Situation Diagnosis Based on Multi-Hazard Risk Assessment

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Abstract

The paper proposes a method of situation diagnosis in natural and man-made systems to support real-time decision-making in conditions of disasters and multi-disasters. The situation diagnosis method is based on identifying the areas that contain valuable objects with an assessment of the value above a certain critical level, that are at maximum risk. The proposed method of diagnosing the situation is based on the disposition of the set of valuable objects at critical risk, the set of active disasters, and the set of manpower and resources for response operations. The result of applying the method is a categorization of the situations which allows decision-makers to quickly make adequate decisions in real time.

Keywords

Modelling, multi-risk assessment, wind erosion, dust storm, cascade effects.

1. Introduction

The sabulous, or arenaceous surfaces, such as sands and coasts are quite susceptible to wind erosion and movement. In the Kherson region, those are the Oleshky Sands, also known as Low Dnipro Sands that are located nearly 30 km east of Kherson and are the largest in whole Europe, of about 15 km long with five-meter dunes. It is believed that they were forming due to the moving of continental ice nearby the Dnipro River, which was brought from the north along the Dnipro and fetched plenty of soil, which remained after the melting of the glacier. This soil formed barriers and dams that separated the glacial lakes from the lower riverbed [1].

A couple of decades ago there was a polygon in the Oleshky Sands, and on the score of this, there is a risk of hidden explosives. Fortunately, the visitors are prohibited from visiting those areas; however, we will not consider such risks, at least for now, therefore let us return to the earlier-mentioned issues instead.

Initially, the sands were not meant to be here at all. However, in the late eighteenth century sheep began to be gazed here, which eliminated the grass, thereby freed the sands and, through wind erosion, they were able to move and shift along [1, 2].

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According to the temperature and precipitation frequency, the Oleshky Sands can be referred to as semi-deserts. There are some trees, such as pines and birches; the gooseberries, the short-haired cornflower, the thyme, the small-flowered tree, pine trees - ordinary and Crimean, as well as the apple tree, the hawthorn, and the white-bearded birch trees. There is also a lake located underground at nearly 300-400 metres; nevertheless, scientists have determined that it is better not to obtain water from it as its levels may lower and the forests will not be able to suppress sand moving and saltation [2].

The vegetation in the sands is lacking frequency, subsequently, the air in there heats up while the air humidity lowers, respectively. The climatic conditions are such that the sands can heat up to 70 degrees in summer! As a result, the raindrops evaporate immediately, and the rain frequency is less there than in any other area in that region.

Those above-mentioned indicators are just a drop in the ocean amongst numerous hazards and risk probabilities. It’s crucial to analyze risk from different hazards, their interactions, and cascading effects in the given area. This will allow us to diagnose the situation for decision making.

2. Related works

The multi-risk assessment problem is reflected in numerous scientific publications. For instance, J. C. Gill and B. D. Malamud [4] in their research studies consider an overview and visualization of the interactions between twenty-one natural hazards, consisting of six groups of risks, such as geophysical, hydrological, atmospheric, biophysical and space risks.

In this study, scientists highlight the importance of limiting the interaction of hazards and strengthening the importance of a holistic approach to the assessment of natural hazards. The authors showcased an analysis of the relationship between the intensity of the primary hazard and the intensity of the secondary. Another aspect of the hazard interaction that may be limited is the relationship between the primary hazard intensity and the secondary hazard intensity. Their approach helps those who study individual hazards in the context of other hazards and facilitates effective hazard analysis by workers working to reduce and manage disaster risk.

J. C. Gill and B. D. Malamud continued their research of hazard interactions and cascades within multi-hazard methodologies. The scientists examine the generalization of the differences between the single and the multilayer risk approaches that combine such interactions, emphasizing the importance of integrating interactions between different aspects of the Earth's system, as well as human activities, on an improved methodology of integrated support, when approaches with different risks support a holistic assessment of the potential risk of disaster. They advocate an approach that goes beyond simply superimposing multiple single hazards on an approach that also encompasses the interaction between these hazards.

In their previous study, the researchers took twenty-one different natural hazards and found as many as ninety possible interactions between four hundred and forty-one combinations. Authors consider the interactions that exist between natural hazards, anthropogenic processes and the environment; relationships that arise sequentially to form risk interaction networks called cascade effects or domino.

The scientists have also identified five possible types of hazards that can occur if a site is susceptible to many hazards, using four hazards: hurricanes, floods, landslides and volcanic eruptions as examples. The first ones are natural (geophysical) hazards that cause other natural hazards. Those are eruptions, avalanches, landslides, earthquakes etc. The next ones are hydrological, such as deluge or drought. As a third type, there are certain earth processes representing subsidence, heave and collapse of ground. The penultimates are atmospheric hazards (tornado, cyclones, hail, snow, lightning and thunderstorm). Finally, the wildfire relates to the last, biophysical type. Moreover, hurricanes can cause deluge, shifts, landslides; human activities also cause natural hazards: when building roads, a slope may occur and cause a landslide; deforestation can also exacerbate saltation and climate change. The third type is networks of the interaction of dangers, known as cascades. For example, a storm can cause hundreds of landslides, some of which can fill rivers up and cause floods that, in turn, can give rise to further landslides. The combination of at least two dangerous events is quite unpredictable as the threats demonstrate the limitations of assuming the independence of individual hazards in a multi-layered single-hazard approach, whereas technological failures and catastrophes are not usually the result of conscious choice or desired process.

The human factor is usually the deliberate result of conscious decisions that can eventually lead to serious consequences. Although such effects can often be managed through established procedures, anthropogenic processes often still lead to natural hazards. Thus, in the context of this article, technological hazards are perceived by researchers as unintentional.

There are many interactions between examples of hazards and processes described in the three groups: natural hazards, anthropogenic processes and technological disasters discussed above and specific sets of interacting hazards. It is here that the authors use the term interaction to denote the effects of one hazard or process on another hazard or process and distinguish trigger relationships (for example, an earthquake that caused a landslide; groundwater abstraction that causes subsidence); increasing the probability ratio (for instance, fire increases the probability of landslides; subsidence of the soil or increase the probability of flooding). Scientists have highlighted three different relationships between specific natural hazards, anthropogenic processes and technological hazards or catastrophes. In addition to paired relationships where one primary hazard causes a secondary natural hazard, these interactions can be combined to form a network of hazard interactions. This development of an improved risk assessment and characterization system will help better classify and respond to different types of hazards, improve the integration of interoperability networks into multi-hazard methodologies; conduce theoretical and practical understanding of hazards and reduce disaster risk.

Sanam K. Aksha, Lynn M. Resler, Luke Juran & Laurence W. Carstensen Jr. [5] in their research “A geospatial analysis of multi-hazard risk in Dharan, Nepal” discuss how to use geospatial and socio-economic data, to assess the various risks in Daran, Nepal. This study introduces a model for spatial risk assessment applied to a location for which the availability of spatial data is limited in terms of quality, quantity and access. The aim is to use relevant, publicly available geospatial data to assist local decision-makers in the efficient allocation of resources by developing a procedural model for compiling a composite risk map. The priorities of this study are mainly individual hazard assessments and social vulnerability assessments for the city of Daran.

The researchers considered landslides, floods and earthquakes for a comprehensive hazard assessment using statistical methods and the analytical process of the hierarchy. They used a social vulnerability index to create a vulnerability map of the study area, which was then combined with a multi-hazard map to create a general risk map. Their results indicate that eastern Daran along the Ceuta River and southwestern Daran on the left bank of the Sardis River are at high risk for many hazards. Central Daran and the hills in the western part of the city are classified as low-risk areas. In general, Nepal is susceptible to many natural hazards, ranging from regularly occurring hazards such as floods, landslides and avalanches, to less frequent but higher risks such as earthquakes.

To conduct the study, the scientists used a general linear model to assess the danger of landslides in Daran. To use the presence of the offset, the researchers superimposed individual hazard maps using a weighted overlay tool in ArcGIS to prepare an integrated hazard map of the study area. Since the study area is exposed to constant risk for all three types of hazards, the authors believe that each of them has the same relative importance and uses the same weight in the preparation of an integrated hazard map. Each hazard map was classified and then evaluated using the Jenks Natural Break classification method provided by ArcGIS.

Giulio Zuccaro, Daniela De Gregorio and Mattia F. Leone [6] describe multi-risk as cascade effects that are a timeline of consecutive events characterized by cause or effect relationships and time interaction among different phenomena independently generated by the same triggering event. The events in the timeline can be natural disasters, such as hurricanes, landslides, tsunami, deluge or anthropogenic - technological waste, arsons, attacks; there are also damages on exposure at risk.

The purpose of this paper is to develop an approach to diagnosing the situation based on a spatially distributed multi-hazard risk analysis. Such diagnostics provides decision-makers with information about the spatial distribution of risk, the distribution of the manpower and resources for response operations, based on which the situation refers to a certain class, reflecting the degree of its criticality.

3. Actual risks and their solutions

There are plenty of natural hazards and risks that endanger and put at risk all around.

Figure 1 integrates the information on natural hazards interactions and cascading effects that take place within the Oleshky Sands. In figure 1, climate change is depicted as the main cause of most hazards emerging recently. For instance, climate shifting leads to either heavy rains or green winters and droughts. It also lures a ton of pests and insects into the crop fields and steppes that may harm the harvest.

But anthropogenic factors are still present. These are deforestation, using fertilizers and chemicals, arsoning dry grass, sand mining and many more. Combining these two factors cannot guarantee any risk-free environment ever.

The works [7-10] present an approach to the analysis of spatially distributed multi-hazard risk based on an event-tree model of disaster spreading. The proposed event-tree model allows representing not only the propagation of individual disasters but also their interaction, including cascading effects (Figure 1).

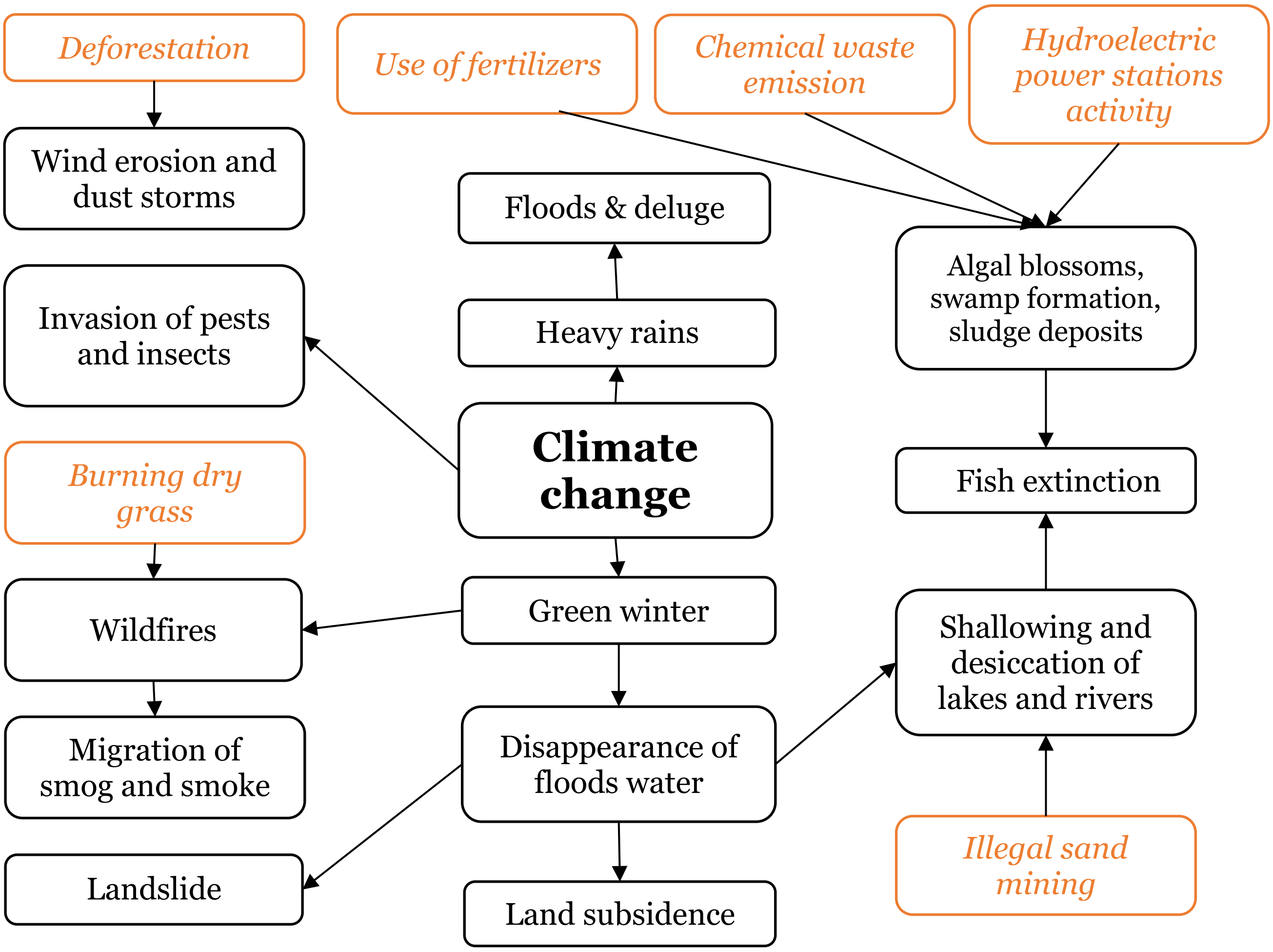

Figure 1: Ubiquitous cascading effects

4. Diagnosing the situation

A certain part of the territory in the conditions of catastrophe r at time t is characterized by an integrated dynamic spatially distributed assessment of multi-risk:

$$R^{t}_{\Omega} = \{R_i\,(t)\forall o_i \in O^{*}t)\}$$

Our task is to assign a set of characteristics to a particular class of situations $\check{S} = \{\check{S}_0, \check{S}_1, \dots \check{S}_n\}$. To do this, one must specify a set of classes of possible situations $\check{S}_1 \cup \check{S}_2 \cup \dots \cup \check{S}_n = \check{S}$. Let $p_{i,}\, i = 1, \dots, n$ be a set of possibilities for their occurrence and $X = \{x_1, x_2, \dots, x_m\}$ be a set of characteristics related to the classes of situations $\check{S}$. An integrated risk assessment for each class of situations $R_\Omega \in X$ is included in the characteristics set.

Let s^* be the current situation, and X^* be a vector of characteristics for the situation s^*. As a result of poor visibility, some characteristics of X^* may be vague or inaccurate. Let each characteristic of $x \in X$, $i = 1, \dots, m$ to have a range of possible values $E \cup e$, $i = 1, \dots, m$, e^* called the value of uncertainty. Characteristics from the vector X can be described by intervals using an approximate approach, intervals with membership functions using an interval fuzzy set, and some may be empty.

The diagnostic task is about identifying a possible class of situations $\check{S}^* \in \check{S}$ that can explain a set of indeterminate characteristics X^* for the current situation s^* and is the problem of pattern recognition [7]. Each situation corresponds to a specific point or neighbourhood of a point in the Cartesian space of characteristics. Each unrecognized situation that has characteristics should be mapped to a set of classes of possible situations $\check{S} = \{\check{S}_0, \check{S}_1, ..., \check{S}_n\}$. As a result of uncertainty in the estimates of some characteristics, it is not always possible to determine exact matches.

The situation in the destructive processes should be estimated based on the location of valuable objects, which are in conditions of maximum risk as well as the location of the concentration of ways and methods designed to eliminate natural emergencies. The set of areas on which the manpower and resources for response operations are located: $Z = \{z_1, z_2, ..., z_n\}$. Thus, to diagnose the situation of destructive processes at the time it is necessary to specify:

1) the set of valuable objects at critical risk: $O^*(t) = \{o_1, o_2, ..., o_k\}$;
2) the set of destructive processes: $F(t) = \{F_1(t), F_2(t), ..., F_i(t)\}$;
3) the set of the manpower and resources for response operations: $Z = \{z_1, z_2, ..., z_n\}$.

To diagnose the situation at the moment for each object $o \in O^*(t)$, it is necessary to estimate the minimum time t for which the contour of the destructive processes from the set $F(t)$ will reach this object, as well as the minimum time required to move assets from the nearest location. Each object corresponds to two sets: the set of time intervals for which the contours of the destructive processes will reach this valuable object $T_{o_iF} = \{t_{o_iF_1}, t_{o_iF_2}, ..., t_{o_iF_i}\}$ and the set of time intervals required to deliver ways and methods from their locations: $T_{o_iZ} = \{t_{o_iZ_1}, t_{o_iZ_2}, ..., t_{o_iZ_n}\}$.

The first set is dynamic. After setting for each object of these two sets, we need to find the smallest value of each set. After that, each valuable object will correspond to the pair: $t_{o_iF} = \min(T_{o_iF})$, $t_{o_iZ} = \min(T_{o_iZ})$. The situation in the destructive processes at the time is given by the set of the following pairs: $\check{S}^t = \{(T_{o_iF}(t), T_{o_iZ}(t)) \mid \forall o_i \in O^*(t)\}$.

We distinguish the following classes of situations in the detrimental activities:

1) a class of non-critical situations when there is enough time to deploy ways and methods to eliminate natural emergencies $\check{S}_1$: $(\forall o_i \in O^*(t))(t_{o_iF} > t_{o_iZ})$;

2) a class of critical situations, when the task of rescuing objects is difficult to achieve, hence, it is necessary first of all to direct ways and methods for any of the valuable objects the inequality is fair for $\check{S}_2$: $(\exists o_i \in O^*(t))(t_{o_iF} \leq t_{o_iZ})$;

3) a class of particularly critical situations when the task of rescuing objects may be unattainable: $\check{S}_3$: $(\forall o_i \in O^*(t))(t_{o_iF} > t_{o_iZ})$.

To present the information for a certain point in time, we constructed the risk surface that reflects a normalized assessment of the level of risk for each cell. The surface reflects the convex areas with maximum risk (Figure 2).

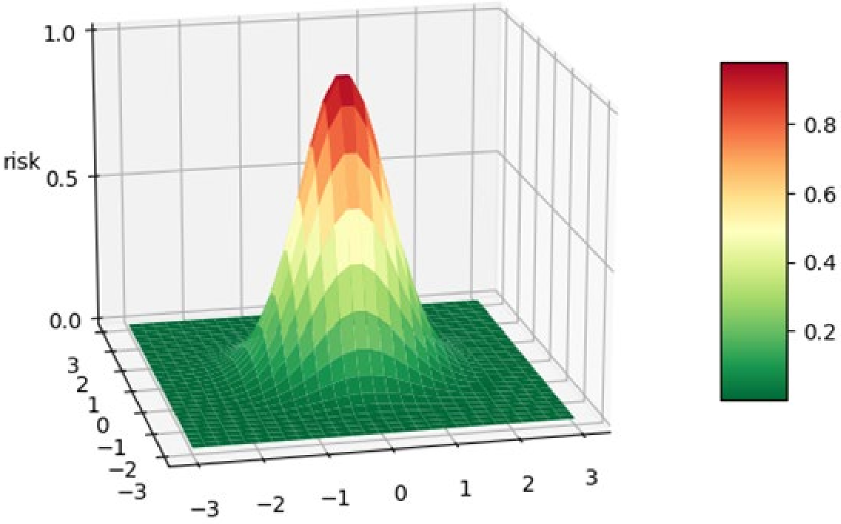

Figure 2: Risk assessment surface sketch

Such a surface can be constructed in dynamics for discrete sequential moments in time. A risk surface can be built both for active disasters that actually spread in time and potential disasters. This will allow making decisions at all stages of the disaster management cycle, from reactive actions to long-term adaptation and resilience building.

5. Conclusions

In this paper, we determined key concepts of situation diagnosis based on spatially distributed multi-hazard risk analysis. Solving the problem of situation diagnosis in natural and man-made systems is extremely important to support real-time decision-making in conditions of disasters and multi-disasters. The situation needs to be diagnosed in order to make adequate decisions to minimize the risks. To diagnose the situation, it is necessary to identify areas that contain valuable objects with an assessment of the value above a certain critical level, that are at maximum risk.

The proposed method of diagnosing the situation is based on the disposition of the set of valuable objects at critical risk, the set of active disasters, and the set of manpower and resources for response operations. The method allows separating the situation into different classes such as the class of non-critical situations when there is enough time to deploy ways and methods to eliminate natural emergencies, the class of critical situations, when the task of rescuing objects is difficult to achieve, the class of particularly critical situations when the task of rescuing objects may be unattainable, etc.

The method is intended for use in real-time decision support systems.

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