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# Geographic Distribution of the b-value in north Morocco and its Surrounding for Seismic Zones Identification

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**Abstract**

Earthquakes are one of the deadliest hazards. To reduce their effects, seismic hazard assessments are applied to predict the levels of ground motion during future possible large earthquakes. The assessments depend on the so-called recurrence relationship. The recurrence relationship is based on the average or mean earthquake (denoted by the a-value) and the tectonic activity (denoted by the b-value). The seismotectonic activity in the study area has not been well studied. Hence, seismic hazard assessments may not provide adequate information for earthquake mitigation and preparedness strategies. An important step for seismic hazard assessments is the determination of the homogeneous seismic zones or sources. The present work aims to define seismic zones using the spatial records of past earthquake activities. The methodology adopted begins with building a complete catalog based on local catalogs and international data center products. Besides, the magnitudes are homogenized to the moment magnitude scale. The area is subdivided into several blocks. For each block, the Gutenberg-Richter formula is fitted to get the b-value. The parameters are then mapped to define seismic sources in the study area. The results show high b-value in the north of the study area. This area witnessed two moderate earthquakes near Al Hoceima City. To the south, b-value determined was low between 0.6 to 0.8. Low b-value may indicate high shear stress. This manuscript was prepared before Al Haouz earthquake with magnitude Mw=6.8. This event occurred in a region with low seismicity which may indicate a seismic gap.



**Keywords:** Seismic b Value Anomalies, Spatial and Temporal Distribution, Gutenberg-Richter Frequency Formula, North Morocco, Southern Spain.

## 1. Introduction

The investigation of the Gutenberg-Richter parameters, a and b values, has been used to analyze seismic activity in different areas of the world. Several authors have used the b-value computation successfully (Husein et al., 1995; Xie et al., 2019; Enescu and Ito, 2003; Chen et al., 2022). One of the most well-known empirical relationships in seismology between the number of earthquakes N in a given area and the magnitude M is the Gutenberg-Richter equation (Gutenberg and Richter, 1944; Nekrasova and Kosobokov, 2006). This equation can be expressed as:

$$\log_{10} N = a - b.M \quad (1)$$

where 'N' indicates the global number of earthquakes. The constant 'a' indicates the level of seismic activity of a region, whereas the slope 'b' represents the size distribution of its earthquakes, and it's called seismic b value (Kijko and Smit, 2012).

Within the last few decades, parameter b has received significant attention and has been treated in numerous statistical, analytical, and evaluation techniques (Xie et al., 2019; Enescu and Ito, 2003; Alvarado-Corona et al., 2014; Chen et al., 2022). It has been reported that the b-value fluctuates either spatially and/or temporally (Huang and Beroza, 2015). Several mechanisms can cause the change in the seismic b value (Maden and Öztürk, 2015): the presence of heterogeneity, the anomaly in the thermal gradient, the temperature gradient, the fracturing degree, and the shear stress concentration. According to several authors (Main et al., 1989; Botvina et al., 2012; Singh, 2016), it is discovered that stress remains the principal component, affecting the b-value and its changes.

In the literature, various approaches have been used to estimate the seismic b value. The most popular method for estimating the seismic b value is the maximum likelihood (Aki, 1965; Utsu, 1965). The equation for calculating the b-value in the Aki-Utsu formulation is the following (Kijko and Smit, 2012):

$$b = \frac{\log_{10} e}{M - M_c} \quad (2)$$

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where e represents the natural logarithms, M denotes the average magnitude, and $M_c$ is the magnitude of completeness.

The determination of the seismic b values needs to recognize the completeness magnitude of the earthquake catalog (Vorobieva et al., 2013). Estimating the seismic b value is considered an important issue for analyzing and evaluating the probability of occurrence of an earthquake. Most of the time, the seismic b value is very close to 1 and can change depending on many factors: the estimating method choice, the variation of the magnitude range, and the earthquake catalog. Many authors have investigated the spatial variability of b. There have been many studies in different parts of the world about the spatial and temporal variation of the seismic b value. El-Sayed and Wahlström (1996) studied the spatio-temporal distribution of the b value in different areas of Egypt to investigate the state of rock stress. Using the maximum likelihood approach, Lombardi et al. (2005) estimated some hazard assessment parameters, especially the b value in Central and Northern Italy. Khan et al. (2011) has estimated the spatial characterization of the b value for Northeast India. Through the medium of an earthquake catalog in the period between January 1984 and March 2002 in the NE of Japan island arc, a map of b value distribution has been created and discussed (Cao and Gao, 2002).

This study focuses on spatial-temporal variations of the seismic b-values of the Instituto Geográfico Nacional IGN catalog for Northern Morocco. In this paper, a map of the distribution of the seismic b value in this area was estimated using the maximum likelihood method. The results of this study were compared and correlated with the seismicity and tectonics of the study area. This study will help us understand the processes that control large earthquakes and their spatial variations (Naghoj et al., 2010; Al-Tarazi and Qadan 1997; Nicholas et al., 2022). Also, it can help us comprehend plate dynamics and practical applications like improving the quality of the seismic of building codes and Moroccan seismic code, PRPS2011 of Morocco (RPS 2000 (2011)). To the best of our knowledge, this is the first attempt to analyze the geographic distribution of the b-value in Morocco and its surrounding.

## 2. Data

This study uses a database of earthquakes obtained from IGN in Northern Morocco for the period between January 1980 and September 2022. It is limited by latitudes 31°S–36°N and longitudes -9E–-1E. This seismicity database consists of 16170 events with a magnitude less than 6.3 that occurred at depths less than 185.3 km. The website of the National Geographic Institute (IGN) from which we obtained the earthquake catalog is https://www.ign.es/web/ign/portal/sis-catalogo-terremotos (IGN).

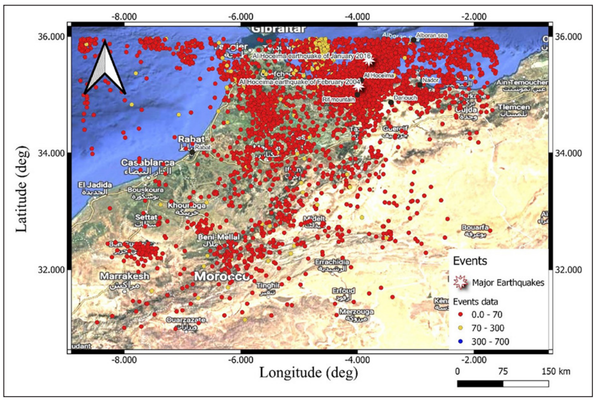

**Figure 1.** Distribution of earthquakes analyzed. The depth range of these earthquakes is displayed in color

Figure (1) shows the distribution of all earthquakes used in this study between January 1980 and September 2022. Stars represent the principal main shocks within this period. The first one happened on 24 February 2004 and the second on 25 January 2016. Both shocks are located around Al Hoceima City (Boulanouar et al., 2013; Kariche et al., 2018). The declustering found 357 clusters of earthquakes, a total of 7928 events (out of 16170).

Figure (1) displays the declustered catalog containing 16170 events. The declustering events are plotted in blue, red, and green colors to show the depth variations of these events. It is clearly observed that most events are recorded in the area of Rif Mountain, especially the belt between Al Hoceima and the Nador cities. This belt is present in the convergence zone between the two large continental plates: Africa and Eurasia. Furthermore, there exists an active series of faults in this area.

Before calculating the seismic b-values, a magnitude frequency distribution plot is carried out to see the completeness of the data, so that the completeness of magnitude ($M_c$) is obtained. Earthquakes with magnitudes smaller than $M_c$ are discarded (Aki, 1965). The histogram of the number of earthquakes per unit of time is shown in Figure (2).

In order to study the spatial distribution of the b value, a grid system was applied. Using 50 events per node and a maximum likelihood in each grid space of 0.25°×0.25°, the b value was determined.

The histogram shows that the recorded earthquakes increase with time. This increase is most likely due to the increase of seismological stations in the region. To overcome this problem, the minimum magnitude of completeness is adopted to include only data that is completely recorded throughout the time span considered in the present study.

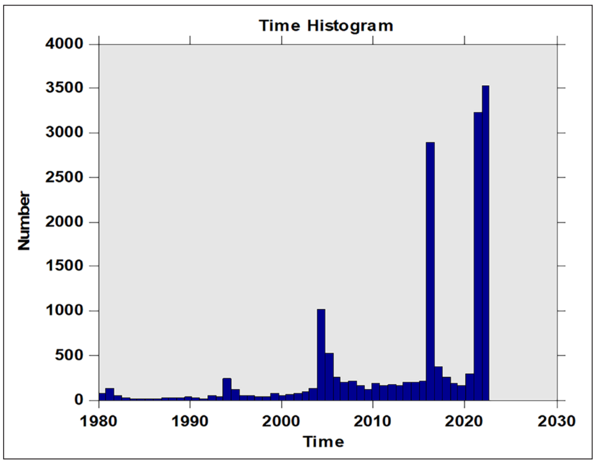


**Figure 2.** Histogram of the number of earthquakes depending on time

## 3. Results and Discussion

Figure (3) illustrates the magnitude frequency distribution, which shows the magnitude relationship with the number of earthquakes that have occurred in the period study. The red color in Figure (3) shows the curve produced by magnitude completeness ($M_c$).

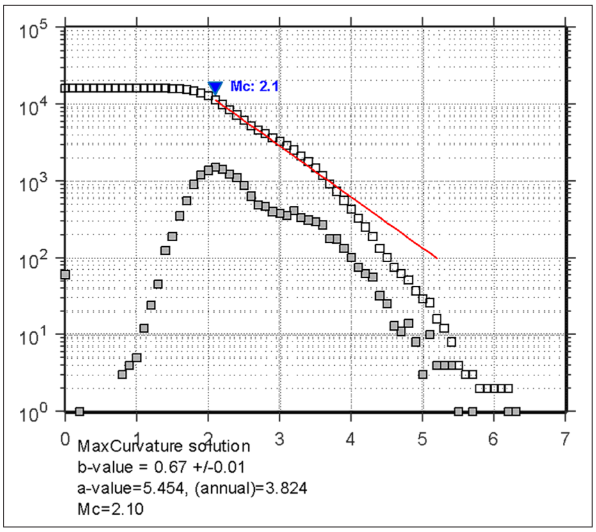


**Figure 3.** The plot shows the variation of cumulative number with the magnitude in Northern Morocco for the period between January 1980 and September 2022. From the figure, b=0.67+/-0.01, and $M_c = 2$

Based on the frequency magnitude variation (Figure 3), the b value of Northern Morocco is 0.67. This value seems to be lower than many other areas, like: b=1.3 for the Zinkgruvan mine in Sweden (Nuannin et al., 2002) and b=1.1 for the eastern Anatolia region in Turkey (Maden and Öztürk 2015). This low value of the b value may be due to the existence of a highly stable space in the study area. Also, it may be explained by the low number of events of high magnitude. Jafari (2008) found that for the different zone in Iran, the values of the parameter are under one. These low values of b indicate the relative abundance of larger earthquakes versus smaller earthquakes. Figure (4) shows the histogram of magnitude (M). The maximum peak magnitude observed during the period of this investigation was recorded as 2.2, with about 1500 events. The majority of the magnitudes ranges from 1.5 to 4.5.

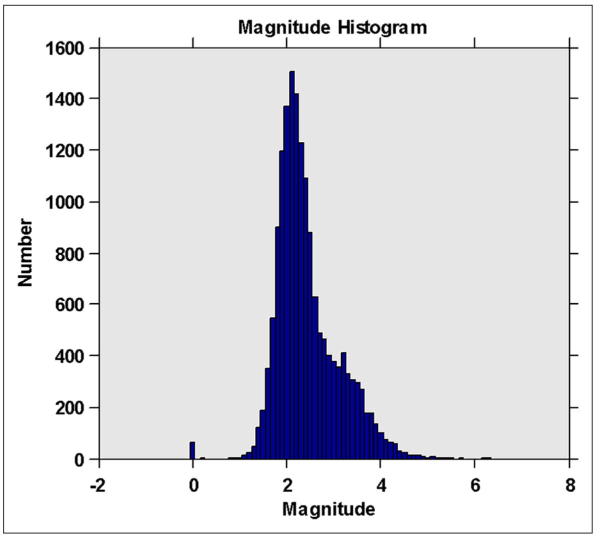


**Figure 4.** Histogram for the earthquake magnitude used in this study

### *3.1. Spatial variation of the seismic b value*

Figure (5) shows the spatial distribution of the seismic b value in the Northern Morocco region as estimated using the IGN catalog for the period between 1980 and 2022. The magnitude of completeness is 2.1, and the area, limited by latitudes 30°S- 36°N and longitude -9°E -1°E was divided into 1015 grids of 0.25°×0.25° (with 50 events or more). The classic approach of Gutenberg-Richter is frequently employed for the estimation of the Frequency–Magnitude, especially for probabilistic earthquake precursors and seismic hazards. The number of earthquakes N that happen in a particular area as a function of their magnitude M is described by the Gutenberg-Richter law. The parameter ‘a’ is strongly related to the level of seismicity. The increase in parameter ‘a’ reflects higher seismicity, whereas parameter ‘b’ is affected by the tectonics of the area and their stress regime. As the area is subjected to shear stress the b value decreases, a lower b-value indicates that the area under study is probably under high stress.

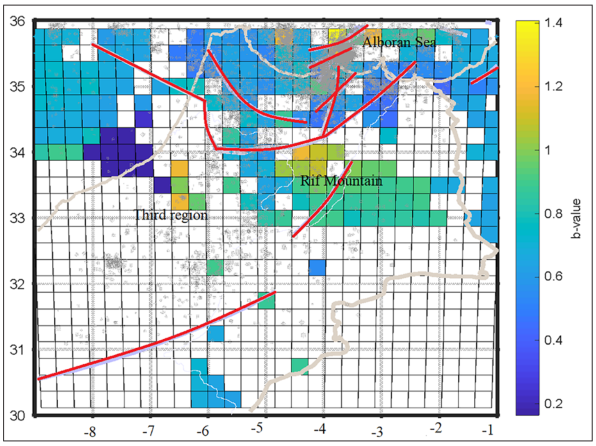


**Figure 5.** Map of spatial variation of the seismic b-value in Northern Morocco from the IGN catalog between 1980 and 2022. The red thick lines represent the main faults across the study region.

he spatial distribution of the seismic b value in Northern Morocco is studied in this study. Figure (5) shows the spatial distribution of this parameter with a palette of colors, which indicates a low b value by blue color and a high one by yellow. The b-value map indicates that the range of the b-value is between 0.2 and 1.4. because of the adoption of the declustering procedure and the low number of events recorded in the precise grid. A significant portion of the grid cells is missing and is producing no results (i.e. white grids). Kulhanek (2005) found that the spatial variation around the Matano fault, Indonesia, of the b value varies between 0.3 and 1.8. The map (Figure 5) shows that the high value of the b parameter is indicated in about three regions. The first region, in the Alboran Sea, points out three parts: near Al Hoceima City, where b is around 1.4, a few kilometers at sea from the city of Dariouch with about b=1.2 and in the Alboran Sea near Tetouan City, especially in the region where the depth of the seismic events exceed 110 km (see Figure 1). The second region corresponds to the intersection zone between the external zone of the Rif Mountain and the Neogene basins. This is the area below the large fault that limits the Rif in gray color where the b value varies between 1 and 1.2. This is due to the high seismotectonic zone and the very seismic activity. This area is where the two strong earthquakes happened, one on 24 February 2004 and the other on 25 January 2016. The area around Al Hoceima City has a high-stress accumulation due to the tectonic movement and the presence of high seismic activity. Region three in the west of the study area and below the Rif Mountain has three to four cells, two in green, two in orange, and one in blue. In this region, the value of b fluctuates between 0.2 and 1.2. It is a clear anomaly of the b value that needs to be looked at separately by adding other catalogs. Average values of parameter b (between 0.6 and 0.8) were observed in most of the other regions. A low value of b value of about 0.2 is observed surrounding Rabat City. This may be due to the lack in number of earthquakes in this region.

### *3.2. Temporal Variations of B-value*

Many research studies have been conducted to investigate temporal changes in the b value (Aitouche and Djeddi, 2018; Huang and Beroza, 2015). According to this research, strong earthquakes are generally accompanied by a decrease in the b value and an increase comes before (Sammonds et al., 1992). Monterroso (2003) supports this idea by using data from Central America. According to Molchan and Dmitrieve (1990), the b value drops by half during the hours preceding the mainshock. Figure (6) shows the temporal variation of the b-value in the Northern Morocco region during the period between January 1980 and September 2022. It is clear from Figure (6) that the b value does not constantly fluctuate during the period of the catalog. The fast increase and decrease are observed about three times. These peaks correspond clearly to the two main shocks, especially the two main earthquakes, cited in the map of the b value.

Three jumps in the b-value and cumulative number of earthquakes are observed from figures (6) and (7). The first jump is observed due to the activities accompanied Al Hoceima earthquake on May 26th, 1994. However, this jump was small possibly due to the lack of seismologic stations at that time. The other two jumps occurred following two moderate earthquakes that shocked the area. However, an interesting feature is observed that the b-value decreases after the occurrence of the mainshock. Before the next mainshock, b-value increases to a peak then decreases again. A remarkable feature is the increase again in 2023 that preceded the event of Al Haouz (Mw=6.9) that occurred after the submission of this manuscript. This observation might be useful for predicting future large events in the study area.

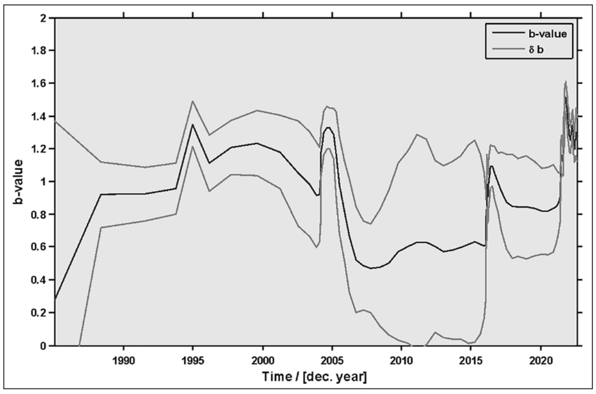


**Figure 6.** The seismic b-value variation accompanied by their standard error curves versus the time in Northern Morocco, using IGN the catalog for earthquakes that occurred in this region in the range of 1980 to 2022.

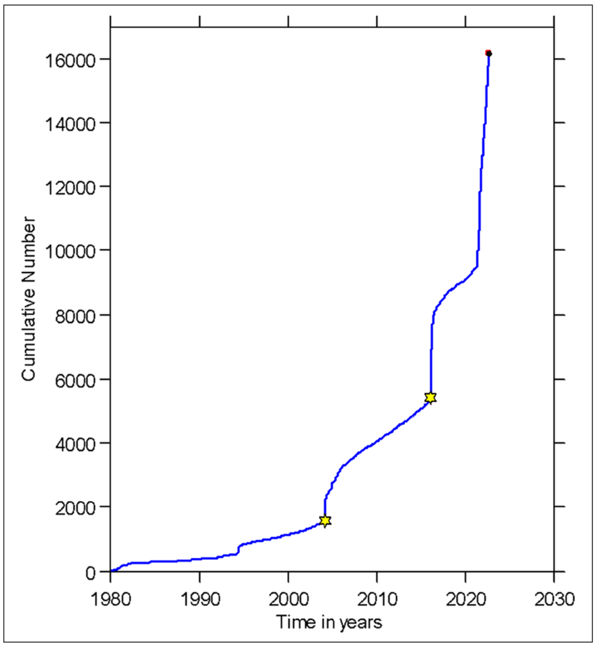


**Figure 7.** The Cumulative number of events vs time in years. The two gold stars represent the main shocks in the study area

## 4. Conclusions

The spatial variations of b values in Northern Morocco were examined, using 16170 events selected from the IGN catalog with magnitude completeness of 2.1 between January 1980 and September 2022. The declustering found 357 clusters of earthquakes, a total of 7928 events (out of 16170). This study revealed significant three anomalies of the seismic b values.

The first one exists in the region of the Alboran Sea, especially between AL Hoceima and Nador cities, where b is around 1.4, around Al Hoceima city about b=1.2, a few kilometers at sea from the city of Dariouch. The second region corresponds to the intersection zone between the external zone of the Rif Mountain and the Neogene basins where the b value varies between 1 and 1.2. Region three in the east of the study area and below the Rif Mountain has three to four cells, two in green, two in orange, and one in blue. In this region, the value of b fluctuates between 0.2 and 1.2. These anomalies are related to the high value of the b parameter. We observed a high value of b value in the Alboran Sea which is related to a high-stress pressure indicator and a high seismic b value in the other region which indicated the presence of high crustal heterogeneity. Regarding the two main shocks that happened at Al Hoceima City, one in January 2016 and the other in February 2004. We discovered a good correlation of b-value change. At the moment of triggering of these earthquakes, the value b begins to increase to a maximum value in almost a year. This shows that the change of the value b can be used as a precursor in this region. This phenomenon is consistent with several studies. The results of this study can be used in other fields, such as civil engineering, especially for seismic design.

**Acknowledgments**

All data used in this study are collected from the IGN catalog https://www.ign.es/web/ign/portal/sis-catalogo-terremotos (24 September 2022)

All figures used in this paper were made using the program Zmap 7 software. This software was run with Matlab R2010a software.

**Author's Contributions**

Conceptualization, methodology, software, validation, formal analysis, investigation, resources, data collection, writing – original draft preparation, writing – review and editing, visualization, supervision, A. Boulanouar; methodology, software, investigation, writing, A. Khalil; analysis, interpretation, writing – review, and editing, J. Sebbani; analysis, interpretation, writing – review, and editing, A. El Ouali; methodology, software, analysis, data collection, writing, A. Rahmouni.

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