Fuzzy Logic Model for Natural Risk Assessment in SW Bulgaria

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Abstract. Assessing the natural risk is a major issue for the responsible risk management and the sustainable regional development of SouthWestern Bulgaria. The paper presents a fuzzy logic model for complex estimation of the natural risk in the SW Bulgaria region, based on the available information sources and the expert knowledge. The risk assessment problem is defined as a multicriterial task that evaluates several input variables (indicators for natural hazards). A hierarchical fuzzy logic system with four inputs and one output is designed in the Matlab software environment using Fuzzy Logic Toolbox and Simulink. The simulation investigations are done for five geographic areas in SW Bulgaria. The areas are ordered by the decreasing degree of complex natural risk. This fuzzy system is part of the Web Integrated Information System for risk management of natural disasters which will be developed.

Keywords: risk management, risk assessment, fuzzy logic model, natural hazards, Europe, SW Bulgaria

1. Introduction

Despite tremendous progress in science and technology, natural phenomena considerably affect the socioeconomic conditions of all regions of the globe. Natural events such as earthquakes, landslides, floods, etc. are commonly known as natural hazards. The monitoring of natural hazards, the evaluation of their impact and the general risk assessment are decisive steps towards the selection and dimensioning of adequate protective measures. Since the 1960s, natural disasters worldwide have more than tripled and economic losses have increased more than eight-fold [1].

Located on the Balkan peninsula, SE Europe, Bulgaria is a country (covering 111 000 km^2 with 7.4 million inhabitants) exposed to natural hazards, such as earthquakes, floods, landslides, debris flows, forest fires, hail storms, rock falls, snow avalanches, storm surge and wind storms [2]. Southwestern (SW) Bulgaria is the region with the most expressed tectonic and seismotectonic activity on the whole territory of the country. The existence of a set of active faults is one significant feature of this region. Besides with the seismic activity, which is concentrated in the Krupnik-Kresna area, the combination of many endogenous and exogenous factors (recent vertical crustal movements, erosion and ground water level fluctuations) provoke the activation of gravitational processes [3, 4, 5, 6, 7].

A region in SW Bulgaria where an international transport corridor № 4, connecting Eastern Europe with Greece (see Fig. 1) is studied in this paper. The road highway E79, railway line and gas pipeline along the Struma River are a part of the national critical infrastructure. Hence, there is a need for a risk management to be performed in respect to the natural hazards. In conditions of global economic crisis and limited financial resources the efficient prevention and risk mitigation require the decision making process to based on the comprehensive investigations and complex risk assessment.

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There are many qualitative and quantitative methods for the complex risk assessment. However, it is necessary to point out, that the natural risk assessment is done under the subjective and uncertain conditions. The intelligent methods are an appropriate tool for natural risk assessment. These methods using the fuzzy logic theory provide adequate processing of the expert knowledge and uncertain quantitative data [8, 9].

The aim of this paper is to propose a fuzzy logic model for natural risk assessment in SW Bulgaria using the available information and the expert knowledge. The natural risk of the studied region is assessed based on the seismic and geological hazards taking into account the potential flood threats. The studies for five local areas Dupnitsa, Blagoevgrad, Simitli, Kresna and Sandanski in SW Bulgaria (see Fig.1) are performed. The fuzzy logic model is designed in the Matlab software environment as a hierarchical system with four inputs and one output. The obtained results can support the natural risk management.
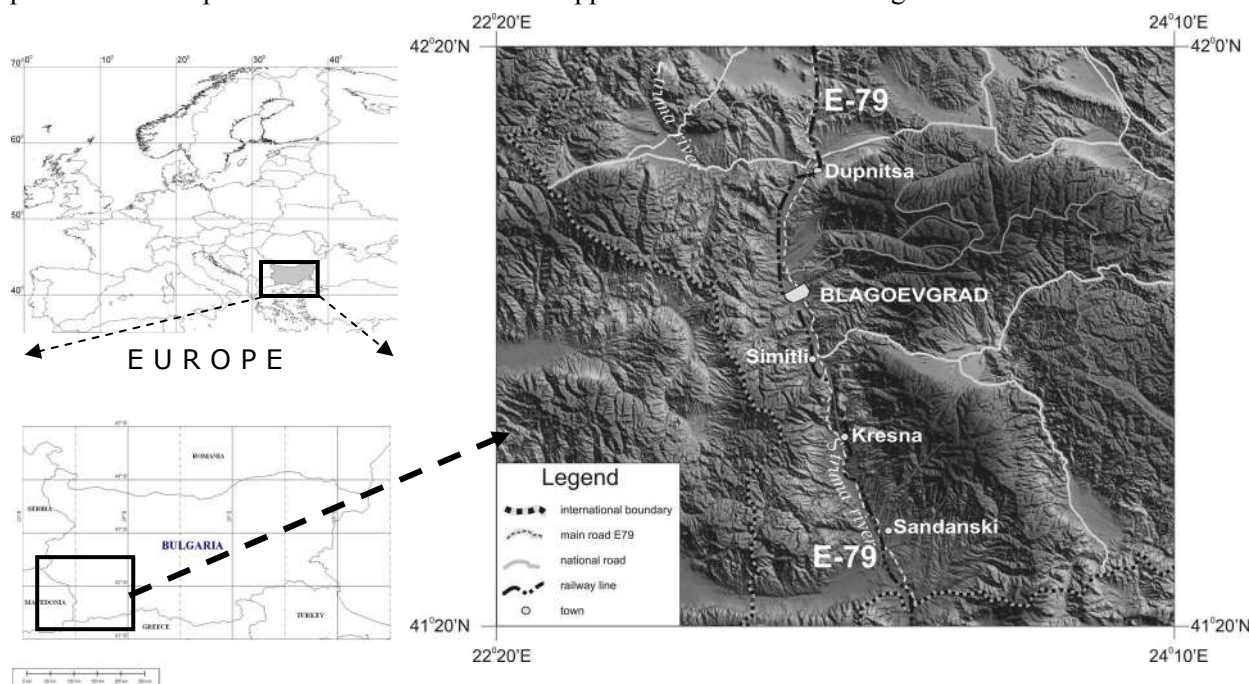

Fig.1: Location of the studied region.

2. SW Bulgaria Region and Data Sets

Bulgarian territory is characterized by high level of seismic hazard and this assessment is based on the large number of strong and weak earthquakes, some with significant catastrophic consequences in the recent past. The present-day weak seismicity, as monitored by the National Operational Telemetric System for Seismic Information network indicates the formation of two seismic zones with obvious differentiation as one of them is a large active polygon spread over one-third of SW Bulgaria. The strongest earthquake with magnitude M=7.2 in SE Europe occurred on April 4, 1904 and this value is accepted in the world earthquake catalogues. It is well known as Kroupnik earthquake [2, 6, 7].

Over the last century several big and destructive landslides have been observed with different degree of the landslide hazard, as parts of them have happened in SW Bulgaria. In this region the manifestation of active landslides and mud-rock falls can be closely connected with the contemporary tectonic activity, the erosion and the rainfalls [3, 5]. The Simitli graben is one of the typical landslide zones in SW Bulgaria.

The particular information and the expert knowledge for the natural hazards mentioned above are available in the form of the thematic maps (for example: seismic hazard, geological hazard, gravitational processes), the quantity statistical data and the quality expert evaluations. In this paper, the natural risk is assessed for the Dupnitsa, Blagoevgrad, Simitli, Kresna and Sandanski areas located from north to south of the international transport corridor № 4 along the Struma River (Fig. 1). These areas are characterized with different level of vulnerability according to the natural hazards typical for the studied region.

3. Fuzzy Logic System for Environmental Risk Assessment

The fuzzy logic model is designed as a hierarchical structure with several inputs and one output [9]. The number of inputs corresponds to the linguistic variables (indicators), which described the natural hazards. The output represents a complex risk assessment.

In this study, four indicators for the natural risk assessment for the SW Bulgaria region are defined using the expert knowledge and published thematic maps for the seismic, gravitational, geological and flood hazards [1, 3, 4, 6]. The indicators of the fuzzy logic model are input variables of the designed fuzzy system. The fuzzy system inputs are defined as follow: Input 1 "Landslides" (landslips, creep); Input 2 "Mud-rock flows"; Input 3 "Floods"; Input 4 "Seismic hazard".

The proposed fuzzy logic model is designed as a three-level hierarchical fuzzy system with previously defined four inputs. The every level includes one fuzzy logic subsystem with two inputs. The fuzzy logic system output gives the complex assessment of the natural risk in studied region of the SW Bulgaria. A scheme of the three-level hierarchical fuzzy system is presented on Fig. 2.
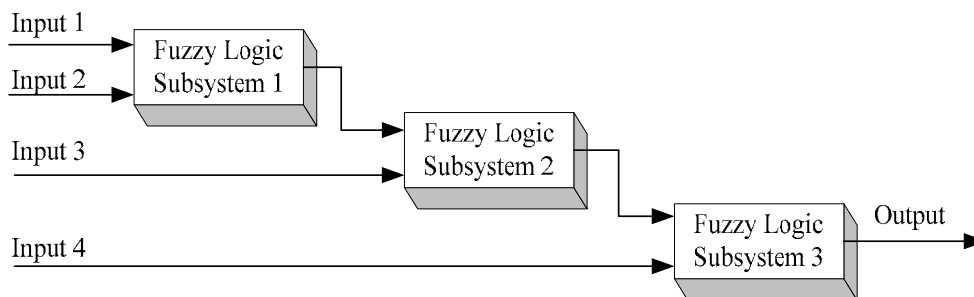

Fig. 2: Three-level hierarchical fuzzy system.

The inputs of the first fuzzy logic subsystem are Input 1 "Landslides" and Input 2 "Mud-rock flows", and the linguistic output variable is defined as Intermediate variable 1 "Gravitational processes".

The inputs of the second fuzzy logic subsystem are Intermediate variable 1 "Gravitational processes" and Input 3 "Seismic hazard", and the linguistic output variable is defined as Intermediate variable 2 "Geomorphological processes".

The inputs of the third fuzzy logic subsystem are Intermediate variable 2 "Geomorphological processes" and Input 4 "Floods". The output of the fuzzy subsystem is output of the whole fuzzy system. This output variable gives the complex natural risk assessment relevant to the defined four input indicators. The value of the complex assessment is a criterion for final decision making about the degree of natural risk for the studied regions. The higher value corresponds to the higher risk degree.

4. Design of Fuzzy Logic Model

Inherently qualitative features of indicators are rather quantitative values, which are usually represented by linguistic variables. Information and decision are closely linked and different methods exist to make a decision on the basis of imperfect information. Expertise is always required to define the types of possible phenomena, to assess the natural hazard and risk levels and to propose prevention measures. Expert judgements depend on quality and uncertainty of the available information that may result from measures, historical analysis, subjective testimonies, possibly conflicting, and assessments done by the experts themselves.

In fuzzy logic system the input linguistic variables (four indicators and two intermediate) are represented by three fuzzy membership functions: "Low", "Middle", and "High". The input variables are assessed in the interval [0, 10] using trapezoid membership functions. The fuzzy logic system output (complex risk assessment) is described by five fuzzy membership functions: "Very low", "Low", "Middle", "High", and "Very high". The complex natural risk is assessed in the interval [0, 100] using triangular membership functions. The input and output membership functions are shown in Fig. 3.
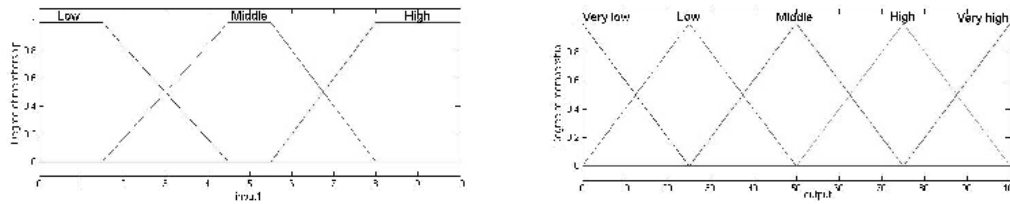
Fig. 3: Membership functions of the input indicators and the fuzzy system output.

The inference rules in the fuzzy logic system are defined through "IF - THEN"-clause. Rule numbers of the knowledge base per each of the fuzzy logic subsystems are 9. Some of the inference rules are defined as follow:

IF "Landslides" is "High" and "Mud-rock" is "Middle" THEN "Gravitational processes risk" is "Middle";

IF "Gravitational processes risk" is "Low" and "Floods" is "Middle" THEN "Geomorphological processes" is "Low";

IF "Gravitational processes risk" is "High" and "Floods" is "Middle" THEN "Geomorphological processes" is "High";

IF "Geomorphological processes" is "Low" and "Seismic hazard" is "Low" THEN "Natural hazards" is "Very low";

IF "Geomorphological processes" is "Low" and "Seismic hazard" is "High" THEN "Natural hazards" is "Middle";

IF "Geomorphological processes" is "High" and "Seismic hazard" is "High" THEN "Natural hazards" is "Very high".

The fuzzy logic hierarchical system is designed in Matlab environment using Fuzzy Logic Toolbox and Simulink. The three fuzzy subsystems are built in the Mamdani type fuzzy inference system. The inference surfaces in 3D for the three fuzzy logic subsystems are given on Fig. 4.
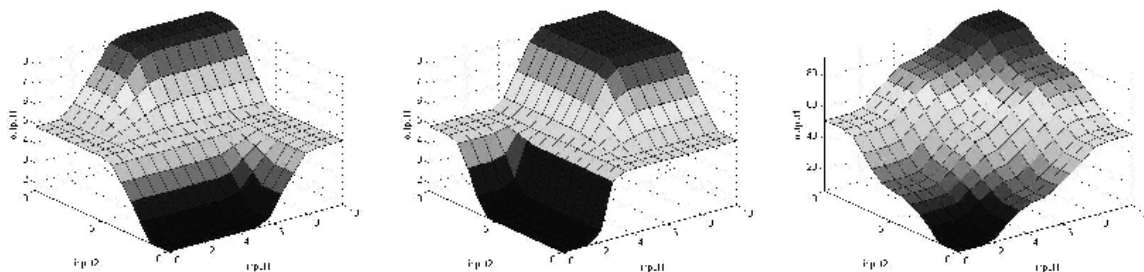

Fig. 4: Surfaces of the fuzzy logic subsystems.

5. Fuzzy Logic Model Application

Risk-base prioritization incorporates the scientific decision making aspects, such as vulnerability estimation (value of indicator), and potential damage value, such tolerance to the consequence of failure. The definition of risks zones is based on the extrapolation of historical information known on particular natural hazard events using morphology based analysis. The designed fuzzy logic model is used to assess the natural risk of five areas in the SW Bulgaria region. These areas - Dupnitsa, Blagoevgrad, Simitli, Kresna and Sandanski - are exposed to the several types of the natural hazards. Values of indicators represent integrate evaluations based on expert knowledge and analysis of the quantity information. Particular indicator values for each of the five local areas are supplied for relevant inputs of the fuzzy logic system and four simulations are performed. Input data and output obtained results are presented in Table 1.

The results show the Kresna area has the highest value of the complex natural risk according to the defined input indicators. The areas ordered by the decreasing degree of natural risk are Simitli, Dupnitsa and Blagoevgrad respectively. The complex natural risk is lowest for the Sandanski area.

Therefore, the Kresna and Simitli areas have a high vulnerable level according to the considered natural hazards. For this reason, the stakeholders have to take the relevant management decisions to mitigate the potential dangerous consequences by priority for these local areas.

Table 1: Input data and simulation results

Criterion	Input 1 Landslides	Input 2 Mud rock	Input 3 Floods	Input 4 Seismicity	Evaluation
Dupnitsa area	8	8	6	7	72
Blagoevgrad area	6	6	5	8	63
Simitli area	9	8	7	9	86
Kresna area	7	10	8	10	92
Sandanski area	6	4	4	7	53

The fuzzy logic model is designed using only four natural hazard indicators. Further research is needed particularly regarding the implementation of additional indicators (meteorological, hydrological, etc) and expanding the inference rules for obtaining the more comprehensive risk assessment of the studied region.

6. Conclusions

A fuzzy logic model for complex assessment of the natural risk in five regions of the SW Bulgaria is proposed. The natural risk of the studied regions is assessed using available map information and the expert knowledge for seismic hazards, geological processes, and potential flood threats. The fuzzy logic model is designed as a hierarchical system with four inputs and one output in Matlab software environment using Fuzzy Logic Toolbox and Simulink. The simulation investigations are done for five geographic areas in SW Bulgaria (Dupnitsa, Blagoevgrad, Simitli, Kresna and Sandanski). The risk assessment results contribute for increasing the risk management efficiency and can support the stakeholders to take more informed decisions for the sustainable regional development of SW Bulgaria. The designed fuzzy system is part of the Web Integrated Information System for risk management of natural disasters which will be developed.

7. References

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