SEISMIC ACTIVITY AND SEISMOTECTONIC CHARACTERISTICS OF THE SEISMIC SOURCE ZONES OF KOSOVO

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ABSTRACT

Kosovo is characterized by a relatively high seismic activity as it is located in the Alpine-Mediterranean seismic belt. The thickness of the seismogenic zone in the Earth's crust plays an important role in seismotectonics, affecting fault-system architecture and relative fault activity, earthquake size and distribution within a fault system, as well as long-term accumulation of tectonic deformation. The very high relief and large depressions make Kosovo a very geomorphologically complex country. The recent geological period is characterized by the neotectonic processes which have conditioned the formation of many structural units that are expressed by intensive uplifting and sinking movements. The territory of Kosovo is divided by a large number of blocks along the faults due to these prevailing movements' tendencies. Contacts between these blocks are expressed through normal faults, along which differentiations of the order of amplitude of about 2000 m, have occurred during the neotectonic phase. Accurate analysis of the hypocenter parameters is essential in understanding the seismotectonic characteristics of Kosovo as the magnitude of the historical earthquakes that have hit the Kosovo are re-evaluated. This study represents basic data of seismicity and neotectonic characteristics for the assessment of seismic hazard of Kosovo.
Keywords: neotectonic structure, seismicity, seismotectonics, seismogenic zones

1. INTRODUCTION

The territory of Kosovo represents from a seismicity point of view a space where indigenous catastrophic earthquakes are expectable along with earthquakes originating from the seismic sources in the bordering regions. In both cases damages are considerable.

There is a long history of earthquakes hitting Kosovo. Here we can mention the earthquake of 1456 that hit the city of Prizren with intensity IX on MSK-64, and the earthquake of 1662 in the Peja district with intensity VIII on MSK-64 scale have caused considerable material damages. In addition, historical earthquakes could be considered the earthquake of 1921 in Gjilan-Viti- Ferizaj region, with epicenter intensity IX on MSK 64 scale. The 1980 Kopaonik earthquake had intensity VIII on MSK-64 scale in the northern part of Kosova. In 2002, region of Gjilan was hit by an earthquake of seismic intensity VII +1/2 on MSK-64 scale. The earthquake of March 2010 hit Istog, with epicentral seismic intensity of VII. Kosovo's territory has been also affected by the strong earthquakes, which epicenters were in the Republic of North Macedonia, Albania, Montenegro and Serbia. This short review of the seismic activity affecting the territory of Kosovo throughout the time, points out that this region should be considered as a region with high seismic hazard potential. There is a growing urbanization process in Kosovo which makes awareness about the seismic hazard necessary. Integrating data from various field such as seismologic, geologic, tectonic data is of great importance for the assessment of seismic hazard.

2. Neotectonic structure of Kosovo

Neotectonic research in the territory of Kosovo is closely related with the studies on the morphostructure units resulting from the neotectonic movements that have occurred during Pliocene and Quaternary, in the so called neotectonic stage. Investigation about the neotectonic activity in Kosovo is closely related to the early recognition of geological structure for the detect of the relation between early tectonic movements and neotectonic.

The neotectonic stage in the territory of Kosovo was characterized by the tectonic processes, which have resulted in formation of new morph-structure units: morph-structure with dominant tendency of uplifting trend and sinking. We emphasize that the grounds noticed with new volcanic activity occupies a special place in Kosovo and with them are related many useful minerals.

2.1. Structures characterized by uplifting trends

In neotectonic map, the areas with dominant uplifting tendency are limited with neotectonic izolines of deformations, where the real value of vertical rise during Neogen and Quaternary can be observed. Today, remains of past volcanic activity are manifested with termal waters that are common in Kosovo and throughout Balkan region. Areas of Kosovo with dominant uplifting trend are divided into these three separate units: Uplifting, High Intensity, and Low intensity units, fig. 1 (Elezaj).

2.2 Structures characterized by sinking trends

The neotectonic units that represent sinking morphostructure are very much expressed in the territory of Kosovo. These are large lowlands known as Neogen depressions and are characterized by large accumulation of molasic material, and large reserves of coal (fig.2).

The Neogen depressions are: i) Dukagjini Depression which is subdivided into smaller parts such as the Peja, Gjakova, Prizreni and Bellanica Depressions, ii) Drenica Depression, iii) Kosovo Depression which includes the smaller Podujeva and Morava Binçës Depressions, and iv) Krivarekës Depression. The past-volcanics are currently manifested through water thermo-minerals water phenomenon, which proves the existence of expressed geothermal field.

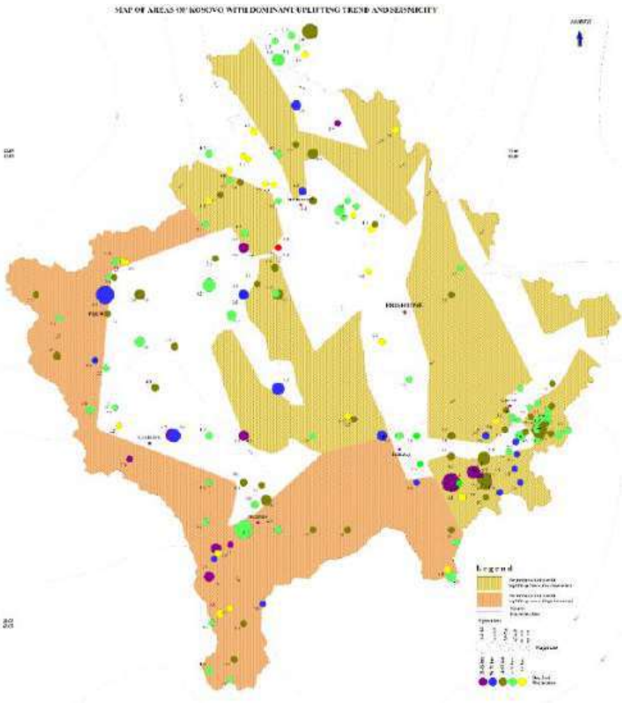


Fig. 9: Map of Kosovo. Neotectonic Units with uplifting trend and neotectonic depression.

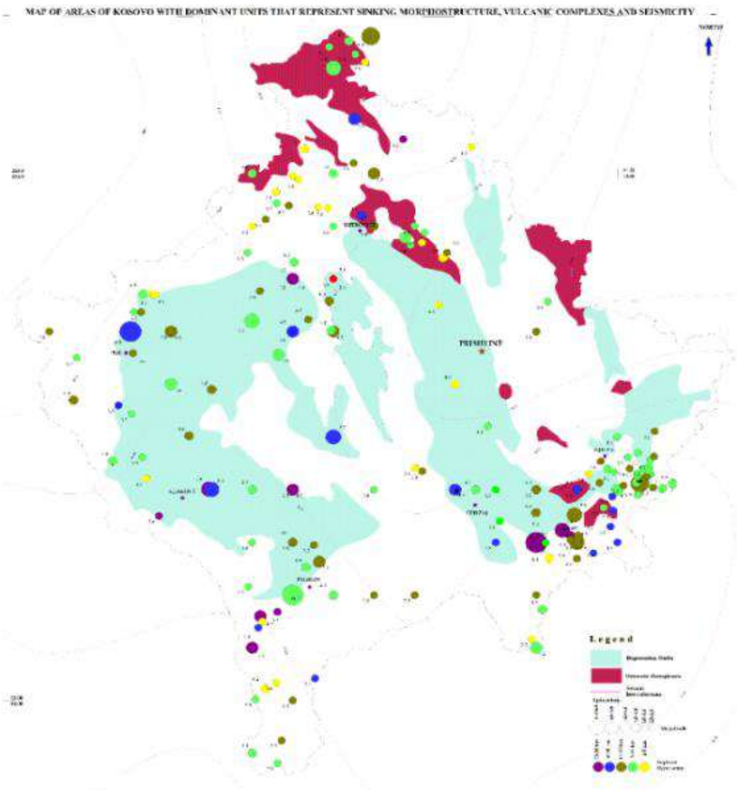


Fig.2: Map of Kosovo. Sinking morphostructure volcanic complexes and seismicity.

3. Seismicity of the territory of Kosovo

The earthquake catalogues of Albania, Montenegro, Croatia, Serbia, Macedonia, Greece (Thessaloniki), the earthquake bulletins of the International Seismological Centre (ISC), the southern and southern-eastern European earthquake catalogues were all used for an accurate seismic hazard study.

A new catalogue for the territory Kosovo was compiled illustrating the 156 earthquake events with magnitude M≥3.5 from 1456 to September 31, 2020.

However, such studies are continuously updated with new information. Kosovo is characterized by high seismic activity. Most of the earthquakes are earthquake foci as they occur within a few tens of kilometers of the surface. They are generated in the Earth's crust, maximum 15-25 km deep underground, tab.1, fig.3. In this case they are classified as *shallow-focus earthquakes*.

Tab.1 Number of earthquakes according to the Magnitude and Intensity

Number of Earthquakes	**112**	**60**	**22**	**11**	**3**	**3**
Magnitude	3.5-3.9	4.0 - 4.4	4.5 - 4.9	5.0 - 5.4	5.5 - 5.9	6.0 - 6.2
Intensity	4.16-4.83	5.0 - 5.66	5.83 - 6.5	6.6 - 7.33	7.5 - 7.6	8.73 – 9.0

Here we can mention: the Prizreni earthquake of June 16, 1456 (MS=6.0; 42.200oN, 20.700oE) epicentral intensity of $VIII_{1/2}$, the Peja earthquake of November 11, 1662 (MW=6.0; 42.700oN; 20.300oE) epicentral intensity of $VIII_{1/2}$ degree, the Ferizaj-Viti earthquake of August 10, 1921 (ML=6.1; 42.300oN; 21.300oE) epicentral intensity of IX degree, the Viti earthquake of august 15.1921 (Ml = 5.4; 42020’ N, 21020’ E) epicentral intensity of VIII degree, the Gjilan earthquake of September 02.1921 (Ml = 5.0; 42024’ N, 21030’ E) epicentral intensity of VIII degree, the Kaçanik-Viti earthquake of October 03.1921 (Ml = 5.6; 42020’ N, 21020’ E) epicentral intensity of VIII degree, the Gjakova earthquake of September 03.1922 (Ml = 5.3; 42025’ N, 21025’ E) epicentral intensity of VII1/2 degree, the Prizren earthquake of September 26.1945 (Ml = 5.0; 42015’ N, 21045’ E) epicentral intensity of VII degree, the Klina earthquake of February 05.1947 (Ml = 5.2; 42030’ N, 21045’ E) epicentral intensity of VIII degree, the Kopaonik earthquake of May 18, 1980 (MW=5.7; 43.307oN; 20.867oE) epicentral intensity of VIII degree, the Gjilani earthquake of April 24, 2002 (MW=5.7; 42.440°N, 21.590°E), epicentral intensity of VIII degree, the Istog earthquake of march 10, 2010 (Ml = 5.2; 42.763440N, 20.628110E) epicentral intensity of VII degree, the Vushtrri earthquake of November 18, 2013 (MI=4,8; 42.9 N; 21.014 E) epicentral intensity of VI degree.

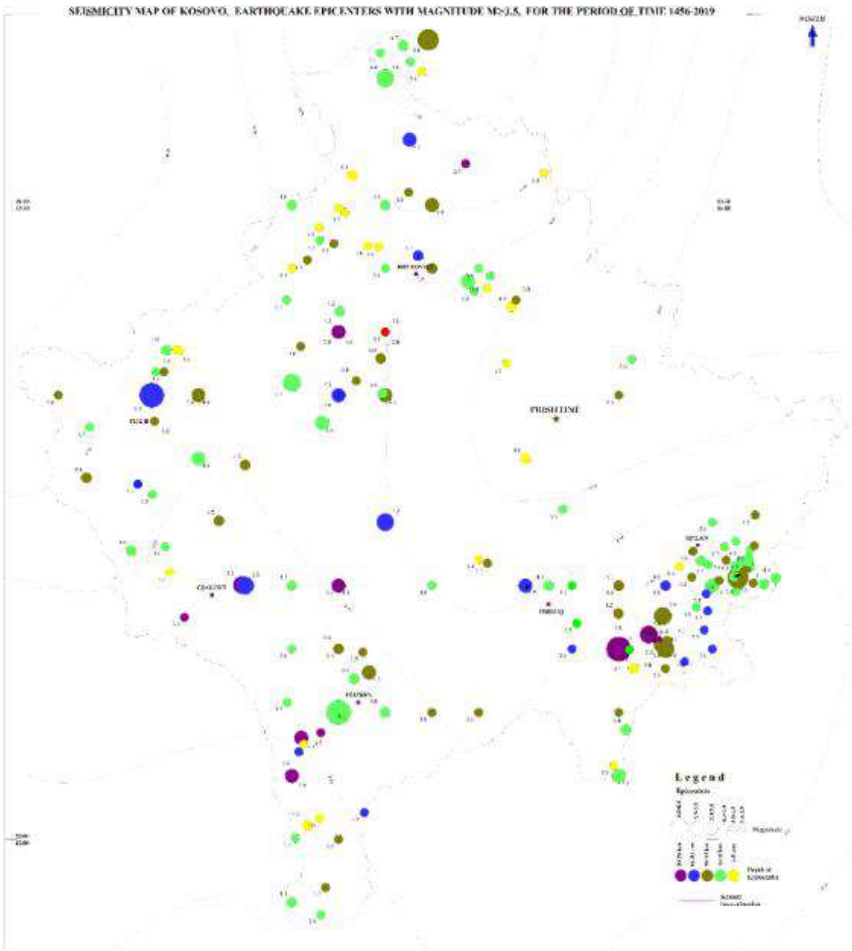


Fig. 3: Map of earthquake epicentres.

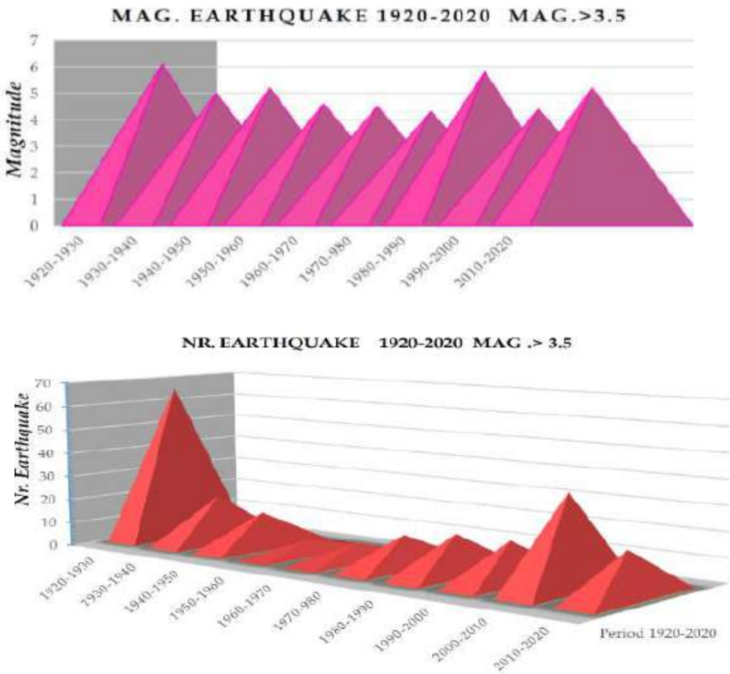


Fig. 4: Chart of Earthquakes' number and magnitude of every decade.

The Figure 4 depicts earthquakes' number and magnitude of every decade.

4. Macroseismic intensity attenuation and PGA attenuation based Earthquakes catalog of Kosovo territory

Seismic attenuation describes the energy loss experienced by seismic waves as they propagate. In this case, three earthquakes with approximate magnitude and with different depths, 7km, 14km and 20 km were considered. They result in different extinction values, where at a distance of 100 km the 7 km depth quake has much higher attenuation values than the 20 km depth quake at a distance of 100 km. Table 2 and figure 5 report the attenuation in 100 km in the territory of Kosovo, reporting one intensity scale difference for the 7 km and 20 km- deep earthquake.

$$I - I_o = -3.227 \log \sqrt{1 + \frac{\Delta^2}{h^2}} - 0.0033\left(\sqrt{\Delta^2 + h^2} - h\right)$$

Papazachos and Ppaioannou (1977)

$$I_{max} - I_i = 4.2 \log (R_i/h)$$

Hadzvieski and Pekvski (1975)

Tab.2 Attenuation of Intensity at the distance of 100 km

I 10 = 7.21	I 20 = 6.96	I 30 = 6.65	I 40 = 5.55	I 50 = 6.10	I 60 = 5.85	I 70 = 5.64	I 80 = 5.44	I 90 = 5.25	I 100 = 5.08
I 10 = 6.25	I 20 = 5.53	I 30 = 5.00	I 40 = 4.59	I 50 = 4.26	I 60 = 3.98	I 70 = 3.74	I 80 = 3.52	I 90 = 3.32	I 100 = 3.14
I 10 = 7.06	I 20 = 6.58	I 30 = 6.14	I 40 = 5.77	I 50 = 5.45	I 60 = 5.19	I 70 = 4.90	I 80 = 4.74	I 90 = 4.54	I 100 = 4.37
I 10 = 5.41	I 20 = 4.49	I 30 = 3.90	I 40 = 3.47	I 50 = 3.13	I 60 = 2.84				
I 10 = 5.92	I 20 = 5.16	I 30 = 4.67	I 40 = 4.20	I 50 = 3.87	I 60 = 3.59	I 70 = 3.34			
I 10 = 6.21	I 20 = 5.63	I 30 =5.14	I 40 =4.75	I 50 =4.43	I 60 = 4.15	I 70 = 3.91	I 80 = 3.69	I 90 = 3.50	I 100 = 3.32
I 10 = 6.98	I 20 = 6.73	I 30 = 6.42	I 40 = 5.32	I 50 = 5.87	I 60 = 5.62	I 70 = 5.41	I 80 = 5.21	I 90 = 5.02	I 100 = 4.85
I 10 = 6.43	I 20 = 6.08	I 30 = 5.72	I 40 =5.39	I 50 = 5.10	I 60 = 4.84	I 70 = 4.61	I 80 = 4.40	I 90 = 4.22	I 100 = 4.04
I 10 = 6.83	I 20 = 6.13	I 30 = 5.71	I 40 = 5.35	I 50 = 5.04	I 60 = 4.77	I 70 = 4.54	I 80 = 4.33	I 90 = 4.13	I 100 = 3.96
I 10 =5.80	I 20 = 5.00	I 30 = 4.44	I 40 = 4.02	I 50 = 3.68	I 60 = 3.40	I 70 = 3.15	I 80 = 2.93	I 90 = 2.74	I 100 = 2.56
I 10 = 6.04	I 20 = 5.20	I 30 = 4.63	I 40 = 4.21	I 50 = 3.87	I 60 = 3.58	I 70 = 3.33	I 80 = 3.12	I 90 = 2.92	I 100 = 2.74
I 10 = 6.80	I 20 = 6.00	I 30 = 5.44	I 40 = 5.02	I 50 = 4.68	I 60 = 4.40	I 70 = 4.15	I 80 = 3.93	I 90 = 3.74	I 100 = 3.56
I 10 = 7.20	I 20 = 6.68	I 30 = 6.23	I 40 = 5.85	I 50 = 5.53	I 60 = 5.26	I 70 = 5.02	I 80 = 4.81	I 90 = 4.62	I100 = 4.44
I 10 = 6.85	I 20 = 5.96	I 30 = 5.38	I 40 = 4.95	I 50 = 4.61	I 60 = 4.33	I 80 = 4.08	I 80 = 3.86	I 90 = 3.66	I 100 = 3.48
I 10 = 8.00	**I 20 =7.33**	**I 30 = 6.81**	**I 40 = 6.41**	**I 50 =6.08**	**I 60 = 5.80**	**I 70 =5.55**	**I 80 = 5.34**	**I 90 = 5.14**	**I 100 = 4.96**
I 10 = 8.16	I 20 = 7.81	I 30 = 7.45	I 40 = 7.12	I 50 = 6.83	I 60 =6.57	I 70 = 6.34	I 80 = 6.13	I90 = 5.95	I 100 = 5.77
I 10 = 8.33	**I 20 =7.98**	**I 30 = 7.62**	**I 40 = 7.29**	**I 50 =7.00**	**I 60 = 6.74**	**I 70 =6.51**	**I 80 = 6.30**	**I 90 = 6.12**	**I 100= 5.94**

* Results of macroseismic intensity attenuation, based on Earthquakes catalog of Kosovo

The Graph in the Figure 5 plots the intensity attenuation at a distance of 100km.

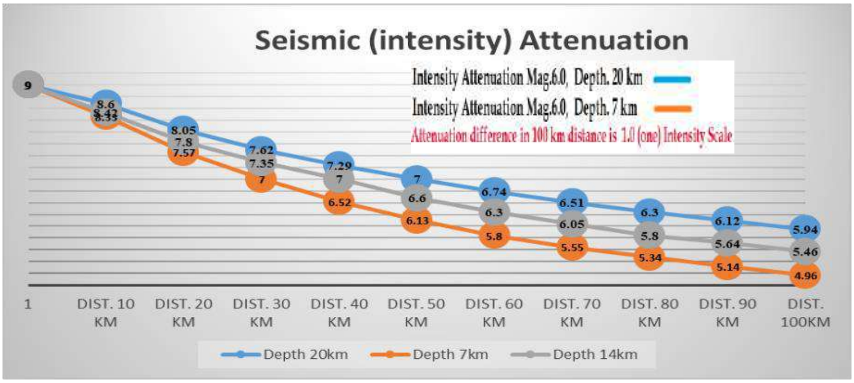


Fig. 5. Intensity attenuation at a distance of 100km.

4.1. Results of PGA attenuation

Attenuation model of PGA which includes magnitude (Mag.6.0) and distance to 100 km, in the Kosovo territory is here reported.

The table 3 and the figure 6 show the Peak ground acceleration attenuation relationships for the European area proposed by Ambraseys:

$$\log(a^*) = -1.39 + 0.266\,m - 0.922\log(r)$$

Tab.3 Attenuation of PGA at a distance of 100 km.

Attenuation PGA In 100 km	PGA 5 =0.3643	PGA 10 =0.197	PGA 20 =0.102	PGA 30 = 0.07	PGA 40 = 0.054
PGA 50 =0.044	PGA 60 = 0.037	PGA 70 = 0.032	PGA 80 = 0.028	PGA 90 = 0.025	PGA 100= 0.023

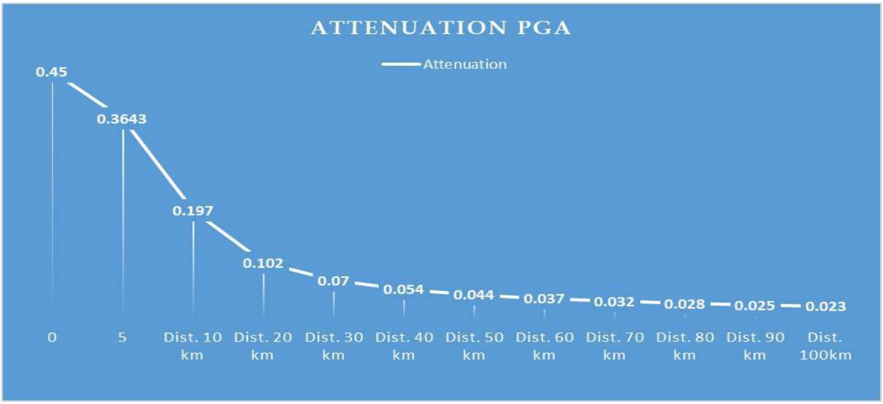


Fig 6: Graphical representation of PGA attenuation at a distance of 100km.

5. Seismotectonic characteristics of Kosovo

Synthesis and analysis of neotectonic data and their correlation with seismological data for the assessment of seismotectonic activity are in the present study made. New tectonic processes, which appear from time to time as seismic phenomena, are the earthquakes generated by active, causal faults of earthquakes, which represent seismic sources. The morphologic study of the faults and their classification based on the seismic risk assessment is of primary importance. The existing seismic data provide information about the tectonic activity of the existing faults for a short historical period. The seismic data of Kosovo provide information about the last century, while some documents inform only about the strong earthquakes of an earlier period.

Seismic activity assessment based on the existing data and the research carried out so far are means to address a more detailed information about the seismotectonic characteristics of Kosovo can be given in more detail than the seismological statistics. Based on the aforementioned seismic parameters, a map with all seismotectonic elements such as active faults, earthquake epicentres and their focal mechanisms, seismic source zones, and geological criteria of seismicity was compiled.

The map in the figure 7 seismogenically illustrates all the seismic parameters.

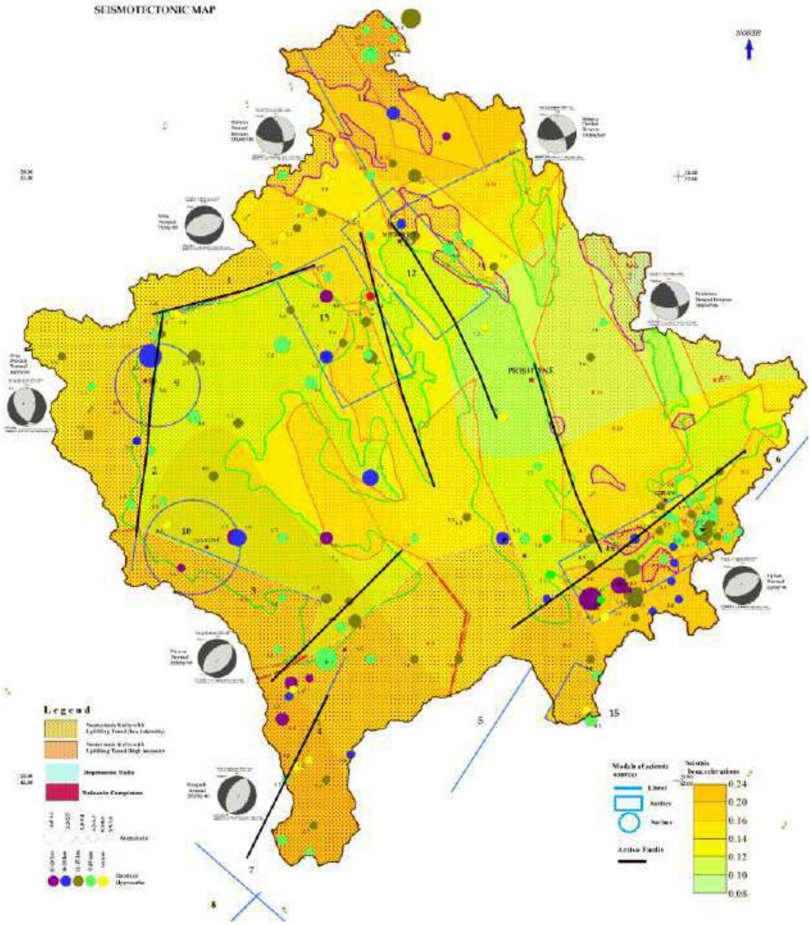


Fig.7: Seismotectonic Map of Kosova.

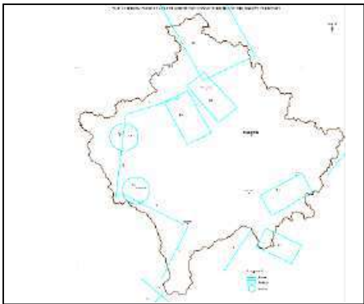
6. Seismic sources in Kosovo

The definition of seismic sources with respect to the maximum possible expected magnitude of future earthquakes is of a particular importance for the seismic hazard assessment. Delineation of seismic source zones is a fundamental step in probabilistic seismic hazard approach. A description of future earthquakes is based on a combination of the knowledge of the past earthquakes and of the geological features (active faults) along which they occurred (Elezaj 2002; Aliaj *et al*., 2010).

6.1. Seismic sources in Kosovo and their geometric characteristics

It is already known that the exclusive use of seismological data for does not provide the required results, as other additional, geological, geodetic and geophysics data would be needed. The general six seismic zones defined for Kosovo were divided into 15 seismic sources capable of generating earthquakes with the maximum magnitude up to 6.5, (Table 1). The earthquakes that are not included in the defined seismic sources are here defined as the background seismicity. The locations of the sources are identified based on the recorded hypocentral position of past earthquakes and the geological and seismological information. The spatial distribution of hypocenters is then divided into different zones based on their shape and seismicity.

Considering the aforementioned information and basing on the existing seismological data, a model of seismic sources of Kosovo involving part of the neighboring countries and consisting of 7 areas and 8 line sources fig.8 which characteristics are in the Table 2 presented was created.



Source No.	Source Name	ALFA/T	BETA	Occurred M	Expected Max	Depth (km)	Length/Area
		Line Source					
1	Istok	3,5468	-1,3129	6.0	6.0	15,0	32,0
2	Pec					15,0	33,0
3	Djakovica					15,0	34,0
4	Prizren					12,0	33,0
7	Korab	3,4855	-1,1822		5,0	15,0	41,0
7	Korab	4,7797	-1,4859	6.0	6,5	15,0	41,0
6	Elbasan-1	1,4957	-0,4023		4,0	15,0	154,0
6	Elbasan-1	6,1006	-1,5306	6.6	7,0	15,0	154,0
5	Tetovo	1,2623	-1,0186	5.7	6,0	10,0	46,0
8	Vranje	1,2430	-0,9930	5.0	5,0	20,0	33,0
		Circular source					
9	Zona Pec	3.5468	-1,3129	6.1	6,5	15,0	177,0
10	Zona Djakovica	3.5468	-1,3129	6.1	6,5	15,0	177,0
		Rectangular source					
12	Srbica-1	9.4841	-2,9841	4.5	5,0	15,0	439.0
13	Srbica-2	9.4841	-2,9841	4.5	5,0	15,0	381.0
14	Urosevac	3,3504	-1,3418	5.6	6,5	15,0	347.0
11	Kopaonik	4,4957	-0,8720	6.0	6.0	10,0	1404.0
15	Skopje	3,6669	-1,3929	6.1	6,5	4,5	394.0
	Kosovo						

Fig. 8: Seismic sources in Kosovo.

6.2. Seismic Source Zone Model in Kosovo

In geophysics and seismology, the seismogenic layer covers the range of depths within the crust or lithosphere in which most earthquakes originate. A fundamental step in any probabilistic seismic hazard analysis (PSHA) is the delineation of seismic source zones and the identification of seismically active faults (Araya and Der Kiureghian 1988).

The geological criterion is related to the processes that occurred during the neotectonic stage, which marked the main morphostructures formed in the today's relief. These processes are a continuation of the early neotectonic stages and therefore serve as reliable data for the prediction of the location and strength of future earthquakes. Based on the existing data, the Dukagjini region represents the most active seismotectonic area of Kosovo. The Peja-Istog and Peja-Decan faults can be singled out disjointedly as active zones, morphologically notable and of a regional character. This region is prone of strong earthquakes which maximum magnitude is 6.1 - 6.5. The Prizreni and Dragashi faults are the most active faults in the south-western area. Here, the maximum magnitude of earthquake is 6.3 - 6.5. The South-eastern area is also transverse, which is delineated by the Quaternary Lowland of Morava e Binçës, from Ferizaj to Viti towards Gjilani. The strongest earthquakes have a maximum magnitude of 6.2 -6.5 Richter. The central area, the lateral detachments of the Kosovo Lowland are not morphologically expressed and do not show any tectonic activity. The existing data report that the most active disconnections during the Pliocene epoch were the Sitnica and Çyçavica Drenica disconnections. These two disconnections are morphologically prone to seismic events. Here, the maximum magnitude of earthquakes is 5.5 - 6.0. The Kopaunik region, in the north of Kosovo, where volcanism was typical of the Neogene period, represents the end of the separations of the Vardar direction with the transverse ones. Earthquakes of magnitude between 5.8 and 6.2 are here expectable (fig.9).

The zones of seismic sources are :

1. Prizren-Gjakova-Dragash, maximum magnitude M = 6.3 - 6.5 Richter,
2. Ferizaj-Viti-Gjilan, maximum magnitude M = 6.2 - 6.5 Richter,
3. Istog-Peja-Decan, maximum magnitude M = 6.1 - 6.5 Richter,
4. Kopaonik, maximum magnitude M = 5.8-6.2 Richter,
5. Drenas - Skenderaj, maximum magnitude M = 5.5 - 6.0 Richter,
6. Prishtina-Mitrovica, maximum magnitude M = 5.5 - 6.0 Richter,

These areas prone to strong earthquakes.

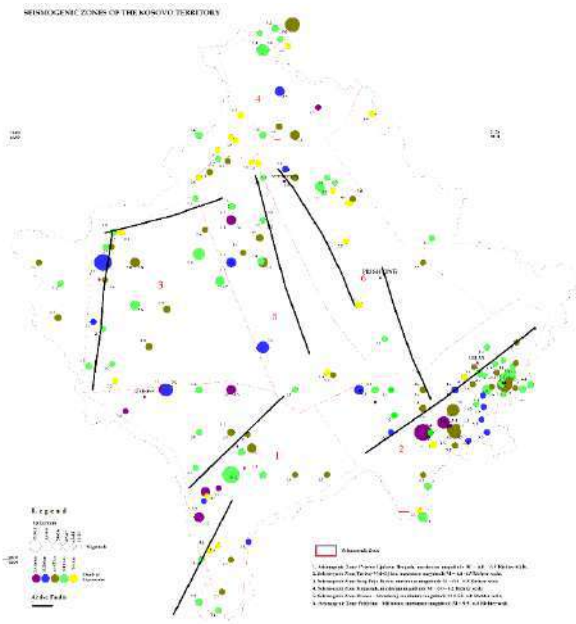


Fig. 9: Seismic Source Zones of Kosovo.

2. CONCLUSIONS AND RECOMMENDATIONS

The aforementioned data show that the major part of the territory of Kosovo can be considered as area with average seismic hazard (0.10g<PGA<0.24g). The Kopaoniku zone in the north of Kosovo, the Prizren- Djakova zone, especially in the east-southeast of Prizreni, close to the Albanian border, the Peja-Istog zone, the Ferizaj-Viti-Gjilan zone, especially in the Skopje direction, the Drenas- Skenderaj zone and the Prishtina-Mitrovica zone can be considered as zones with high seismic hazard.

The seismological monitoring network of Kosovo has been recently created, and the scientific research has already begun.

The seismic hazard maps are frequently updated to include the latest seismologic data at a local, regional and global level. Issues to be addressed to would be: i) further investigation about the hypocenter parameters of the earthquakes in Kosovo and, ii) the re-evaluation of the magnitude of the historical earthquakes in Kosovo.

The results here reported can be improved if: i) further improvement of the seismicity parameters through the updating of the earthquake data base for Kosovo and the surrounding areas are made, ii) a regional seismotectonic model that correlates seismicity with the active tectonic faults, their focal mechanism, etc. is created and, iii) more accurate models for the prediction of ground motion parameters based on regional strong motion records in Kosovo and the surrounding areas are created.

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