International Journal of Basic and Applied Sciences, 14 (5) (2025) 834-839

International Journal of Basic and Applied Sciences

Website: www.sciencepubco.com/index.php/IJBAS
https://doi.org/10.14419/hyq46y73
Research paper

Study and Analysis of Seismic Activity Characteristics and Intensity Across Different Regions of Kosovo

Shemsi Mustafa [1,2], Besian Sinani [1], Visar Krelani [1] *

[1] UBT - Higher Education Institution "Lagja Kalabria" p.n. 10000 Prishtine http://www.ubt-uni.net
[2] Seismological Department – Ministry of Economy
**Corresponding author: visar.krelani@ubt-uni.net*

Received: July 14, 2025, Accepted: August 22, 2025, Published: September 24, 2025

Abstract

This study, which is based on 1,078 seismic events, aims to investigate and analyze the characteristics and intensity of seismic activity in various regions of Kosovo. Through the collection and evaluation of seismic data, the research identifies patterns, frequency, and magnitude of earthquakes, providing insights into the seismic behavior of the area. The analysis also examines the spatial distribution of seismic events and highlights regions with higher seismic risk. The findings contribute to improving the understanding of seismic hazards in Kosovo, which is essential for disaster preparedness and mitigation efforts. This study provides a scientific basis for developing effective policies and strategies to reduce the impact of earthquakes on the population and infrastructure

Keywords: *Intensity, Epicenters, Hypocenters, seismic wave*

1. Introduction

The Balkan region experiences a lot of earthquakes because it sits where several large pieces of the Earth's crust (called tectonic plates) meet and move against each other. These plates—the African, Eurasian, and Anatolian plates—create many cracks (faults) in the Earth's surface, which cause earthquakes. Because these earthquakes can be dangerous to people and buildings, countries in the area are working together to better understand and prepare for these events by sharing information and monitoring seismic activity in a coordinated way.
Kosovo is located on the Eurasian plate, and the Eurasian plates come into contact. This makes Kosovo part of a high-risk earthquake zone, just like other countries around the Mediterranean. The main cause of earthquakes here is the movement and collision of these tectonic plates, plus the rotation of a smaller plate called the Adria microplate.
The movement of these plates has created many faults across the region, and these faults are where earthquakes happen. Kosovo lies within this active seismic area and is therefore prone to earthquakes.
A comprehensive catalogue of 1,078 seismic events recorded in Kosovo between 2008 and 2021 has been compiled, detailing source parameters, macroseismic intensities, and the extent of macroseismic fields. Located in a seismically active zone, Kosovo is exposed to both local and regional earthquakes, which pose significant risks to infrastructure and human safety, particularly in densely populated urban areas. The strongest event during the studied period reached a magnitude of 5.2 and intensity VII on the Modified Mercalli Intensity (MMI) scale. Historical records reveal even more powerful earthquakes, with magnitudes of up to 6.1, underscoring the region's long-standing seismic vulnerability. Recent seismicity is primarily associated with fault zones in Istog, Pejë, Gjakova, Prizren, Gjilan, and northern Kosovo. Accurate seismic hazard assessment requires the integration of seismic catalogues with geological and tectonic data. This multi-disciplinary approach is vital for understanding seismic risks and guiding effective mitigation strategies to protect communities and infra-structure.
In this research, earthquake catalogs [2] were also used to facilitate the analysis of each seismic event in the region [12], [17]. Additionally, models proposed by several authors were employed to estimate the intensity distribution in each area, specifically the attenuation with distance [3].

1.1 This study will focus on two main areas:

- **Seismic Activity**: This will involve analyzing the frequency, magnitude, and geographical distribution of seismic events (earthquakes) in Kosovo from 2008 to 2021.
- **Maximum Intensity Distribution**: This will map and analyze the areas affected by the strongest seismic events in terms of intensity, using the Modified Mercalli Intensity (MMI) Scale.

1.2 The study may include the following components:

- **Data Collection**: Gathering earthquake data from relevant sources, such as seismic monitoring networks.
- **Analysis**: Investigating the spatial and temporal patterns of seismic events in Kosovo.

Maximum Intensity: Studying areas of Kosovo that experience the highest intensities during major seismic events and understanding how these events affect the region.

This research aims to provide a comprehensive understanding of seismic hazards in Kosovo, which will contribute to more informed risk assessment and mitigation strategies

2. Seismic Events and Trends (2008–2021)

Between 2008 and 2021, a total of 4,051 earthquakes were recorded within the geographical area defined by latitudes 41.50°–43.50°N and longitudes 19.50°–22.20°E. Of these, 2,973 occurred in the surrounding region, with magnitudes reaching up to 6.4 on the Richter scale and intensities ranging from I to IX. Specifically in Kosovo, 1,078 earthquakes were registered, with magnitudes up to 5.2 and intensities ranging from I to VII. [1]

Result:

The monitoring process enabled the collection of real-time data for both local and regional seismic events. Each recorded earthquake includes detailed parameters such as the exact time (date and hour), the energy released (expressed in magnitude on the Richter scale), the geographical coordinates, and active faults. All data have been processed and reviewed (see Table 1 and Figure 1). [1], [2], [11], [17].

Like every country in the region and the world, Kosovo has its own seismological network for monitoring seismic events within the country and beyond in real time.

By obtaining real-time data from SeisComP seismic programs and compiling seismic event bulletins—including all parameters such as depth, magnitude, and coordinates on a weekly, monthly, and yearly basis- we have been able to create Excel tables that support the development of a seismicity map for the territory of Kosovo (see Table 1 and Figure 1).

Based on seismic events during the period in question, these data have enabled us to compile a seismicity map, also known as an epicenter map. This map serves as the primary basis for seismic parameters used in seismological studies. When compiling seismicity maps, data from neighboring countries in the region are also included to allow comparison of earthquake parameters. This is necessary to ensure the area is covered with the most accurate data possible.

Compilation of bulletins with seismic data in Excel and integration of this data into the MapInfo program, where it is presented with geographic coordinates, precise magnitudes, and depths obtained from the seismological network.

Table 1: Number of earthquakes during the years 2008 - 2021

Nr of Earthquake periods 2008 - 2021	2388	950	418	146	68	26	8	7	0	1
Mag.	1.0-1.9	2.0-2.4	2.5-2.9	3.0-3.4	3.5-3.9	4.0-4.4	4.5-4.9	5.0-5.4	5.5-5.9	6.0-6.4
Intensity	1.5	1.6-2.3	2.5-3.1	3.3-4.0	4.1-4.8	5.0-5.6	5.8-6.5	6.6-7.3	7.5-8.1	8.3-9.0

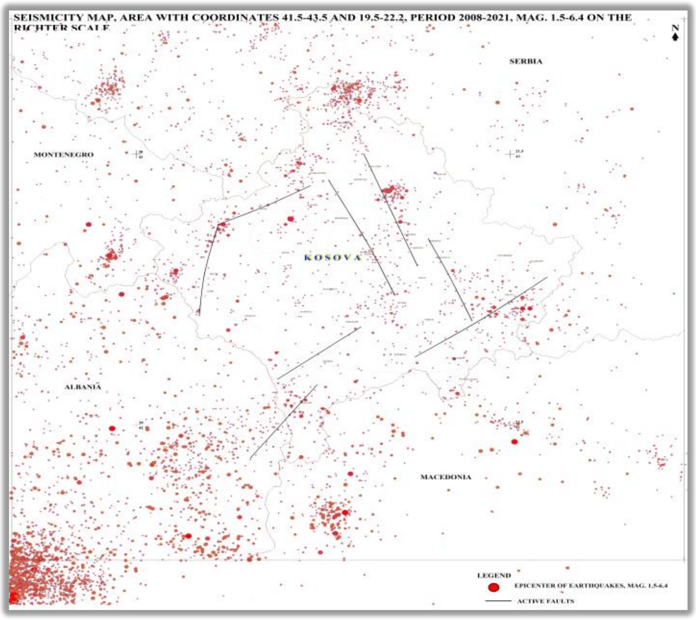

Fig. 1: Seismicity map of the Kosovo area during the period 2008-2021, for which macroseismic data were used in the present study

3. Seismic Activity Trends and Annual Variations

From 2008 to 2021, the number of seismic events recorded in the country and the region shows that the years 2010, 2013, and 2015 experienced higher intensity, both in terms of the number of earthquakes and their magnitude (see graphs 1 and 2).

In 2010, a total of 243 earthquakes occurred within the geographical coordinates (41.50°N - 43.50°N) and (19.50°E - 22.20°E). Of these, 109 earthquakes were recorded within the territory of Kosovo, with magnitudes ranging from 1.5 to 5.2 on the Richter scale. The areas affected by earthquakes of this intensity included Ferizaj, Istog, Malishevë, Pejë, Deçan, Mitrovica, Gjilan, Leposaviq, Podujevë, and Vushtrri.

In 2013, 330 earthquakes were recorded within the same geographical coordinates (41.50°N - 43.50°N) and (19.50°E - 22.20°E). Out of these, 189 earthquakes occurred in the region, with magnitudes up to 4.4 on the Richter scale and intensity VI. In Kosovo, 141 earthquakes were recorded with magnitudes up to 4.8 on the Richter scale and intensities ranging from I to VI.
In 2015, 342 earthquakes occurred, again within the geographical coordinates (41.50°N - 43.50°N) and (19.50°E - 22.20°E). Of these, 222 earthquakes were recorded in the region, with magnitudes up to 5.8 on the Richter scale and intensities ranging from I to VIII. In Kosovo, 120 earthquakes were recorded, with magnitudes up to 4.1 on the Richter scale and intensity V.
In other years, the seismic intensity was lower according to the earthquake events (see graphs 1 and 2).

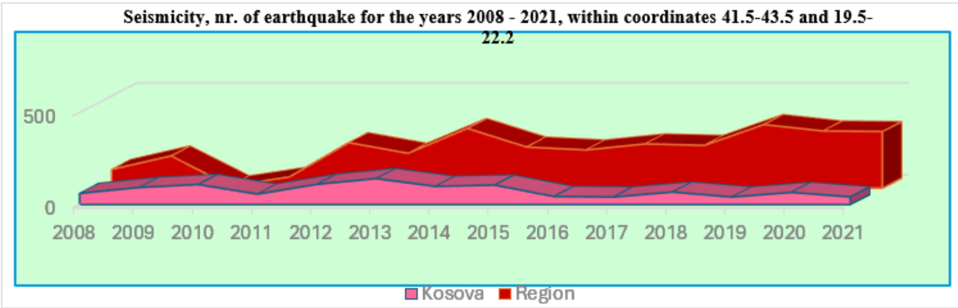

Fig. 2: Seismicity, nr. of earthquake for the years 2008 - 2021, within coordinates 41.5-43.5 and 19.5-22.2

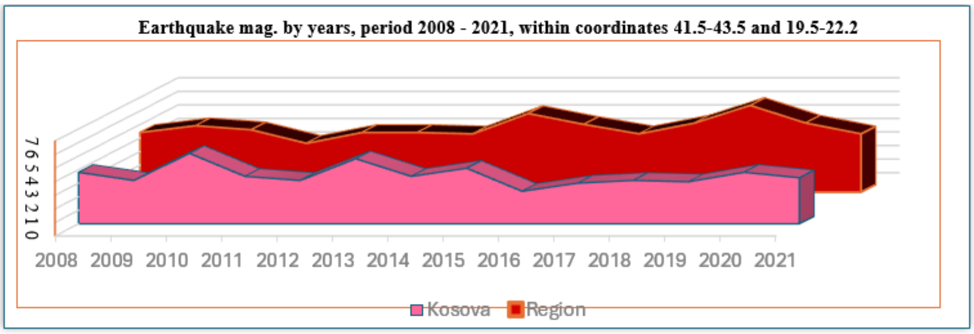

Fig. 3: Earthquake mag. by years, period 2008 - 2021, within coordinates 41.5-43.5 and 19.5-22.2

4. Analysis and calculation of the physical and seismic parameters of earthquakes in the areas, attenuation of macroseismic intensity

During the years 2008–2021, a total of 1,078 seismic events were recorded in the country of Kosovo, with magnitudes reaching up to 5.2 and intensities ranging from I to VII.
The macroseismic data used in this study consist of observed macroseismic intensities of shallow earthquakes that occurred in the examined area during the specified period. These data include a satisfactory number of intensity observations and the macroseismic intensity values for each earthquake at specific locations within the area where they were recorded.
Notably, the years 2010, 2013, and 2015 experienced some high-intensity and large-magnitude earthquakes. It was possible to reliably determine the epicentral intensity and focal depth for many of these events, and for some, the calculated error in the intensity was also established (see Table 2 and Figure 2).
The areas in question are those with the highest risk according to the historical earthquake catalog. In the past, these active fault zones—such as the Gjilan and Peja faults—have generated earthquakes with magnitudes up to 6.0 on the Richter scale, as evidenced by seismic activity during the period from 2008 to 2021. Below are the data for active faults from the European Fault Source Model 2020 (EFSM20):
Gjilan Fault

- Min Depth (km): 1
- Max Depth (km): 12
- Strike (deg): 65–80 LD
- Dip (deg): 50–70 LD
- Rake (deg): 240–270
- Slip Rate (mm/y): 0.05–0.3
- Max Magnitude (Mw): 6.5

Peja Fault

- Min Depth (km): 1
- Max Depth (km): 12
- Strike (deg): 5–15
- Dip (deg): 40–65 EJ
- Rake (deg): 200–240
- Slip Rate (mm/y): 0.1–0.5
- Max Magnitude (Mw): 6.5

Data provided by the Seismological Network of Kosovo [2].
For the maximum intensity extinction, we have used the formulation of Papazachos (1992). This relation assumes that the main energy source for each event can be calculated from a point epicenter, and therefore, the Kovesligethy relation can be used:

$$I = I_0 = \text{n}\log\sqrt{1+\frac{\Delta^2}{h^2}} + \text{c}(\sqrt{\Delta^2 + h^2} - \text{h}) \qquad (1)$$

Where I0 is the intensity at the epicenter, I is the intensity at distance Δ, h is the depth of the source, n is the geometric spreading factor, and c is the inelastic attenuation coefficient.
All macroseismic parameters of each event have been studied and calculated. The results of the three earthquakes for the period in question are presented in the corresponding columns of Table 2; the relation of attenuation for the Balkan region is determined: [3].
The calculations for different attenuation distances from the earthquake epicenter, based on the known intensity at the epicenter, have been carried out using the relation from Papaioannou and Papazachos 1992 and 1998). At distances of up to 100 km, there are more than 10 intensity points with varying distances between them. Among these points, reference locations such as cities, towns, and villages were selected, as shown in Table 2 and Figure 2.

$$I = I_0 = -3.227\log\sqrt{1+\frac{\Delta^2}{h^2}} + 0.0033(\sqrt{\Delta^2 + h^2} - \text{h}) \qquad (2)$$

Table 2: Physical data of the three earthquakes and attenuation of macroseismic intensity

Istog earthquake 10.03.2010 42.76 20.62, Depth 5.22km, M 5.2	**Vushtrri earthquake 18.11.2013 42.863 21.01, 4, Depth 4km M 4.8**	**Peja earthquake 21.01.2015 Istog Depth=5km, M=4.1**
Physical parameters of the earthquake	**Physical parameters of the earthquake**	**Physical parameters of the earthquake**
Maximum acceleration of ground shaking: ag = 0.150g	Maximum acceleration of ground shaking: ag = 0.129g	Maximum ground acceleration: ag = 0.0843g
- Velocity of ground shaking: Vg=0.06836 m/s	Maximum velocity of ground shaking: vg=0.05026 m/s	Maximum ground velocity: vg=0.0246m/s
---- Ground displacement: dg=0.004072 m	Maximum ground displacement: dg=0.002692 m	Maximum ground displacement: dg=0.00110 m
Earthquake duration: tg=6.8s	Duration of the earthquake: t=5.12 s	Duration of the earthquake: tg=3.090 s
Energy released at the source: E=1012.2 J	Energy released at the source: E= 398107170553.5 J	Energy released at the source: E=35481338923.35 J
Attenuation of macroseismic intensity	**Attenuation of macroseismic intensity**	**Attenuation of macroseismic intensity**
I Epicenter, I_0 - 7	Epicenter, I_0 - 6	Epicenter, I_0 - 5
Epicenter – Istog 10 km, I - 6.03	Epicenter – Vushtrri 5 km, I - 5.96	Epicenter – Peja 9 km, I - 4.72
Epicenter – Skenderaj 13 km, I - 5.88	Epicenter – Mitrovica 11 km, I - 5.47	Epicenter – Istog 12 km, I - 4.53
Epicenter - Mitrovica 25 km, I - 5.44	Epicenter – Besjane 15 km, I - 5.27	Epicenter – Skenderaj 35 km, I - 3.83
Epicenter – Peja 26 km, I - 5.41	Epicenter – Skenderaj 20 km, I - 5.08	Epicenter – Gjakova 40 km, I - 3.75
Epicenter – Drenas 26 km, I - 5.41	Epicenter – Prishtina 25 km, I - 4.93	Epicenter – Mitrovica 45 km, I - 3.67
Epicenter – Deçan 36 km, I - 5.20	Epicenter – Leposaviq 30 km, I - 4.81	Epicenter – Leposaviq 55 km, I - 3.54
Epicenter – Gjakova 44 km, I - 5.07	Epicenter – Istog 43 km, I - 4.58	Epicenter – Prishtina 65 km, I - 3.43
Epicenter – Prishtina 45 km, I - 5.05	Epicenter – Gjilan 57 km, I - 4.40	Epicenter – Prizren 65 km, I - 3.43
Epicenter – Podujevo 50 km, I - 4.98	Epicenter – Peja 63 km, I - 4.33	Epicenter – Ferizaj 77 km, I - 3.32
Epicenter – Jarinje- Lep. 50 km, I - 4.98	Epicenter – Gjakova 70 km, I - 4.26	Epicenter – Gjilan 95 km, I - 3.18
Epicenter – Prizren 61 km, I - 4.85	Epicenter – Prizren 74 km, I - 4.22	
Epicenter – Gjilan 76 km, I - 4.71	Epicenter – Hani Elezit 83km, I - 4.15	
Epicenter – Kaçanik 78 km, I - 4.69		
Epicenter – Kamenica 81 km, I - 4.67		
Epicenter – Dragash 90 km, I - 4.60		

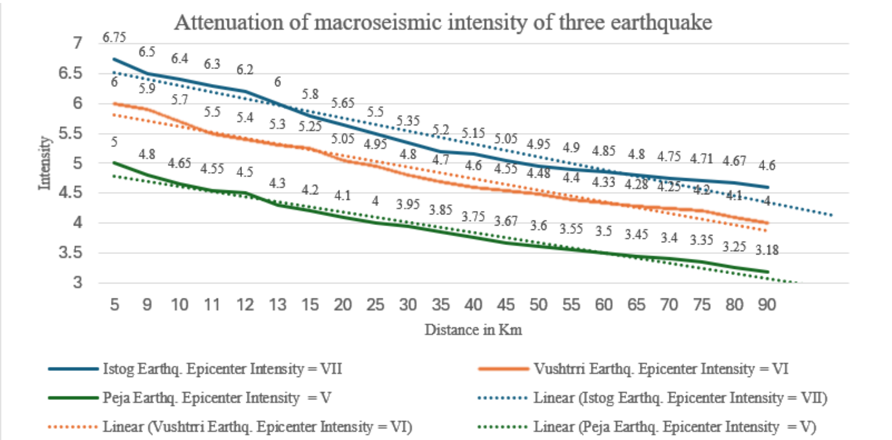

Fig. 2: Intensity values at a distance. Attenuation of the macroseismic intensity of the three earthquakes

4.1 Results

Based on the data obtained during seismic monitoring by the Kosovo Seismological Network [1], which recorded all seismic events within Kosovo and its surrounding areas, the macroseismic data and field observations in Pleistocene regions reveal important insights. From the information collected on earthquake sensitivity across all affected areas during the period 2008–2021, seismic activity was observed throughout the region. The areas of Peja, Vushtrri, Prizren, Leposaviq, Ferizaj, and Gjilan were among the most vulnerable to earthquakes within Kosovo, experiencing magnitudes ranging from 1.5 to 5.2 on the Richter scale, with intensities between III and VII. In neighboring regions, earthquakes reached magnitudes of 3.5 to 6.4, with intensities ranging from IV to IX.
All seismic events and their epicenters during this period have been studied using the MapInfo 12.5 software. The territory was divided into 5 km² units to provide a detailed analysis of the areas affected by earthquakes.

In seismology, it is known that pleistoseisms represent the projection of an earthquake's focus onto the Earth's surface. Therefore, the dimensions of pleistoseisms can also serve as a measure of the size of the earthquake focus. These characteristics offer opportunities for further research regarding the size, energy, and potential consequences of earthquake foci. Here, we note that the isoseismal parameter is primarily used to determine seismogenic sources in Kosovo.

For processing isoseismal maps and determining the main earthquake parameters, various models and formulas proposed by different authors have been applied [1], which establish correlations between the key earthquake parameters. Based on the seismicity recorded during this period, the affected regions, and the analysis of seismic parameters such as intensity and acceleration, we were able to compile a map showing the distribution of seismic intensity across the territory of Kosovo. Isoseismic presentation on Figure 3.

The calculations for different attenuation distances from the earthquake epicenter, based on the known intensity at the epicenter, have been carried out using the relation from Papaioannou and Papazachos (1992 and 1998). At distances of up to 100 km, there are more than 10 intensity points with varying distances between them. Among these points, reference locations such as cities, towns, and villages were selected, as shown in Figure 2

Based on the studies and calculations of the physical parameters of earthquakes from the epicenter to attenuation at various distances, all points with intensity values have been mapped. The MapInfo program connects points with the same intensity to create isoseists for the zone, as shown in Figure 3.

Once all the data has been calculated and we have the results for each point referenced from the epicenter, the MapInfo program was used to connect all points with equal values, generating isoseisms - contours with equal seismic intensity.

Terminology:

Isoseista: A line on a map connecting points that experienced the same earthquake intensity during an event. It visualizes the spatial distribution of shaking intensity.

Pleistoseista: A line delimiting the area with the most severe earthquake damage, typically located around or near the epicenter.

Modified Mercalli Intensity (MMI) Scale: A widely used scale that measures the effects of an earthquake on people, buildings, and the environment at specific locations. It ranks observable damage using Roman numerals from I (not felt) to XII (catastrophic destruction). Unlike magnitude scales (e.g., the Richter scale), which measure the earthquake's strength at its source, the MMI focuses on local effects.

Seismic Activity (Seismicity): The occurrence of seismic events over a specific period within a particular area or territory.

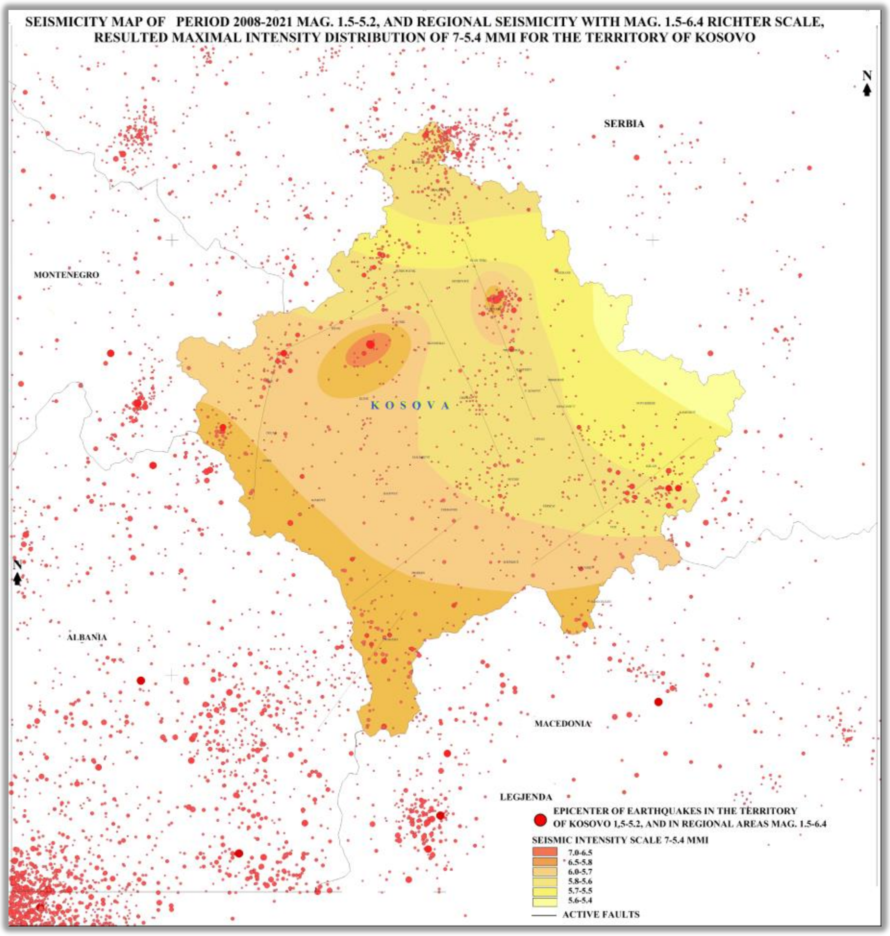

Fig. 3: Map of the distribution of maximum seismic intensity throughout the territory of Kosovo

The collection and compilation of seismic event bulletins for each year—used in the calculation of physical and seismic parameters of earthquakes—focus on events of higher intensity, which better represent the distribution of maximum seismic intensity across the territory of Kosovo. These calculations, covering the period from 2008 to 2021, produced significant results.

Using the MapInfo program, all calculated data for various attenuation (extinction) distances with the same values are processed. The program connects all points with equal values, generating isoseists—contours of equal seismic intensity.

In this way, attenuation relationships are adjusted for site effects and used in determining macroseismic intensities in the specific location (city, town, or village) where the site belongs. This improved methodology has already been applied in seismic hazard assessments in Greece (Papaioannou and Papazachos, 1992 and 1998).

This approach assumes that the main source of energy for each event can be modeled from a single epicentral point.

5. Conclusions and Recommendations

It is standard practice in many countries to regularly update seismic hazard maps at defined intervals, ensuring they reflect the latest advancements in seismology at the local, regional, and global levels.

An important recommendation is to conduct microseismic studies for all urban areas in Kosovo. These studies are crucial for obtaining highly accurate seismic parameters, which play a significant role in urban planning and construction projections.

The general goal of earthquake engineering is the identification and mitigation of seismic hazards. A microseismic study of a region produces detailed maps that predict seismic hazards at much smaller scales. It is essentially the process of subdividing a region into smaller areas with varying potential for hazardous earthquake effects, defining their specific seismic behavior to support engineering design and land-use planning.

The rapid urbanization of Kosovo over the past two decades requires an integrated approach that considers all aspects of land use planning and urban development. Urban areas have been exposed to seismic activity from various seismic sources (both local and distant), contributing to potential seismic risk. Microzonation of urban spaces, based on the analysis of seismic, geological, and geophysical data, provides a foundation for effective land use planning aimed at reducing overall seismic risk.

The determination of geological and geomechanical characteristics of the investigated urban zones is carried out using geotechnical and geophysical techniques (refraction and reflection). The results of local site effects are presented through three-dimensional (3-D) analysis of ground response, using borehole data and shear-wave velocity profiles obtained within the urban areas

In conclusion, we consider this study a significant step forward in the philosophy and methodology of seismic risk assessment in Kosovo. However, the findings and models presented here can be further improved through:

- Continued enhancement of seismicity parameters by regularly updating the earthquake database for Kosovo and surrounding regions;
- Development of a comprehensive regional seismotectonic model, linking seismicity with active tectonic faults, their focal mechanisms, and associated dynamics.
- Implementation of more accurate models for predicting ground motion parameters, based on localized data from strong-motion events in Kosovo and neighboring areas.

In summary, this report and its findings represent a solid achievement in the field of seismic risk assessment for Kosovo. They form a foundational basis for developing a modern, science-based policy aimed at reducing the risks and consequences of future earthquakes.

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