Towards a New Seismic Hazard Assessment of Albania

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ABSTRACT:
The probabilistic approach for the seismic hazard assessment of Albania, undertaken in the framework of the NATO SfP 983054 project, is now consolidated and the results, expressed in terms of PGA, have been computed for return period 475 years, corresponding to probability of exceedance 10-percent in 50 years. The reference site condition is firm rock, defined as having an average shear-wave velocity of 800 m/sec in the top 30 meters corresponding to site class A of the Eurocode 8 provisions. Thus, they are in full agreement with the standards of the European seismic code (Eurocode8) for seismic zonation and building codes. If the map corresponding to 475 years return period is chosen as the reference to establish a new regulatory national seismic zonation, design acceleration will be much higher than that applied in the current regulation. That implies the competent authorities should take into consideration the obtained results in order to improve the existing design code on a more reliable and more realistic basis in order to increase the safety level of constructions in the country.

Keywords: Seismic hazard, PSHA, smoothed-gridded seismicity.

1. INTRODUCTION

The continuous improvement of procedures for defining the seismic hazard at regional, national and local scale is essential for the optimum design of earthquake-resistant structures. Several attempts have been made the last years to express the seismic hazard in terms of ground acceleration using the probabilistic approach (Kuka *et al.*, 2003, Aliaj *et al*. 2004). However, is imperative to develop a new seismic hazard assessment of the country using the more advanced probabilistic methodologies, which will comprise the foundations for the definition of a new seismic zonation and a new design code, according to the Eurocode 8 requirements.

Here, we present the recent achievements towards a new probabilistic seismic hazard assessment for Albania, undertaken in the framework of NATO SfP 983054 project “Harmonization of Seismic Hazard Maps for the Western Balkan Countries” funded by Science for Peace and Security Programme of NATO (Akkar et al. 2007). The new seismic hazard assessment builds upon extensive research and database compilation carried out over the last three years by the institutions participating in this project. Both the historical and the instrumental earthquake database was vastly improved and converted to a uniform moment magnitude scale. Finally, we implemented a new computation methodology based on the smoothed-gridded seismicity approach and on a logic tree, to fully characterize the seismic hazard and its associated uncertainties.

2. SEISMICITY DATA

A homogeneous earthquake catalogue, compiled and revised by Sulstarova et al. (2002, 2005), which contains more than 700 events with magnitude $M_S \geq 4.5$, was used as the core of the seismological database. It covers the time period 58 BC up to 31/12/2005, and the area between 18.5-21.5°E and 39-43°N. The size of the earthquakes is given in terms of surface-wave magnitude M_S. This catalog was later completed adding all the events with $M_L \geq 3.5$, occurred in the above area during the period 1964-2008 (Peçi et al., 2000). Because seismic hazard evaluation needs computing of the seismic activity at least 100-150 km beyond the national boundary, a seismicity working file for the area 18-24°E and 38-44.4°N was compiled, revising the above catalog, and extending by at least one degree its geographical borders. This file was produced by cautiously merging the extended Albanian catalog with the ISC bulletins, as well as the earthquake catalogs compiled by the relevant neighbor institutions, such as Podgorica, Zagreb, Belgrade, Skopje and Thessaloniki. When these catalogs have different interpretations for any event, the highest priority was generally given to the catalog of the country where that event occurred.

Compilation of a homogenous earthquake catalog, by expressing the size of the earthquakes in a unified magnitude scale, is the first step in the seismic hazard evaluation. Because at present almost all Predictive Ground Motion Models (PGMM) use moment magnitude as one of the explanatory variables, it is indispensable to have a homogenous unified earthquake catalog in terms of M_W, for both historically known and the instrumentally recorded events. Unfortunately, seismological institutions of the region report the information regarding the earthquakes in different magnitude scales (M_L, M_S, m_b, M_W, etc.). For the historical events they use the epicentral intensity, I_0, and later convert it in M_S or any other equivalent magnitude, using regression models with I_0 and other focal parameters as input (Karnik, 1996). For the instrumental period, usually the earthquake size is expressed in terms of local magnitude, M_L. But the instrumentation and procedures used for M_L determination are rather different, thus the M_L magnitudes reported up to know by different centers cannot be considered as equivalent. Hence, it is not possible to define a unique regional relation connecting M_L to M_W or to any other magnitude scale. Therefore local relations have to be derived.

Procedure followed to estimate the moment magnitude M_W for all the events included in the extended seismicity file covering the area [18-24°E, 38-44.4°N] was:

- The converted or re-estimated magnitudes reported in Karnik (1996) are in M_S scale consistent with the Prague formula. They are converted to M_W using formulas (18-20) derived by Scordilis (2006).
- Magnitude M_S in the catalogue of Tirana and other neighbor institutions, as well as M_S reported in the bulletins of ISC, are considered as estimated using the Prague formula. They also are converted to M_W using the equations (14-15) derived by Scordilis (2006).
- *mb* magnitudes from ISC bulletins are converted to M_W using the relevant formula (eq. 22) derived by Scordilis (2006).
- The earthquake catalogue published by Thessaloniki (Papazachos et al., 2000) is expressed in terms of moment magnitude, M_W.
- To enable conversion to M_W of the local magnitudes M_L calculated by the seismological centers of the region, we initiated a detailed statistical investigation regarding the relationships between M_L magnitudes reported by them, and the moment magnitude M_W. A considerable dataset from the above mentioned agencies was used, accepting as reference the moment magnitude obtained from the Harvard centroid moment tensor solutions (Dziewonski et al., 1981) and the regional moment tensor solutions (INGV-Rome and ETHZ-Zürich). More than 260 moment tensor solutions for medium-strong events in the Western Balkan region, varying from M_W=4.0 to M_W=7.0, have been calculated for 1977-2008. The method used is that of errors-in-variables regression. The empirical relations obtained for Tirana, Podgorica, Zagreb, Belgrade and Skopje (Table 1, Duni et al. 2010), are used to convert M_L reported by them to the moment magnitude M_W.

Table 1. Correlative relationships between moment magnitude M_W and local magnitude M_L.

Agency	Regression equation	Number of events	Determination coefficient, R^2	Stand. dev. of regression, s_e
Tirana	$M_W = 1.624 + 0.743 M_L$	102	0.74	0.301
Pogdorica	$M_W = 0.218 + 0.985 M_L$	46	0.93	0.163
Zagreb	$M_W = 0.165 + 0.979 M_L$	34	0.92	0.167
Belgrade	$M_W = 0.324 + 0.963 M_L$	18	0.87	0.200
Skopje	$M_W = 0.912 + 0.880 M_L$	23	0.85	0.210
Thessaloniki	$M_W = 0.383 + 1.010 M_L$	109	0.83	0.220

A map which depicts the spatial distribution of epicenters of earthquakes used in the present study is shown in the Figure 1. It is obvious that seismicity is not uniformly distributed within the region.

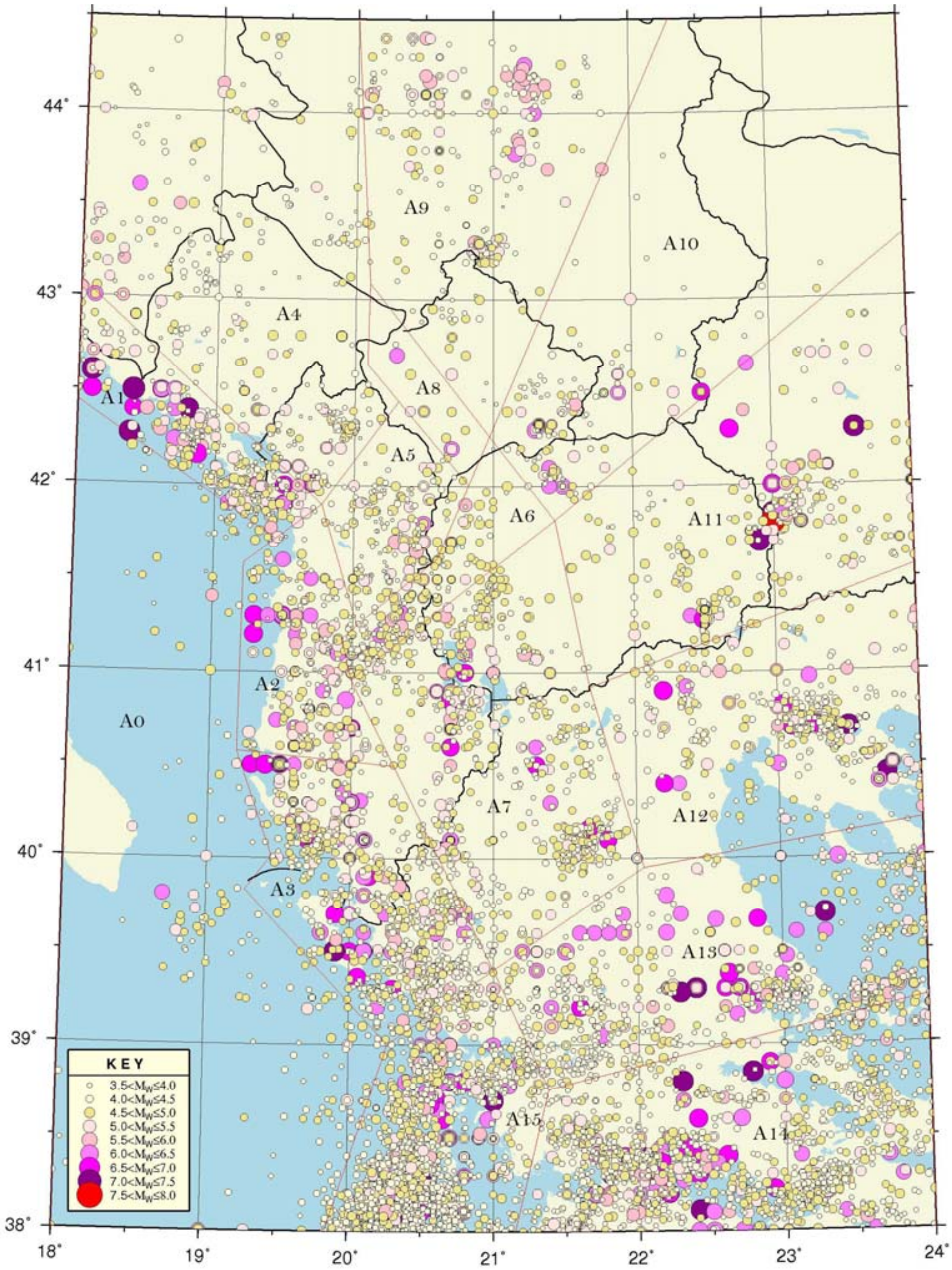

Figure 1. Distribution of the earthquake epicenters in the study region (510 B.C.–31/12/2008, $M_W \geq 4.0$), and the seismotectonic zones used for seismic hazard assessment.

2.1. Data completeness

Modeling of seismicity in a certain region depends on estimation of the parameters characterizing the magnitude-rate distribution. Since historical data records are incomplete, it is important that the probabilistic model accounts for this deficiency. A prerequisite for a successful seismic hazard evaluation is to assess the data completeness, that is to assess the magnitude above which the catalogue can be considered as reasonably complete, or alternatively to assign time intervals in which a certain magnitude range is likely to be completely reported. The identification and application of several completeness intervals, the use of different observation periods and magnitude ranges gives an estimate of the variations of the modeled parameters, which is important for successful hazard estimation.

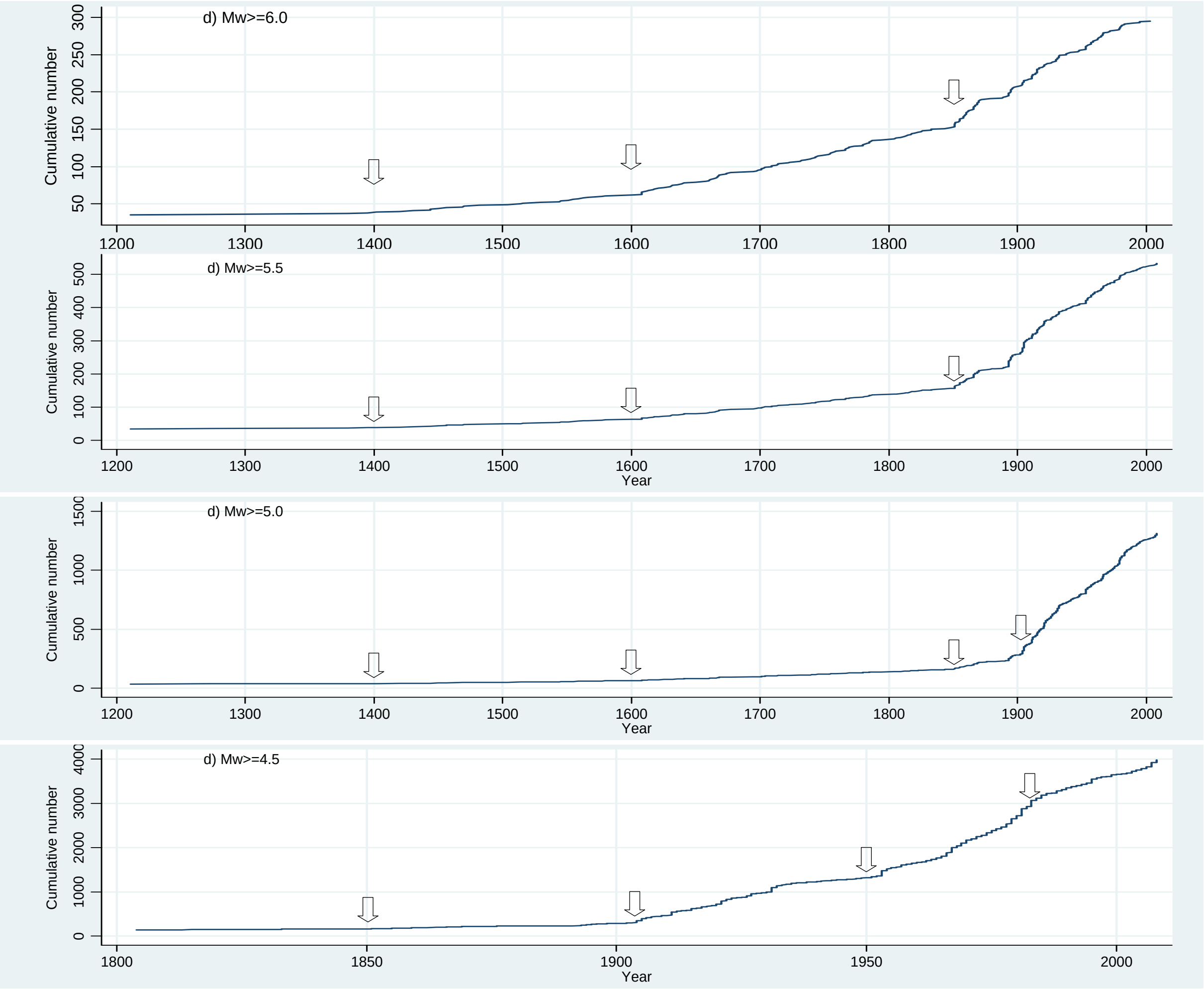

Figure 2. Cumulative number of seismic events with magnitude larger or equal to *4.5*, *5.0*, *5.5* and *6.0*; the arrows indicate the points where changes the curve slope.

Data completeness levels are estimated from the earthquake catalogue, by using the cumulative number of events *versus* time graphs, in order to evidence slope changes, assuming that the most recent change in slope occurs when the data became complete for magnitudes above the reference (Gasperini and Ferrari, 2000). Inspecting the cumulative number *versus* time graphs (Fig. 2) for the area [18.5-21.5°E, 39-43°N], we identified five points in time corresponding to the magnitude thresholds 4.5, 5.0,5.5, 6.0 and 6.5, where the graph slope changes are evidenced. So, the relevant catalogue can be considered complete since 1950 for earthquakes with $M_W \geq 4.5$, since 1905 for earthquakes with $M_W \geq 5.0$, since 1850 for earthquakes with $M_W \geq 5.5$, and since 1600 for earthquakes with $M_W \geq 6.0$.

2.2. Declustering of the catalogue

Earthquakes are usually spatially and temporally clustered. For most hazard related studies, it is required that the seismicity behaves in a time-independent fashion, in order to avoid biasing the average-rate assessments with data from, for example, prominent aftershock sequences that may not be representative of the average behavior of a crustal volume. To model earthquake occurrence in time, it is assumed that they follow a Poisson process with constant recurrence rate λ. Declustering attempts to separate the time-independent part of seismicity (background) from the time-dependent or clustered parts (aftershocks, foreshocks and swarm type activity).

Firstly, we investigated whether or not the temporal distribution of events within our catalog is Poissonian, which would argue that declustering may not be necessary. So, we modeled the inter-earthquake time intervals (*T*) between successive events, by using the Weibull distribution for *T*, and found that the process cannot be considered as a Poissonian one. Therefore, the catalog has to be purged of aftershocks and foreshocks prior to modeling of the magnitude frequency distribution and any further hazard analysis. The seismicity data file was made Poissonian by tagging the main shocks and applying simultaneously a distance-window and two time-windows for eliminating foreshocks and aftershocks. The window parameters are dependent on the main shock magnitudes. Using a space-time magnitude dependent window, we identified the independent events and removed all aftershocks and foreshocks from the sample. This new subcatalogue, purged of aftershocks and foreshocks, is used to estimate adequately the seismicity parameters, and in the other calculations for seismic hazard assessment.

3. SEISMICITY PARAMETERS

Reliable evaluation of the seismic hazard is interdependent on the accurate estimation of seismicity parameters, such as the magnitude-frequency relation coefficients (*a*- and *b*-values in G-R relation), the mean annual rate of seismic activityλ, the completeness level of the seismic data M_{min} above which the earthquake catalogue can be considered to be complete, and the regional maximum magnitude M_{max}. Seismic activity rate is estimated using the double truncated exponential recurrence relationship, in order to confine the range of magnitudes, eliminating the contribution of very small earthquakes at the lower end and unrealistic high magnitude earthquakes at the high end.

The recurrence parameters have been evaluated by maximum likelihood approach (*MLE*), as it is described in Bollinger et al., (1993), Weichert (1980) and Berril and Davis (1980), taking into account different magnitude observation periods (data completeness). Another method used to estimate the recurrence parameters is the historical-parametric approach proposed by Kijko and Selevoll (Kijko and Selevoll, 1989, 1992; Kijko, 2004), which is based on the observed seismicity. Except the instrumental data, this approach considers the earthquake macroseismic information gathered during the course of the history, as well. The results obtained using both methods, for each of areal source zones included in the study area (Figure 1), are shown in the Table 2. Comparing the estimates taken by the two approaches doesn't indicate any significant difference. The zone delineation has been performed taking into account the similarity of the geodynamic behavior, as well as the homogeneity of the spatial earthquake epicenter distribution. Each of the identified zones is characterized by a specific frequency-magnitude relationship derived by the historical data (macroseismic intensities) as well as instrumental ones.

The maximum possible earthquake, M_{max}, is recognized as a critical parameter with considerable influence on the final hazard, at least for long return periods. It is the seismicity parameter the most difficult to assess, because the physical understanding of M_{max} is poor and because the database to derive this parameter is statistically very limited. We used the Kijko-Selevoll approach based on observed seismicity, but considered also the previous estimates based on geological consideration (Aliaj *et al.*, 2004). The maximum magnitude historically observed in the study region is $M_W=7.7$. For the region [18.5-21.5E, 39-43N], which comprises the Albanian territory, the maximum magnitude observed is $M_W=7.2$ for the historical period, whereas the maximum observed magnitude for the instrumental period is $M_W=6.9$. The final assessments of M_{max} for every zone are given in the last column of the Table 2. These estimations are further used in the hazard computation. The Kijko-Selevoll estimates for M_{max} seems to be reasonable, accounting for the long return periods of the large earthquakes on the Albanian territory.

Table 2. Recurrence parameters, estimated by MLE: Bollinger *et al.* (1993) and Kijko-Selevoll (1989, 1992)

Source zone	Number of events	M_{max} (obs)	Bollinger *et al.*, (1993)			Kijko-Selevoll (1989, 1992)			M_{max} accepted
			a-value	*b*-value	λ ($M_W \geq 4.5$)	*b*-value	λ ($M_W \geq 4.5$)	M^*_{max}	
A0	43	6.0	7.129 ± 0.465	1.628 ± 0.098	0.633 ± 0.086	1.920 ± 0.26	0.590 ± 0.09	6.06 ± 0.12	6.1
A1	57	7.2	3.889 ± 0.096	0.918 ± 0.018	0.575 ± 0.048	0.900 ± 0.10	0.540 ± 0.09	7.54 ± 0.35	7.3
A2	77	6.8	4.599 ± 0.133	1.031 ± 0.026	0.913 ± 0.060	1.070 ± 0.09	0.770 ± .10	6.85 ± 0.11	6.9
A3	247	7.0	5.592 ± 0.284	1.133 ± 0.057	3.105 ± 0.066	1.300 ± 0.065	2.860 ± 0.20	7.18 ± 0.21	7.0
A4	60	5.7	4.987 ± 0.181	1.127 ± 0.037	0.826 ± 0.076	1.160 ± 0.20	0.670 ± 0.10	5.78 ± 0.13	6.0
A5	37	6.1	5.329 ± 0.237	1.277 ± 0.048	0.504 ± 0.074	1.08 ± 0.18	0.550 ± 0.09	6.43 ± 0.34	6.5
A6	41	6.2	5.135 ± 0.304	1.201 ± 0.061	0.536 ± 0.069	1.030 ± 0.16	0.50 ± 0.08	6.28 ± 0.13	6.6
A7	133	6.7	5.857 ± 0.380	1.247 ± 0.077	1.763± 0.070	1.400 ± 0.09	1.730 ± 0.16	6.91 ± 0.23	6.8
A8	7	6.0	4.185 ±0.751	1.161 ±0.152	0.091 ±0.069				6.3
A9	45	5.9	4.400 ± 0.184	1.032 ± 0.037	0.571 ± 0.067	1.230 ± 0.27	0.310 ± 0.07	6.13 ± 0.27	6.1
A10	24	6.5	4.052 ± 0.236	1.021 ± 0.046	0.287 ± 0.061	0.810 ± 0.20	0.160 ± 0.05	6.75 ± 0.27	6.7
A11	85	7.7	5.795 ± 0.59	1.277 ± 0.117	1.120 ± 0.069	1.480 ± 0.15	0.690 ± 0.10	8.00 ± 0.32	7.7
A12	93	7.0	6.101 ± 0.490	1.333 ± 0.098	1.265 ± 0.073	1.580 ± 0.10	1.230 ± 0.13	7.21 ± 0.23	7.2
A13	141	7.0	5.432 ± 0.244	1.153 ± 0.048	1.756 ± 0.064	1.270 ± 0.09	1.520 ± 0.15	7.32 ± 0.34	7.2
A14	272	7.0	6.256 ± 0.315	1.267 ± 0.061	3.595 ± 0.066	1.320 ± 0.070	1.800 ± 0.16	7.33 ± 0.34	7.2
A15	247	7.4	5.447 ± 0.248	1.119 ± 0.048	2.584 ± 0.060	1.190 ± 0.06	2.480 ± 0.19	7.73 ± 0 .34	7.4

4. HAZARD COMPUTATION

Evaluation of the seismic hazard is performed using the smoothed-gridded methodology (Frankel 1995, Lapajne et al., 2003), which is based on seismic activity rate inferred from the earthquake catalogue. Hazard calculations are accomplished using the OHAZ 6.0 software (Zabukovec et al., 2007), developed in collaboration with the Seismological Office of the Environmental Agency of Slovenia. Seismic hazard was calculated at grid cells (5x5 km) covering the study region [18.0°-24.0°E, 38°-44.4°N]. First, the seismicity rates are determined at every grid cell by counting the earthquakes with magnitude greater or equal to the minimum magnitude ($M_W=4.5$), and adjusting this value using a maximum likelihood method (Weichert, 1980) that accounts for variable completeness. Then, the adjusted earthquake rates are spatially smoothed using a two-dimensional Gaussian smoothing operator with correlation distance 20 km, and an elliptical smoothing oriented according to the main tectonic faults in the region.

Based on the smoothed seismicity rates and the under mentioned PGM equations, probabilistic hazard curves that depict the annual frequency of exceedance at given ground-motion levels are calculated at the cells included within a smaller grid ([19.5°-21.5°E, 39°-43.0°N]) covering the Albanian territory. To calculate the hazard from a particular source, we apply a doubly-truncated exponential magnitude-frequency distribution, with *b*-values as those shown in the Table 2. The minimum magnitude is $M_W=4.5$, while M_{max} values vary from *6.0* to *7.7*, according to the seismotectonic zones identified in the region (Table 2, last column).

Because the ground-motion relations are generally the parameter with the largest uncertainty, the hazard is estimated using three wellknown PGM equations: Bindi et al., 2009 (USP96), Berge-Thierry et al. 2003 (BTh03) and Boore and Atkinson 2008 (BA08). Then, the mean weighted values of the relevant estimates using each of these models, accepting as weights w_1=0.5 for USP96 model, w_2=0.3 for the BTh03, and w_3=0.2 for BA08 model, were accepted as final results. Assessment were performed for rock conditions, with 800 m/sec shear-wave velocity in the upper 30 m of the soil section, that corresponds to Class A according to Eurocode 8 soil classification. The maximum source-site distance and the magnitude range used in the integation, were choosen in accordance with their magnitude-distance domain: D_{max}=100 km and $5 \leq M \leq 7.5$ for USP96; D_{max}=100 km and $4.5 \leq M_S \leq 7.5$ for BTh03; D_{max}=200 km and $5 \leq M_W \leq 7.5$ for BA08.

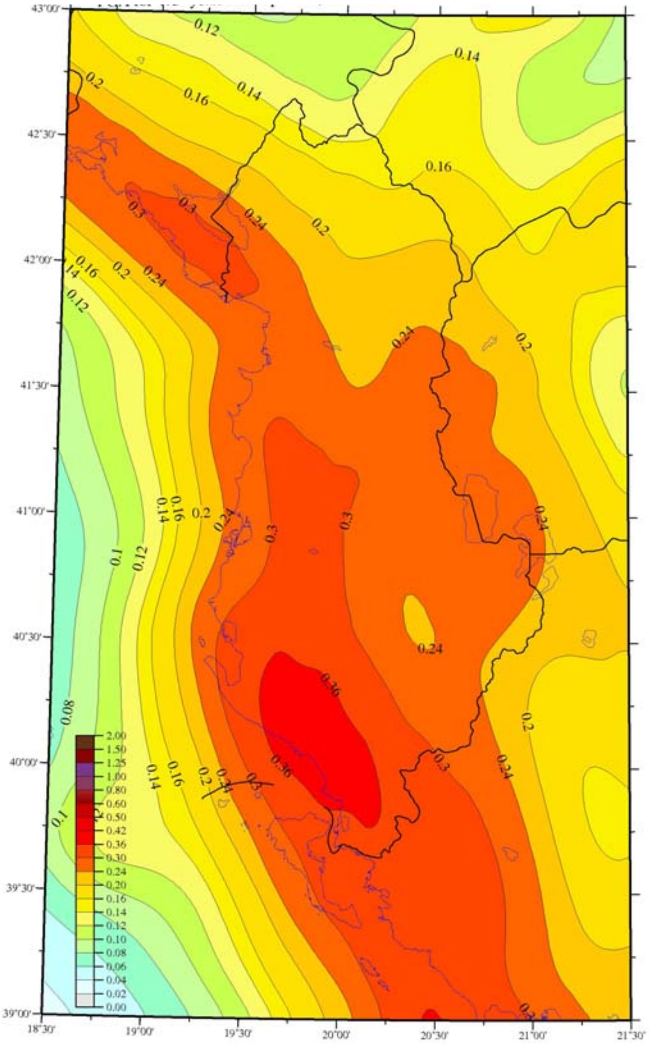

Figure 3. Probabilistic seismic hazard maps for PGA (475-year Return period, rock conditions).

To obtain the hazard maps we interpolated the mean hazard curves at specified annual frequency of exceedance. The hazard model assumes Poisson (time-independent) event occurrence. Figure 3 shows a seismic hazard map for PGA on uniform firm rock site conditions (800m/s shear-wave velocity in the upper 30 m of the crust) at 10-percent probability of exceedance in 50 years, corresponding to 475 years of return period.

The seismic hazard results indicate that very few areas can be considered safe, part of Northern Albania, where values less than 0.15g are expected. The northwestern and the southern part of the country represent the area with the highest hazard. Lushnja-Elbasan-Dibra area also reveals a high hazard. Acceleration ranges from 0.2 g approximately in all the territory, up to 0.3-0.38g in northwestern and southwestern part of the country.

If this map is chosen as the reference to establish a new regulatory national seismic zonation, design acceleration will be much higher than that applied in the current regulation. That implies the competent authorities should take into consideration the obtained results to improve the existing design code on a more reliable and more realistic basis in order to increase the safety level of constructions in the country.

The obtained results can be considered reliable, however are still under analysis and should be refined, improving the earthquake database and the seismotectonic model of the region. In addition, more elaborate probabilistic analysis should be performed using the logic tree approach, to consider modeling uncertainty.

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