Rapid assessment of the forecasted seismic intensity by analysis of the distribution of epicenters – case of Tebessa city (north-east Algiers)

Kamel Belkhiri* & Mehdi Kalla

Laboratory of Natural Hazards and Spatial Planning, Institute of Earth and Universe Sciences, University of Batna 2, 53 Road of Constantine, Fésdis, Batna 05078, Algeria
*Corresponding author, email: Kam.belkhiri@gmail.com

AGEOS

Abstract: This paper presents a rapid assessment procedure of the maximum seismic intensity in Tebessa. The macro-seismic and instrumental data were exploited from the seismicity of North-Eastern Algeria spread over the period 1856 – 2013. The data was studied in two steps: (1) attenuation of the seismic intensity by the relations of Shebalin and Ganse, and (2) estimation of the seismic hazard by the probabilistic method, which resulted in a maximum seismic intensity of 6.12 for a return period of 475 years on the Modified Mercalli scale, which could affect the city of Tebessa.

Key words: Eastern Algeria, city of Tebessa, seismicity, intensity, rapid assessment

1. INTRODUCTION

Seismic data are of great importance for public authorities as a decision and planning aid for urbanisable areas and the corresponding construction measures. This study aims to analyse the available historical and instrumental seismic data for the Nememcha region to provide a rapid assessment of the expected intensity in the event of an earthquake. According to Bezzeghoud et al. (1996) and Roussel (1973a), the area studied, where the city of Tebessa is located (Latitude: 35°24′15″ North - Longitude: 8°07′27″ East), has always been considered as an area of very low seismic activity because the few events reported did not exceed the intensity (MMI) = V. The distribution of seismic magnitudes in time and size is generally treated by extreme value theory and is formulated on the basis of the following assumptions: (a) the prevailing conditions must be almost the same in all cases, and (b) the highest observed values are independent of each other. This theory has been successfully applied by many researchers in recent decade (Al Abbasi et al., 2018).

In this study, a process of identification and characterization of the seismic sources likely to produce effects on each point of the target area was carried out. This was followed by the prediction of the size of future earthquakes with prediction of the maximum seismic intensity, caused by these future earthquakes. The mathematical approach to perform this calculation is known as Probabilistic Seismic Hazard Assessment (PSHA). The concept of seismic source to present seismicity using the probabilistic approach was introduced by Cornell (1968). Three types of sources were differentiated: source points, source lines or source faults and source zones. In this case, the source-point was used to identify the epicentres of the earthquakes conceded when a potential source of earthquakes is geographically concentrated in relation to the focal distance D separating it from the site. The ground motion parameter is a function of distance and magnitude or intensity. Thus, the results obtained also aim at improving the seismological model currently used in Algeria, whose scale and level of precision are limited to the microspatial territorial dimension.

2. STRUCTURAL GEOLOGY AND MACRO-SEISMIC DATA SET OF THE STUDY AREA

2.1. Structural geology

The region of study is part of a vast palaeogeographic province extended on both sides of the Algerian-Tunisian border called the Algerian-Tunisian Atlasic basin (Figure 1). It is one of the basins of the Atlasic domain of the eastern Maghreb elongated in a north-east-south-west direction in the relatively wide north-eastern edge of North Africa at the level of its south-western part which corresponds to the Aures and it narrows progressively towards the Tunisian NE. The Mellègue Mountains form the eastern extension of the Saharan Atlas. It is a set of massif structurally oriented NE-SW whose main structural features are: tectonic accidents, anticlines and synclines, the appearance of Triassic formations and collapse ditches.

Research on the structure of the study region (Dubourdieu, 1956) has revealed the existence of several groups of regional impotence faults which have played a primordial role in the present structure, some of which are responsible for the location of Triassic points on the surface. The NE-SW directional faults are of NE orientation (30°, 60°) and are represented at the Ouenza Anticline by a so-called main or peak fault with a maximum release of about 200 metres. Concerning the NW-SE transverse faults, they affect the deepest resistance layers of the Albo-Aaptian of Hameimat Nord and connect them to the Bulconian marls (Othmanine, 1987), the mineralisation of Hameimat Nord-Est. controlled by these faults. The tectonic pattern that affects the Mellègue Mountains is relatively flexible and has led to the formation of chains and depressions that are oriented NE-SW corresponding to anticlines and synclines

Manuscript received 2021-03-29
Revised version accepted 2021-09-07

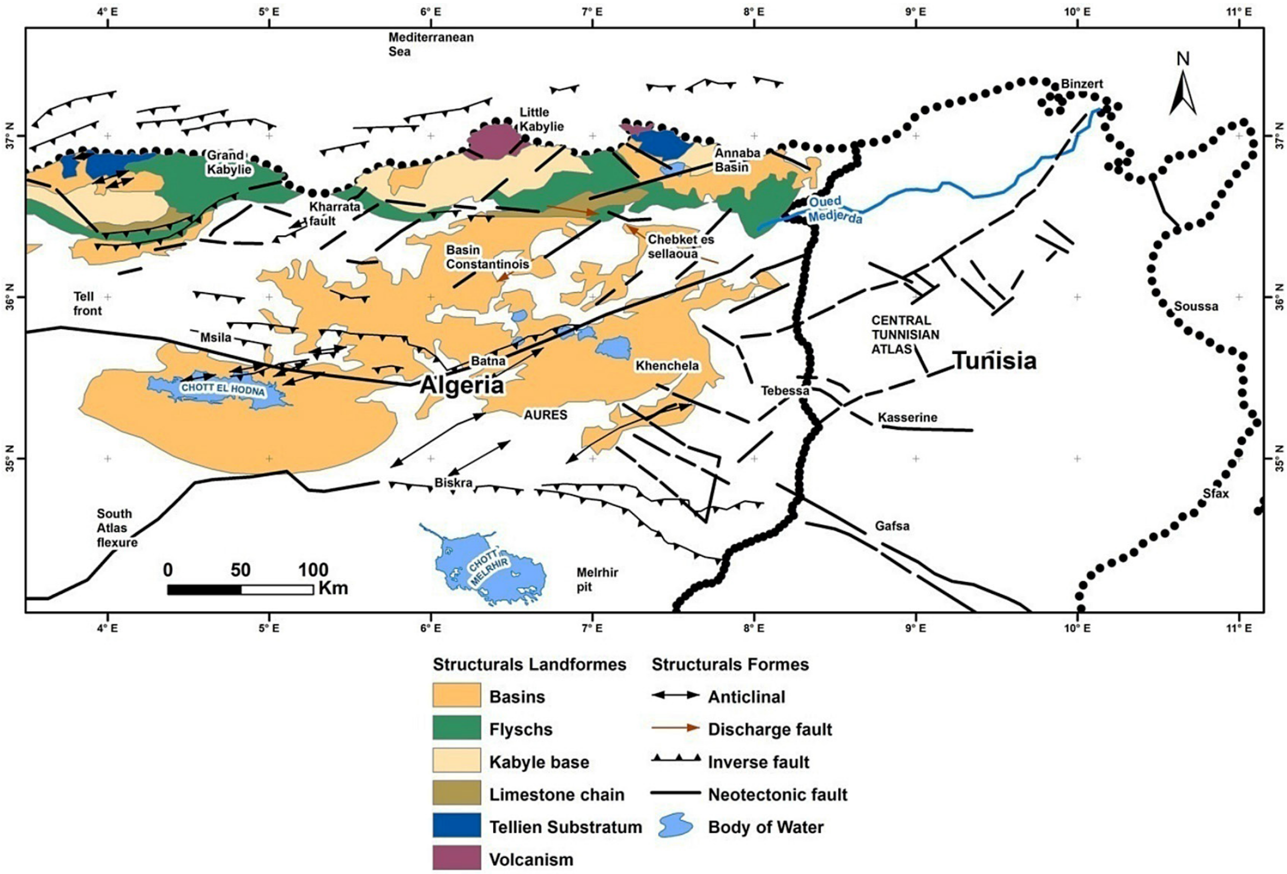

Figure 1. Situation of the North of Tebessa in the structural and palaeogeographic context of the Algerian-Tunisian Atlas basin

Source: Burollet and Desforges (1982) and Herkat (1999)

with large radii of curvature. Their skeleton is provided by the competent limestone levels. These folds are the result of Neogene compressions, the exact age of which has been discussed.

The most important Triassic outcrops are in the form of evaporitic domes with no outcropping salt, or vast clay-gypso-dolomitic formations. They are numerous between Tenis in Tunisia and Tebessa in Algeria; this is the area of the diapirs. In this zone, diapirism is manifested at different stages, i.e. polyphase diapirism (Dubourdieu, 1956; Thibiéroz & Madre, 1976; Masse & Chikhi-Aouimeur, 1982; Perthuisot & Rouvier, 1992; Kowalski & Hamimed, 2000). The Triassic formations are brought to the surface following the Albo-Aaptian and Tertiary - Quaternary distension phases, between which an Eocene (Fini-Lutetian) compressive phase occurred (Chabane, 2015). The triggering of halokinetic phenomena is linked to the tilted block distension which characterised the eastern Saharan Atlas during the Cretaceous, after fracturing of the ante-salt substratum (Vila, 1980). The mobilisation of the saliferous material is favoured by its creep and the existence of fragile zones in the saliferous post cover, thus provoking its ascent and upward migration (Salmi-Laouar, 2004).

2.2. Seismo-tectonic context of the study area

The active Alpine and Himalayan belts extend from Southwest Asia to the Atlantic Ocean. In the Mediterranean region, this belt is characterized by a permanent convergence movement of the African and Eurasian tectonic plates with a NW-SE convergence direction, indicated by most of the geological or geodetic models (Argus et al., 1989; Altamimi et al., 2007; Calais et al., 2003; D'Agostino et al., 2008; DeMets et al., 1990, 1994, 2010; Fernandes et al., 2003; McClusky et al., 2003; Serpelloni et al., 2007; Sella et al., 2002; Reilinger et al., 2006; Nocquet et al., 2006; Kreemer & Holt, 2001; Prawirodirdjo & Bock, 2004). This regional geodynamic context has generated in the North of Algeria, over a band of about 200 to 300 km wide, a set of tectonic structures (folds, faults) with a general direction perpendicular to the direction of convergence of the tectonic plates. In the eastern region, earthquakes seem to be rather decreasing due to a reorientation of the stress field (Bounif et al., 1987; Meghraoui, 1988; Beldjoudi et al., 2009), as well as a relatively high seismic activity. This seismicity is superficial; hence, it often has a destructive character.

2.3. Seismicity in North-eastern Algeria

The data analysed correspond to the geographical region located between latitudes 34.5° N and 38° N and longitudes 5° E and 8.5° E (Figure 2). The basis of the macro-seismic and instrumental data was used by Harbi (2001) and Harbi et al. (2003a, 2003b). The author compiled a catalogue of earthquakes for north-eastern Algeria (4° - 9.5° E, 33° -38° N) based on the determination of the macroseismic information available in 1900, and on the comparison between the most recent catalogues (Benouar, 1994; Mokrane et al., 1994). He merged them into a unified and homogeneous catalogue (where the type of amplitude and intensity is, respectively, indicated). The other catalogue of Harbi et al. (2010) treats the seismicity of the same region, between the period 1850 to 2010, and provides information on date, time, location and depth according to availability and the different magnitude values: Mb (magnitude of volume waves), Ml (local magnitude), the magnitudes of surface waves (Ms) are determined based on Benouar's empirical relations.

The CRAAG (Astronomy, Astrophysical and Geophysical Research Center), in charge of seismological observation and monitoring in Algeria, contains the original data and the unified fields from 1856-2013 period, resulting from the following processes:

• identification of the same earthquake in the catalogues: CRAAG, Harbi et al. (2010) and the ISC (International Seismological Centre), which provides many more events, especially small earthquakes, as well as the USGS/NEIC (National Earthquake Information Centre) catalogues;

• hierarchy of macro-seismic and instrumental locations;

• homogenize seismic data, i.e. giving a single type of parameter (magnitude or intensity) of the same scale the magnitude of the surface waves Ms. This choice is due to its use by all international bodies, and intensity in MSK-MM.

In addition, the most recent information on the spatial distribution of the maximum intensity over the region is presented by the map of calculated maximum intensities (IMC) of Boughacha et al. (2004) and is verified by comparing the map of observed maximum intensities (IMO) of Roussel (1973b) and the map (IMO) Io ≥ V modified by Bezzeghoud et al. (1996). This makes it possible to identify the degree of intensity (V) for our study area. The northern part of the southern Atlas flexure has very low seismicity, with the exception of the regions of Biskra and Batna where few events of intensity IX have been observed (Ayadi & Bezzeghoud, 2015).

3. DATA

3.1. Distribution of seismic events recorded

The basic version provided by CRAAG is the most credible source of seismic data for our implementation and covers well the targeted region as a source (5°– 8.5°E and 34.5°– 38°N). It extends from 1856 to 2013 and contains 3185 seismic events. The latter includes several essential parameters, allowing the description of the earthquakes, such as the date (day/month/year) and the exact time of the origin (hour-minute-second), its epicentral coordinates (longitude and latitude), the magnitude of the surface waves (Ms) and the depth of focus in kilometres

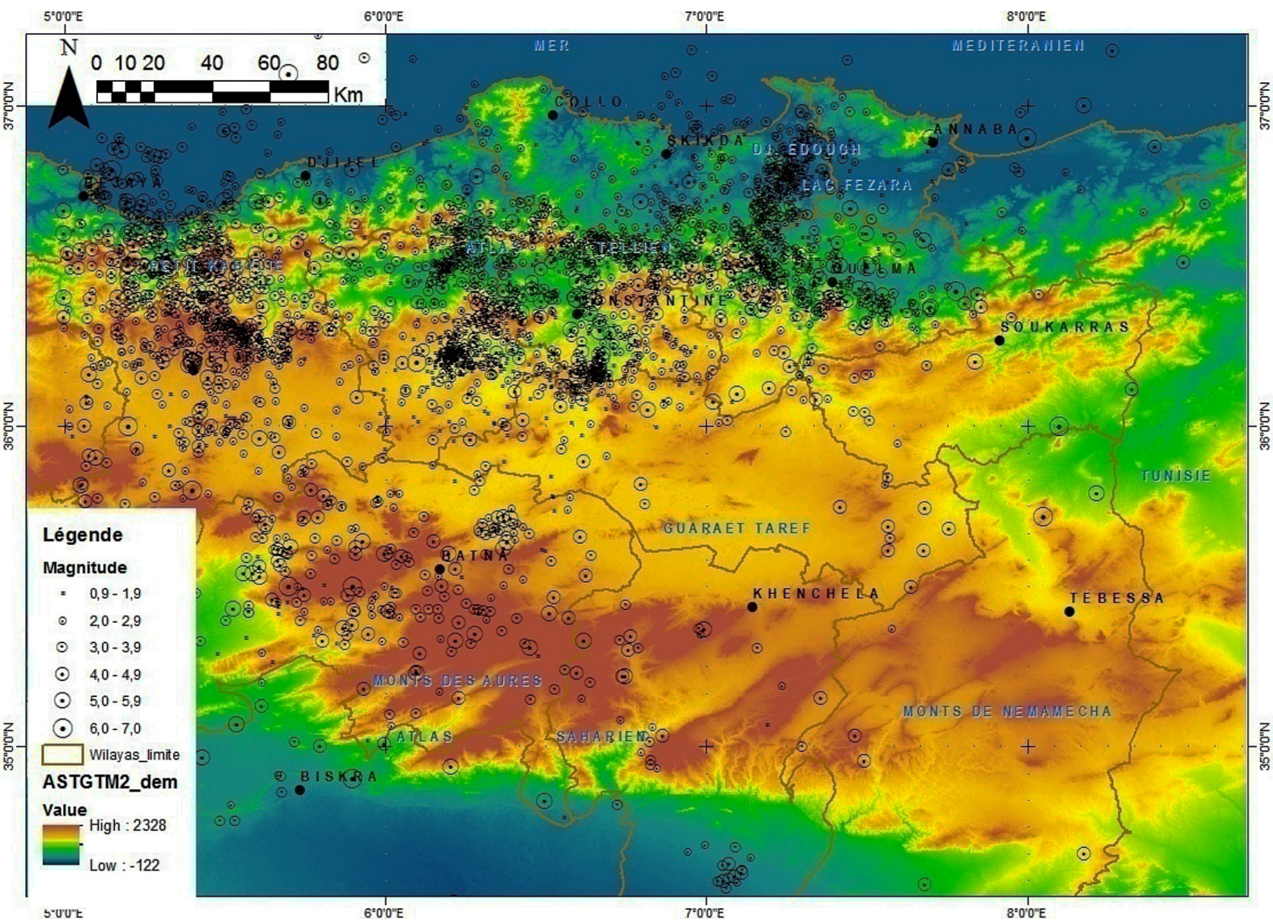

Figure 2. Map of macroseismic and instrumental epicentres in north-eastern Algeria (period 1856–2013)

(km). Only 65 of the 3185 maximum intensity values are received at the epicentre indicated in the Modified Mercalli Scale (MM) of degree between III-IX, in the period 1856-1985. The spatial distribution of all cumulative seismic events in the region (Figure 2), gives a general representation of the seismicity of the target area for the period (1856-2013). It can be noted that the epicentres are concentrated more particularly along the coastline, in the Tellian Atlas (Figure 2). Moving southwards the frequency of seismicity decreases very significantly. It should be noted that this region is characterised by fairly moderate seismic activity.

(Figure 2). An adjustment between epicentral intensity and local magnitude was made using the method of least squares to overcome the problem of the lack of values for epicentral earthquake intensities in north-eastern Algeria during the period 1856-2013. This allowed the establishment of a simplified but efficient empirical law to quickly estimate the probable epicentral intensities in the epicentres (I_0) (Equation 1). The model developed under this law (Figure 5) does not take into account neither site nor source effects to adapt as well as possible to the data collected.

3.2. Seismic level

The distributions by degree and class of magnitude of the catalogued earthquakes that shook the region of Northeast Algeria during the space-time 1856-2013 are presented in Figures 3a and 3b.

As well as the seismic events after 1900 are presented in Figure 4.

First of all, the analysis shows a clear increase in the number of earthquakes recorded between 2005 and 2010 (Figure 3a) and, particularly the class of magnitudes 0.9-3.9, presents 96 % of sampling (Figure 3b).

We also find in Figure 4 the stagnation in the recording of the seismic phenomenon during the period 1900-1995 (this is due to the voluntary destruction of the measuring stations, during the period of insecurity that Algeria crossed), followed by a progressive improvement of the matched seismic data visible from the year 2000, which reflects the emergence of a new strategy adopted by the CRAAG, in order to renovate the quality and the number of the seismic monitoring network in Algeria.

This can be seen by the number and degree of magnitude recorded during this period.

3.3. Seismic intensity perceived in the epicentres

Firstly, the source points of seismic activities that can influence the seismicity of the study area and which are concentrated in north-eastern Algeria were identified

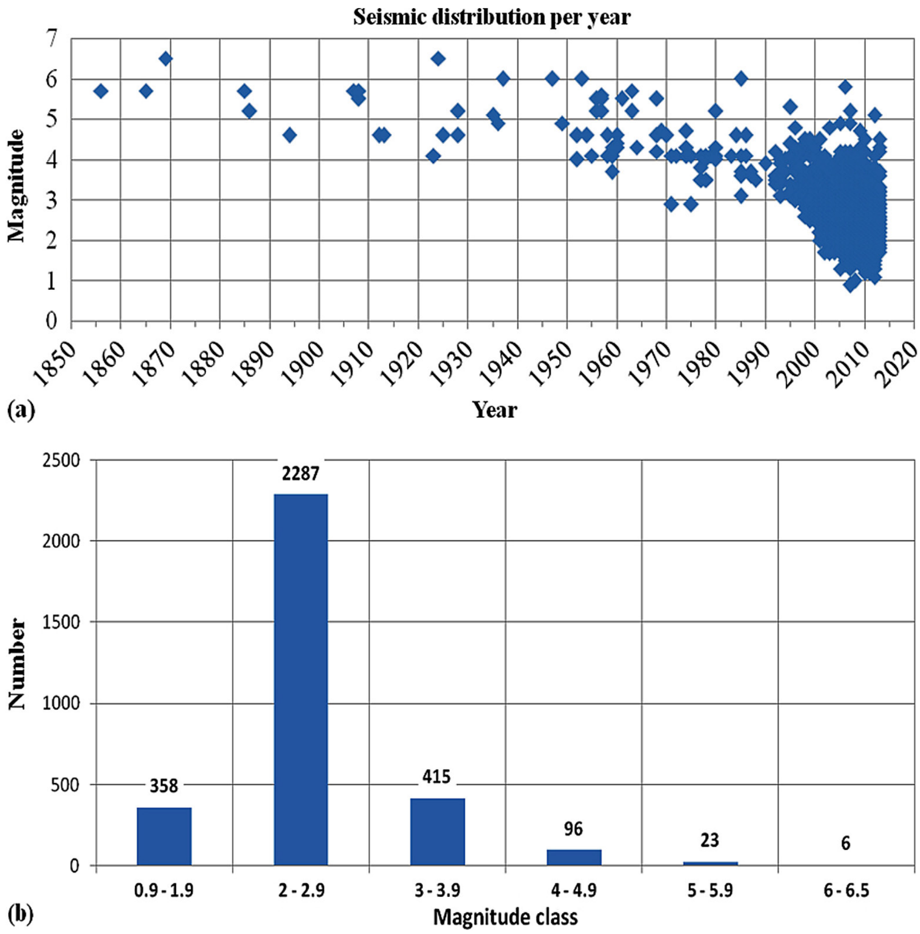

Figure 3. Distribution of earthquakes, (a) in degree of magnitude per year and (b) by class of magnitude, in period (1856–2013)

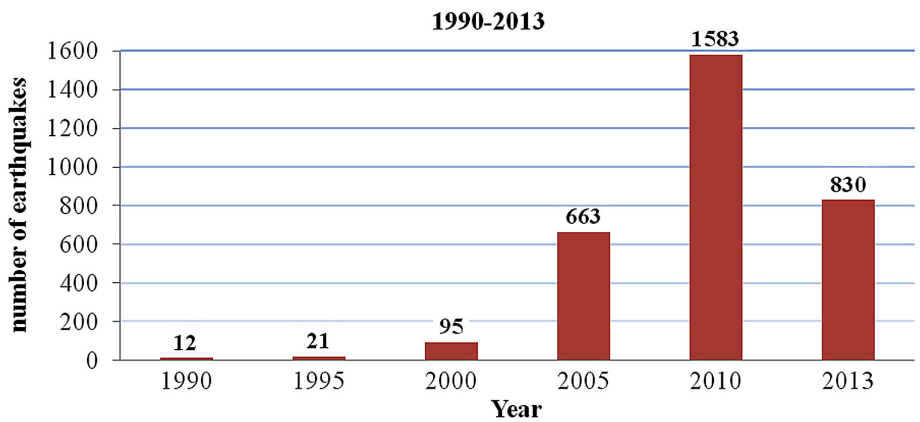

Figure 4. Histogram of the number of earthquakes per year period (1990–2013)

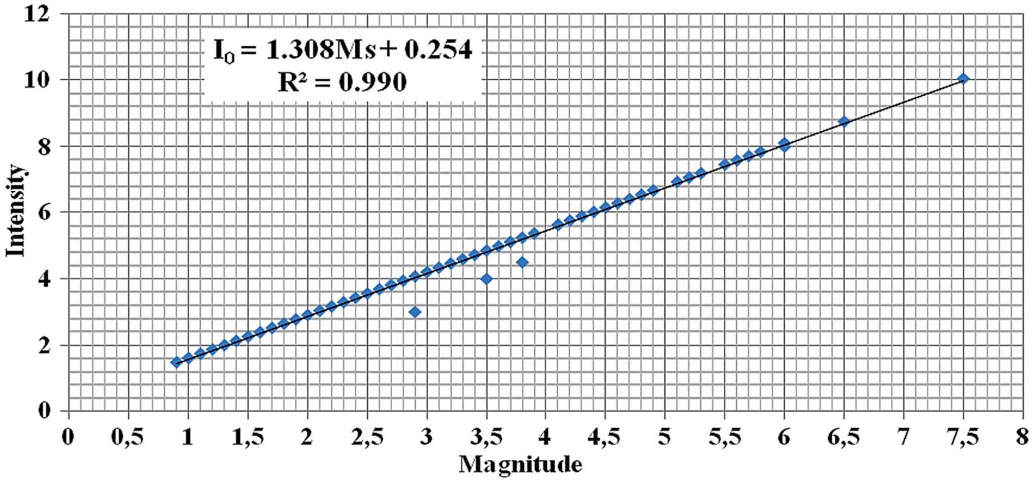

Figure 5. Probable epicentral intensity curve at the epicentre of north-eastern Algeria

$$I_0 = 1.3 \text{ Ms} + 0.254 \qquad (R^2 = 0.99) \qquad (1)$$

where:
I_0: epicentral intensity at the epicentre,
Ms: macro-seismic magnitude,
R^2: coefficient of determination.

4. METHODS

The probabilistic approach to seismic intensity assessing is based on calculation of the annual incidence rate of an intensity at a site for a given return period. Cornell (1968) introduces the concept of seismic source to present seismicity through a probabilistic approach (Dominique, 1999).

Following the poor knowledge of the seismicity of the North-East of Algeria, it is proposed that this seismic area is homogeneous, and also each catalogued seismic epicenter is supposed to be the source point that can propagate seismic waves to the target site of city of Tebessa. The following probabilistic methods and procedures were used to estimate the seismic hazard (Ameer et al., 2004):

a) frequency-magnitude relationship: the methods developed by Gutenberg and Richter and Hwang and Huo were used for the estimation of seismic activity parameters (b-value and maximum regional magnitude Mmax) and the recurrence rate from moderate to high magnitude.

b) determination of extreme values: the calculation of extreme values of magnitude or intensity corresponding to a certain return time, i.e. having a certain probability of occurrence.

The frequency model used to describe the statistical behavior of extreme values is the Gumbel statistical distribution (double exponential law or Gumbel law) (Ameer et al., 2004).

Based on previous work in this area (Mohammadi & Bayrak, 2015; Shanker & Singh, 1997), also the statistical parameters for the first Gumbel (GI) and Gutenberg and Richter (G-R) distributions were estimated using both least squares and maximum likelihood techniques while in the case of the third Gumbel (GIII) distribution, only the maximum likelihood technique is used to estimate the seismic parameters.

4.1. Identification of all sources of earthquakes in Tebessa

The processing of seismic data by the epicentral intensity attenuation relations is guided by the following phases:

During the first phase, we completed the degree of missing the epicentral intensity of the earthquakes listed, by relation (1), then we determined the epicentral and focal distances of each epicenter (point source) and of the target area (city of Tebessa).

Phase two determines the degree of seismic intensity expected at the level of the target zone, by each epicenter (source, point) according to the relations of Table 1, the treatment derives from the values of positive and other negative intensity on the target zone. This made it possible to select 159 seismic epicenters of positive maximal seismic intensity values observed at the target site (I_{cMax}^{obs}). These epicenters are contained within a radius (≤ 200 km) around the target area (city of Tebessa), shown in Figure 6.

where:
I_0: intensity at the epicentre,
Ic: local intensity (target area),
h: depth of the hearth (10 km),
Δ: distance to the epicentre (km),
$r = [\Delta^2+h^2]^{1/2}$ distance focal (km),
M: instrumental magnitude (catalogued from source area).

Tab. 1. Attenuation relationship equations of epicentral intensity calculation

Author	Relation		Intensity scale
Shebalin (1968)	$I_c = I_0 - 3.6 \log (r/h)$	(2)	MSK
Ganse1 (1980)	$\ln I_c = \ln I_0 - 0.10 - 0.00196\,\Delta - 0.076 \ln \Delta$	(3)	MM
Ganse2 (1980)	$\ln I_c = \ln (1.5\,M - 1.5) + 0.0477\,\Delta - 0.022\,\Delta - 0.055 \ln \Delta$	(4)	MM

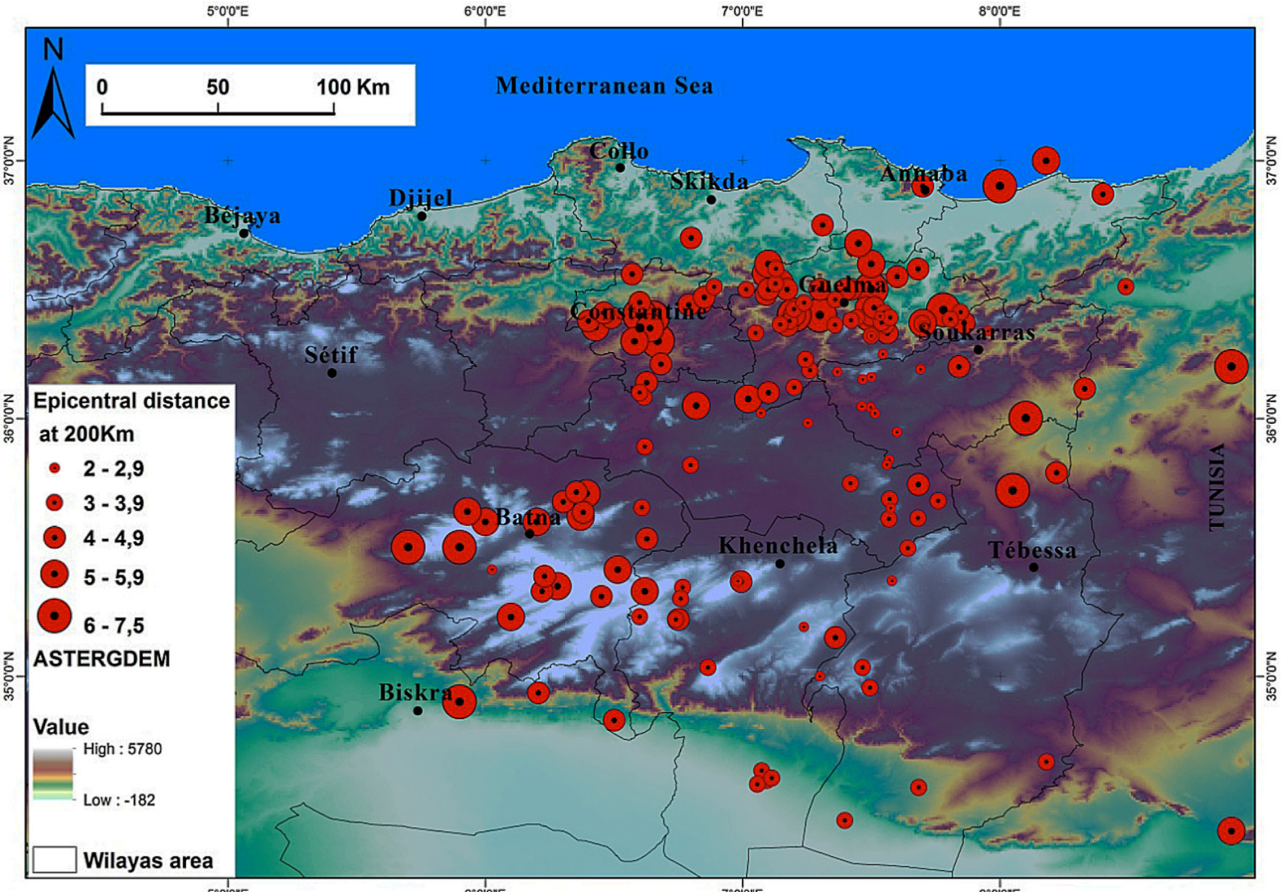

Figure 6. Map of the macro-seismic and instrumental epicentres less than 200 km from the city of Tebessa (period 1856 – 2013)

At the end of the attenuation of the epicentral intensity, the average distribution of the selected earthquakes (N=159) according to the epicentral distances from the city of Tebessa was as follows:

$0\ \text{km} \le \Delta \le 50\ \text{km}$; N = 6, (3.8 %) $I^{obs}_{cMax} = 5.1$ (MM)
$50\ \text{km} \le \Delta \le 100\ \text{km}$; N = 21, (13.21 %) $I^{obs}_{cMax} = 4.2$ (MM)
$100\ \text{km} \le \Delta \le 150\ \text{km}$; N = 78, (48.42 %) $I^{obs}_{cMax} = 4.4$ (MM)
$150\ \text{km} \le \Delta \le 200\ \text{km}$; N = 54, (33.96 %) $I^{obs}_{cMax} = 3.9$ (MM).

Therefore, the characteristics of the earthquake of 22/09/1995 (coordinates of the epicentre: lat. 35°–72°N, long. 05°– 08°E; instrumental magnitude M = 5.3; epicentral intensity $I_0 = 7.2$, calculated by Equation 1; epicentral distance $\Delta = 35$ km from the target area city of Tebessa) allowed to determine the maximum intensity observed $I^{obs}_{cMax} = 5.1$ (MM) in the city of Tebessa.

4.2. Probabilistic assessment of seismic hazard

For the estimation of extreme values of a seismic magnitude or intensity, the following probabilistic methods were used:

4.2.1. Frequency - magnitude relationship

The seismic events occurring in North-East Algeria for the time interval (1856-2013) contain 159 selected seismic events assumed as identically distributed independent variables.

We propose the Gutenberg-Richter (1956) law relation 5, and the Hwang and Huo (1994) law relation 6 (Lungu et al., 1997) for their study.

a) Relation frequency-magnitude (Gutenberg and Richter, 1956)

$$\mathrm{Log}_{10}(N_c/an) = a - b.\,Ml \qquad (5)$$

where:
Ml: local magnitude,
a and b: specific constants of the study area (b: spawning of the distribution, a: the logarithm of the number of earthquakes of zero magnitude),
N_c/an: the number of cumulative magnitude per year greater than or equal to Ml.

The working relation for the study area is:

$$\mathrm{Log}_{10}(N_c/an) = 3.491 - 0{,}45\ Ml$$

b) Relation frequency-magnitude (Hwang and Huo, 1994)

$$N(\ge Ml) = e^{\alpha-\beta M}.(1-e^{-\beta(M_{max}-M)})/(1-e^{-\beta(M_{max}-M_0)}) \qquad (6)$$

where the values of and are determined by relations 7 and 8.

$a = 3.5,\ b = 0.45$

$$\alpha = 3.5 * Ln(10) = 8.038 \quad (7)$$

$$\beta = 0.45 * Ln(10) = 1.036 \quad (8)$$

$M_{Max} = 6.5, M_0 = 3$

After solving the system of linear equations, the working form of Equation (6) is expressed below. The calculated frequency magnitude curve is presented in Figure 7.

$$N(\geq Ml) = e^{8.038-1.036M}.(1 - e^{-1.036(6.5-M)})/(1 - e^{-1.036(6.5-3)})$$

Figure 7 results:

- the regression line adjusts well to the data, except for the strong magnitudes ($Mi \geq 6$),
- the recurrence curve Figure 7 (Gutenberg & Richter and Hwang & Huo) gives the following information:
- maximum magnitude for the Algerian northeast is $M_{max} = 6.5$,
- maximum magnitude for the epicentral distance zone (DE ≥ 200 km); $M_{max} = 6$.

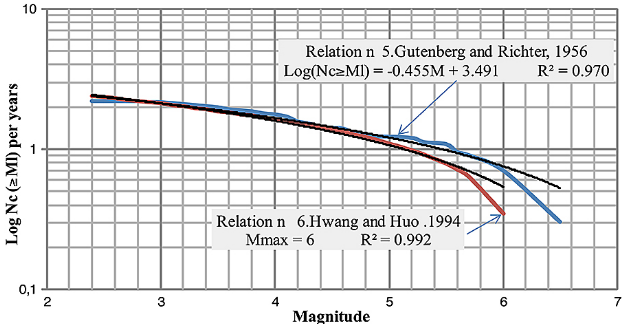

Figure 7. Frequency-magnitude relationship for the northeast Algeria targeted region as a source (5°– 8.5°E and 34.5°– 38°N) (period 1856–2013)

The advantage of using the reduced variable is that the expression of a quantile is then linear equation (13)

$$Mt = a + b.mt \quad (13)$$

The points of the series to be adjusted can be plotted in a system of axes (M – m). It is possible to adjust a line which passes best through these points and to deduce from them the two parameters a and b of the law.

In practice, this essentially involves estimating the probability of not exceeding G^I_M (Mi) that should be assigned to each value Mi. Estimation of the distribution function G^I_M (Mi) using the empirical frequency.

On a sorting of the series by increasing values allowing to associate with each value its rank i. Simulations have shown that for Gumbel's law, it is necessary to use the empirical Hazen frequency

$$G^I_M (Mi) = (i - 0.5)/n \quad (14)$$

where i is the rank in the data series classified by increasing values, n is the sample size, Mi the value of rank i.

Let us recall again that the return time T of an event is defined as being the inverse of the frequency of occurrence of the event.

$$T = 1/(1 - G^I_M (Mi)) \quad (15)$$

b) We applied the GIII equation (16) distribution in the source zone North-East of Algeria to assess the seismic intensity in the target city of Tebessa in terms of upper limit magnitude (w) and possible earthquake magnitude that can occur in the next 475 years (Mohammadi & Bayrak, 2016; Tsapanos et al., 2014).

4.2.2. Extreme values determination by the Gumbel I and III distribution

a) The objective is to estimate the extreme value of the magnitude (M_{max}) corresponding to a certain return time, and to certain given probability of occurrence. The frequency model used to describe the statistical behaviour of extreme values is the Gumbel statistical distribution (double exponential law).

The distribution function of the Gumbel law of Burton (1979) is expressed as follows:

$$G^I_M = e\left[-e^{-[\beta(M-u)]}\right] \quad (9)$$

where:

adjustment coefficients with the following reduced variability: takes:

$$\left[\beta = \tfrac{1}{b} \text{ and } a = u\right] \quad (10)$$

where:

a and b are the parameters of the Gumbel (I) model.

The distribution is then written by the two relations (11 and 12) as follows:

$$G^I_M = e\left[-e^{(-m)}\right] \quad (11)$$

$$m = -\,ln\left[-\ln\left(G^I_M(M)\right)\right] \quad (12)$$

Tab. 2. Central parameters of seismic magnitude and intensity for the city of Tebessa (period 1856–2013)

	Magnitude	Epicentral intensity	Intensity			
			Shebalin	Ganse (1-2)	Ganse (2-2)	City of Tebessa
Average	3.79	3.98	1.48	2.59	1.23	1.6
Median	3.6	3.7	0.95	2.38	0.76	1.3
Mode	3.5	3.1	4.31	3.68	3.61	3.8
Max. value	6.5	9	5.16	4.63	5.52	5.1
Standard deviation	0.83	2.01	5.16	4.63	5.52	1.1

Tab. 3. Magnitude (M), epicentral intensity I_0 and intensity of Tebessa (local I) obtained by the methods of Gumbel I and Gumbel III

Gumbel's Method	Magnitude Gumbel-I			Magnitude Gumbel-III		
Return period per year	Magnitude	Epicentral Intensity	Intensity city of Tebessa	Magnitude	Epicentral Intensity	Intensity city of Tebessa
50	6.91	6.26	5.54	6.93	6.29	5.56
100	7.51	6.86	6.14	7.17	6.53	5.80
200	8.11	7.46	6.74	7.34	6.69	5.97
475	8.85	8.21	7.48	7.49	6.84	6.12
	a = 3.42	a = 4.705	a = 1.272	w = 6.5	w = 9	w = 5.1
	b = 0.65	b = 0.85	b = 0.45	u = 3.5	u = 3.1	u = 3.8
	R^2 = 0.98	R^2 = 0.98	R^2 = 0.95	k = 4.60	k = 6.21	k = 2.56

$$G^{III}_{(M)} = e\{-[(w - M)/(w - u)]^k\} \quad (16)$$

Where w is the upper limit of the initial variable M, u is its greatest characteristic value and k is the shape parameter which is also called the inverse of the measure of dispersion.

Let Mi (with i =1, 2, 3, ..., n) are the observed earthquake magnitudes in the time period 1856–2013 for the source zone.

The probability that M is an extreme value of the magnitude is given by the cumulative distribution equation

$$M = w - (w - M)[-\ln(P(M)]^{\lambda} \quad (17)$$

This is a nonlinear function that is to be fitted to the observed annual extremes. If mi (i = 1, 2, ..., n) are annual extreme magnitudes in a given region during n successive years, then these observed values are arranged in ascending order, so that $m_1 < m_2 < \ldots m_n$. Following, the plotting point probability value at mesh defined by

$$P(mi) = i/n + 1 \quad (18)$$

where i = 1, 2, 3 ..., n is the rank and n is the number of observations.

As λ=1/k then plotting M as ordinate and as abscissa, draws a straight line which is intercepted and with – (w - M) as a slope (Equation 18).

The magnitude probable extreme M_{max} for a period of T years could be determined by relation 19 proposed by Burton (1979) in Mohammadi & Bayrak (2016)

$$M_{max} = w - (w - M)[-\ln(1 - \lambda)/T]^{\lambda} \quad (19)$$

Gumbel's third distribution theory is used to assess the seismic parameters of the study area. These seismic parameters are determined by following steps introduced in Mohammadi & Bayrak (2016) and Jaiswal et al. (2002).

The results of the GI and GIII methods are presented in the Tables 2, 3, and Figure 8 shows the curve of extreme values of epicentral intensity (GI-GIII).

The results presented in Table 3 could be shared in two categories:

- strong values for 50 – 100 years return time
- stronger values for 200 – 475 years return time.

Also, the magnitude of large dimensions acquired is that of Gumbel1 (Mmax GI = 8.11–8.85 for 200–475 years return time).

5. RESULTS AND DISCUSSION

The analysis and taking into account of the seismic information available over a century and a half (1856–2013) follows that the seismicity of the city of Tebessa is determined by the earthquakes of depth approximately 10 km, which occur in a radius of less than 200 km around the city of Tebessa.

From the presentation of the magnitude-frequency curves (Figure 7), we deduce that the maximum magnitude predicted in the North-East of Algeria would be of the order of 6.5 (Richter), according to the resolution of the Gutenberg &Richter equation, while that of the target area, city of Tebessa of the order of 6 (Richter) by the Hwang & Huo relation.

In this perspective, the two relations (5, 6), sound very complementary for the purpose to frame the degree of observation of the maximum magnitude of the source zones and the target zone.

Our results are close to the results of previous work in the Aures Nememcha zone, such as the probabilistic study of Pelaez et al. (2005) with Mmax = 6.8 and the deterministic study of Aoudia et al. (2000) with Mmax = 6.1.

Note that the value of the extreme intensity expected in the target zone (city of Tebessa) $I^{obs}_{T.max}$ = 6.12 (MM), for a return period of 475 years, which attests to an increase of one degree compared to that determined by Bezzeghoud et al. (1996) and Roussel (1973a) for the region of Nememcha I = V (MM).

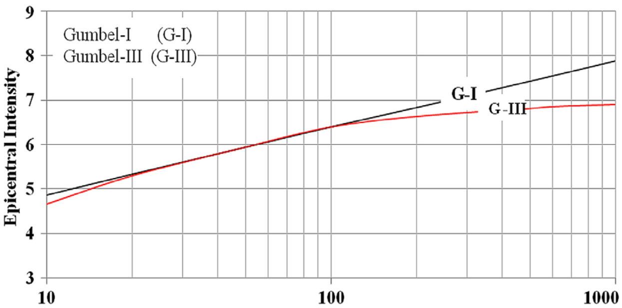

Figure 8. Graphical representation of the distributions extreme values of Gumbel I and III for epicentral intensity (I_0) (period 1856 -2013)

These results consolidate our methodology provided an adequate opportunity to improve the quality of the forecast of the targeted area.

Also deduces that the environment is more homogeneous and capable of producing large earthquakes. The most illustrative example of this phenomenon is the earthquake of September 22, 1995, at 11:20, with a magnitude of 5.3 which struck the region of Tebessa in the Nememcha Mountains. The earthquake was located about 5 km east of a sinistral displacement-type tectonic lineament (Guemache, 2010). The earthquake was limited to a 35 km strip of the target area of the city of Tebessa.

6.CONCLUSION

The methodology adopted in this work may seem rather simplistic, but it has an advantage for preliminary reconnaissance in areas of weak seismic data.

The method merges the frequency-magnitude law (Gutenberg & Richter and Hwang & Huo) and the parameters of Gumbel's asymptotic type I and type III distributions using seismic data of Northeast Algeria during the space-time (1856–2013). The methods showed better results for the 150-year-magnitude-sample analyzed, especially for the overall fit of the Gumbel type III distribution.

It has been found that the conventional approach based on the frequency-magnitude relationship gives ceiling limits on the magnitude that do not exceed the large value of the sample. So, I believe that the method is not suitable for modeling rare and large earthquakes.

The logical extreme value approach predicted for the study area (city of Tebessa) $I^{obs}_{T.max}$ = 6.12 MM is with a magnitude at the epicenter Ml = 7.5 for a return period of 475 years. We can consider this maximum intensity observed as a very useful seismic hazard parameter, which informs us quickly and in advance of the extent of the damage expected in the event of a similar earthquake.

References

Al Abbasi J.N., Risan H.K. & Resen I.A., 2018: Application of Kumaraswamy Extreme Values Distributions to Earthquake Magnitudes in Iraq and Conterminous Regions. *International Journal of Applied Engineering Research* ISSN 0973-4562 Volume 13, Number 11 (2018), pp. 8971–8980. *Research India Publications*. http://www.ripublication.com

Altamimi Z., Collilieux X., Legrand J., Garayt B. & Boucher C., 2007: ITRF2005: a new release of the International Terrestrial Reference Frame based on time series of station positions and earth orientation parameters. *Journal of Geophysical Research* 112, B09401, http://dx.doi.org/10.1029/2007JB004949

Ameer A.S., Sharma M.L., Wason H.R. & Alsinawi S.A., 2004: Seismic Hazard Characterization and Risk Evaluation Using Gumbel'S Method of Extremes (G1 and G3) and G-R Formula for Iraq. In: 13th World Conference on Earthquake Engineering Vancouver, *B.C., Canada. Paper* No. 2898, *Vancouver*, p 13.

Aoudia A., Vaccari F., Suhadolc P. & Meghraoui M., 2000: Seismogenic potential and earthquake hazard assessment in the Tell Atlas of Algeria. *J Seismol* 4: 79–98.

Argus D.F., Gordon R.G., DeMets C. & Stein S., 1989: Closure of the Africa Eurasia North America plate motion circuit and tectonics of the Gloria fault. *J. Geophys. Res.*, 94: 5585–5602

Ayadi A. & Bezzeghoud M., 2015: Seismicity of Algeria from 1365 to 2013: Maximum observed intensity map (MOI2014). *Seismol Res Lett* 86: 236–244, https://doi.org/10.1785/0220140075.

Beldjoudi H., Guemache M.A., Kherroubi A., Semmane F., Yelles-Chaouche A.K., Djellit H., Amrani A. & Haned A., 2009: The Lâalam (Béjaïa, North-East Algeria) moderate earthquake (Mw = 5.2) on March 20, 2006. *Pure Appl Geophys* 166:623–640 . https://doi.org/10.1007/s00024-009-0462-9.

Benouar D., 1994: The seismicity of Algeria and the Maghreb during the twentieth century. *Imperial College London, UK*.

Bezzeghoud M., Ayadi A., Sebai A., Ait Messaoud A., Mokrane A. & Benhallou H., 1996: Seismicity of Algeria between 1365 and 1989. Map of maximum observed intensities (MOI). *IGN, Avances en Geofisica y Geodesia,* 107–114.

Boughacha M.S., Ouyed M., Ayadi A. & Benhallou H., 2004: Seismicity and seismic hazard mapping of northern Algeria: Map of maximum calculated intensities (MCI). *J Seismol* 8:1–10. https://doi.org/10.1023/B:JOSE.0000009513.11031.43.

Bounif A., Haessler H. & Meghraoui M., 1987: The Constantine (northeast Algeria) earthquake of October 27, 1985: surface ruptures and aftershock study. *Earth Planet Sci Lett* 85: 451–460.

Burollet P.F. & Desforges G., 1982: Dynamique des bassins néocrétacés en Tunisie. Mém géol Univ Dijon 7: 381–389

Burton P.W., 1979: Seismic risk in Southern Europe through India examined using Gumbel's third distribution of extremes values. *Geophys. J. R. Aster. Soc.*, 59: 249–280.

Calais E., DeMets C. & Nocquet J.M., 2003: Evidence for a post-3.16-Ma change in
Nubia-Eurasia-North America plate motions? *Earth. Plan. Sci. Lett.*, 216, 81–92.

Chabane K., 2015: Le Cenomanien-Turonien du Nord de Tebessa (Algerien, Nord-est). These Doctorat Université de Badji Mokhtar Annaba

Cornell C.A., 1968: Engineering risk analysis. *Bull. Seismol.* Soc. America, vol. 58, n° 5, p. 1583–1606.

D'Agostino N., Avallone A., Cheloni D., D'Anastasio E., Mantenuto S. & Selvaggi G., 2008: Active tectonics of the Adriatic region from GPS and earthquake slip vectors. *Journal of Geophysical Research* 113 (B12), 12413.

DeMets C.R., Gordon G., Argus D.F. & Stein S., 1990: Current plate motions. *Geophys. J. Int.*, 101: 425–478.

DeMets C.R., Gordon G., Argus D.F. & Stein S., 1994: Effect of recent revisionsto the geomagnetic reversal time scale on estimates of current plate motions. *Geophys. Res.* Letters, 21: 2191-2194.

DeMets C.R., Gordon G. & Argus D.F., 2010: Geologically current plate motions. *Geophysical Journal International* 181 (1), 1–80.

Dominique P., 1999: Evaluation probabiliste de l'aléa sismique: état de l'art. Rap. *BRGM* R39010, 73 p., 14 fig.

Dubourdieu G., 1956 : Etude géologique de la région de l'Ouenza (confins algéro-tunisien). Thèse Sci. Paris, pub1serv.cart Géol. *Algérie. Bull.* n°10, vol.1, 659p

Fernandes R.M.S., Ambrosius B.A.C., Noomen R., Bastos L., Wortel M.J.R., Spakman W. & Govers R., 2003: The relative motion between Africa and Eurasia as derived from ITRF2000 and GPS data. *Geophysical Research Letters* 30 (16), 1828, http://dx.doi.org/10.1029/2003GL017089

Ganse R.A., 1980: Expected-Intensity Searches and Attenuation Coefficients for China, Turkey and Yugoslavia. *Seismological Research Letters* 1980; 51 (2): 26–27 doi: https://doi.org/10.1785/gssrl.51.2.26

Guemache M.A., 2010: Evolution géodynamique des bassins sismogènes de l'Algérois(Algérie): Approche pluridisciplinaire (méthodes géologiques et géophysiques. USTHB, n° d'ordre : 01/2010-D/S.T, Alger

Harbi A., 2001: Analyse de la sismicité et mise en évidence d'accidents actifs dans le Nord-Est Algérien. U.S.T.H.B, Alger, Algérie

Harbi A., Maouche S. & Benhallou H., 2003a: Re-appraisal of seismicity andseismotectonics in the north-eastern Algeria part II: 20th century seismicity andseismotectonics analysis*J Seismol* 7:221–234 https://doi.org/10.1023/A:1023571316216.

Harbi A., Maouche S. & Benhallou H., 2003b: Re-appraisal of seismicity and seismotectonics in the north-eastern Algeria part I: Review of historical seismicity. *J Seismol* 7: 115–136.

Harbi A., Peresan A. & Panza G.F., 2010: Seismicity of Eastern Algeria: A revised and extended earthquake catalogue. *Nat Hazards* 54: 725–747. https://doi.org/10.1007/s11069-009-9497-6.

Herkat M., 1999: La Sédimentation de haut niveau marin du cretacé supérieur de l'Atlas Saharien Oriental et des Aurès. U.S.T.H.B, Alger

Jaiswal K., Gupta S. & Sinha R., 2002: Estimation of maximum magnitude earthquakes in peninsular India using extreme value statistics. Conference: 12th Symposium on Earthquake Engineering. At: Department of Earthquake Engineering, IIT Roorkee https://www.researchgate.net/publication/328277795

Kreemer C. & Holt W.E., 2001: A no-net-rotation model of present-day surface motions.*Geophysical Research Letters* 28 (23), 4407–4410, http://dx.doi.org/10.1029/2001GL013232.

Kowalski W. & Hamimed M., 2000: diapirisme polyphase ou glacier de sel albien dilemme du matériel triasique des confinsalgéro-Tunisiens. *Bull du Serv géologique l'Algérie* 11:29–60.

Lungu D., Zaicenco A., Cornea T. & Van Gelder P., 1997: Seismic Hazard: Recurrence and Attenuation of Subcrustal (60–170 km) Earthquakes *ICOSSAR'97, Kyoto, Japan*. Nov. 24–28.

Masse J.P. & Chikhi-Aouimeur F., 1982: La plate-forme carbonatée de l'Ouenza (Sud Constantinois, Algérie). Organisation et Dynamique durant l'Aptien supérieur. *Géol. Méditer., Marseille*, vol. IX, n° 3, pp. 259–267

McClusky S., Reilinger R., Mahmoud S., Ben Sari D. & Tealeb A., 2003: GPS constraints on Africa (Nubia) and Arabia plate motions. *Geophysical Journal International* 155, 126–138, http://dx.doi.org/10.1046/j.1365-246X.2003.02023.x.

Meghraoui M., 1988: Géologie des zones sismiques du nord de l'Algérie (paléosismologie, Tectonique active et synthèse sismotectonique). université de Paris sud, Orsay, France

Mohammadi H. & Bayrak Y., 2015: An evaluation of earthquake hazard parameters in the Iranian Plateau based on the Gumbel III distribution. *J Seismol* 20:615–628. https://doi.org/10.1007/s10950-015-9547-3.

Mohammadi H. & Bayrak Y., 2016: Regional Variations of the ω-upper Bound Magnitude of GIII Distribution in the Iranian Plateau in the Iranian Plateau. *Acta Geophys* 64: 1004–1033. https://doi.org/10.1515/acgeo-2016-0038.

Mokrane A., Aït Messaoud A., Sebaï A., Menia N., Ayadi A. & Bezzeghoud M., 1994: Les séismes en Algérie de 1365 à 1992. In: Benhallou H, Bezzeghoud M (eds) Publication du Centre de Recherche en Astronomie, Astrophysique et Géophysique. Alger, Bouzaréah, p 277.

Nocquet J.M., Willis P. & Garcia S., 2006: Plate kinematics of Nubia–Somalia using a combined DORIS and GPS solution. *Journal of Geodesy* 80, 591–607. http://dx.doi.org/10.1007/s00190-006-0078-0

Othmanine A., 1987: Les minéralisations en fluorine, barytine, Pb, Zn et fer sidéritique autour du fossé de Tebessa-Morsott (Algérie). Relation entre paléogéographie aptiènne, diapirisme, structure et métallogénie. Université Pierre et Marie Curie, Paris VI, France

Peláez J.A, Hamdache M. & Casado C.L., 2005: Updating the probabilistic seismic hazard values of Northern Algeria with the 21 May 2003 M 6.8 Algiers earthquake included. *Pure Appl Geophys* 162:2163–2177. https://doi.org/10.1007/s00024-005-2708-5.

Perthuisot V. & Rouvier H., 1992: Les diapirs du Maghreb central et oriental: des appareils variés, résultats d'une évolutionstructurale et pétrogénétique complexe. *Bull la société géologique Fr* 163: 751–760.

Prawirodirdjo L. & Bock Y., 2004: Instantaneous global plate motion model from 12 years of continuous GPS observations. *Journal of Geophysical Research* 109, B08405,

Reilinger R.E., McClusky S., Vernant P., Lawrence S., Ergintav S., Cakmak R.,Ozener H., Kadirov F., Guliev I., Stepanyan R., Nadariya M., Hahubia G.,Mahmoud S., Sakr K., ArRajehi A., Paradissis D., Al-Aydrus A., Prilepin M.,Guseva T., Evren E., Dmitrotsa A., Filikov S.V., Gomez F., Al-Ghazzi R. & Karam G., 2006: GPS constraints on continental deformation in the Africa–Arabia–Eurasia continental collision zone and implications for the dynamics of plate interactions. *Journal of Geophysical Research* 111 (B5), B05411, http://dx.doi.org/10.1029/2005JB004051

Roussel J., 1973a: L'activité sismique en Algérie de 1951 à 1970 inclus. Extrait duBulletin de la Société d'Histoire Naturelle de l'Afrique du Nord. Tome 64 (1973)-Fascicules 3 et 4. *Imp. SNED-Alger*, 185–210

Roussel J., 1973b: Les zones actives et la fréquence des séismes en Algérie (1716-1970).Extrait du Bulletin de la Société d'Histoire Naturelle de l'Afrique du Nord. Tome 64 (1973)-Fascicules 3 et 4. *Imp. SNED-Alger*, 211–228.

Salmi-Laour S., 2004: Contribution a l'étude géologique et geochimie des isotopes stables (S, O, C,) des mineralisations polymetalliques (Zn-Pb-F-Ba-Fe-Hg) de la zone des DIAPIRS du nord de Tebessa (NE ALGERIEN). Annaba, Algérie

Sella G.F., Dixon T.H. & Mao A., 2002: Revel: A model for recent plate velocities from space geodesy. *J. Geophys*. Res

Serpelloni E., Vannucci G., Pondrelli S., Argnani A., Casula G., Anzidei M., Baldi

P. & Gasperini P., 2007: Kinematics of the Western Africa–Eurasia plate boundaryfrom focal mechanisms and GPS data. *Geophysical Journal International* 169 (3), 1180–1200.

Shanker D. & Singh V., 1997: Seismic Risk Analysis for the occurerence of medium size earthquakes in Kangra region of Himachal Pradesh, INDIA. *Proc Indian Natl Sci Acad* 63A: 197–202.

Shebalin N.V., 1968: Methods of application of seismic engineering data for regional seismity. Regional seismity in the USSR, Nauka *Publ. House, Moscow*, pp. 95–111

Thibiéroz J. & Madre M., 1976: Le gisement de sédirite du Dj. Ouenza (algérie) est controlé par un golf de mer aptienne. *Bull la société d'Histoire Nat l'Afrique du Nord* 67: 3–4.

Tsapanos T.M., Bayrak Y., Cinar H., Koravos GC., Bayrak E., Kalogirou EE., Tsapanou A.V. & Vougiouka GE., 2014: Analysis of largest earthquakes in Turkey and its vicinity by application of the Gumbel III distribution. *Acta Geophys* 62:59–82 . https://doi.org/10.2478/s11600-013-0155-8.

Vila J.M., 1980: La chine alpine d'algérie oriontale et des confins Algéro-Tunisiens. Paris VI.