An Approach for a Complex Assessment of the Geo-ecological Risk from Natural Disasters in a Geographic Region

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Abstract: The paper proposes an approach for a complex assessment of the geo-ecological risk of a certain geographic region on the basis of quantitative and qualitative datum about the potential natural disasters. A fuzzy logic model is designed. The type of the threats, consequences and interdependencies between infrastructure objects are taken into account. The geographic region is considered as a complex system of interconnected and mutually influencing elements. The expected damages are directly and/or indirectly connected with life quality deterioration.

Keywords: Risk, Geo-ecological risk, Damages, Threats, Vulnerabilities, Natural disasters

INTRODUCTION

The analysis and assessment of the geo-ecological risk from natural disasters in a particular geographic region could bring to the avoiding or reduction of the consequences from the negative impact of different threat types [2].

The risk is an expected damage from the occurrence of a particular dangerous phenomenon (event or process) due to its intensity, time and place, as well as in correspondence with the vulnerability level of that place [1].

The geo-ecological risk for a given geographic region is bound to the possibility of oversetting its normal condition (damage, annihilation, disrupted functioning, capacity reduction, etc.) due to the occurrence of critical natural disasters.

In this paper, the complex assessment of the geo-ecological risk is taken as an integral measure for the level of negative impact of the natural disasters over the geographic region. Because of that the assessment of the geo-ecological risk is presented as a functional relationship between “Damages” and “Probability”.

The damages, that are related to the geo-ecological risk, depend on the vulnerability level of the geographic region and the threat strength, predetermined by the intensity of the natural disaster, i.e.
Damages = F(Vulnerability, Threat).

The vulnerability reflects the natural capacity of the given geographic region to withstand any natural disaster.

The threat reflects the potential danger for a possible occurrence of a natural disaster with a given intensity.

The threat occurrence probability takes into account the occurrence frequency of a given natural disaster for a fixed time period in the investigated threat geographic region.

In the risk assessment, the consequences from the threats are subjected to a preliminary quantitative and/or qualitative assessment. It is assumed that there is information for the threat frequency (probability) and intensity, as well as for the strength of the damages.

It is necessary to emphasize, that the geo-ecological risk assessment of the geographic region is done under subjective and uncertain conditions. This justifies the usefulness of applied intelligent assessment methods with fuzzy logic [3].

The purpose of the paper is to propose an approach for a complex assessment for a geo-ecological risk of a certain geographic region on the basis of quantitative and qualitative information for potential natural disasters. The approach is based on fuzzy logic, by which the subjectivity in the expert knowledge and indefiniteness of quantitative data.

**A FUZZY LOGIC APPROACH FOR A COMPLEX ASSESSMENT OF THE GEO-ECOLOGICAL RISK**

The proposed approach for a complex assessment of the geo-ecological risk in a given geographic region comprises several stages.

**Vulnerability Determination of the Geographic region**

Vulnerability determination of a given geographic region is performed. It is assumed that the vulnerability depends on the peculiarities of the geographic region that in the greatest extend influence the damages from a natural disaster.

Most frequently the following geographic peculiarities are analyzed: geological structures, rock and soil moisture, level of underground waters, landslides, mud-rock flows, swamps, deforest, etc.

**Threat Definition for a Geographic region**

Threat (dangers) definition for the given geographic region is performed, that are related with damages with determined intensity. The natural disasters directly affect the condition of the natural environment.

The most common natural disasters over the territory of our country are presented in the following table.
### Geographical Environment and Resources

#### Natural Disasters

<table>
<thead>
<tr>
<th>N</th>
<th>Disaster</th>
<th>Basic Criteria</th>
<th>Striking Factor and Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Earthquakes</td>
<td>Force or intensity – up to Magnitude 12</td>
<td>Soil dislocation, cracks, landslides, fires, destruc-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>tions, human casualties</td>
</tr>
<tr>
<td>2</td>
<td>Landslides, landslips</td>
<td>Mass, speed of flow</td>
<td>Masses of rocks, material losses</td>
</tr>
<tr>
<td>3</td>
<td>Mud-rock flows (seli)</td>
<td>Mass, speed of flow</td>
<td>Mud-rock flow, material losses</td>
</tr>
</tbody>
</table>

#### Hydrological Processes and Phenomena

<table>
<thead>
<tr>
<th>N</th>
<th>Disaster</th>
<th>Basic Criteria</th>
<th>Striking Factor and Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Floods</td>
<td>Increase river levels</td>
<td>Flooded riverside areas, material losses, human cas-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>sualties</td>
</tr>
<tr>
<td>2</td>
<td>Dry spells</td>
<td>High temperatures and low humidity</td>
<td>Agricultural damages, decreased soil fertility, fires</td>
</tr>
<tr>
<td>3</td>
<td>Snow flows and glaciations</td>
<td>Over 20 mm rainfall for 12 hours</td>
<td>Snowdrifts – complications in the road</td>
</tr>
</tbody>
</table>

#### Meteorological Processes and Phenomena

<table>
<thead>
<tr>
<th>N</th>
<th>Disaster</th>
<th>Basic Criteria</th>
<th>Striking Factor and Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Strong wind</td>
<td>Speed over 15m/s</td>
<td>Material losses</td>
</tr>
<tr>
<td>2</td>
<td>Tornado phenomena</td>
<td>Speed over 30m/s</td>
<td>Material losses</td>
</tr>
<tr>
<td>3</td>
<td>Dust storms</td>
<td>High temperatures, low humidity, dust</td>
<td>Agricultural damages, decreased soil fertility, fires</td>
</tr>
<tr>
<td>4</td>
<td>Hailstorms</td>
<td>Size of ice grains, intensity</td>
<td>Agricultural damages</td>
</tr>
<tr>
<td>5</td>
<td>Wet snow</td>
<td>Amount and moisture content of snow</td>
<td>Damages over forests, fruit gardens, electro con-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ductive network</td>
</tr>
<tr>
<td>6</td>
<td>Fog</td>
<td>Horizontal vision - below 500 m</td>
<td>Transport, air purity</td>
</tr>
<tr>
<td>7</td>
<td>Silver thaw</td>
<td>Intensity</td>
<td>Transport, Agriculture</td>
</tr>
<tr>
<td>8</td>
<td>Fires</td>
<td>Temperature</td>
<td>Thermal impacts, material losses, biosphere and soil</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>damages</td>
</tr>
</tbody>
</table>

Criteria exist for each natural disaster type, with which the damage intensity is determined, that is used for characterization of the expected threat.

Most frequently the strength of the natural disasters is classified as a Small, Medium, Large and Catastrophic intensity.

**Damage assessment for a geographic region from a natural disaster**

A damage assessment for the analyzed geographic region with a determined vulnerability level is performed when a natural disaster with a different intensity occurs.
The $D_1$, $D_2$, $D_3$ and $D_4$ variables are introduced, which describe the potential damages when a natural disaster occurs, correspondingly with a small, medium, large and catastrophic intensity.

It is assumed that the values of the variables $D_i$, $i=1,...,4$ vary from zero to ten in order to achieve an uniformity and comparability between the expert assessments of the potential damages due to different natural disasters.

**Probability calculation for the natural disaster occurrence with a defined intensity**

The probability calculation for a natural disaster occurrence with a given intensity is performed.

The accumulated quantitative information (a priori and a posteriori) and expert knowledge for threat types with different intensity is used.

It is proposed the probability assessments to reflect the possibility for the occurrence of different natural disasters within one year period.

The $P_1$, $P_2$, $P_3$ and $P_4$ variables are introduced which represent the occurrence probability for a given natural disaster, correspondingly with a small, medium, large and catastrophic intensity.

**Determined assessment of the geo-ecological risk**

A variable $GER$ is introduced which represents a complex assessment of the geo-ecological risk of the observed geographic region from natural disasters with different intensities.

The determined complex assessment of the geo-ecological risk, $GER$, is calculated as follows:

(1) \[ GER = P_1.D_1 + P_2.D_2 + P_3.D_3 + P_4.D_4 \]

It is important to emphasize that the calculation of the geo-ecological risk for a given geographic region is performed in the conditions of subjectivity and incomplete definiteness.

The assessment of the potential damages, $D_i$ as result of the occurrence of a certain natural disaster is based on an incomplete quantitative information and subjective knowledge of the experts regarding the region vulnerability and the intensity of the observed threat.

The intensity assessments themselves for a certain natural disaster are also represented with linguistic variables (*Small*, *Medium*, *Large* and *Catastrophic* intensity), which are by themselves qualitative, rather than quantitative variables.

The indicated peculiarities for the assessment of the geo-ecological risk quite naturally lead to the idea for the inclusion of the fuzzy logic approach, which accounts for the subjectivity and indeterminateness.
Fuzzy logic assessment of the geo-ecological risk

The idea is to develop a fuzzy logic model that describes quite well the subjectivity in the assessments of different experts regarding the size of the potential damages for a geographic region with a various intensity of the natural disaster.

In fact the proposed fuzzy model should be taken as a complex assessment for the level of the geo-ecological risk from natural disasters in a given geographic region.

In the current paper the fuzzy logic model is established on the basis of a determined functional dependency (1), in which the potential damages of \( D_j, \ i = 1, \ldots, 4 \) and the complex assessment of the geo-ecological risk \( GER \) are defined as linguistic variables.

Five values for the linguistic variables \( D_j, \ i = 1, \ldots, 4 \) are introduced to reflect five levels for each of the four types of damages.

The proposed five levels of damages are set with five fuzzy subsets, correspondingly: Very small, Small, Medium, Large and Very large.

All linguistic variables vary in the \([0, 10]\) interval and they are set with a trapezoid member functions (see Figure).

A node point vector \( \alpha = (\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5) \) is introduced, which in the particular case has the following form: \( \alpha = (1,3,5,7,9) \).

Each \( D_j, \ i = 1, \ldots, 4 \) variable has a corresponding membership function \( \mu_{ij}, \ j = 1, \ldots, 5 \) to the five fuzzy subsets.

The membership function \( \mu_{ij} \) are defined with the following formulae:

\[
\mu_{i1} = \begin{cases} 
1, & 0 \leq D_i < 1.5 \\
10(2.5 - D_i), & 1.5 \leq D_i < 2.5 \\
0, & 2.5 \leq D_i \leq 10 
\end{cases} \\
\mu_{i2} = \begin{cases} 
0, & 0 \leq D_i < 1.5 \\
10(D_i - 2.5), & 1.5 \leq D_i < 2.5 \\
1, & 2.5 \leq D_i < 3.5 \\
10(4.5 - D_i), & 3.5 \leq D_i < 4.5 \\
0, & 4.5 \leq D_i \leq 10 
\end{cases}
\]
For the linguistic variable – complex assessment of the geo-ecological risk $GER$, five levels are introduced too, as shown in the following Table:

<table>
<thead>
<tr>
<th>GER intervals</th>
<th>Levels of the geo-ecological risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>$8 \leq GER \leq 10$</td>
<td>“Very large geo-ecological risk”.</td>
</tr>
<tr>
<td>$6 \leq GER \leq 8$</td>
<td>“Large geo-ecological risk”</td>
</tr>
<tr>
<td>$4 \leq GER \leq 6$</td>
<td>“Medium geo-ecological risk”</td>
</tr>
<tr>
<td>$2 \leq GER \leq 4$</td>
<td>“Small geo-ecological risk”</td>
</tr>
<tr>
<td>$0 \leq GER \leq 2$</td>
<td>“Very small geo-ecological risk”</td>
</tr>
</tbody>
</table>

The complex assessment of the geo-ecological risk on the basis of the proposed fuzzy logic model is calculated as follows:

$$GER = \sum_{i=1}^{4} \sum_{j=1}^{5} \alpha_{ij} \mu_{ij}.$$ 

(3)  

The obtained value for $GER$ shows the level of the geo-ecological risk in the observed geographic region.

CONCLUSIONS

The proposed fuzzy logic model produces a complex assessment for the geo-ecological risk that is comparative to the corresponding summary assessment of the experts (geologists, hydrologists, meteorologists, financiers, ecologists, etc.).
REFERENCES