Regional and temporal evaluation of seismicity in the Vlora-Elbasani-Dibra Transversal Fault Zone, Albania

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ABSTRACT

Characteristics of seismic activity along the Vlora- Lushnja-Elbasani-Dibra (V-L-E-D) Transversal Fault Zone are analyzed between 1964 and 2015. There are a total of 2814 events in the time interval 1964 and 2015 with $M_d \geq 1.7$. This study is focused on the correlation of seismotectonic *b*-value, precursory quiescence *Z*-value, and interrelationships between some other seismicity parameters. The distribution of the relatively low *b*-value coincides with the tectonic compression field which acts along the V-L-E-D Transversal Fault Zone. The distribution of the relatively low *b*-value coincides with the tectonic compression field which acts along the V-L-E-D Transversal Fault Zone. Anomalously low *b*-value areas coincide more or less with the spatial distribution of $M \geq 5.0$ earthquakes and their known rupture extents. Temporal changes in *b*-value may be related to the stress variations in these times before and after the main events. The lowest *Z*-values show that the variations in seismic activity rate are not significant, and the highest *Z*-values demonstrate a decrease in seismicity rate. In the *Z*-value maps for all parts of the V-L-E-D, three areas exhibit significant seismic quiescence: centered at 41.00°N-19.78°E (region A, around Lushnja), 40.99°N-20.03°E (region B, in the Cerriku), 40.81°N-19.86°E (region C, including Kucova). In addition to these three significant areas, there are some small quiescence areas in different parts of the V-L-E-D.

Key words: *Vlora-Lushnja-Elbasani-Dibra Fault Zone, seismic activity, b-value, Z-value, decompose*

INTRODUCTION

The Albania region is a seismically active area with tens of destructive large earthquakes over the past twenty centuries as revealed from the historical sources [7] [16]. The main cause of Albanian seismicity is the collision of Adria with the Albanian orogen. This continental collision directly influences on the inner part of the country, on the longitudinal and transverse faults cutting across the eastern and north-eastern part of Albania [2] [9]. The Lushnja-Elbasani-Dibra (V-L-E-D) Transversal Fault Zone in Albania is a major tectonic feature with a well-defined fault trace and an established history of seismicity. Activity of the V-L-E-D during the 20th century began with the destructive Peshkopia earthquake in 1920 in northeast Albania and migrated westwards by a series of destructive earthquakes in 1921, 1930, 1935, 1942, 1959, 1962, 1967, 1982, 2009, and 2014 [2] [10] [16]. In the present study, our main goal is to analyze the spatial and temporal properties of seismicity pattern in the VLED Transversal Fault Zone in order to better understand the seismic hazards in this significant area.

I. GEOLOGIC, TECTONIC / NEOTECTONIC SETTINGS OF ALBANIA

The main geological structures found within the Albanian territory are called the Albanides, which are part of the Dinaric-Albanid-Hellenic arc of the Alpine orogen. They are located between Helenides in the south and Dinarides in the north, which together form the Dinaric branch of the Mediterranean Alpine Belt. The Vlora-Elbasani-Dibra (V-L-E-D) Transversal Fault Zone [10] [17] (Fig. 1) with north-east strike dislocates the structure of the Albanides along their entire width. It is expressed by Vlora and Lushnja flexure, Dumrea diapire dome, Elbasani Quaternary depression, Labinoti transversal structure, marked by important quaternary infill (Melo, 1986), Golloborda transversal horst continues toward the Tetova Quaternary graben in FYROM [17] (Fig. 1).

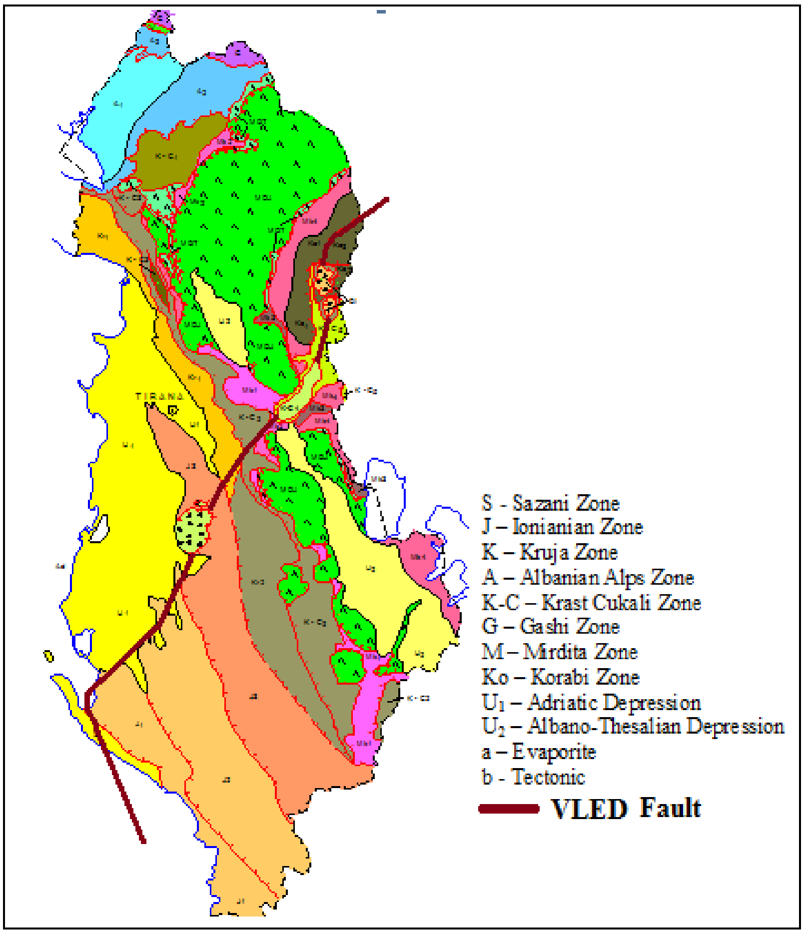

Fig. 1. Schematic tectonic map of Albania and seismic source zones in the VLED Transversal Fault Zone.

This fault zone, NE trending for approximately 100 km in Albanian territory, is composed of fragmentary normal faults cutting across the Krasta zone and dividing the Mirdita ophiolites zone in two main segments [2] (Fig. 1). Based on the analysis of the focal mechanisms of moderate and strong earthquakes, the V-L-E-D transverse fault zone plays an important role in the seismotectonics of Albania, as well as of the FYROM [2] [8] [15].

II. DATA AND DESCRIPTIONS OF THE METHODS

Epicenter distributions of all earthquakes (*Md*≥1.7) and the principal main shocks (*Md*≥4.5) in the study region are shown in Figure 2. The focal depth analysis reveals that this seismicity was mainly generated in the shallow upper crust under tectonic conditions that were described earlier [6-7]. The Vlora-Lushnje-Elbasani-Dibra transverse fault zone has experienced many damaging earthquakes during the past 95 years [8], [9] [15] [16]. The Elbasani section has ruptured during earthquake occured on 18 December 1920, (I=VIII degree), 31 March 1930 (*M* 5.7) and 19 May 2014 (*M* 5.2). The Dibra earthquake of 30 November 1967 (*M* 6.7) is one of the greatest earthquakes that occurred in Albania.

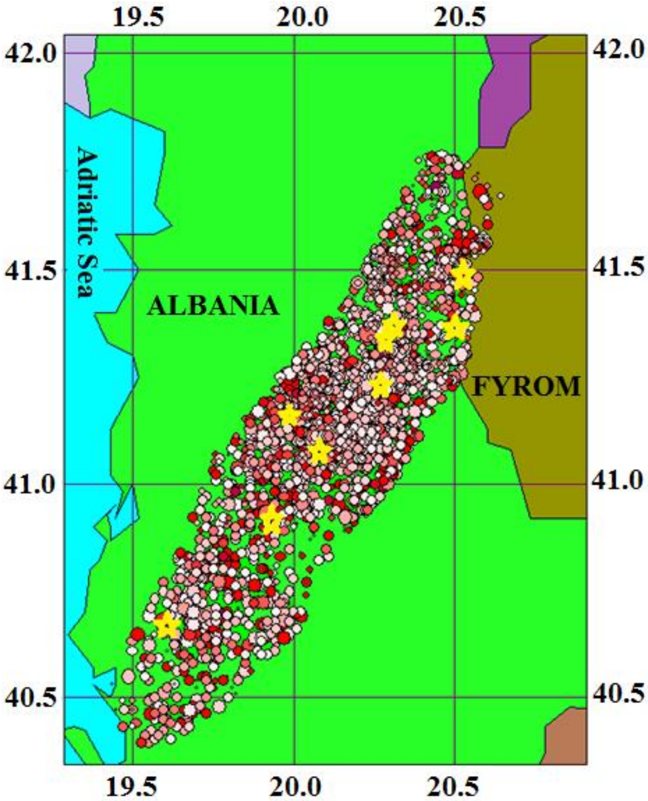

Fig. 2. Epicenter distributions of all earthquakes with Md≥1.7 and depth<70 km in the VLED Transversal Fault Zone between 1964 and 2015. Stars represent the principal main shocks with Md≥4.5.

The Dibra section have occurred other earthquakes 30 March 1921 Peshkopia (I=VIII-IX degree), 27 August 1942 Peshkopia (*M* 6.0), 6 September 2009 Gjorica (*M* 5.4). The Lushnja-Fieri section have occurred 1 Shtator 1959 Lushnja (*M* 6.2), 18 Mars 1962 Fieri (*M* 6.0), 16 November 1982 Fieri (*M* 5.4). The earthquakes that occurred in the Vlora segment are: 21 November 1930 Qaf-Llogaras (*M* 6.0). The behavior of seismic activity analyzed in this study is restricted to shallow events (<50 km). There are a total of 2814 events in the time interval 1964 and 2015 with *Md*≥1.7. In order to characterize the seismic behavior, a number of statistical parameters are used; namely size-scaling parameters (such as slope of recurrence curve *b*-value), temporal and spatial distribution of earthquakes with characteristics of seismic quiescence *Z*-value as well as the histograms of temporal, spatial and magnitude distribution along the Vlora-Lushnja-Elbasani-Dibra fault zone.

III.1. Magnitude-frequency relation (*b*-value) and magnitude completeness, *Mc*

The relationship between the size of an earthquake and its frequency of occurrence named as FMD (Gutenberg & Richter, 1944) [4] and defined as:

$$\log_{10} N(M) = a - bM \tag{1}$$

where $N(M)$ is the cumulative number of events with magnitudes equal to or larger than M. The parameters a and b are constants. The a-value shows the activity level of seismicity. The b-value is the slope of the frequency-magnitude distribution. The b-value has been shown to be inversely related to the shear stress in the crust [20]. b-value is positively correlated with the increasing heterogeneity in the crust [5] and shows strong heterogeneity in finer scales. The b-value can be estimated from the maximum likelihood method [1]:

$$b = 2.303 / (M_{mean} - M_{min} + 0.05) \tag{2}$$

where M_{mean} is the average value of magnitude and M_{min} is the minimum completeness magnitude in the seismicity catalogue to be analyzed. 0.05 value in this equation is a correction constant. The 95% confidence limits on the estimates of b-value are $\pm 1.96\ b/\ n$, where n is the number of events used to make estimation. The completeness magnitude, *Mc*, is an important parameter for many seismicity studies [13]. In these studies, the usage of the maximum number of events available is necessary for high-quality results. Tendency of decreasing of b-values in temporal distributions before the large main shocks can be used as an indicator of the next earthquake [12]. Estimating of *Mc* can be made by the assumption of Gutenberg–Richter's power-law distribution against magnitude [20].

III.2. Decomposing of catalogue and precursory quiescence *Z*-value

Some activities such as foreshocks, aftershocks, earthquake swarms, generally mask temporal variations of the number of events and the related analysis. The elimination of the dependent events from the catalogue is necessary for the reliable analysis of seismicity rate changes. In order to decompose (or decluster) the data based on the algorithm developed by Reasenberg (1985), *ZMAP* software in Wiemer (2001) is preferred [21]. In study region, there are 2814 events with magnitudes greater than or equal to 1.7. *Mc* value for region is 2.5 and the number of earthquakes exceeding this completeness value is 1992. The decomposing process took away 460 events and 16% of the earthquakes were removed from the whole catalogue of region. Thus, the number of events for *Z*-value analysis was taken as 2354 for the VLED Fault Zone. In order to rank the significance of quiescence, the standard deviate *Z*-test is used [19], generating the Log Term Average (LTA) function for the statistical evaluation of the confidence level in units of standard deviations:

$$Z = (R1 - R2)\ (S1 / N1 + S2 / N2)^{1/2} \tag{3}$$

where $R2$ is the mean seismicity rate in the foreground window, $R1$ is the average number of events in all background period, S and N are the standard deviations and the number of samples, within and outside the window. The Z-value calculated as a function of time, letting the foreground window slide along the time period of catalogue, is called LTA.

III. RESULTS OF SEISMICITY ANALYSIS AND DISCUSSION

A detailed investigation of the seismicity behavior in the V-L-E-D Transversal Fault Zone in Albania is made by using the Gutenberg–Richter *b*-value, seismic activity rate changes, *Z*-value and also by evaluating the histograms of the temporal, spatial and magnitude distribution in time intervals between 1964 and 2015. As a result, this study is focused on the correlation of seismicity *b*-value, seismic quiescence *Z*-value, and interrelationships between some other seismicity parameters. The cumulative number of earthquakes *versus* time in the region for original catalogue and for decomposed events is shown in Figure 3. As shown in Figure 3, there is no significant change of reporting as a function of time between 1964 and 1974 for region. But further on, great seismic changes are seen in this area, especially after 1980. Also, time-number histogram for between 1964 and 2015 indicate an increase in the number of recorded events in the year of 2012 (Fig. 4).

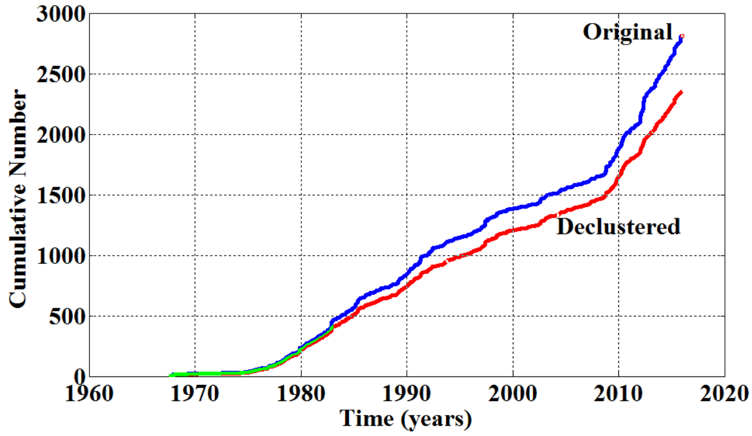

Fig. 3. Cumulative number of earthquakes versus time for the original and decomposed events.

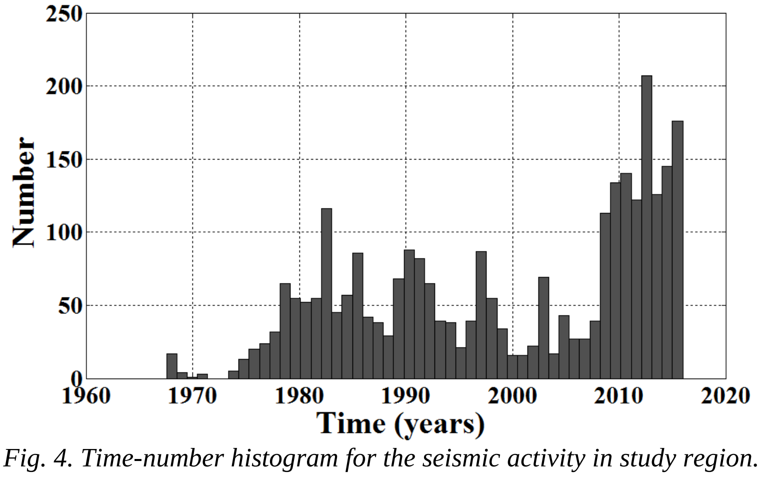

Fig. 4. Time-number histogram for the seismic activity in study region.

Because many stations have been constructed in recent years, especially after 2003 provides the real time data with the modern on-line and dialup seismic stations and V-SAT stations in Albania. Magnitude of earthquakes in this catalogue ranges from 1.7 to 6.7 with an exponential decay in their numbers from the lower to higher magnitudes. Figure 5 defines the magnitude-number histogram for the seismic activity of region. Most of the earthquakes are between 2.0 and 3.5, and a maximum *Md* 2.5 is observed (Fig. 5). In order to investigate the seismic quiescence and the frequency-magnitude relationship, the change of *Mc* as a function of time is determined using a moving window approach. *Mc* is estimated for samples of 50 events per window for region by using the earthquake catalogue containing all 2814 events of *Md*≥1.7.

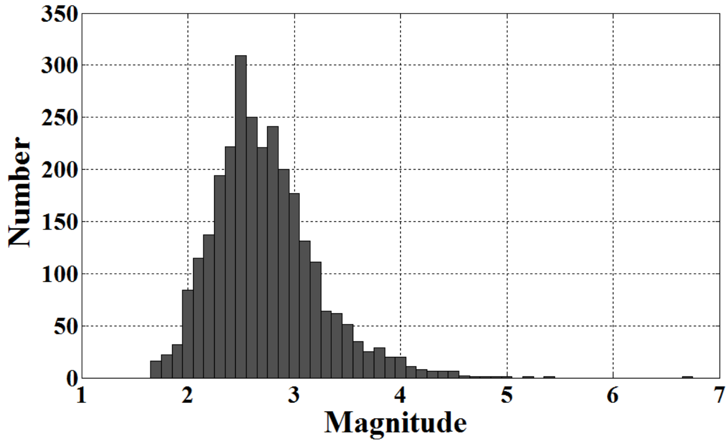

Fig. 5. Magnitude-number histogram for the seismic activity in study region

Figure 6 shows the variations of *Mc* with time for all parts of the V-L-E-D. For this region, *Mc* value is rather large and varies from 3.0 to 4.0 between 1964 and 1979 while *Mc* decreases to about 2.5 between 1989 and 1993 (Fig. 6). Then, it decreases to about 2.4 in the beginning of 1998. However, there is a great value about 3.3. This large value is observed after the 2007 Kuturman compound earthquake sequence. Therefore, it can be said that *Mc* generally shows a non-stable value in the different parts of the V-L-E-D. However, it can be easily said that *Mc* value varies between 2.5 and 3.7 in the V-L-E-D. Using *ZMAP* software, the *b*-value in Gutenberg–Richter (1944) relation calculated by the maximum likelihood method, because it yields a more robust estimate than the least-square regression method [1].

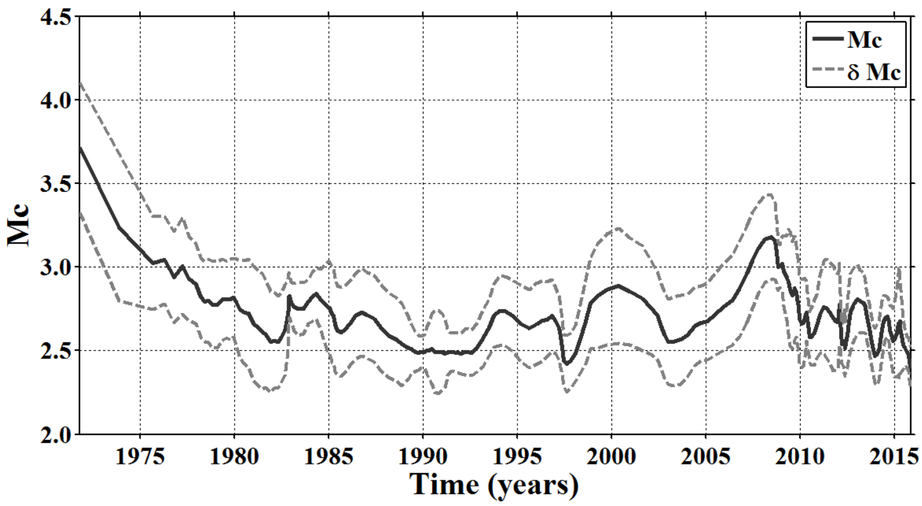

Fig. 6. Magnitude completeness, Mc, as a function of time. Standard deviation, δMc, of the completeness (dashed lines) is also shown. Mc value is calculated for overlapping samples, containing 50 events.

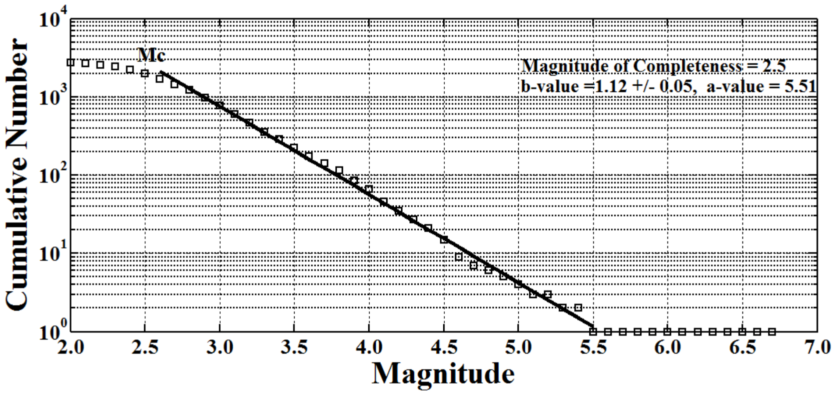

Fig. 7. Magnitude-frequency-relation for all earthquakes between 1964 and 2015. The b-value and its standard deviation, as well as the a-value in the Gutenberg– Richter relation are calculated.

Gutenberg–Richter (G-R) low describes the statistical behavior of seismic zones in energy domain using the frequency magnitude of earthquakes [3]. Figure 7 shows the plots of cumulative number of the earthquakes against the magnitude for all parts of the V-L-E-D. The whole catalogue includes 2814 earthquakes (M_d1.7) for epicentral depths less than 50 km. The Mc value is calculated as 2.5 and using this value the *b*-value is calculated as 1.12 ± 0.05 and a-value 5.51 (Fig. 7). The *b*-value and its standard deviation are determined with the maximum likelihood method, as well as the *a*-value of Gutenberg–Richter relation. The tectonic earthquakes are characterized by the *b*-value from 0.6 to 1.5 and are more frequently around 0.9. It is clearly seen that the earthquake catalogue matches the general property of events such that magnitude-frequency distribution of the earthquakes is well represented by the Gutenberg–Richter law with a *b*-value typically close to 1. The variation of the *b* value as a function of time for the V-L-E-D Transversal Fault Zone is analyzed (Fig. 8). A systematic increase in *b*-value can be observed until 1983 with *b*>1.2. The *b*-value shows a great decrease with *b*≈0.7 before the occurrence of 1985 February 21 earthquake and 1990 May 14 and a clear increase after the second main shock (Fig. 9). Such a kind of behavior is also observed for some strong earthquakes in region [10]. There is a clear tendency of decrease with *b*≈0.8 before the 2007 April 16 Kuturman compound earthquake and an increase with *b*>1.0 after the main shock (Fig. 8). Many factors can cause perturbations of the normal *b*-value.

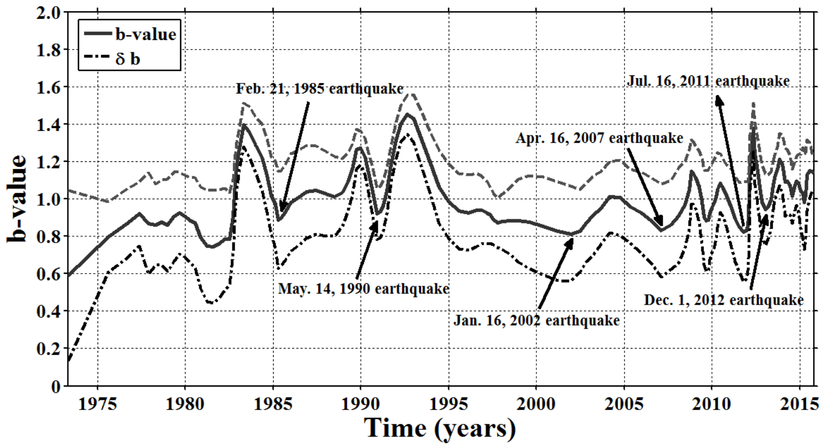

Fig.8. b-value variations versus time. b-value was estimated for overlapping samples of 75 events. Standard deviation, δb, of the b-values (dashed lines) is also shown. Arrows show the great decrease in b-values before the strong events in study region.

The *b*-value for a region does not reflect only the relative proportion of the number of large and small events in study area, but is also related to the stress condition over the region [18]. Therefore, it is considered that the anomalies of decreases in *b*-value before the main shocks may be due to an increase in effective stress and can be used as an indicator of the next earthquake by observing the changes in *b*-value with time in the study region. Also, temporal increase in *b*-value may be related to the stress changes in these times before and after the main shocks [12], [13]. In the areas of increased complexity in the active fault system associated with lower *b*-value, the stress release occurs on fault planes of smaller surface area [11]. Spatial distribution of the standard deviate *Z*-value for the V-L-E-D Transversal Fault Zone is presented for the beginning of 2010 (Fig. 9). Each *Z*-value is represented with different colors: the lowest *Z*-values are displayed with blue and show that the change in seismicity rate is not significant, and the highest *Z*-values are represented with red and demonstrate a decrease in seismicity rate. Each *Z*-value in this representation is estimated in correspondence of a different grid point. The computed *Z*-values are then contoured and mapped. To obtain a regional variation of the seismic quiescence mentioned earlier, the Reasenberg (1985) [14] algorithm is applied to decompose the data. The areas under analysis were divided into rectangular cells spaced 0.02° in longitude and latitude. The nearest earthquakes, *N*, at each node are taken as 50 events after some preliminary tests for all regions and the seismicity rate changes are searched within the maximum radius changes by a moving time window, T_W (or i*wl*), stepping forward through the time series by a sampling interval as described by Wiemer & Wyss (1994) [19].

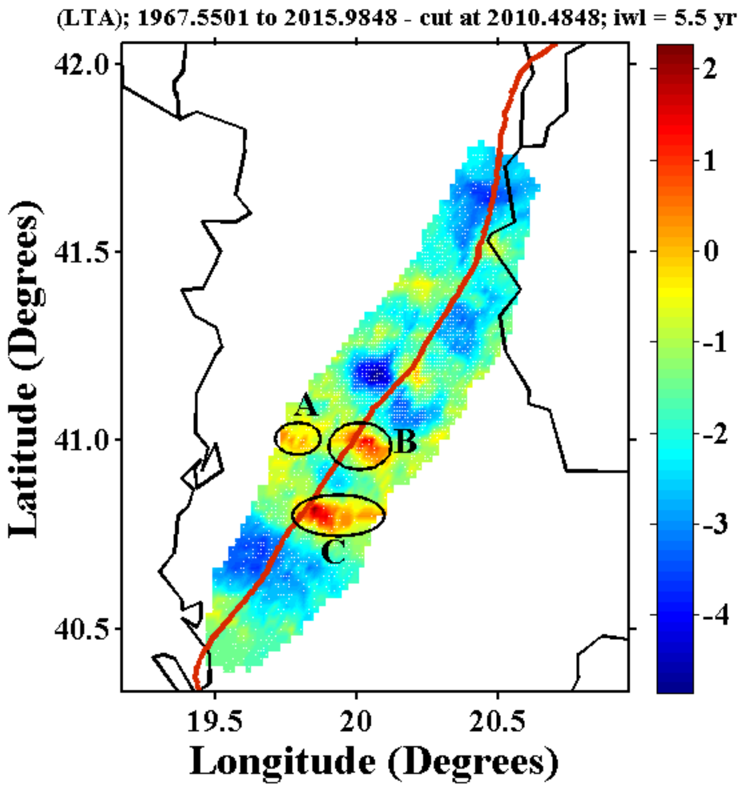

Fig. 9. Spatial distribution of Z-value in the beginning of 2010 with T_W (iwl) equal to 5.5 years. White dots show the decomposed events.

The shape of the LTA function strongly depends on the choice of the length of the foreground window (*iwl*).While the statistical robustness of the LTA function increases with the size of *iwl*, its shape becomes more and more smooth, if the *iwl* length exceeds the duration of the anomaly. The time window, T_W, equal to 5.5 years is used. Since the quiescence anomalies obtained in Figure 9 are the best represented at the epicentral areas for T_W equal to 5.5 years, this time window length is used to image the spatial variation of the seismicity rate changes. For each grid point we binned the earthquake population into many binning spans of 28 days for all regions in order to have a continuous and dense coverage in time. The *N* and T_W

values are generally selected accordingly to enhance the quiescence anomaly and this choice does not influence the results in any way. Figure 9 shows the spatial variation of Z-values for region. As shown in Figure 9, there are three areas (A, B, and C) exhibiting significant seismic quiescence. In addition to these three significant areas, there are some small quiescence areas. However, since these small quiescence areas are not very clear it is considered that they are not as significant as the other three quiescence areas. As a result, *Z*-value variation is represented in the beginning of 2010. Clear quiescence anomalies were identified at several seismogenic sources. In the *Z*-value maps for all parts of the V-L-E-D, three areas exhibit significant seismic quiescence. Covering the V-L-E-D, the first significant quiescence is estimated centered at 41.00°N-19.78°E (region A, around Lushnja) and the second one is estimated centered at 40.99°N-20.03°E (region B, in the Cerriku). The third significant anomaly is found centered at 40.81°N-19.86°E (region C, including Kucova).

IV. CONCLUSIONS

Temporal and regional assessments of the recent seismic activity are performed in order to put forth the seismic behavior in the V-L-E-D Transversal Fault Zone in Albania. So, a few seismic parameters are used such as size-scaling parameters (such as slope of recurrence curve *b* value), precursory quiescence *Z*-value, temporal and regional variations of earthquakes as well as the histograms of temporal, spatial and magnitude distributions. For this purpose, statistical analysis techniques based on the seismic tool *ZMAP* are used. The instrumental earthquake catalogues of ASN between 1964 and 2015 are compiled and finally 2814 crustal earthquakes of magnitude equal and greater than 1.7, with depths less than 70 km are obtained. Seismicity characteristics in the V-L-E-D Transversal Fault Zone show an important increase, especially after 2003. Analysis of completeness magnitude shows a value between 2.7 and 2.9 for the V-L-E-D Transversal Fault Zone. *b*-value for study is close to 1.0 and typical for earthquake catalogues. Temporal distributions of *b*-values show a strong tendency of decreasing before the large main shocks and this behavior can be used as an indicator of the future earthquake. Reasenberg algorithm is used to separate the dependent events and the earthquake catalogue is decomposed for the standard deviate *Z*-value estimation. Importance of seismicity changes is measured at the nodes of a 0.02° grid space in longitude and latitude for the V-L-E-D Transversal Fault Zone. There are three regions exhibiting significant quiescence anomaly on the V-L-E-D Transversal Fault Zone in the beginning of 2010. These three anomalies are observed centered at 41.00°N-19.78°E (region A, around Lushnja), 40.99°N-20.03°E (region B, in the Cerriku), 40.81°N-19.86°E (region C, including Kucova). These areas of seismic quiescence recently observed, which started at the beginning of 2010 in three aforementioned regions, can be considered as the most significant. The V-L-E-D Transversal Fault Zone was struck with strong earthquakes in recent years. Therefore, spatial and regional prediction of the next strong earthquake in the V-L-E-D Transversal Fault Zone would be useful.

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