Modeling processes of seismological phenomena in the Carpathian region

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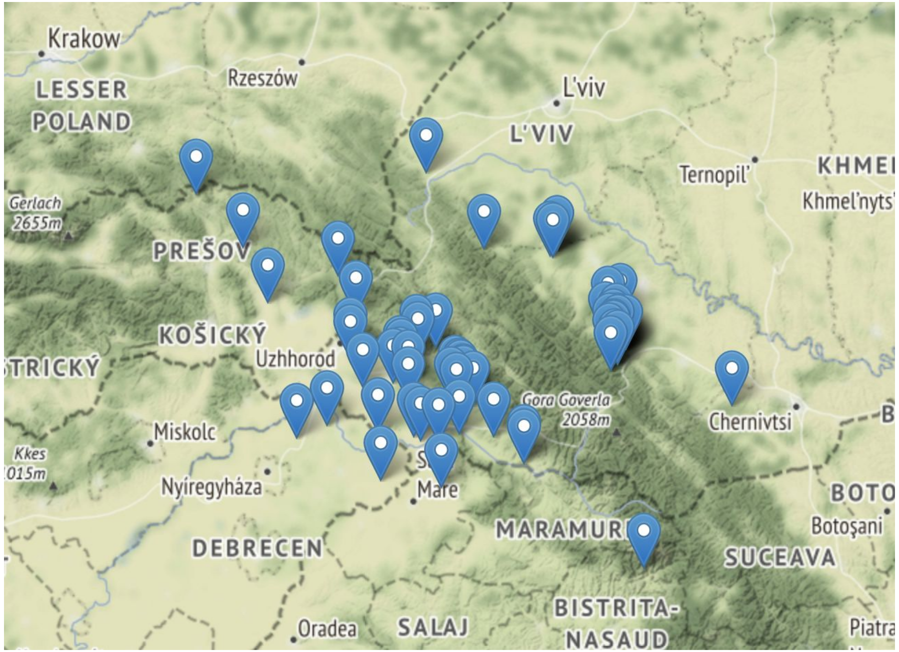
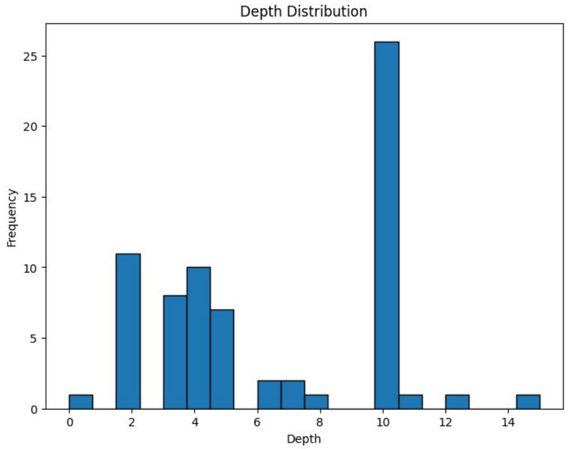
1. Overview of the problem

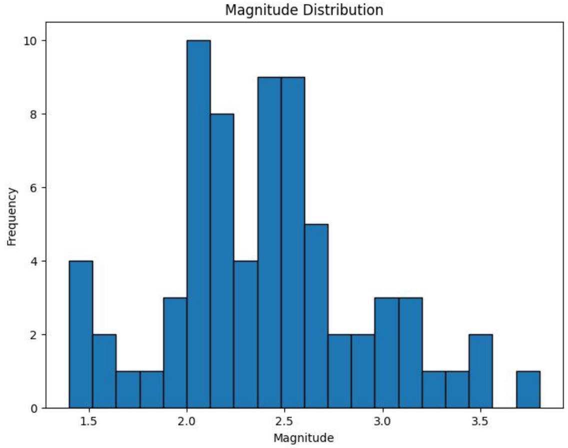


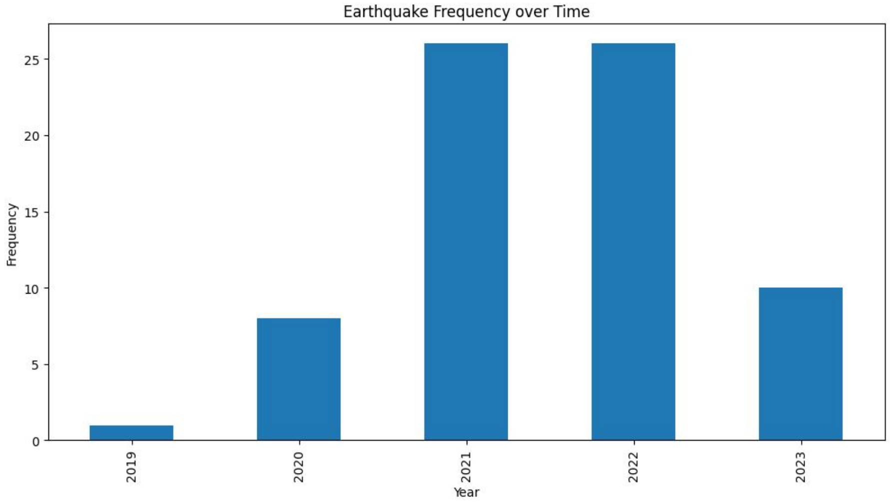
More than 120 thousand square kilometers, or around 20% of the entire geographical area of Ukraine, are categorized as seismically risky zones. These regions are vulnerable to earthquakes of magnitudes between 6 and 9 on the MSK-64 scale. A significant population of 10.9 million people, or approximately 22 per cent of the nation's entire population, reside inside these seismically dangerous zones. Specifically, 2.16 million people (4.2%) and 7.98 million people (15.5%) respectively dwell in locations with 6-point scale earthquake activity and 7-point scale earthquake activity, respectively. Additionally, 0.79 million people (1.5%) live in regions with a seismic activity rating of 8 to 9. Figure 1 shows the epicenters of earthquakes in the Carpathian region from 2019-2023.

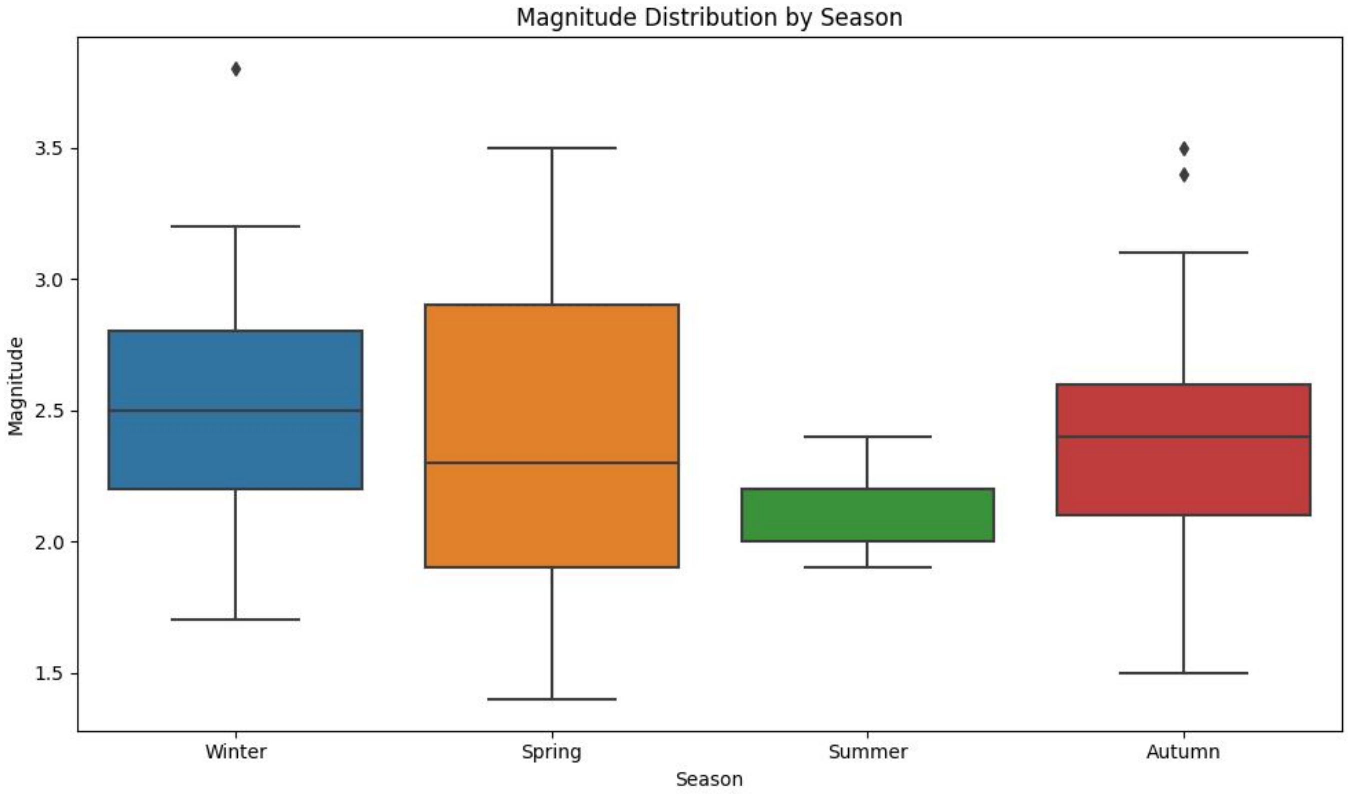


3. Methods and Materials

After careful analysis and comprehensive examination of seismic data, it is irrefutable that earthquakes predominantly occur at a depth of 10 meters. Moreover, it is evident that seismic events with magnitudes ranging from 2 to 2.5 exhibit the highest frequency among all recorded earthquakes. These empirical findings establish a compelling correlation between earthquake occurrence and specific depth levels, shedding light on the magnitude distribution within this seismic phenomenon






Magnitude Distribution by Season
Magnitude
3.5
3.0
2.5
2.0
1.5
Winter
Spring
Summer
Autumn
Season

4. Research Problem Statement

The primary objective of this study is to use fuzzy logic to estimate the degree of risk associated with each seismic event. We seek to generate an accurate and dependable evaluation of earthquake risk by merging the magnitude and depth data. To do this, we specify membership functions and create regulations based on subject-matter expertise or predetermined standards. Following that, a fuzzy control system makes use of these elements to determine the danger posed by each earthquake.

5. Implementation

The next presented formulas represent the mathematical expressions for the triangular membership functions used in the fuzzy logic system:

For the magnitude variable:

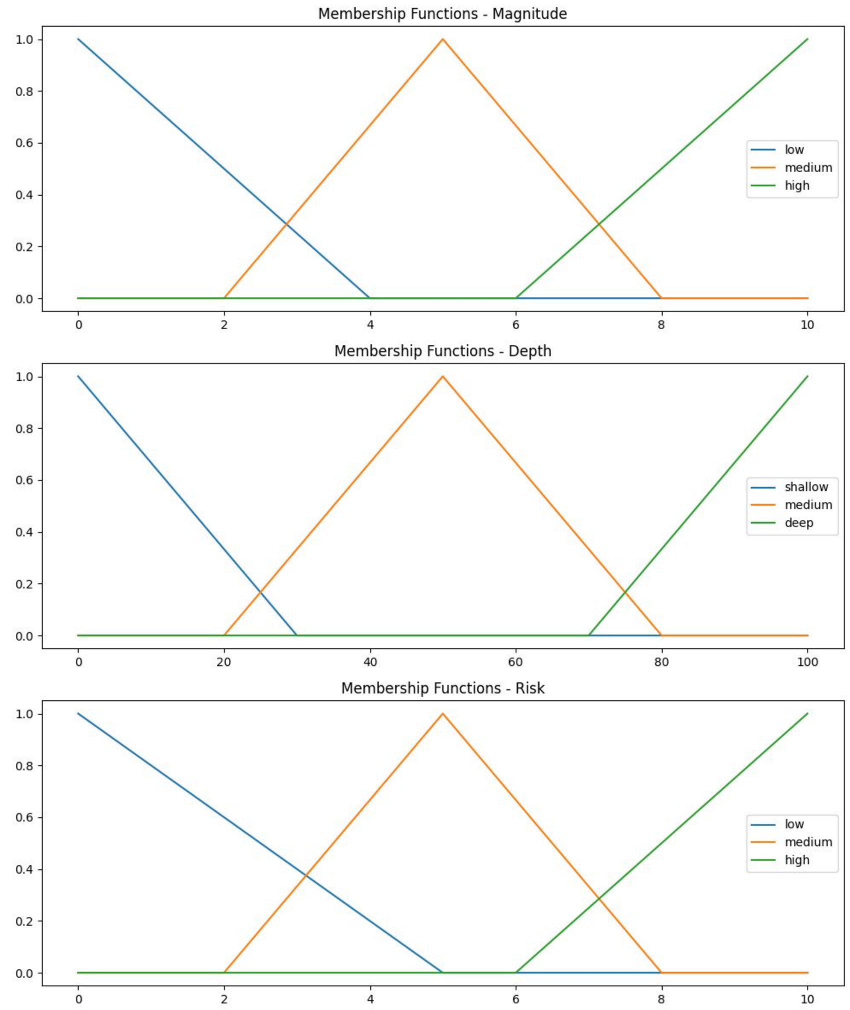
1. Low: triangular membership function with the range [0, 0, 4]
   a. $\mu_{low}(x) = max(0, min(\frac{x-0}{4-0}, \frac{4-x}{4-0});$
2. Medium: triangular membership function with the range [2, 5, 8]
   a. $\mu_{medium}(x) = max(0, min(\frac{x-2}{5-2}), min(\frac{8-x}{8-5}, \frac{x-2}{8-2});$
3. High: triangular membership function with the range [6, 10, 10]
   a. $\mu_{high}(x) = max(0, min(\frac{x-6}{10-6}, \frac{10-x}{10-6});$

For the depth variable:

1. Shallow: triangular membership function with the range [0, 0, 30]
   a. $\mu_{shallow}(x) = max(0, min(\frac{x-0}{30-0}, \frac{30-x}{30-0});$
2. Medium: triangular membership function with the range [20, 50, 80]
   a. $\mu_{medium}(x) = max(0, min(\frac{x-20}{50-20}), min(\frac{80-x}{80-50}, \frac{x-20}{80-20});$
3. Deep: triangular membership function with the range [70, 100, 100]
   a. $\mu_{deep}(x) = max(0, min(\frac{x-70}{100-70}, \frac{100-x}{100-70});$

For the risk variable:

1. Low: triangular membership function with the range [0, 0, 5]
   a. $\mu_{low}(x) = max(0, min(\frac{x-0}{5-0}, \frac{5-x}{5-0});$
2. Medium: triangular membership function with the range [2, 5, 8]
   a. $\mu_{medium}(x) = max(0, min(\frac{x-2}{5-2}), min(\frac{8-x}{8-5}, \frac{x-2}{8-2});$
3. High: triangular membership function with the range [6, 10, 10]
   a. $\mu_{high}(x) = max(0, min(\frac{x-6}{10-6}, \frac{10-x}{10-6});$


Membership Functions - Magnitude
low
medium
high
Membership Functions - Depth
shallow
medium
deep
Membership Functions - Risk
low
medium
high

6. Experiment

Python was employed to apply fuzzy logic to the dataset and determine the membership functions. The following is an overview of how this process was implemented:

Membership functions for magnitude:

- low: $\mu_{low}(x) = trimf(x, [0, 0, 4]);$
- medium: $\mu_{medium}(x) = trimf(x, [2, 5, 8]);$
- high: $\mu_{high}(x) = trimf(x, [6, 10, 10]);$

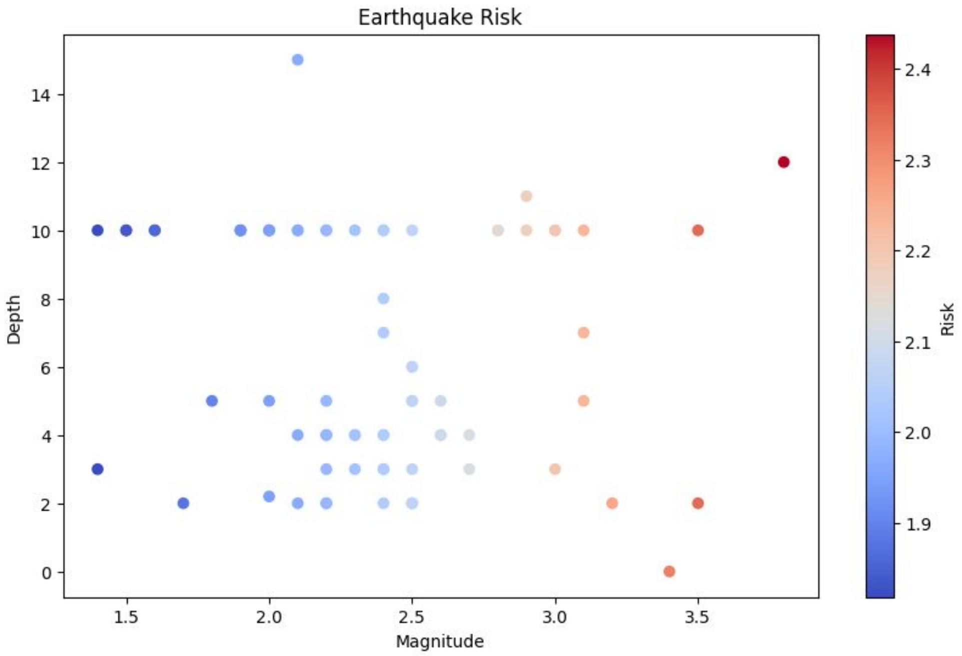
Membership functions for depth:

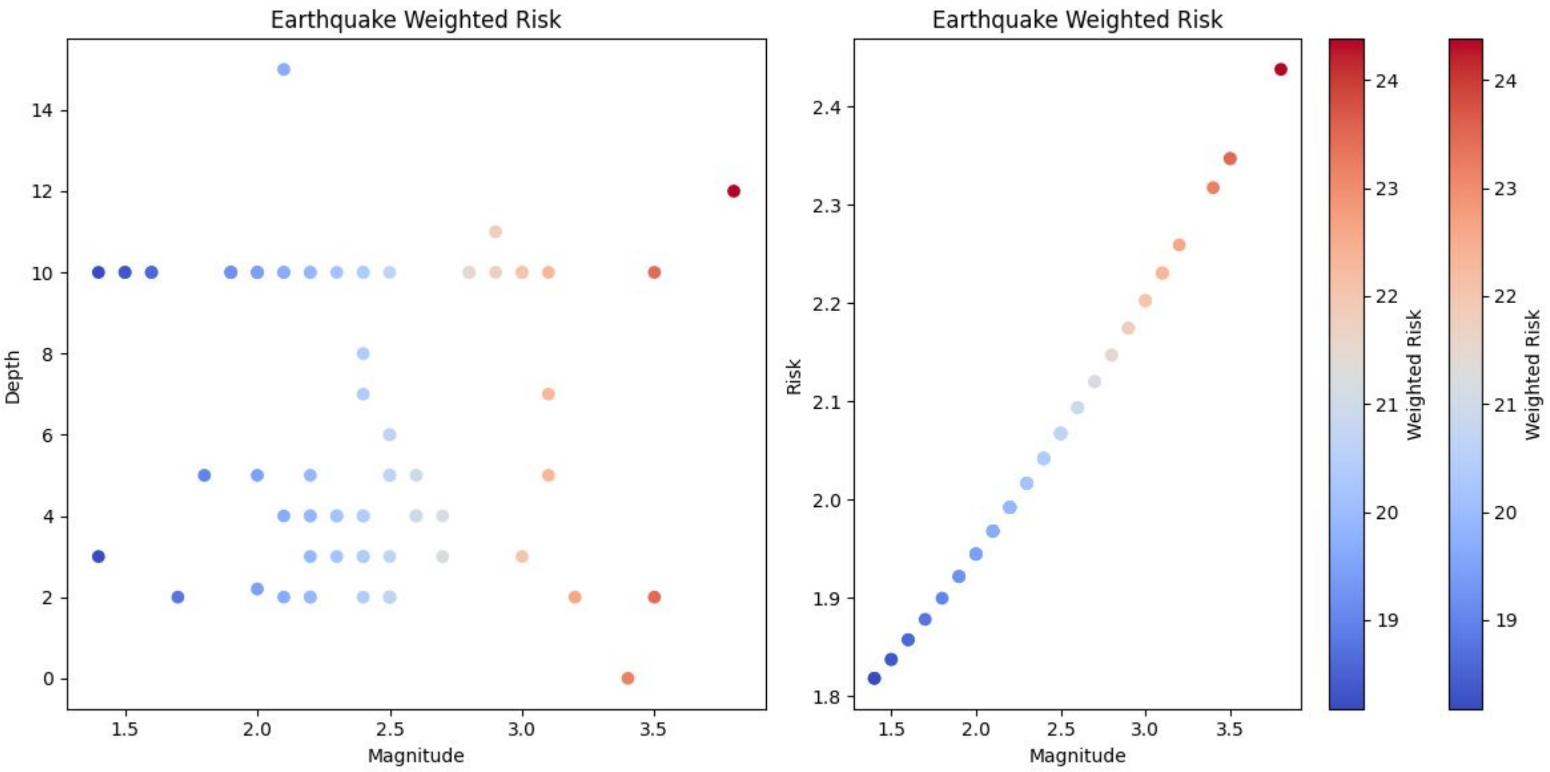
- shallow: $\mu_{shallow}(x) = trimf(x, [0, 0, 30]);$
- medium: $\mu_{medium}(x) = trimf(x, [20, 50, 80]);$
- deep: $\mu_{deep}(x) = trimf(x, [70, 100, 100]);$

Membership functions for risk:

- low: $\mu_{low}(x) = trimf(x, [0, 0, 5]);$
- medium: $\mu_{medium}(x) = trimf(x, [2, 5, 8]);$
- high: $\mu_{high}(x) = trimf(x, [6, 10, 10]);$

The calculated level of risk for each earthquake is represented by "Risk," the output of the fuzzy control system. A scatter plot visualization technique is used to make these risk estimates easier to understand and interpret. By providing a graphic depiction of the risk levels, this visualization technique enables academics and stakeholders to identify patterns, trends, and significant areas of concern.





Earthquake Weighted Risk
Depth
Magnitude
14
12
10
8
6
4
2
0
1.5
2.0
2.5
3.0
3.5
Earthquake Weighted Risk
Risk
Magnitude
2.4
2.3
2.2
2.1
2.0
1.9
1.8
Weighted Risk
24
23
22
21
20
19
Weighted Risk

7. Conclusions

The conducted research allows to expand the understanding of the complex dynamics of seismic phenomena and the ability to predict and manage their consequences, using fuzzy modeling in the study of earthquakes.The intrinsic complexity of these events can be more accurately captured by including uncertainty and inaccuracy in earthquake models, allowing for more accurate earthquake prediction, comprehensive hazard assessment, and effective strategies for building resilient communities in earthquake-prone regions through continuous improvement of fuzzy modeling approaches and collaboration between experts in other industries.

Prospective directions for the development of the performed studies are the introduction of various types of membership functions and the study of the influence of their parameters on the capabilities of fuzzy models for modeling the uncertainties that exist in experimental data.

8. Acknowledgements

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THANK YOU FOR YOUR ATTENTION!