

The Influence of Spatial Variations of Gutenberg-Richter Parameter (b-value) in the Red Sea Seismicity

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Abstract: The spatial variations of Gutenberg-Richter parameter b-value during the period 1990 to 2014 in The Red Sea was calculated. The study area was divided into 4 different seismic sub-regions. We calculated the spatial variation of b-value in the whole study area of the red sea and in each sub-region separately. The distribution of the b-value is related to the stress levels of the faults. We observed that b-value changes before the major earthquakes in the 4 seismic regions to evaluate the spatial distribution of seismic hazards. The b-values equals to 0.86 is relating to the region (1) that is at the northern part of the Red Sea. The two-middle regions (2) and (3) are about 1.34 and 0.98 respectively. While the Southern region (4) is approximately 0.94. Some have concluded that the b-values drop instantly before large shocks. Others suggested that temporally stable low b-value zones identify future large earthquake locations. Mapping of b-value distribution provides information about the state of stress in that region, i.e. lower b-values associated with epicentral areas of large earthquakes as in region (1) and (4). While higher b-value associated with small earthquakes as in case of region (2) and (3). Bayrak et al. (2017).

Keywords: b-value, Seismic Hazard, Seismicity, Earthquakes, Red Sea

1. Introduction

This Study is aiming to calculate b-value and its spatial distribution over the Red Sea region by using Gutenberg Richter Law that has a critical role on earthquake hazard analysis and understanding the fundamental properties of earthquakes in that area. The red sea in an extension of the Indian ocean located between Africa and Asia, which is bordered by the Gulf of Aden in the south and the Gulf of Agaba and Suez in the north as shown in figure. (1). A long history of earthquakes has dominated in this area where the

both north and south parts are of comparable seismic activity while the central is of lower activity Elisa (2015), and due to the importance of studying the hazard analysis of the earthquakes for the surrounding countries especially Yemen, Saudi Arabia, Sudan, Egypt, and Eretria. Nowadays, it becomes more accessible to obtain reliable earthquakes catalogs from many international and regional resources; therefore, these catalogs would assist seismologists to identify the fundamental properties of earthquakes in this region as well as making adequate hazard assessments.

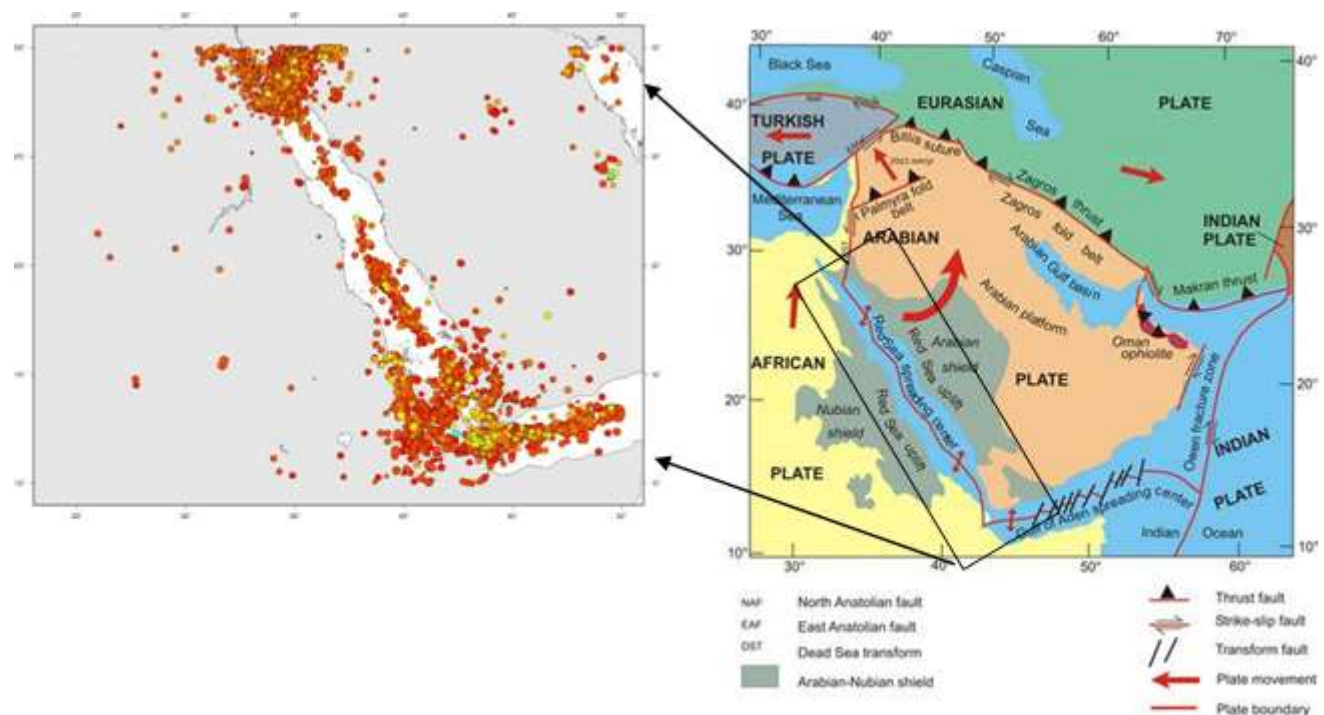


Figure 1: The study area map

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2. Data Acquisition

The data was compiled from the International Seismological Centre (ISC). The earthquake catalog contains a total of 12278 earthquake events with magnitude $1.0 \leq M \leq 6.5$ for the period 1990–2014 as in table. (1). The earthquake data set used in seismicity or earthquake hazard studies must certainly be homogeneous, in other words, it is

necessary to consider seismicity, tectonics, geology, paleoseismology, and other neotectonic properties in a region for an ideal characterization of seismogenic source zones Bayrak et al. (2009). In this study, we used these regions showed in Figure. (2) to investigate the spatial variations of the b parameter.

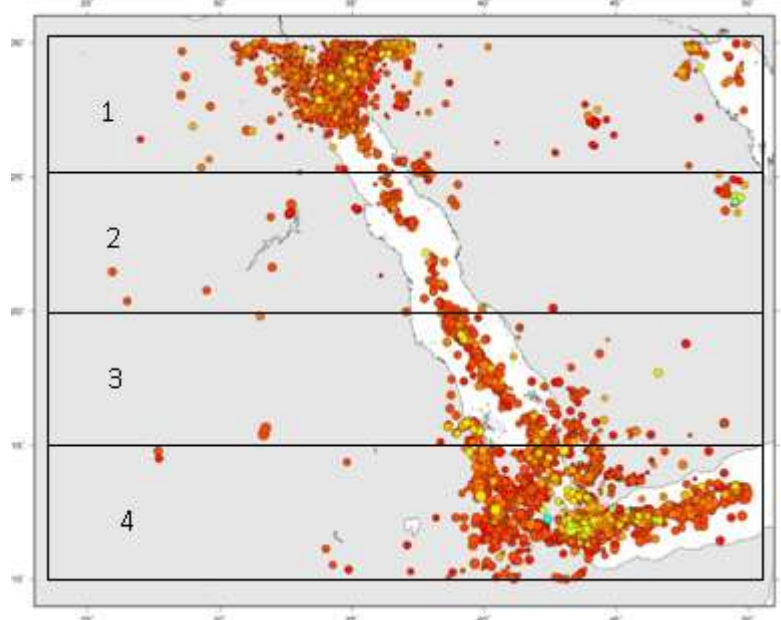


Figure 2: The regions of the study area

Table 1: The Number of Earthquakes(N) and corresponding to Magnitudes(M)

| | | | | | | | | | | | | | | | |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| M | 1.0 | 1.2 | 1.4 | 1.6 | 1.8 | 2.0 | 2.2 | 2.4 | 2.6 | 2.8 | 3.0 | 3.2 | 3.4 | 3.6 | |
| N | 8 | 20 | 44 | 116 | 152 | 348 | 378 | 315 | 329 | 466 | 599 | 441 | 379 | 692 | |
| M | 3.8 | 4.0 | 4.2 | 4.4 | 4.6 | 4.8 | 5.0 | 5.2 | 5.4 | 5.6 | 5.8 | 5.9 | 6.1 | 6.4 | 6.5 |
| N | 590 | 462 | 305 | 169 | 95 | 68 | 28 | 17 | 12 | 13 | 6 | 5 | 3 | 1 | 2 |

3. Methodology

The empirical relationship, known as Gutenberg–Richter (G–R) law, between the frequency of earthquake occurrences and magnitudes can be expressed as in the following formula:

$$\text{Log}(N) = a - b(M);$$

Where N is the cumulative number of earthquakes with magnitude greater or equal to M, a and b are constants. b is the slope of the frequency– magnitude distribution, and a is the activity level of seismicity. Gutenberg and Richter (1944), firstly, estimated the constants known as seismicity parameters. The b-value for a region not only reflects the relative proportion of the number of large and small earthquakes in the region but is also related to the stress condition over the region. Many factors can cause perturbation of the normal b-value. On average, b-value is near unity for most seismically active regions on Earth (Frohlich and Davis, 1993). In a tectonically active region, the b-value is normally close to 1.0 but varies between 0.5 and 1.5 (Pacheco et al., 1992; Wiemer and Wyss, 1997). However, a detailed mapping of b-value often reveals significant deviations. The spatial variation of b-values is related to the distribution of stress and strain (Mogi, 1967; Scholz, 1968). On the other hand, high b values are reported

from areas of increased geological complexity (Lopez Casado et al., 1995), indicating the importance of the multi-fracture area. Increased material heterogeneity or crack density results in high b-values (Mogi, 1962). Thus, low b-value is related to the low degree of heterogeneity, large stress and strain, the large velocity of deformation and large faults (Manakou and Tsapanos, 2000). b-values were first estimated by Gutenberg and Richter (1944) for various regions of the world. They suggested that b-values range from 0.45 to 1.50, while Miyamura (1962) found that b values change from 0.40 to 1.80 according to the geological age of the tectonic area. Through applying Gutenberg Richter Law, it becomes more applicable to calculate the b-value from the relationship between the number of earthquakes recorded and the magnitude. The b-value for any region can be computed using several methods such as linear Least Squares (LS) regression or by the Maximum Likelihood (ML) method. ML method is the most robust and widely accepted method in which b-value is calculated using the formula (Aki, 1965). However, in this study we just used the (LS) method to acquire the b value for each region.

$$b = \frac{1}{\log_{10}[M - (M_{min} - \Delta m)]}$$

where M_{min} is the minimum magnitude or threshold magnitude or magnitude of completeness (MC) for the earthquakes, M is the mean magnitude and Δm is the

magnitude resolution. Motivated by laboratory experiments (Scholz, 1968; Amitrano, 2003), theoretical studies (e.g., Main et al., 1992), and observations (Schorlemmer et al., 2005) showing b-values decreasing with increasing stress, investigators have sought temporal and/or spatial b-value variations that correlate with earthquake occurrence. Two viewpoints prevail: in the first, time-varying b-values are associated with large earthquakes or moment rate changes (Imoto, 1991; Kebede and Kulhanek, 1994; Sahu and Saikia, 1994; Enescu and Ito, 2001; Cao and Gao, 2002; Ziv et al., 2003; Nuannin et al., 2005). In the second, b-values are found constant in time, but spatial variations are related to earthquake occurrence and/or likelihood (Abercrombie and Brune, 1994; Westerhaus et al., 2002; Schorlemmer et al., 2003; Wyss et al., 2004; Schorlemmer et al., 2004; Wyss and Stefansson, 2006).

4. Results

The most important information provided by the spatial variation of b-value determine the stress situation with respect to time. Before medium or large earthquakes b-value generally decreases because of stress condition (Kanamori, 1981; Nanjo and Yoshida, 2017). After the main shock, b-value increases since stress condition decreases. According to these situations, b-values is divided into four different regions. MATLAB Software was used to calculate the spatial variation of b-value in each region separately as well as for the whole study area. The b-value of the whole study area equals to 0.99 as the slope relation shown in figure. (3a). However, Earthquakes Magnitude less than 3.0 are excluded since there is catalogue incompleteness, figure. (3b) due to lack of recording system in that area during the period earlier than 1990 as a reason of establishing some regional seismic networks e.g. in Saudi Arabia (AL-Amri and Al-Amri, 1999) that is obviously demonstrated in figure. (4). The spatial b-value distribution is being obtained by dividing the study area into 4 sub-regions individually as explaining in figures (5: a, b, c, d); excluding the incompleteness in earthquake catalog.

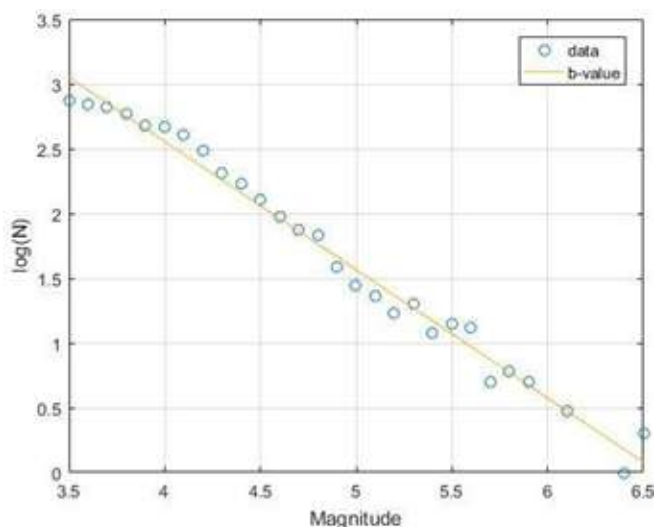


Figure 3a: Calculating the b-value for the whole Red Sea region. $b=0.99 \pm 0.004$

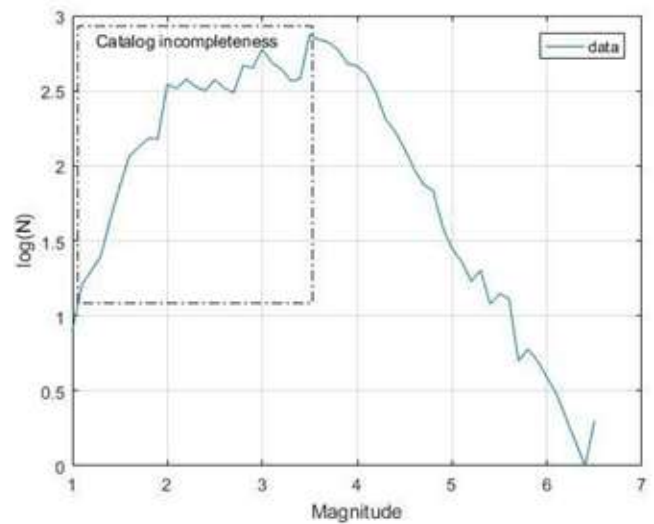


Figure 3b: The data distribution of the study area; showing the incompleteness in ISC Catalog

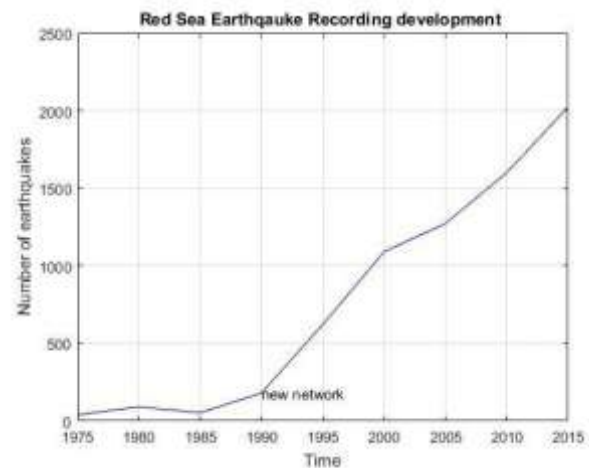


Figure 4a: The development of the Earthquake recording system (1970-2015)

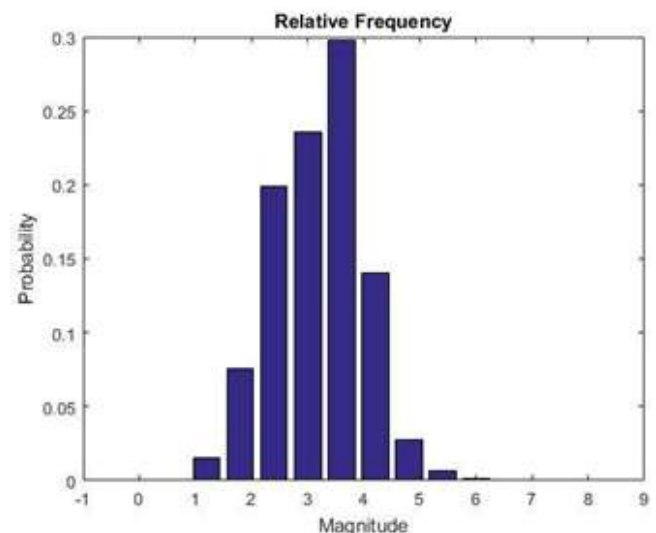


Figure 4c: frequency probability of the earthquake occurrences (1970-2015).

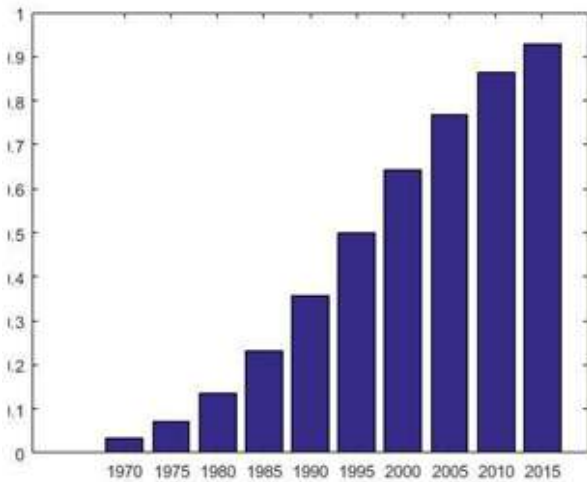


Figure 4b: Accumulative earthquake histogram for the period (1970-2015)

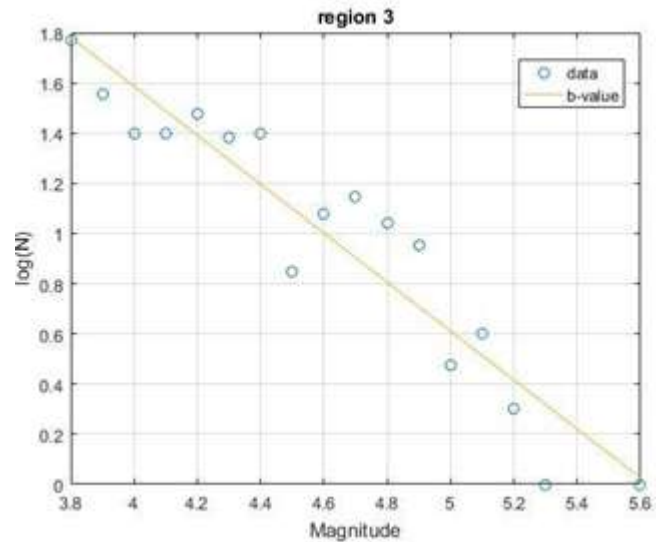


Figure 5c: region 3; $b\text{-value} = 0.98 \pm 0.033$

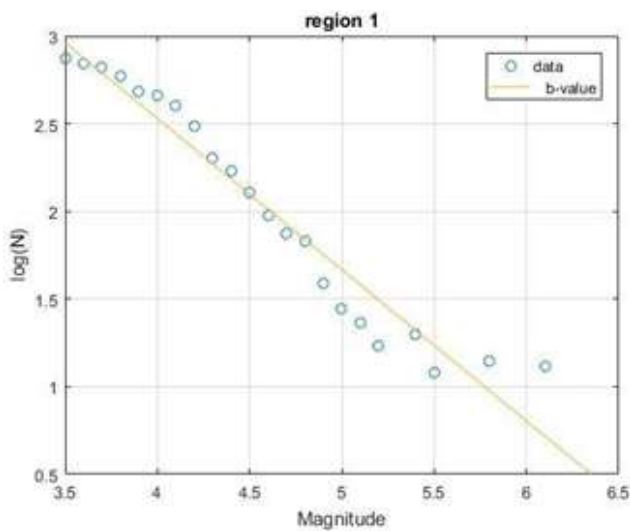


Figure 5a: region 1; $b\text{-value} = 0.86 \pm 0.0024$

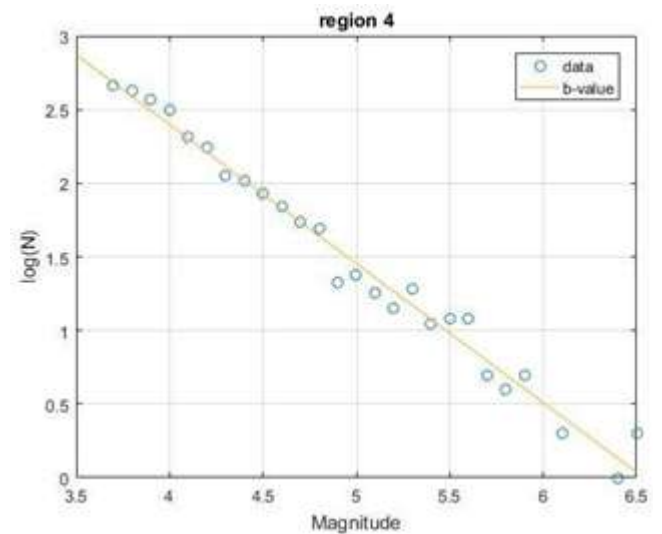


Figure 5d: region 4; $b\text{-value} = 0.95 \pm 0.01$

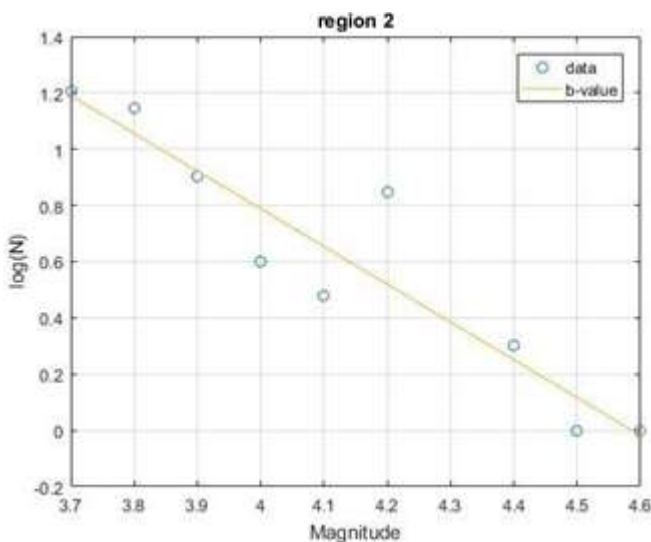


Figure 5b: region 2; $b\text{-value} = 1.31 \pm 0.08$

5. Conclusion

The data analysis indicate that the b-value estimated in Red Sea region is approximately equal to 0.99 for the earthquake completeness catalog ranged from 3.0 to 6.5 magnitude, which indicates that the study area was being affected by a vast range of small to large earthquakes intensity. Therefore, more seismic hazard analysis should be established in that area to monitor the seismicity to reduce the potential hazardous destructions that may cause economical and fatalities in the closely surrounding countries such as Yemen, Saud Arabia, Eretria, Sudan, and Egypt. The earthquake catalogs have been analyzed covering a period between 1990 to 2014 to study the spatial distribution of the G-R (b) parameter of the earthquake epicenters in four regions to reach better understanding of the seismicity in The Red Sea region.

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Author Profile



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