Journal of Civil Engineering and Architecture 18 (2024) 236-243
doi: 10.17265/1934-7359/2024.05.004

Some Statistical Aspects for Algerian Earthquake Catalogue

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Abstract: The scope of this study is to analyze some aspects of the Algerian earthquake catalogue between 1980 and 2009. Seismicity analysis is based on reliable compilation of earthquake catalogs obtained from different agencies. All intensities and magnitudes were converted to M_s magnitude using appropriate relationships. Dependent events were removed using adapted time and space windows. In addition, the completeness of the catalogue as a function of magnitude was determined from the standard deviation of occurrence rate plots, using the Stepp's methodology. The remaining 2,016 independent earthquakes with M_s 2.2 were used to obtain various parameters (*b*-value, *z*-value) to characterize the temporal and spatial seismic activity for the entire northern part of Algeria. Finally, the obtained results are discussed to explain parameters variability.

Key words: Seismic activity, *b*-value, *z*-value change, magnitude of completeness, Algeria.

1. Introduction

A quick review of seismic activity history in northern Algeria shows that the region has been shaken since the early of last millennium by strong earthquakes that destroyed thousands of buildings and caused severe casualties [1], in particular, the 1716 Algiers and the 1790 Oran earthquakes with intensity *I*=X, El Asnam 1980 M7.3 earthquake and recently the 2003 M6.8 Boumerdes earthquake. In the following, seismicity rate changes (*z*-value) and *b* value are used to study the evolution of seismic activity between two different periods [2]. We proceed first by the construction of a homogeneous catalog using conversion of intensities, M_L (local magnitudes) and m_b (body wave magnitudes) to M_s (surface wave magnitudes). Then we estimate the magnitude of completeness m_c for different time periods using MAXC (maximum curvature) method [3, 4]. Finally, *b*-value and *z*-value changes are analyzed according to the methodologies introduced by Weimer and Benoit [5], Wyss [6] and Habermann [7]. The results are presented as maps describing the evolution of seismicity rate during the periods 1980-1993 and 1994-2005. It is found that seismic activity is nowadays concentrated on Mitidja basin near Algiers and the extreme western zone near Oran; whereas seismicity is decreasing around Cheliff basin, Constantine and Annaba.

2. Catalog Data Preparation

The compiled catalog includes events reported in the space window 3 °W-10 °E longitudes and 32 °-37.5 °N latitudes. It includes some parts of seismicity in Tunisia and Morocco which could influence the hazard near Algerian borders. We made an inventory of all available catalogs covering the selected area and compared or combined their respective entries. As any compilation, some events are reported several times and a sequential elimination of doublets and redundant events was performed. The following earthquake sources were used:

(1) CRAAG (1994): The first catalogue published by the CRAAG (Centre de Recherche en Astronomie,

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Astrophysique et Géophysique) of Algeria [8]. It covers the time period 1673-1992.

(2) CRAAG (2002): The second catalog published by the same institution and covering the period 1992-2001 [9]. This source was extended to 2009 using the semi-annual bulletins of the CRAAG seismological database.

(3) Benouar [1]: includes a catalogue covering all the regions of the Maghreb from 1900 to 1990.

(4) Harbi [10], Harbi and Maouche [11]: include a catalogue covering the eastern part of Algeria between 4°-9° E and 33°-38° N within the time period 1850-2000. This source contributed with 166 additional events in the compiled catalog.

(5) IGN catalogue: Instituto Geográfico Nacional, Madrid, Spain [12, 13]. The subcatalog covering the Ibero-Maghreb region for the time period 412-2005 was used.

The compiled catalogue covers the time period 1980-2005 and consists of 5,424 shallow depth events with $M_s \geq 1.5$. Intensities and magnitudes with different scales, were converted to surface wave magnitudes M_s, according to the following regression relations of Casado et al. [14]

$$M_s = -3.44 + 1.65m_b + 0.4P \quad (1)$$

$$M_s = 1.52 + 0.005I_0^2 + 0.7P \quad (2)$$

where m_b and I_0 are respectively, the body wave magnitude and the epicentral intensity, while P is zero for 50-percentile values and one for 84-percentile.

An attempt was made to establish a correlation between ML and Ms (surface wave magnitude) (see Fig. 1). Eq. (3) was obtained using 93 earthquakes from USGS/NEIC (U.S. Geological Survey/National Earthquake Information Center) and ISC (International Seismological Centre) catalogs and local events recorded by the Seismological Network of the CRAAG [15].

$$M_s = 1.11M_L - 0.54 + 0.10P \quad (3)$$

After the homogenization of the catalog, completeness periods corresponding to each selected magnitude cutoffs m_c (Table 1) were established using the Stepp [16] approach.

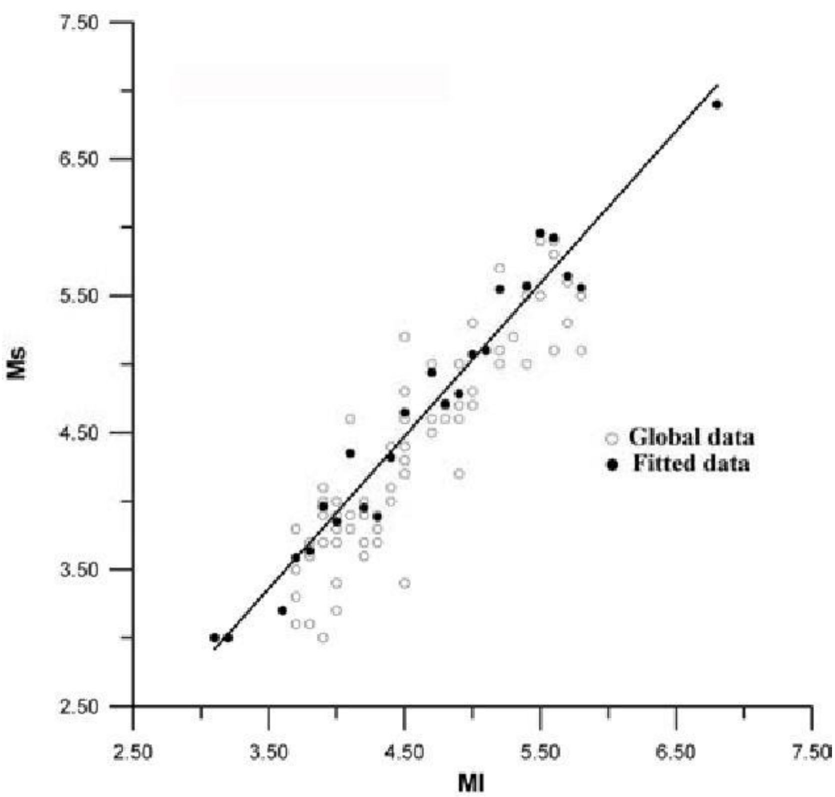
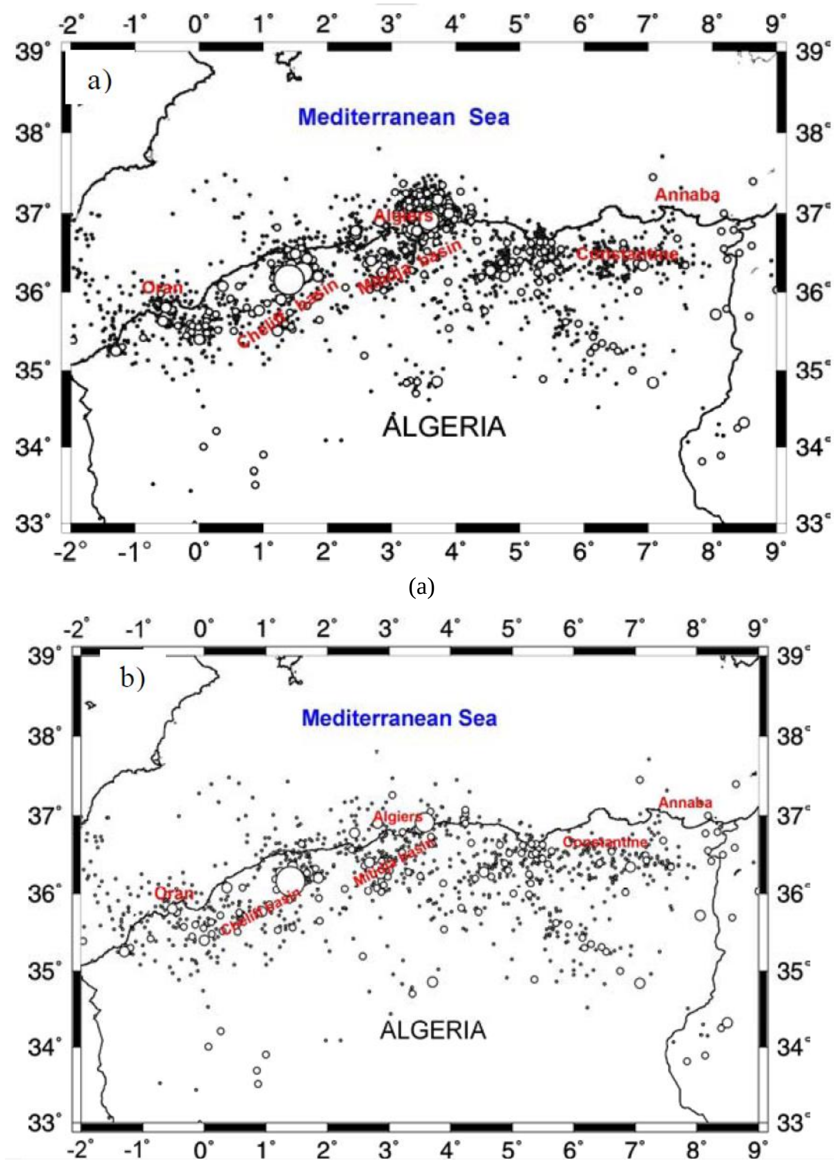


Fig. 1 Empirical regression of M_s on M_L.

Table 1 Completeness periods with the corresponding magnitude ranges found used in Stepp's method.

Magnitude range	Completeness period
[3.5-4.4]	1935-2009
[4.5-5.4]	1885-2009
[5.5-6.4]	1830-2009
6.5	1673-2009



(a) (b)

Fig. 2 Epicenter distribution of seismicity in northern Algeria between 1980 and 2009 (a) before and (b) after declustering.

The main shock catalog is defined as the residual after the identification and the removing of clustered events by Gardner and Knopoff [17] algorithm. A space-time window around and following each event was considered, so that any earthquake occurring within the window is deemed as cluster event. The window is opened wider for stronger predecessor events. The window parameters used in this study are listed in Table 2. They are intermediate between the broad values of Gardner and Knopoff [17].

Table 2 Window parameters used for the declustering procedure.

Magnitude M_s	Distance (km)	Time (days)
2.8	20.4	7
3.5	23.2	26
3.9	26.3	36
4.5	35.2	56
4.8	39	84
5.5	45	262
5.9	47	406
6.8	85	834
7.5	104	943

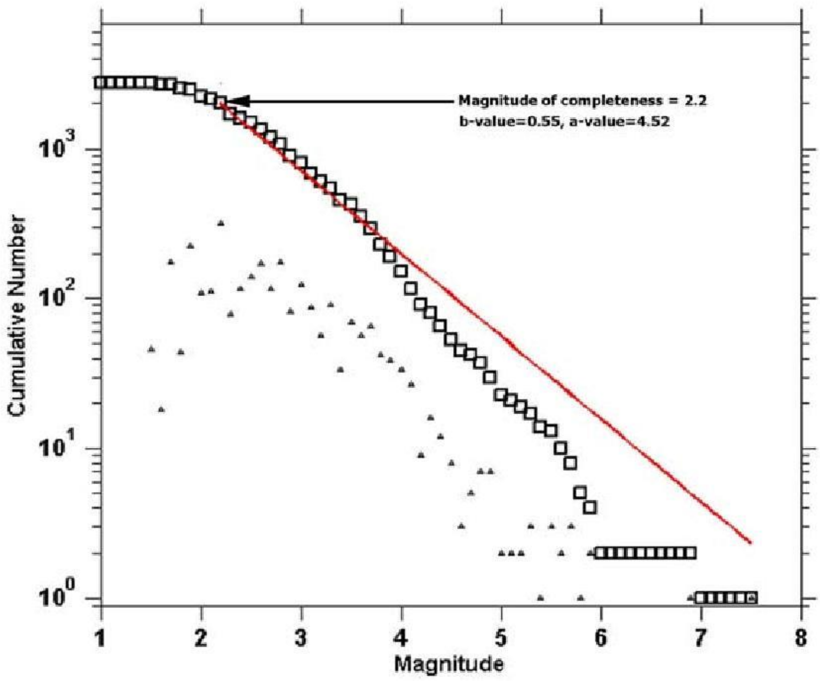


Fig. 3 Estimation of m_c using the MAXC method.

The residual catalog includes 2,016 events with M_s 2.2. Fig. 2 shows the epicenter distribution of earthquakes before and after declustering.

For the periods selected in Table 1, the MAXC method has been used to check m_c estimates [3, 4] (Fig. 3).

3. *b*-Value Analysis

The spatial changes in *b*-value were estimated using ZMap software [18]. The four regions shown in Fig. 4 (A, B, C and D) were considered, with a total of 2,016 events with magnitude M_s 2.2, occurring within the time period 1980-2009.

For spatial mapping of *b*-values in each region, these former are calculated using the MLE (maximum likelihood estimate) [19]. The obtained values are mapped using a regular grid with a cell length l = 5 km and using fixed number of earthquakes (n_i = 30) [5]. *b*-values are quite variable (see Fig. 5). An estimate of the *b*-value standard deviation *b* can be obtained using the formula derived by Aki [19], or that of Shi and Bolt [20].

$$\sigma b = 2.30 \cdot b^2 . \sum_{i=1}^{n} \frac{(M_i - \bar{M})^2}{n(n-1)} \quad (4)$$

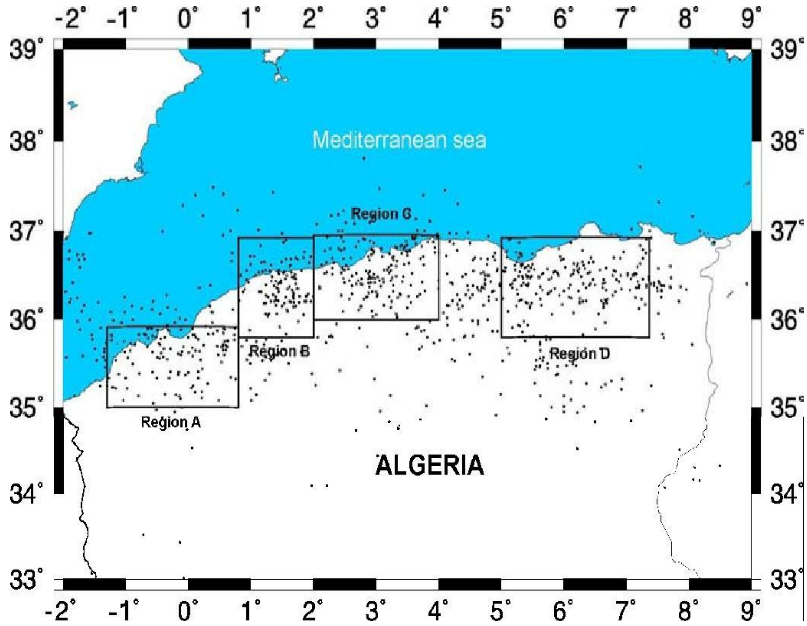


Fig. 4 Seismicity map of events with M_s 2.2 occurring during the period 1980-2009.
Rectangles show the delimitation of the studied regions.

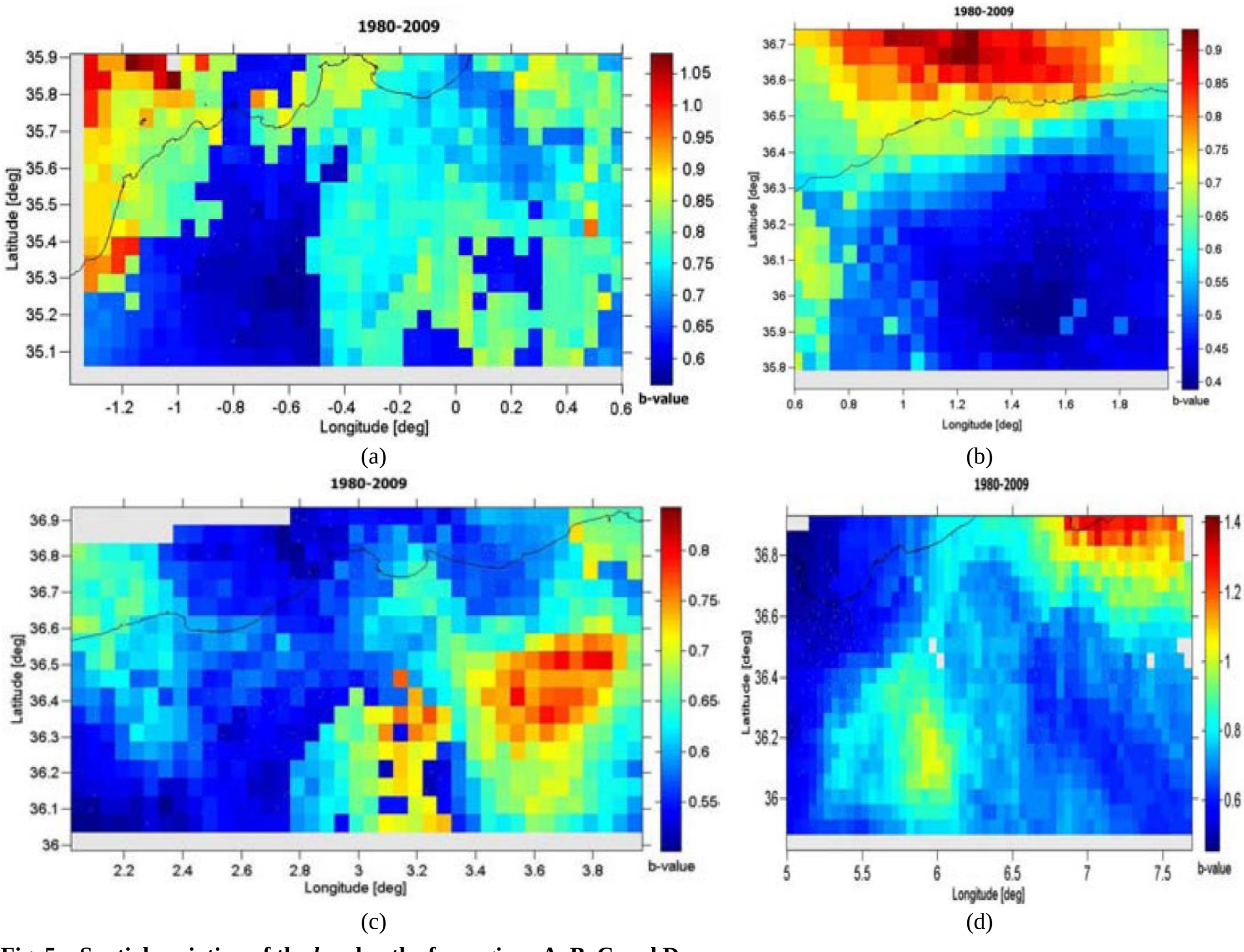
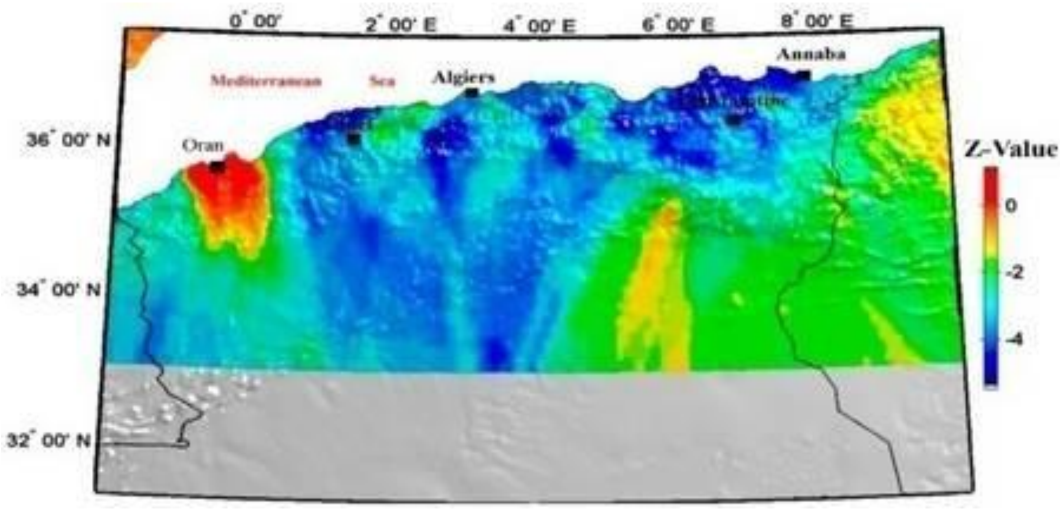
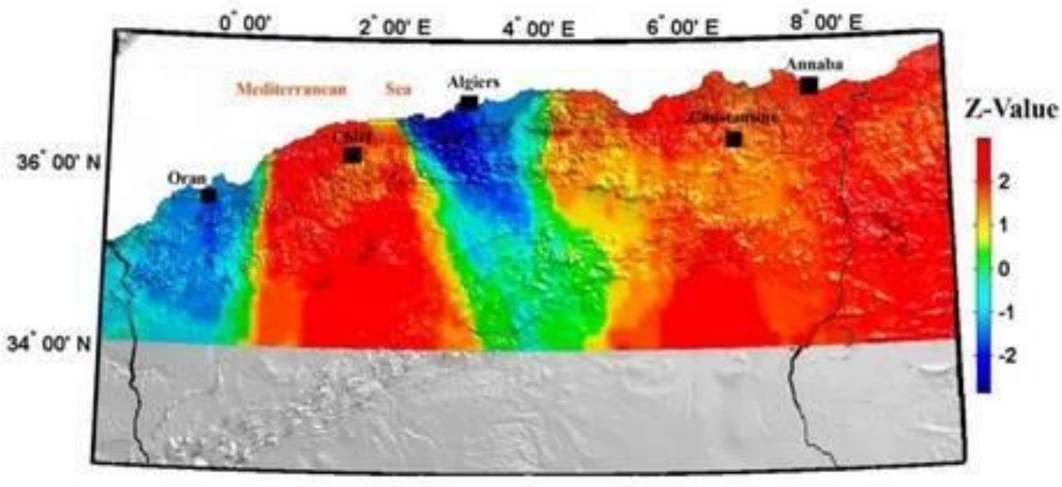


Fig. 5 Spatial variation of the *b*-value the for regions A, B, C and D.



(a)



(b)

Fig. 6 Maximum seismicity changes, in terms of the *z* statistic, as a function of space (a) for the period 1980-1993 and (b) for the period 1994-2005.

where n is the total number of events of the given sample.

For the regions B and C, low b values are registered whereas regions A and D are characterized by high b values in general. This shows that hazard in B and C is high comparing to that of A and D. Thus, seismic activity is higher on B and C. Also low b values in regions B and C are clearly complementary and define a unique low b-value region (Cheliff basin). These results are consistent with those by Aoudia et al. [21] suggesting that the major sources in region B and C are related to local structures formed by thrusts and folds with an E-W to NE-SW trending parallel to the coastline. The largest earthquakes occurred in the alluvium basin (Cheliff and Mitidja basins), which contributed significantly to the seismic hazard and increased the risk in the region.

4. *z*-Value Analysis

To compare seismicity rates, we used the z-value statistics [7]. For each grid point, the z-value at time t is calculated as follows.

$$z(t) = \frac{(\lambda_1 - \lambda_2)}{\sqrt{\left(\frac{\sigma_1}{n_1} + \frac{\sigma_2}{n_2}\right)}} \quad (5)$$

where λ_i, σ_i and n_i are the mean rate, the variance and the number of events in the first and second period to be compared respectively. In our case, we divided the period 1980-1993 into 1980-1986.5 and 1986.5-1993, and the time period 1994-2005 into 1994-1999.5 and 1999.5-2005.

To estimate the rate of seismicity at each grid node, we used the 50 closest events and a time window of 1.5 years. The results corresponding to time periods 1980-1993 and 1994-2005 are shown in Figs. 6a and 6b respectively.

During the second time period 1980-1993, the seismicity increased in the western Cheliff Basins and its surrounding area (dark purple shading in Fig. 6a). We can also observe similar increase at the east Constantine and the corresponding coastal regions. On the other hand, the lowest increase of seismicity rate is observed in Oran and its surrounding area.

During the second time period 1994-2005, there is increase in seismicity in the Mitidja basins and its vicinity (Fig. 6b). The same features with less sharp increase are observed in the vicinity of Oran to the west. Decrease in seismicity rate is observed towards the Cheliff Basins and the whole eastern part of the Northern Algeria.

5. Discussions and Conclusions

The spatial variations of *b*-value and *z*-value are investigated in Northern part of Algeria. The results can be summarized as follows:

- Then *b*-value variations were analyzed in four regions of Northern Algeria. Cheliff region presented the highest seismic potential with low *b*-value indicating high stress concentration.
- The analysis of *z*-values showed that for the period 1980-1993, seismicity rate was increasing around Cheliff and Constantine and there was quiescence around Oran region. At the opposite, for the period 1994-2005, activity rate is decreasing around Constantine and Cheliff, increasing around Mitidja basin and Oran region, increasing in the Mitidja basin and Oran region.

Finally, we hope the result supplies an additional discernment into the problem of finding suitable strategies to improve the quality of regional seismic monitoring in the most seismic regions in Algeria. Our results may also offer some basis for future research related to the earthquake process in the tectonic regions which comprise Algeria.

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