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Seismicity and Tectonics of the Republic of Kosovo

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Abstract: Kosovo is distinguished by a particularly high degree of seismic activity as a result of its location in the alpine-Mediterranean seismic area. The thickness of the seismic zone in the Earth's crust is a crucial element in seismotectonics, as it affects the design of fault systems, relative fault activity, earthquake size and distribution within a fault system, and the long-term accumulation of tectonic deformation. Kosovo's large depressions and high relief make it challenging geomorphologically. The country of Kosovo is divided into numerous chunks along the fault lines because of the inclinations of these prevalent motions. Normal faults, along which differentiations on the order of 2000 m occurred during the neotectonics period, identify the contacts between these blocks. Understanding Kosovo's seismotectonic characteristics requires an exact analysis of hypocenter parameters when historical earthquakes that have struck the country are reassessed for magnitude. This study deals with the seismicity and tectonics of the territorial space of the Republic of Kosovo.

Keywords: Seismicity; tectonics; neotectonics; Kosovo.

1 Introduction

The Republic of Kosovo is located in Southeast Europe (Western Balkan Country), in the center of the Balkan Peninsula, between the coordinates 41°50'58'' to 43° 15'42'' north latitude, 20°01'02'' to 21°48'02'' and the eastern geographic length [1]. It has an area of 10,905.25 km^2, in which 1,798,506 inhabitants live, with a density of 164 inhabitants per square kilometer [2]. The maximum altitude is 2565 m, the minimum is 273.5 m, and the average is 700 m [3]. Several phases of wrinkling, subsidence, tectonic ups and downs, seismic and volcanic activities, transgression, and regression, which the vast region has undergone, have influenced the formation of the relief of the Kosovo territory. The main forms of relief in the territory of Kosovo are mountains, valleys, mountain passes, and gorges. In the peripheral parts, it is characterized by an elevated part of the relief, whereas the central part consists of lowlands. It has a Mediterranean–continental and continental–European climate [3, 4]. The average annual air temperature is 10°C and rainfall is 700 mm [5]. It borders Albania, North Macedonia, Serbia and Montenegro [6]. The Kosovo territory has a diverse geologic structure. Paleozoic, Mesozoic, and Cenozoic formations spread there [7, 8]. Data on the geologic and tectonic construction of Kosovo are those of the 19th century, respectively, from the works of Bouea (1839-1840) and Viquesnela (1842-1843) [9]. However, more comprehensive works were presented in the 20th century by Cvijiq (1901, 1902, 1903, 1911, 1924), Radovanoviq (1907), Kossmat (1924), and Nopsca (1905-1932) [9]. Petković presented the tectonic map in 1957 and 1960, which included the territory of Kosovo.. As per Petković's (1960) findings, Kosovo falls under the Dinarides geotectonic unit, which comprises the Dukagjin tectonic depression and the Kosovo Plain (Fushë Kosovë) [9].. In recent years, in relation to tectonic regionalization, geotectonic units, tectonic detachments, stratigraphy, and morphostructures with a dominant upward trend have been addressed by [7]. The territory of the Republic of Kosovo represents a space within which it is possible to see seismic phenomena that have epicenters in its interior, but these phenomena can have their effects even if they have their foci outside its territory. In both cases of their occurrence, they are characterized by endangering the lives of the community and causing damage to infrastructure and private and public property. Historical data indicates that the territory of the Republic of Kosovo has been impacted by earthquakes throughout history. According to records, since the establishment of the Seismological Network of the Republic of Kosovo in (year 2008), there have been a total of (1100) earthquakes with magnitudes ranging from 1.5 to 5.2 on the Richter scale that have affected the territory of Kosovo.. According to seismic activity, Kosovo has seen three medium-strong

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Table 1: Richter scale of earthquake magnitude [10].

Magnitude level	Category	Effects	Earthquakes per year	Kosovo
<1.0–2.9	Micro	Generally not felt by people, though regorded on local instruments	More than 100,000	
3.0–3.9	Minor	Felt by many people. No demage	12,000 to 100,000	
4.0–4.9	Light	Felt by all. Minor breakage of objects	2000 to 12,000	Light
5.0–5.9	Moderate	Some damage to weak structures	200 to 2000	Moderate
6.0–6.9	Strong	Moderate demage in populated areas	20 to 200	
7.0–79	Major	Serious damage over large areas. Loss of life	3 to 20	
>8.0	Great	Severe destruction and loss of life over large areas	Fewer than 3	

earthquakes with magnitudes of 4.8, 5.2, and 5.7 within the past 15 years, each of which has caused material damage and one fatality. The values reported for the past 15 years were assessed against those presented in Table 1, leading to Kosovo being classified within the light and moderate categories (Table 1).

In the earliest historical data related to earthquakes in this territory, the Prizren earthquake (southwest side of Kosovo) of 1456 was recorded, which had an intensity of IX scale the Medvedev–Sponheuer–Karnik scale (MSK-64), followed by the earthquake of 1662 which had hit the city of Peja (western side of Kosovo) and caused considerable material damage. In addition, the earthquake of 1921 in the Gjilan, Viti-Ferizaj region, with epicenter intensity IX on the MSK 64 scale could be considered a historical earthquake. The 1980 Kopaonik earthquake had an intensity of VIII on the MSK-64 scale in the northern part of Kosovo. In 2002, the Gjilan region was hit by an earthquake of seismic intensity VII +1/2 on the MSK-64 scale. The earthquake of March 2010 hit Istog with an epicentral seismic intensity of VII. The territory of Kosovo was affected by strong earthquakes, whose epicenters were outside its territory, for example, in Albania, North Macedonia, Montenegro, and Serbia [11]. This succinct analysis of the seismic activity that affected Kosovo's territory over the years highlights the fact that this area should be regarded as having high seismic hazard potential. There is a growing urbanization process in Kosovo, which makes awareness of seismic hazards necessary. To assess seismic danger, it is crucial to integrate data from many fields, including seismologic, geologic, and tectonic data.

1.1 Geologic construction

The territory of the Republic of Kosovo is characterized by diverse geologic constructions represented by rocks of different types, ages, tectonic structures, breaking, and folding (Figure 1). The oldest rocks form the basement of the Neo-Proterozoic, which is composed of crystalline schists and granites and represents the products of regional high-grade metamorphism. These rocks mainly appear in the northeast of Kosovo [7, 8]. They belong to the Cambrian age [11] and are represented by kurcite, gneiss, amphibole, micaschist leptinolite, etc. Paleozoic rocks are widespread throughout the territory of Kosovo and are represented by slates, green slates, and crystalline slates with different epidote–actinolite, chlorite–sericitic, albite–chlorite–sericitic, and phyllitic compositions, quartzites, metaconglomerates, phyllites, argillites, marbles, etc. Cretaceous formations are widespread and are represented by limestone, marly limestone, and flysch. Mesozoic rocks (Cretaceous, Triassic, and Jurassic) are spread throughout Kosovo. Triassic is represented by quartzite, marble, marbleized limestone, and ultrabasic rocks [8]. Jurassic is represented by limestones, sandstones, diabase-slate formations, metamorphites, serpentinites, peridotites, dunites, harzburgites, and olistostromic melanges. Tertiary deposits are mainly distributed in the tectonic depressions of the Dukagjin Basin, Fusha and Kosovës, Anamorava, Llapi, and Drenica. Oligocene sediments are represented by lake sediments, clays, conglomerates, sandstones, and so on. Neogene deposits are represented by Miocene and Pliocene sediments. Miocene sediments are represented by clay, sandy clay, conglomerates, lignite, etc., while the Pliocene sediments are represented by clays, conglomerates, sandy-clay sediments, lignite, etc. Quaternary deposits spread in river valleys and are represented by river terrace sediments, alluvial, proluvial, and deluvial products [8].

1.2 Tectonics

According to [12], tectonics is defined as the construction of any part of the Earth's crust, which is determined by

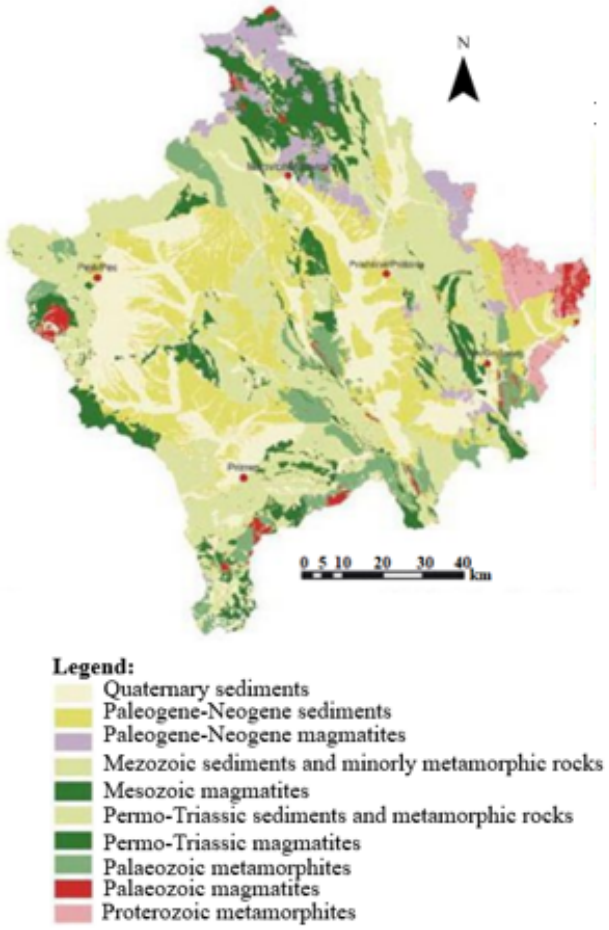

Figure 1: Geologic map of Kosovo ([8] adapted: own study).

the totality of tectonic displacement and the history of its development. Tectonic processes are expressed in nature with tectonic movements of three main types: oscillating, folding, and detachment. Thus, most of the seismic processes in the Kosovo territory are expressed through today's tectonic movements. Many authors have emphasized that tectonic faults increase seismicity in a given region. The territory of Kosovo is delineated by transverse and longitudinal tectonic structures that divide geotectonic units (Figure 2).

1.3 Neotectonics

According to the dictionary of geology [12], neotectonics is a branch of geotectonics that deals with the newest and main tectonic processes of today's relief. Furthermore, many authors date the tectonic movements from the Neogene to the Quaternary, sometimes to the Jurassic, or the beginning of the Cenezoic. Some researchers have associated these movements with the base of the Oligocene,

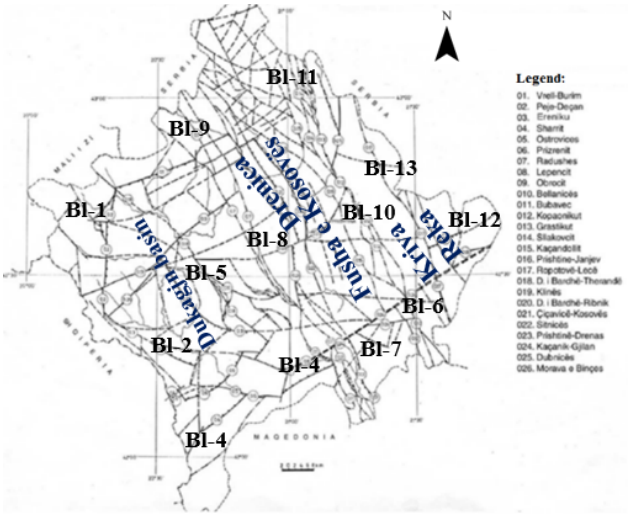

Figure 2: Map of tectonic structures ([7], adapted: own study).

Miocene, or Quaternary. In several different places, neotectonics have not been determined by age. Instead, it is better to use the term new tectonics. The formation of new morphostructural units in the territory of Kosovo has been influenced by tectonic and neotectonic processes that have occurred in this area. These morphostructural units are related to new neotectonic movements during Pliocene and Quaternary [11]. According to [11], as an effect of neotectonic processes in the territory of Kosovo, there are areas with a predominant tendency to rise, divided into 13 blocks (Figure 2): blocks 1, 2, 3, 4 with intense lifting, other blocks (5–13) with lower lifting intensity, and areas with a tendency to submerge. These three represent the depressions of the Dukagjn Basin, The territory of Dukagjin is considered the most seismically active region in Kosovo, as indicated by data from studies [11, 7, 13]. This area has experienced significant seismic activity, including two major earthquakes with magnitudes of Mmax = 6.6 in Prizren and 6.0 in Pejë (Figure 3), which occurred in the years 1456 and 1662 (Figure 2).

1.4 Seismicity

Most seismic processes are expressed through current tectonic movements [14], while the main phenomenon is an earthquake. Earthquakes tell us what is happening deep in Earth. The Balkan region, which includes Montenegro, Albania, North Macedonia, Kosovo (which shares borders with these countries), Greece, Southern Bulgaria, and Western Turkey, is the most seismically active part of the Aegean area and its surrounding regions. This region experiences at least one earthquake with a

magnitude of 6.5 or higher every year [15].. According to [14], over 100,000 earthquakes occur on Earth every year, which are characterized by small damage and even devastating consequences. According to [16] the Balkan Peninsula exhibits the highest seismic activity in western Eurasia. Its typology is mainly characterized by shocks and aftershocks. Considering that the territory of Kosovo is delineated by transverse and longitudinal tectonic faults, they favor the birth of earthquake foci of different degrees and with different consequences (Figure 2). The fact that the development of a seismological network has been in progress since 2008 [17] indicates the beginning of the creation of a wide database of data and information related to earthquakes. However, a catalog of earthquakes presented for a period of time 1456–2002 by [11] enables historical recognition of the occurrence of this movement in the territory of Kosovo. According to [11], [18], [19], there are mainly three powerful areas of seismic generation in the territory of Kosovo: the Prizren-Pejë area (magnitude 6.0 Richter scale), Ferizaj-Viti-Gjilan (M = 6.1), and Kopaonik area (M = 6.0) (Figure 3).

The most powerful earthquakes that hit Kosovo territory are listed in Table 2.

Data on the occurrence of earthquakes [11] for the period from 1456 to 2002 shows that 141 earthquakes occurred in the Kosovo territory. Some of the statistical data are presented in Table 3.

Table 3 shows that the depth of earthquakes varies from 3 to 26 km with an average value of 13.01 km, magnitude from 3.8 to 6.60 and its average value of 4.28, while the intensity varies from 5.0 to 9.0 with an average value of 5.71.

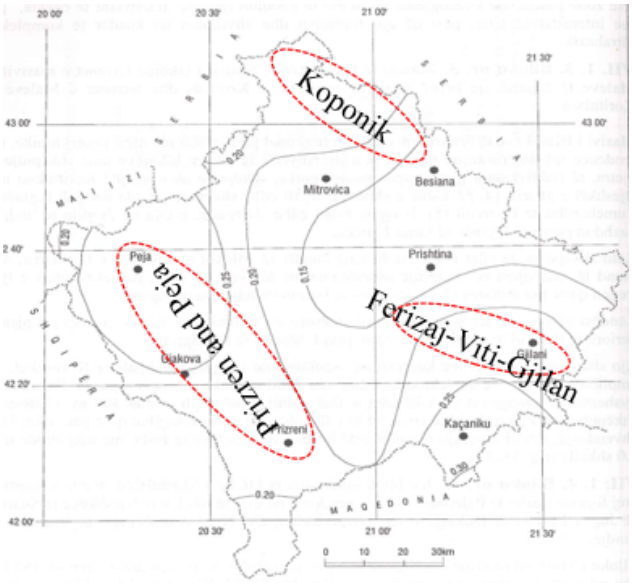

Figure 3: Seismogenic zones ([11] adapted: own study).

Table 2: The most powerful earthquakes in Kosovo.

City/locality	Month.day.year	Epicentral intensity (MMI scale, Pojani,2003)	Reference
Prizren	06.16.1456	6.0	Elezaj, 2002
Pejë	11.11.1662	8.0	
Ferizaj	02.26.1755	9.0	
Ferizaj-Viti	08.10.1921	9.0	
Kopaonik	05.18.1980	6.0	Sulstarova et al, 2001; Orana et al., 1985; Elezaj, 2002.

Table 3: Some statistical data.

Statistics	Depth (km)	Magnitude	Intensity
Average	13.01	4.28	5.71
Min	3.00	3.80	5.00
Max	26.00	6.60	9.00

2 Materials and methods

For realization of this work, a quantitative and comparative methodology interwoven with professional experience was applied. A considerable amount of data and information was collected regarding tectonic, neotectonic, and seismic events that have occurred in the territory of Kosovo. Some of the historical data generated during the writing of this paper are presented in this paper.

3 Results and Discusion

The geologic and seismotectonic peaks of the Republic of Kosovo represent a relatively complicated territory. Based on the data found in this research, over 141 earthquakes have occurred in the territory of Kosovo from 1456 to the present day (e.g., earthquakes in recent years: the earthquakes of Gjilan, Istog, Dragash, and Vitia). For more detailed processing, data on earthquakes within the period 1456–2002 were taken into consideration. Their analysis highlighted that the depth of the earthquake

Table 4: Division by depth.

Depth (km)	The range	Kosova	
		Number of cases	%
Till 60	Small (little one)	90	100
60–300	Average		
Up to 300	Deep		

Table 5: Number of earthquakes, intensity, and percentage of participation.

No. of earthquakes	Intensity	%
82	5	58.16
34	6	24.11
12	7	8.51
10	8	7.09
3	9	2.13

center in this territory varies from 3 to 26 km, with an average value of 13.01 km. Analysis of the depth of the foci showed that 43.2% of them had a depth of <10 km, 29.7% had a depth between 11 and 20 km, and 8.1% had a depth over 21 km. Another comparison was made by categorizing earthquake values based on the depth of their epicenter, as shown in Table 4 [14]. .

The data in Table 5 show that the largest number of earthquakes, 82 or 58.16%, were of intensity 5.

According to the scientific community, the magnitude (or as it is often used in the Richter Scale) expresses the energy of the earthquake released in its wake, regardless of the place of observation. From the data analyzed in this work (period 1456–2002), results show that the magnitude values range from 3.8 to 6.6 with an average value. The magnitudes of the earthquakes that occurred in Kosovo territory were compared to the values given according to the division by the California Earthquake Authority (Table 6). It was found that from the total number of earthquakes that occurred in the territory of Kosovo, the largest number of earthquakes had magnitudes between 4.0 to 4.9 and 3.0 to 3.9, ranking the territory of Kosovo in the light and minor classes (Table 6).

Another comparison of the intensity values for the territory of Kosovo was made by comparing them with the division given by the author [14]; the results are shown in Table 7.

The intensity characterizes the force of the earthquake at the point of observation of the earth's surface. Earthquakes in the territory of Kosovo resulted in

Table 6: Magnitude, class, and description [20].

Magnitude	Class	Description	Kosovo	
			Number of cases	%
>8	Great	Significant damage expected		
7.0–7.9	Major	Damage expected		
6.0–6.9	Strong	Damage may occur	5	3.55
5.0–5.9	Moderate	Minor damage may occur	14	9.93
4.0–4.9	Light	Likely felt	69	48.94
3.0–3.9	Minor	May be felt	53	37.59

Table 7: This division is given by the author [14].

Group	Magnitude	Kosovo	%
First	7.5 < M < 8.5	0	0.00
Second	6.5 < M < 7.5	1	0.71
Third	5.25 < M < 6.5	11	7.80
Fourth	4.25 < M < 5.2	39	27.66
The fifth	3.25 < M < 4.25	90	63.83

intensities ranging from 5.0 to 9.0, with an average value of 5.71 (Table 3). The intensity values of the earthquakes that occurred in the territory of Kosovo were compared to the values according to the modified Mercal intensity scale used in the USA and results showed that, the total number of earthquakes that occurred in the territory of Kosovo corresponds to the intensity of scale 5, placing this territory with moderate occurrence of earthquakes (Table 8).

Taking into consideration the collected data and information and their processing, Figures 4 and 5 were drawn [21]. The magnitude map (Figure 4) shows that the highest magnitude values were in the western (Pejë), southern (Prizreni), and southeastern (Kaçanik) parts of Kosovo.

4 Conclusions

Based on the data, information, literature, and publications of recent years related to seismic and tectonics of the territory of the Republic of Kosovo and the analysis made and presented in this paper, these conclusions and recommendations are reached. The territory of the Republic of Kosovo is characterized by

Table 8: The modified Mercalli Intensity Scale used in the USA [20].

Intensity	Shaking	Description/damage	Kosovo	
			Number of cases	%
I	Not felt	Not felt except by a very few under especially favorable conditions		
II	Weak	Felt only by a few persons at rest, especially on the upper floors of buildings. Delicately suspended objects may swing		
III	Weak	Felt quite noticeably by persons indoors, especially on the upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration similar to the passing of a truck. Duration estimated		
IV	Light	Felt indoors by many, felt outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably		
V	Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop	82	58.16
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight	34	24.11
VI	Very Strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken	12	8.51
VII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned	10	7.09
IX	Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations	3	2.13
X	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rail bent		

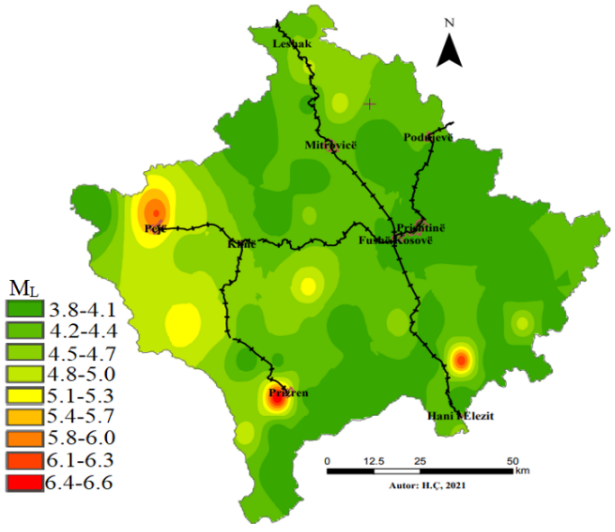

Figure 4: Magnitude distribution map according to earthquake catalog data, period 1456–2002, territory of Kosovo [21].

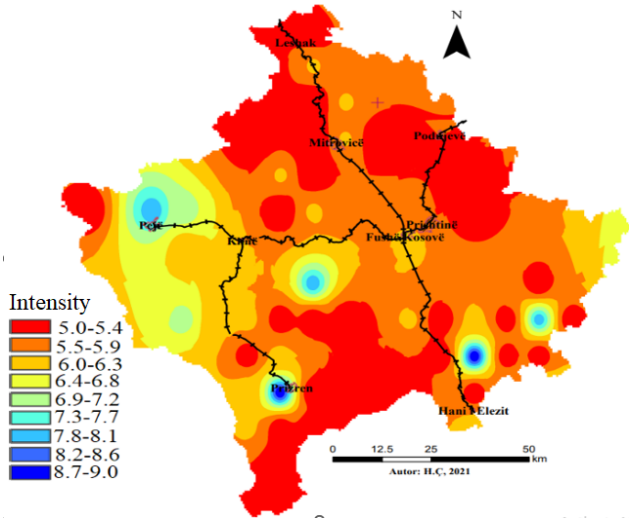

Figure 5: Intensity distribution map according to earthquake catalog data, period 1456–2002, in the territory of Kosovo [21].

diverse geologic constructions represented by rocks of different types, ages, and tectonic structures. Tectonic processes are expressed in nature with tectonic movements of three main types: oscillating, folding, and detachment. Neotectonic processes in the territory of Kosovo include areas with a predominant tendency to rise, divided into 13 blocks. In the territory of Kosovo, there are mainly three powerful areas of seismic generation: Prizren-Pejë, Ferizaj-Viti-Gjilan, and Kopaonik areas. The depth of earthquakes varies from 3 to 26 km with an average value of 13.01 km, magnitude from 3.8 to 6.60 and its average value of 4.28, while the intensity varies from 5.0 to 9.0 with an average value of 5.71. The territory of Kosovo was categorized as light or moderate. The depth of the earthquake center in this territory varied from 3 to 26 km, with an average value of 13.01 km. Earthquakes in Kosovo resulted in intensities ranging from 5.0 9.0. From the total number of earthquakes that occurred in the territory of Kosovo, the largest number had a magnitude between 4.0 to 4.9 and 3.0 to 3.9, ranking the territory of Kosovo in the light and minor class. This study recommends the revision, processing, and construction of a seismic hazard and risk map for the territory of Kosovo to ensure that the level of seismic hazard forecasting is as reliable as possible.

Undertaking the construction of an earthquake map and a database, adhering to the methodology, standards, and guidelines set forth by the European Union. Furthermore, the development of this catalog and database will ensure that earthquake data is accurately and consistently collected and shared among member states, allowing for more effective disaster response and prevention efforts within the European Union..

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