forests covering large areas. Such territories gradually turn into sand deserts and causes the movement of sands (Fig. 7).

Unfortunately, in recent years, these processes have acquired a systemic character, significantly changing the natural landscape in many parts of the territory, which causes serious impacts on the ecosystem and affects slowly proceeding climate changes, exacerbating them.

7.3. The shallowing issue

Shallowing the rivers and lakes in Polissya (the northern part of Ukraine, both the part of the territory of Belarus and Poland) gives rise to fires in Chernobyl. Thereby, the ecological danger in the exclusion zone is caused by the presence of nuclear and radiation hazardous objects. Unfortunately, radioactive contamination can spread far beyond this zone, especially as a result of fires.

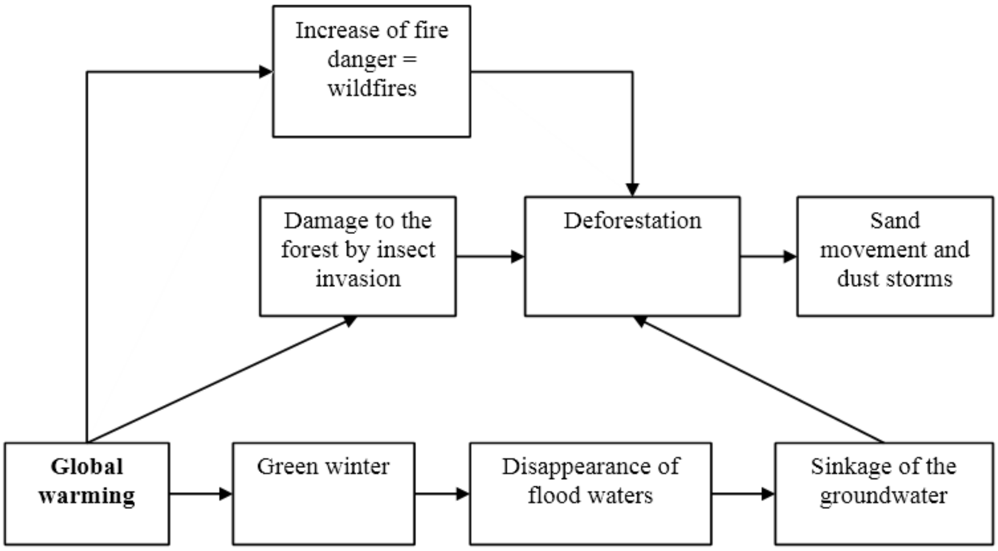

Figure 7: The tree-like primary factors of deforestation

Clearly, the ecosystem of the Kherson region suffers by itself, and, although it causes significant risks to human life, but does not pose an immediate threat to life and health of people. Unlike it, the ecosystem of the Chernobyl exclusive zone is under significant risk of the transfer of radioactive dust that settle down at the forests in this region. The influence of various factors such as strong winds and precipitation during large scale forest fires pose immediate and permanent risk to people health and life (Fig. 8).

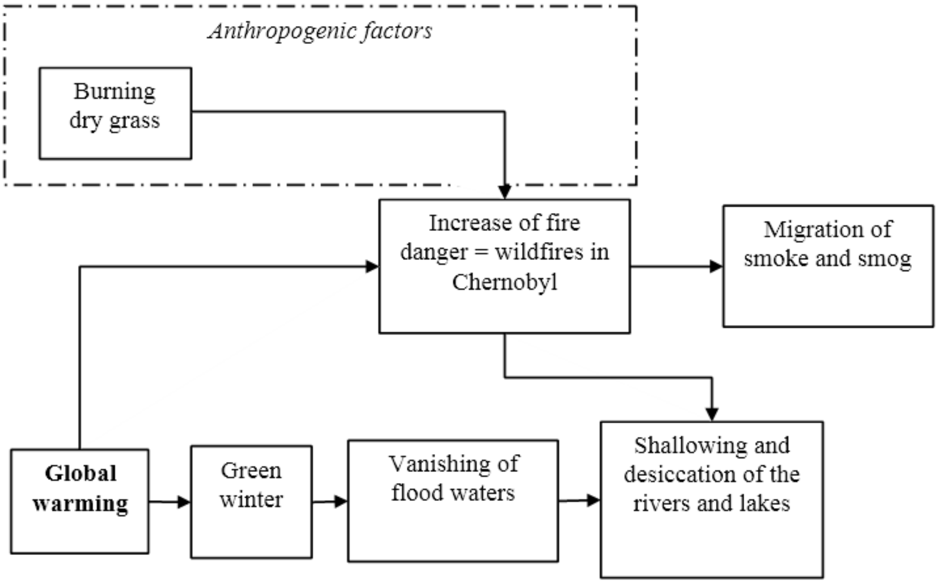

Figure 8: The chain reaction of global warming and anthropogenic factors interference

8. The Results of the Research

The multi-hazard event-based risk model has been realized as a software module using C++ language and PETN Library. This module contains a set of functions and procedures that allow defining events, their structures, and hierarchies, as well as represent various spatially referenced infrastructure objects and assign their value functions. The infrastructure hierarchies can also be defined based on the spatially referenced objects' definitions. The developed software module is intended for use in the decision support system, which aimed to assess spatially distributed dangers, threats and risk with respect to the defined objects. This DSS is based on geoinformation system and was developed with Python, Django, GeoDjango, PostGIS and PostgreSQL database.

The multi-hazard risk model has been approved and tested within the simulated spatial model of Kherson Area, Ukraine. The simulations of multi-hazard disasters have been carried out to assess dangers, threats and multi-risk posed to various objects (such as buildings, quarters, and regions) within the simulated area by multi-hazard disasters. During the experiment, the size of cells, which discretized the Kherson area spatial model, has been varied in the interval of 5 to 50 m. Thus, decision-support queries have been sent to the Decision Support System and their response time has been evaluated and averaged. The obtained result of the simulation is represented in Fig. 9.

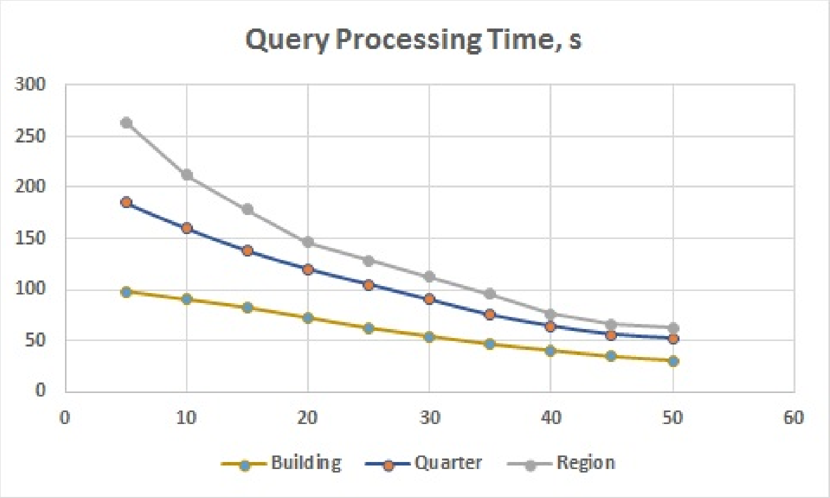

Figure 9: The simulation results

The adequacy of the multi-hazard risk model is confirmed by the above-mentioned experiment. During the simulations, the results have been obtained that allow us to assert that the decision-support system provides sufficient performance for the spatially distributed GIS-based multi-risk assessments. Thus, DSS allows to simulate multi-hazards that contain cascading and triggering effects such as shallowing of Dnipro river and lakes, as well as variety of deforestation issues, dehydration of water sources, etc. Of course, forest fires, tornadoes, sandstorms, and other disasters can be also considered.

Due to the sufficient efficiency of the proposed models, the decision-support system helps decision-maker timely assess threats and risks from emerging events for various infrastructures and objects spatially distributed in an analyzed area of interest.

9. Conclusions

In this paper, we have proposed the approach for multi-hazard risk analysis in cascade (domino) effects occurring in forests, sabulous surfaces, and rivers. It resembles a state-of-the-art technique that alleviates risk-and-threat determining, thus is cost-effective and more reliable than the previous one. We hope it will make the risk analysis nimbler and more precise, although not too overfitted.

The dynamic spatially distributed risk model proposed in the paper can be a theoretical basis of risk-oriented decision support in natural and man-made systems in natural emergencies. The proposed model provides sufficient spatial and temporal detailing. Representation of risk as a process allows to describe the dynamics of risk in real-time systems, gives a more complete picture of the nature of risk, allows to solve the problem of diagnosing the situation in natural and man-made systems and stimulates more informed decisions.

10.References

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