Analysis of spatio-temporal seismic activity in Northern Algeria

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ABSTRACT

This study aims to analyze spatial and temporal evolution of seismic activity during the period 1980-2005 in northern Algeria. The seismicity analysis carried out here is based on reliable compilation of earthquake catalog obtained from different agencies. The homogeneity of the catalog is ensured by the conversion of intensities in the historical part of the catalog and different magnitude scales in the instrumental part to surface magnitude *Ms*, using appropriate relationships. Dependent events are removed using the windowing technique suggested by Gardner and Knopoff (1974). The magnitude of completeness m_c is estimated using the maximum curvature method (Wiemer and Wyss, 2000).
The residual catalog obtained after declustering including 672 events with Ms ≥ 2.8 is used for the estimation of various parameters characterizing the temporal and spatial seismic activity for the entire northern part of Algeria (*b* value, *Z* value, etc...).
The results presented as seismicity rate changes and *b* value variation maps show recent increase in seismic activity around Algiers and Oran cities.

KEYWORDS: Seismic activity, Algeria, *Z* value change, Magnitude of completeness, *b*-value parameter.

1. INTRODUCTION

A quick review of the history of seismic activity in Algeria shows that this region has been shaken since the early of last millennium by strong earthquakes that destroyed thousands of buildings and caused severe casualties (Benouar, 1994). 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 Gutenberg Richter *b* value are used to study the evolution of seismic activity between 1980 and 2005.

Recently, several studies showed that the *b* value is correlated with shear stress and the variations in the heterogeneity of the medium (e.g., Mogi, 1962; Wiemer et al., 2000; Zúñiga et al., 2000) which influence the shape of the magnitude frequency distribution (Aktar et al., 2004). In this context, the study of the *b* value variations may help to characterize stress changes before big earthquakes. In particular, we found significant correlation between the temporal variation of *b* values and the occurrence of El Asnam 1980 M7.3 and Boumerdes 2003 M6.9 earthquakes.

We proceed first by the construction of a homogeneous catalog by the conversion of intensities, local magnitudes M_l and body wave magnitudes m_b to surface magnitudes M_s. Then we estimate the magnitude of completeness for different time periods. Then magnitude of completeness m_c is estimated using MAXC method (Wiemer and Katsumata, 1999; Wyss and Wyss, 2000). Finally, *b* values and *Z* value changes are analyzed according to the methodologies introduced by Weimer and Benoit (1996), Wyss, (1991) and Habermann (1983). The results presented as maps describe 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 include events reported in the space window 3°W−10°E longitudes and 32°N −37.5°N latitudes. Part of seismicity in Tunisia and Morocco which could influence the hazard near Algerian borders is also considered. 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:

CRAAG, (1994): The first catalogue published by the Centre de Recherche en Astronomie, Astrophysique et Géophysique (CRAAG) of Algeria (Mokrane et al., 1994). It covers the time period 1673−1992.

CRAAG, (2002): The second catalog published by the same institution and covering the time period 1992-2001 (Yelles Chaouch et al., 2002). This source was extended to 2005 using the semi-annual bulletins of the CRAAG seismological database.

Benouar (1994): includes a catalogue covering all the region of the Maghreb from 1900 to 1990.

Harbi (2001): includes 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 111 additional events in the compiled catalog.

IGN catalog/Instituto Geográfico Nacional**,** Madrid, Spain (Mezcua and Martínez Solares 1983; Martínez Solares and Mezcua 2002). Its 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 3015 shallow depth events with Ms ≥ 1.5. Intensities and magnitudes with different scales were converted to surface wave magnitudes *Ms* according to the following regression relations of Lopez Casado et al. (2000) and Bellalem (2007),

$$M_s = -3.44 + 1.65 m_b + 40P \tag{1}$$

$$M_s = 1.52 + 0.005 I_0^2 + 0.70P \tag{2}$$

$$M_s = 1.114 M_l - 0.536 \tag{3}$$

Where M_l is local magnitude, m_b is the body wave magnitude, I_0 is the epicentral intensity and P *is* zero for 50-percentile values and one for 84-percentile.
The regression (3) was established using 93 earthquakes from USGS/NEIC and ISC catalogs and local events recorded by the Seismological Network of the CRAAG (Figure1).

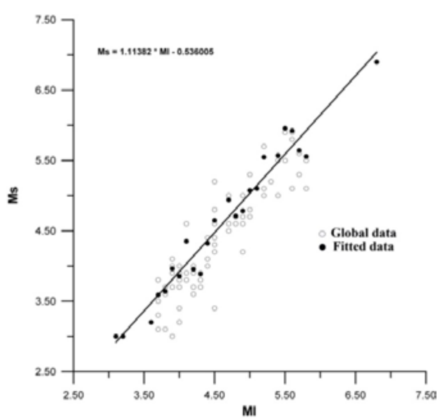

Figure 1 Empirical regression of Ms on Ml

After the homogenization of the catalog, completeness periods corresponding to selected magnitude cutoffs were assessed using Stepp (1972) approach

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

Magnitude range	Completeness period
[3.5-4.4]	1935-2005
[4.5-5.4]	1885-2005
[5.5-6.4]	1830-2005
≥6.5	1673-2005

The mainshock catalog is defined as the residual after the identification and the remove of clustered events by Gardner and Knopoff (1974) algorithm. A space-time window around and following each event was considered, so that any earthquake occurring within the window is deemed a cluster event. The window is opened wider for stronger predecessor events. Table 2 shows the window parameters used. Those are intermediate between the broad values of Gardner and Knopoff (1974).

Table 2 Windows parameters used for the declustering procedure

Magnitude Ms	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

The residual catalog includes 672 events with Ms≥2.8. Figure 2 shows the epicenter distribution of earthquakes before and after declustering

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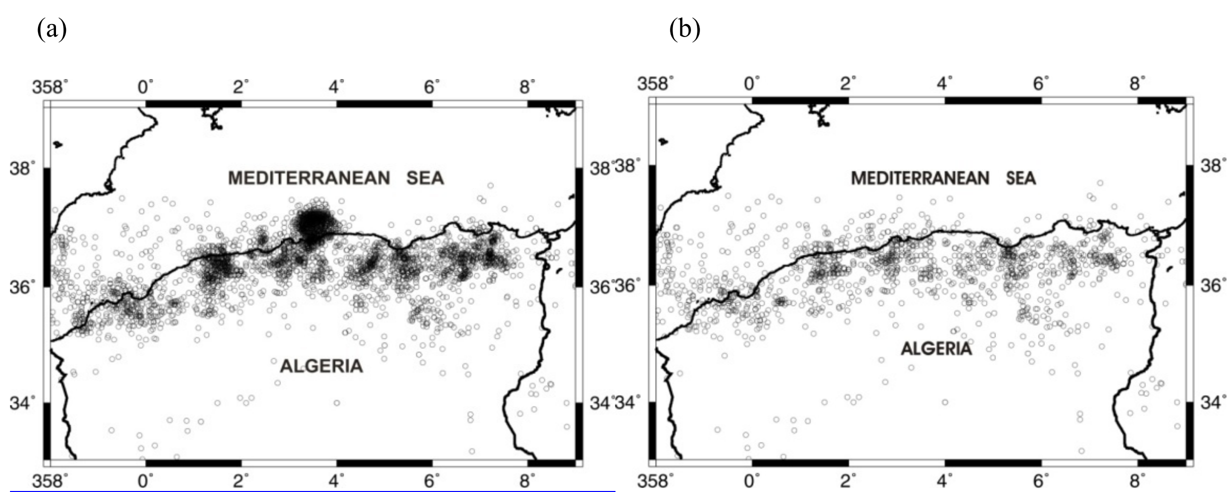


Figure 2. Epicenter distribution of seismicity between 1980 and 2005 in Northern Algeria (a)-before and (b) after declustring.

m_c is usually decreasing with time because the increasing number of seismic network stations and their sensitivity (Wiemer and Wyss., 2000). For the periods selected in Table1, the maximum of curvature method (MAXC) was performed to check estimates of m_c (Wiemer and Katsumata, 1999; Wyss et al., 2000) (Figure 3).

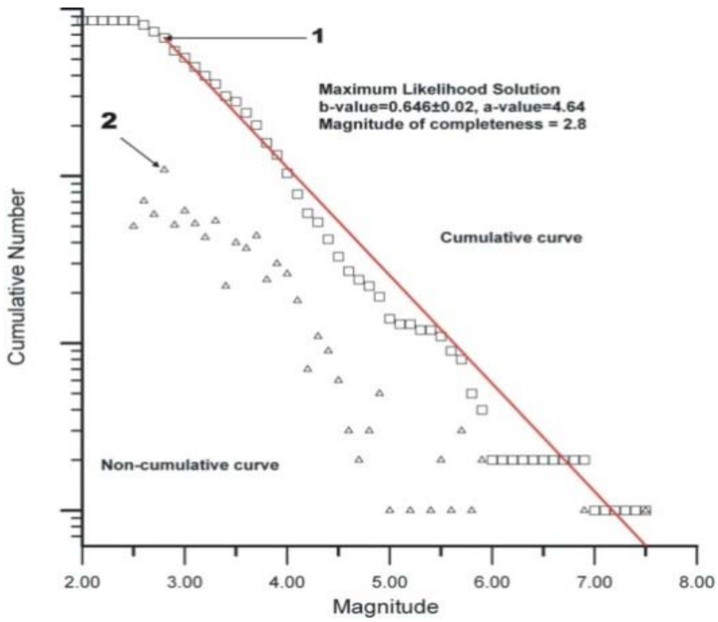


Figure 3. Estimation of the Minimum magnitude of completeness using Maximum curvature method. The arrows point the breakpoints of the cumulative distribution, marking the abscise defining the magnitude of completeness m_c

3 *b* VALUE ANALYSIS

The spatial changes in *b* value were estimated using the ZMAP free software (Wiemer, 2001). The four regions shown in Figure 4 (A, B, C and D) were considered, with a total of 672 events of magnitude Ms≥2.8, occurring within the time period 1980-2005.

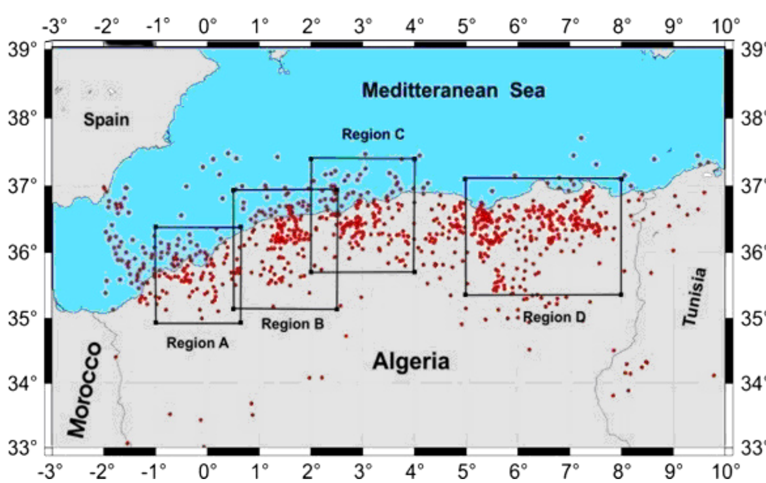


Figure 4. Seismicity map for events with M_s≥2.8 occurred during the period 1980-2005. *Solid rectangles* show the delimitation of the studied regions.

The *b* value in each region is calculated using the maximum likelihood method (Aki, 1965), then mapped using the usual grid technique with a cell length of 5 km and fixed number of earthquakes (Ni=30) (Wiemer and Benoit, 1996). As shown in Figure 5, *b* values are quite variable.

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 and al (2000) 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. Large earthquakes occurred in the alluvium basin (Cheliff and Mitidja basins) contributed significantly to the seismic hazard and risk in the region.

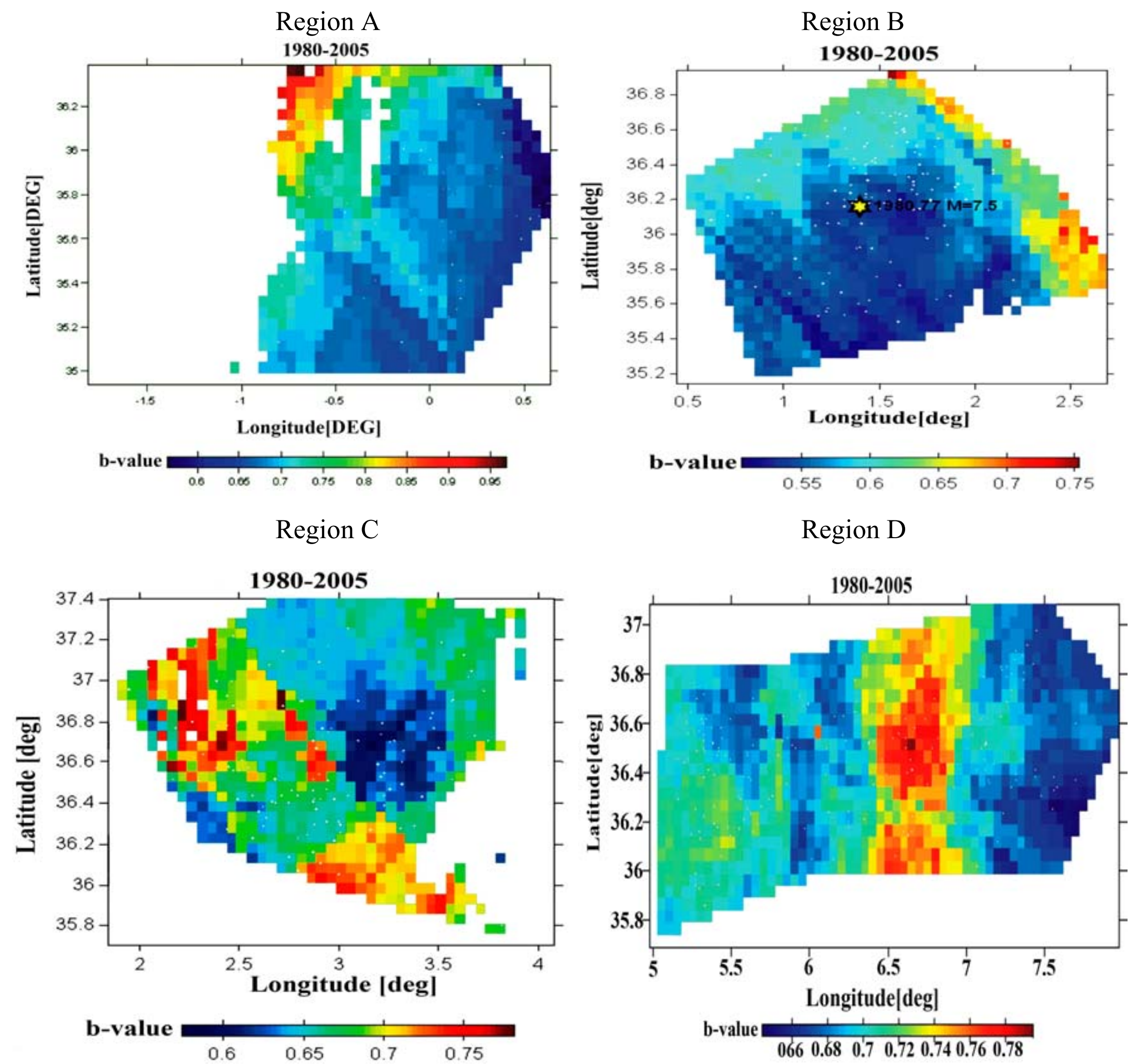


Figure 5. Spatial variation of the *b* value for regions A, B, C and D.

The investigation of the *b* value variation before big earthquakes is limited in our case because of poor data. Thus, the results should be interpreted carefully and the conclusions depend on the significance of our statistical procedures. We examined the temporal variations in *b*-values within epicentral areas of two major shocks: El

Asnam 1980 M7.3 earthquake (occurred in region B at 36.16°N and 1.40E) and the 2003 M6.8 Boumerdes earthquake (occurred in region C at 36.91N and 3.58E).

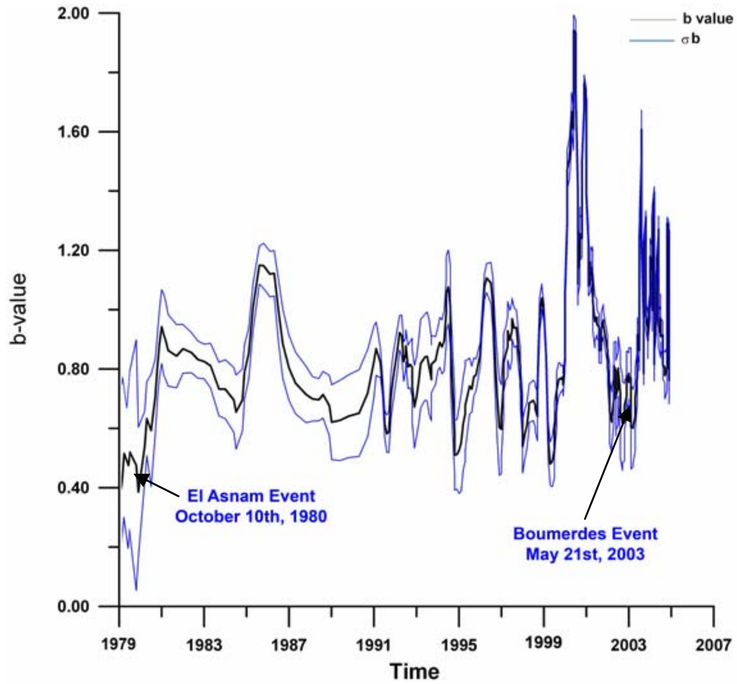


Figure 6 Variation of *b* value for the northern Algeria for the period 1980-2005

The figure above shows temporal variations in *b* value for the whole time period 1980-2005 plotted using a moving time windows with 50 events. Unfortunately, poor data prior to 1980 are masking the drop visible in part prior to the 1980 El Asnam earthquake. Another drop is visible prior to the 2003 Boumerdes earthquake.

4- *Z* VALUE ANALYSIS

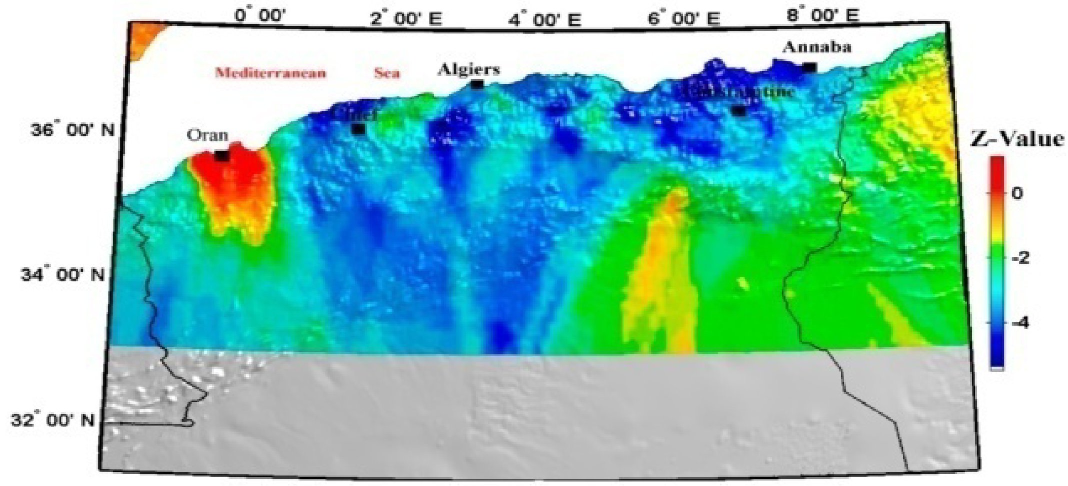
To compare of seismicity rates, we used the *Z* value statistics (Habermann, 1983). For each grid point, the *Z* value at time *t* is calculated as follows.

$$z(t) = \frac{(\lambda_1 - \lambda_2)}{\sqrt{\left(\frac{\sigma_1}{n_1} + \frac{\sigma_2}{n_2}\right)}} \qquad (4)$$

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 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 Figure 7a and b, respectively.

(a)



(b)

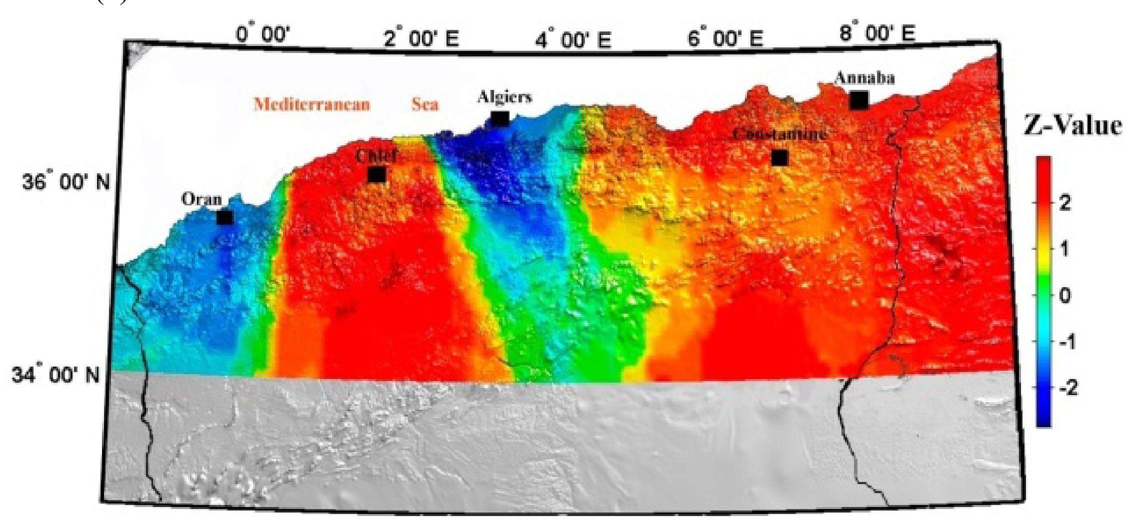


Figure 7 Maximum seismicity changes, in terms of the *Z* statistic, as a function of space (a) for the period 1980-1993 and (b) for the period 1994-2005.

During the second time period 1980-1993, the seismicity increased in the western Cheliff Basins and its surrounding area (dark purple shading in figure7a) we can also observe similar increase in the Eastern Constantine region and the corresponding coastal regions. On the other hand, the lowest increase of seismicity rate is observed in Oran region and its surrounding area.

During the second time period 1994-2005, there is increase in seismicity in the Mitidja basins and its vicinity (Figure 7b). The same features with less sharp increase are observed in the vicinity of Oran to the west. Decrease is seismicity rate in observed towards the Cheliff Basins and the whole eastern part of the Northern Algeria.

5- DISCUSSIONS AND CONCLUSIONS

We constructed a uniform and Poissonian earthquake catalogue covering the time period 1980-2005 and including 672 events with magnitude M≥2.8. 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. Time variation of *b*-values showed two drops consistent with the occurrence of the 1980 El Asnam and the 2003 Boumerdes earthquakes.

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 and increasing around Mitidja basin and Oran region.

REFERENCES

Aki, K. (1965). Maximum likelihood estimate of *b* in the formula log$N$ = a-bM and its confidence limits, Bull. Earthquake Res. Inst **43,** 237–239.

Aktar, M., Özalaybey, S., Ergin, M., Karabulut, H., Tapırdamaz, C., Yörük, A. and Biçmen, F. (2004) Fault zone heterogeneity and variations of seismicity parameters across 1999 İzmit-Düzce earthquake sequence, *Tectonophysics* **391**, 325-334.

Aoudia, A., Vaccari, F., Suhadolc, P., Meghraoui, M. (2000). Seismogenic potential and earthquake hazard assessment in the Tell Atlas of Algeria. *Journal of Seismology*. **4:1**, 79-98.

Bouchon, M. (2004). Spatial variation of aftershock activity across the rupture zone of the 17 August 1999 Izmit earthquake, Turkey, Tectonophysics **391:1**, 325-334.

Bellalem, F. (2007). Aléa sismique en un site, méthodologie et application, Master thesis, Université de M'hamed BOUGARA-Boumerdes, 92pp.

Benouar, D. (1994). Materials of Investigations of the Seismicity of Algeria and Adjacent Regions, Annali Di Geofisica **37:4**, 860 pp.

Casado, L., Molina, C., Giner, J.J. and Delgado, J. (2000). Magnitude-Intensity relationships in the Ibero-Maghrebian region. Nat. Hazards **22:3**, 269-294.

Gardner, J.K and Knopoff, L. (1974). Is the sequence of earthquakes in southern California, with aftershocks removed, Poissonian? Bull. Seism. Soc. Amer **64:5**, 1363-1367.

Gutenberg, R. and Richter, C. F. (1944). Frequency of earthquakes in California, Bull. Seism. Soc. Am **34:4,** 185–188.

Habermann, R.E. (1983). Teleseismic detection in the Aleutian Island Arc. J. Geophys. Res **88:B6**, 5056-5064.

Harbi, A. (2001). Analyse de la sismicité et mise en évidence d'accidents actifs dans le nord-est Algérien, Master thesis, Université des sciences et de la technologie Houari Boumediene (U.S.T.H.B)-Alger, pp 196.

Martínez Solares, J.M. and Mezcua, J. (2002). Seismic Catalog of the Iberian Peninsula (880 B.C.-1900). Madrid, Spain: Ed. IGN (in Spanish).

Mezcua, J. and Martínez Solares, J.M. (1983). Seismicity of the Ibero-Maghrebian Region. IGN report, Madrid, Spain (in Spanish).

Mokrane, A., Ait Messaoud, A., Sebai, A., Ayadi, A. & Bezzeghoud, M. (1994). Publication du Centre de Recherche en Astronomie, Astrophysique et Géophysique. Les séismes en Algérie de 1365 à 1992. Département: Etudes et Surveillance Sismique, ESS, C.R.A.A.G, Alger-Bouzaréah.

Mogi, K. (1962). Magnitude-frequency relation for elastic shocks accompanying fractures of various materials and some related problems in earthquakes, *Bull. Earthquake Res. Inst. Tokyo Univ.* **40,** 831–853.

Peng, Z., Vidale, J.E., Ishii, M and Helmstetter, A. (2007). Seismicity rate immediately before and after main shock rupture from high-frequency waveforms in Japan, J. Geophys. Res **112:B3**.

Shi, Y and Bolt, B.A. (1982). The standard error of the Magnitude-frequency b value, Bull. Seism. Soc. Am **72:5**, 1677-1687.

Wiemer, S. and Benoit, J. (1996). Mapping the b-value anomaly at 100 km depth in the Alaska and new-zealand subduction zones. Geophys. Res. Lett **23:13**,1557-1560.

Wiemer, S. and Katsumata, K. (1999). Spatial variability of seismicity parameters in aftershock zones, J. Geophys. Res **104:13**,135–151.

Wiemer .S. and Wyss, M. (2000). Minimum Magnitude of Completeness in Earthquake Catalogs: Examples from Alaska, the Western United States, and Japan.2000. Bulletin of the Seismological Society of America **90:4**, 859–869.

Wiemer, S. (2001). A software package to analyze seismicity: ZMAP, Seism. Res. Lett **72:3**,373-382.

Wiemer, S. and Wyss, M. (2003). Reply to "Comment on 'Minimum Magnitude of Completeness in Earthquake Catalogs: Examples from Alaska, the Western United States, and Japan, ' by Stefan Wiemer and Max Wyss," by Paul A. Rydelek and I. S. Sacks. Bulletin of the Seismological Society of America **93:4**, 1868–1871.

Wyss, M. (1991). Reporting history of the central Aleutians Seismograph network and the quiescence preceding the 1986 Andreanof Island earthquake, Bull. Seism. Soc. Am **81:4**, 1231-1254.

Wyss, M., Schorlemmer, D. and Wiemer, S. (2000). Mapping asperities by minima of local recurrence time: the San Jacinto-Elsinore fault zones ,J. Geophys. Res **105:B4,** 7829–7844.

Yelles Chaouche, A.K., Deramchi, A., Ferkoul, A. and Aoulaiche, K. (2002). Les séismes en Algérie de 1992 à 2001. Publication du Centre de Recherche en Astronomie, Astrophysique et Géophysique). Les séismes en Algérie de 1365 à 1992. Département: Etudes et Surveillance Sismique, ESS, C.R.A.A.G, Alger-Bouzaréah.

Zúñiga, F.R., Reyes, M.A and Valdés, C. (2000). A general overview of the catalog of recent seismicity compiled by the Mexican Seismological Survey. Geofísica Internacional **39-2**, 161-170.