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Evaluation of b-value variation of earthquakes in Papua New Guinea

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ABSTRACT

This study evaluated the b-value variation of earthquakes in Papua New Guinea region. The data used were extracted from International Seismological Centre (ISC), Pipers Lane, Thatcham, Berkshire, United Kingdom. The selected data consisted of earthquakes with $M_b \geq 2.6$ for the study area from 1st January 1966 to 31st December 2015 (50 years) with focal depth from 0 – 700 km. The data were analyzed using Least Squares (LS) approximation method and SPSS Software version 20.0. The findings of this study categorized b-value into three groups: High, moderate and low. High b-value varies from 1.01 to 1.35, moderate b-value lies between 0.8 and 1.0 and low b-value varies from 0.63 to 0.80. This indicates that the years where high b-values occurred predominantly consist of many earthquakes of moderate magnitudes; slight decrease in b-value is associated with many earthquakes of large magnitudes and low b-value is associated with many earthquakes of small magnitudes. The b-value for the whole study area was calculated to be 0.91. The research hypothesis revealed that there is a significant difference in the b-value between the decade groups from 1966 to 2015. The F-ratio between the decade groups was found to be 3.776 with significant value of 0.010. The implication of this study is that temporal variation and monitoring of b-values will serve as one of the reliable ways of earthquake prediction in Papua New Guinea.

***Keywords*:** b-value, Papua New Guinea, least squares, earthquakes, F-ratio, temporal variation

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1. INTRODUCTION

Papua New Guinea (PNG) is one of the seismically active regions of the world and the islands region is the most seismically active areas of the PNG. Papua New Guinea (PNG) is located on the Pacific ring of fire and is regularly hit by various natural disasters such as earthquakes, volcanic eruptions, tsunami, landslides, cyclones, river and coastal flooding and drought. According to World Bank's Natural Disaster Hotspot study, PNG ranked the 54th position among countries vulnerable to many hazards based on land area. The seismicity of the study area is due to: the two main plates - the Pacific and Indo-Australia plates; interaction of many minor plates within the collision zone-the Solomon Sea,South Bismarck, North Bismarck and Caroline plates; plate deformation-subduction, under thrusting and mountain building and local volcanic earthuakes (Papua New Guinea, 2011).

Most earthquakes happened along plate boundaries and also along areas of deformation. Destructive earthquakes are very common with a total of 197 earthquakes of magnitude 7 and above in 100years. The collision and interaction between the different plates in the study area arouse the interest of the researcher.

Studies have been conducted to evaluate b-value globally. Some researchers are of the opinion that b-value does not vary systematically in different tectonic regime (Bayrak *et al*., 2002). But Schorlemmer *et al*. (2005) and many other researchers showed that *b*-value varies significantly between individual fault zones (Wesnousky, 1994, Schorlemmer and Wiemer, 2005), and even within a given space and time range (Nuannin *et al*., 2005). Though the absolute value of *b*, and even its variability, may mainly depend upon the accuracy of the earthquake catalog, homogenization of the catalog, calculation technique and algorithm employed, various attempts had been made to understand the physical meaning of the *b*-value (Mogi, 1962; Scholz, 1968; Warren and Latham, 1970; Wyss, 1973). However, there is no agreement on the universal value of b.

Mogi (1962) carried out laboratory experiment and suggested that *b* varies with material heterogeneity. Warren and Latham (1973) found a relationship of *b*-value with the thermal state of the rock. Systematic variation of *b*-value also with depth was found in California (Mori and Abercrombie, 1997). Scholz (1968) reported that *b* decreases with the increased stress in the rock. Wyss (1973) carried out his study beyond the laboratory, and found similar inverse relationship of *b* and stress in the California earthquake dataset.

Wiemer and McNutt (1997) and Schorlemmer *et al.* (2003) in their study in volcanic areas of Washington, Alaska and Italy found that high b-value is found to be associated with existence of the magma chambers. This result is interpreted to be the result of low effective stress due to increased pore fluid pressure. Weimer and Benoit (1996) also claim that regions with high *b*-values at the subducting slabs account for magma genesis at Alaska and New Zealand convergent margins.

Schorlemmer and Wiemer (2005) reported low b-value within the rock volume of the 2004 M_w 6.0 Parkfield. Similarly, a study of the Sumatra subduction zone showed that the area around the epicentre of two giant earthquakes, 2004 M_w 9.0 and 2005 M_w 8.7 events happened within the zones of low *b*-values (Nuannin *et al*., 2005).

Abong *et al* (2016) investigated time scale dependence of frequency-magnitude of Gutenberg-Richter's relationship in south Africa. Their fingdings revealed that b-value varies from 0.67 to 1.11.

Awoyemi *et al*. (2017) investigated b-value variations in the African and parts of Eurasian plates. Their findings revealed that b-value varies from 0.6 to 1.3 throughout the study area. Also Adagunodo *et al* (2018) evaluated $0 < M < 8$ earthquake datasets in African – Asian region during 1966 – 2015. Their study found that the value of b-value was 0.61.

1. 1. Regional tectonics and seismicity of the study area

The PNG region is made up of the southern area of Papuan Peninsula and western province is considered as part of the stable Australian craton. The central PNG Highlands is probably a tectonic block that was not initially identified (Wallace *et al*., 2005). Pubellier and Ego (2004) identified the Bird's Head region of Papua province, Indonesia as independent tectonic block which moved away left-laterally from the main collison axis.

According to Ripper and Lerz(1993), in the eastern area, within the collison zone of the major Pacific and India-Australian plates, are the Solomon, South and North Bismarck, and Caroline plates. To the east of the collision zone, bordering and dominating the pacific plate front, is the massive oceanic plateau the Ontong Java Plateau(OJP). It is the largest on earth and was too thick and buoyant to subduct at the Bougainville-Solomon Trench when it reached there 25-20 million years ago. It caused a reversal of the SW - directed subduction to NE-directed subduction 6 million years ago (Yan and Kroenke, 1993; Petterson *et al.*,1999; Mann and Taira, 2004).

This feature is the source of most seismic activity in the region together with the subduction of the Solomon plate at both this front and and the south Bismarck plate front. The subduction is the cause of the opening of the Woodlark and Manus Basins.

2. METHODOLOGY

2. 1. Source of data

The data set for this work were extracted from International Seismological Centre (ISC), Pipers Lane, Thatcham, Berkshire, United Kingdom (http://www.isc.ac.uk/). The selected data consisted of earthquakes with $M_b \geq 2.6$ for the study area from 1st January 1966 to 31st. December 2015 (50years) with focal depth from 0 – 700 km. The data set comprised date of occurrence of earthquake, origin time, coordinates of epicentre, magnitude, event identification, focal depth of earthquake and event ID. The region of study is situated within the coordinates; 0º S – 12º S and 138º E – 160º E (Figure 1). A total of 36,466 events were employed in the study.

2. 2. Method

The b-value was calculated for each year from 1966 to 2015 (50 years) and the results were grouped in an interval of ten (decade) years as follows: 1966-1975, 1976-1985, 1986-1995, 1996-2005 and 2006-2015.

2. 3. Frequency-Magnitude relationship

Richter developed a relationship for the frequency–magnitude distribution (FMD), in the form:

$$LogN = a - bM \quad (1)$$

for a given region and time interval, eqn(1) gives the cumulative number of earthquakes (N) with magnitude (M), where **a** and **b** are positive, real constants. **a** gives information about the seismic activity. It is determined by the event rate and for a given region depends on the volume and time window used. **b** is a tectonic parameter that describes the properties of the seismic medium.

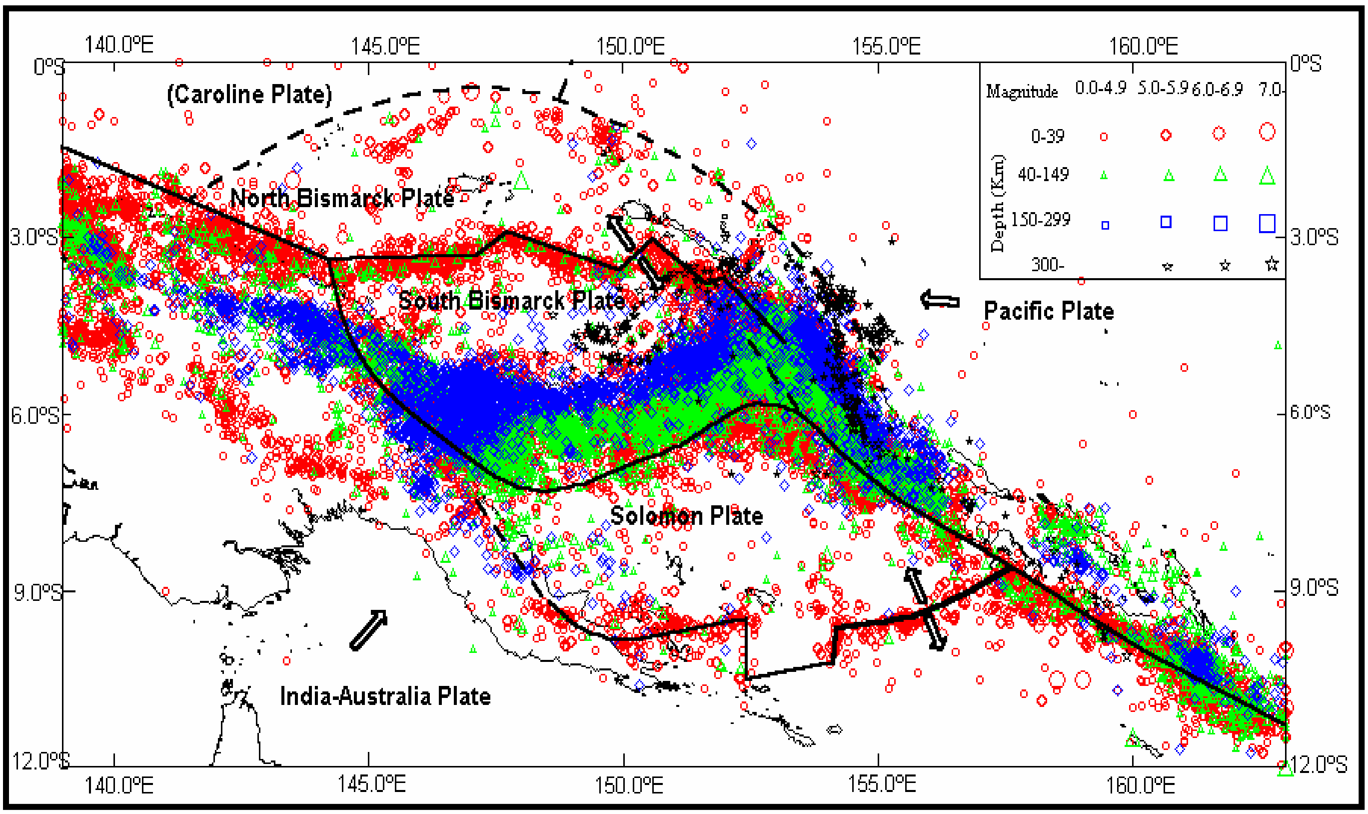

Figure 1. PNG seismicity superimposed on the tectonic plate boundaries (from Ripper and Letz, 1993). Red circles denote depth range 0-39 km, green triangles denote range 40-99 km, blue diamonds denote range 100-299 km and black stars denote depths greater than 300 km.

3. RESULTS A DISCUSSION

The frequency-magnitude distribution was conducted for a period of 50 years from 1966 to 2015 in the study area. A plot of cumulative number of earthquakes was plotted against magnitude and the graph is as shown (Figure 2). The b-value, a-value and magnitude of completeness were evaluated.

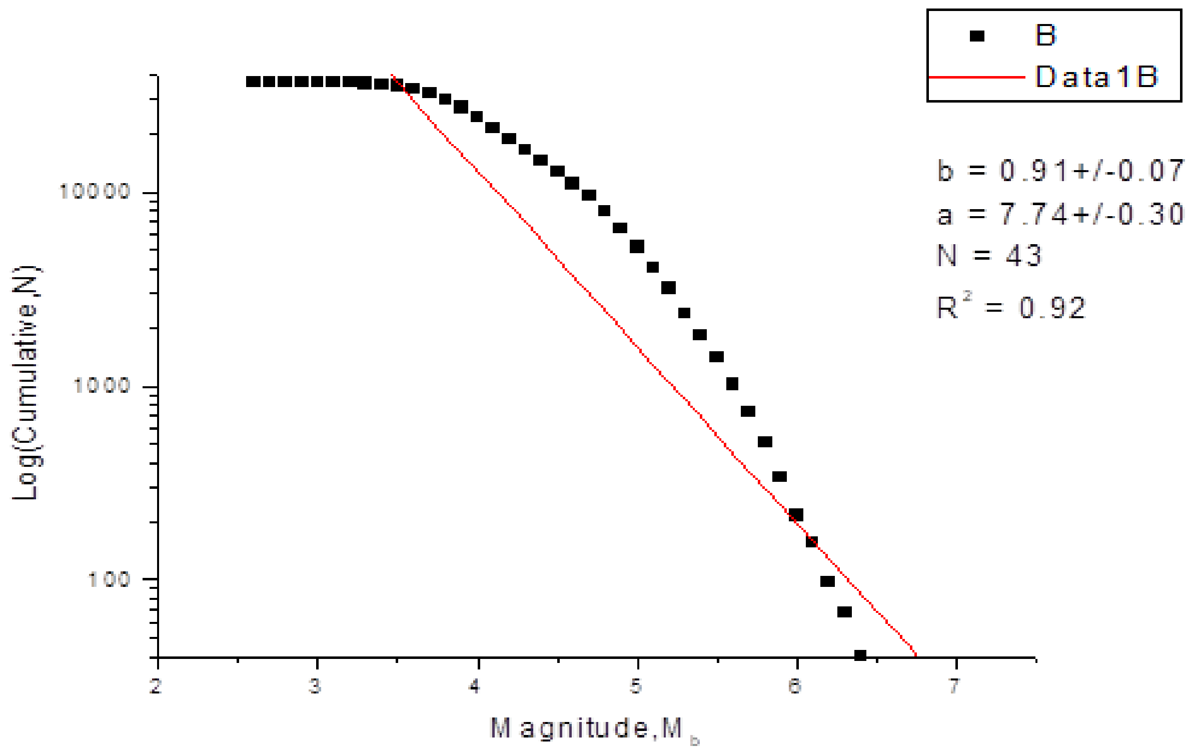

Figure 2. Cumulative frequency – magnitude graph

The b-value of earthquakes calculated for the study area (50 years) was found to be 0.93 (Figure.2). It is observed that the temporal variations of b-values (Figure 4 – Figure 8) varies between 0.63 and 1.35. High values of b were observed in years 1966, 1967, 1971, 1972, 1974, 1977, 1978, 1979, 1998 and 2000. In these years b-value varies between 1.01 and 1.35 with the highest mean magnitude between 5.3 and 5.4 and is predominantly consist of many earthquakes of moderate magnitudes.

The years 1968, 1970, 1973, 1975, 1976, 1987, 1988, 1990, 1991, 1992, 1993, 1994, 1996, 1997, 1999, 2001,2002, 2003, 2004, 2005, 2006, 2007, 2008, 2010, 2011, 2012, 2013, 2014 and 2015 showed a slight decrease in b-value. For these years b-values lie between 0.8 and 1.0 and the mean magnitude of earthquakes within these periods lies between 5.4 and 5.5. This implies that these years are made up of earthquakes of numerous large magnitudes.

The lowest b-values were found in years 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1989, 1995 and 2009 and vary between 0.63 and 0.80 with lowest mean magnitude between 4.6 and 4.7 are dominated by earthquakes of small magnitudes.

Observation from Table 2 shows that earthquakes with magnitude 2.0-2.9 constitute (0.04%), 3.0 - 3.9 (33.5%), 4.0 - 4.9 (52.2%) and 6.0 - 6.9 (0.60%). This indicates that earthquakes of magnitude range 4.0 - 4.9 is the most predominant, followed by earthquakes of magnitude 3.0-3.9, then 5.0 - 5.9 with the least in the magnitude range 2.0 - 2.9 and 6.0 - 6.9 respectively. Also the number of events varies arbitrarily over time in earthquake magnitude 2.0 - 2.9, 3.0 - 3.9, 5.0 - 5.9 and 6.0 - 6.9 except in the magnitude 4.0 - 4.9 which increases with increase in time. The trend is as shown in Figure 3.

Table 1. Temporal variation of b-value for ten(decade) year period in the study area from 1966-2015.

Year	b-value	Year	b-value	Year	b-value	Year	b-value	Year	b-value
1966	1.11	1976	0.99	1986	0.73	1996	0.93	2006	0.97
1967	1.35	1977	1.08	1987	0.99	1997	0.93	2007	0.98
1968	0.8	1978	1.17	1988	0.82	1998	1.02	2008	0.91
1969	1.11	1979	1.07	1989	0.65	1999	0.97	2009	0.79
1970	0.86	1980	0.63	1990	0.86	2000	1.03	2010	0.91
1971	1.04	1981	0.66	1991	0.94	2001	0.95	2011	0.89
1972	1.1	1982	0.67	1992	0.88	2002	0.94	2012	0.87
1973	0.92	1983	0.75	1993	0.84	2003	0.94	2013	0.88
1974	1.01	1984	0.77	1994	0.86	2004	0.95	2014	0.93
1975	0.92	1985	0.74	1995	0.77	2005	0.95	2015	0.86

Table 2. Number of earthquakes reported for each decade from 1966 to 2015.

No. of decade	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	Total
1966-1975	0	1	505	1058	56	1620
1976-1985	1	282	1374	1148	39	2844
1986-1995	5	656	3433	1099	31	5224
1996-2005	5	6013	6697	688	35	13438
2006-2015	3	5274	7021	989	53	13340
Total	14	12226	19030	4982	214	36466
%	0.04	33.5	52.2	13.7	0.60	100.0

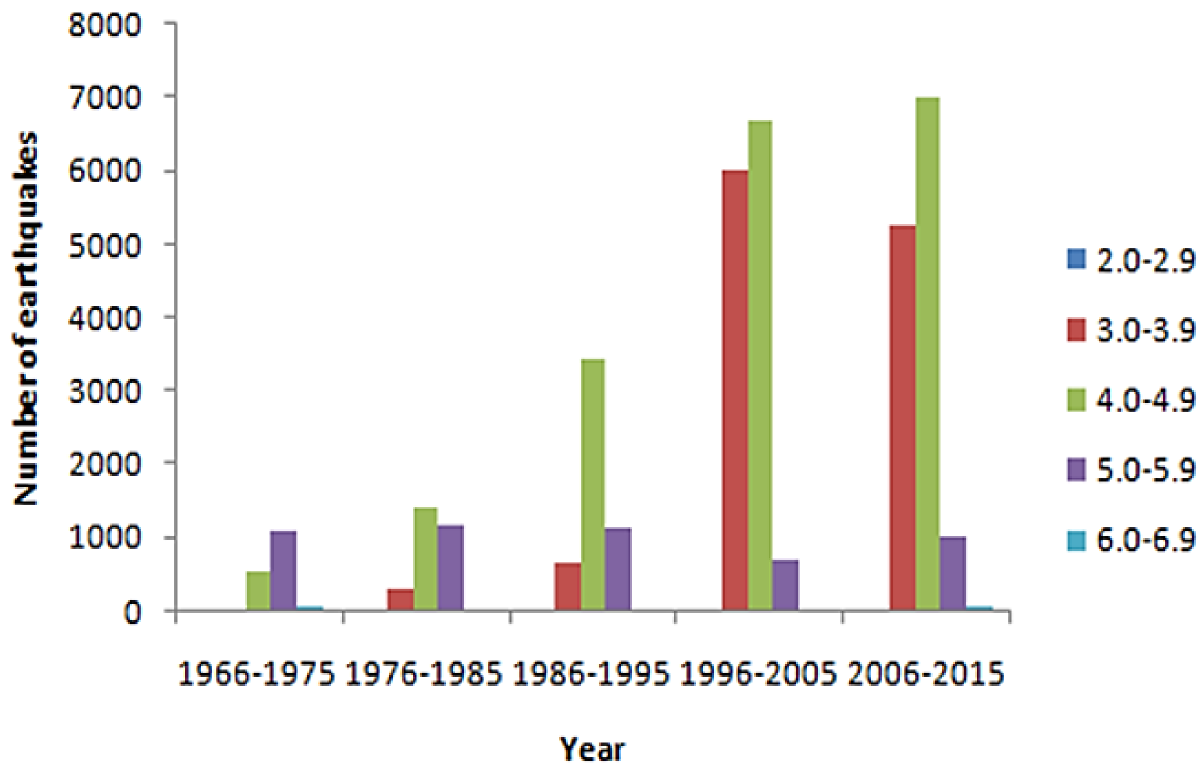

Figure 3. Number of earthquakes reported for each decade from 1966 to 2015 grouped in five magnitude ranges

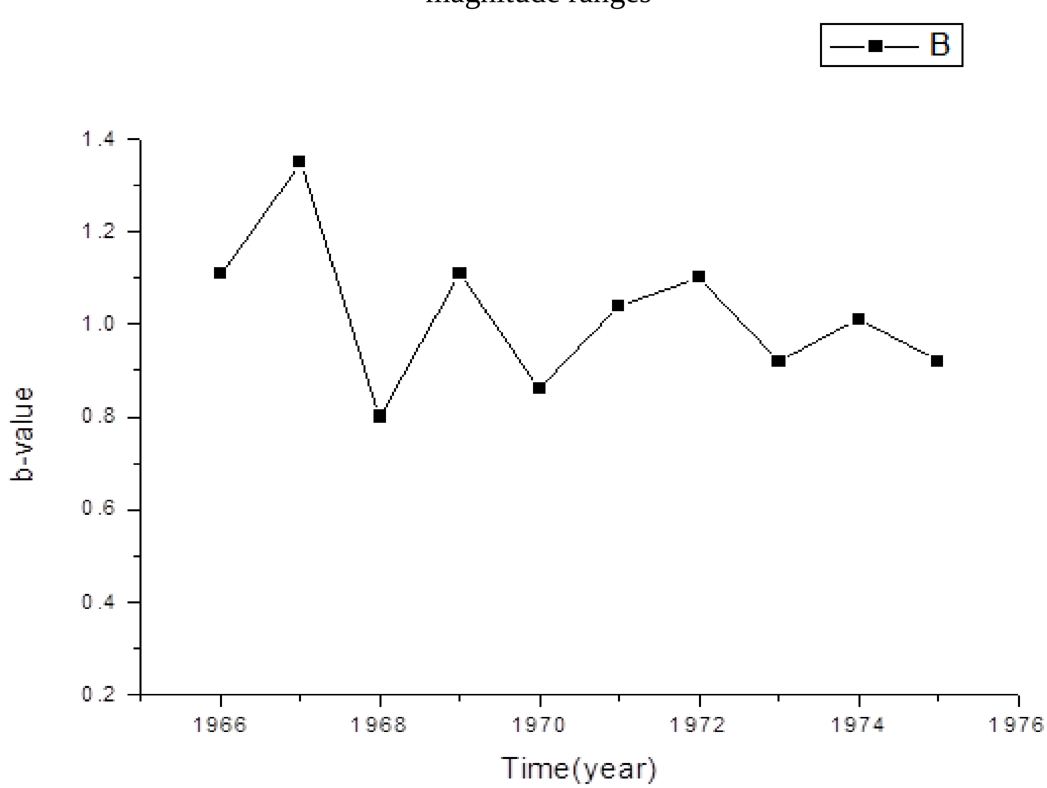

Figure 4. Temporal variation of b-value from 1st January 1966 to 31st December, 1975

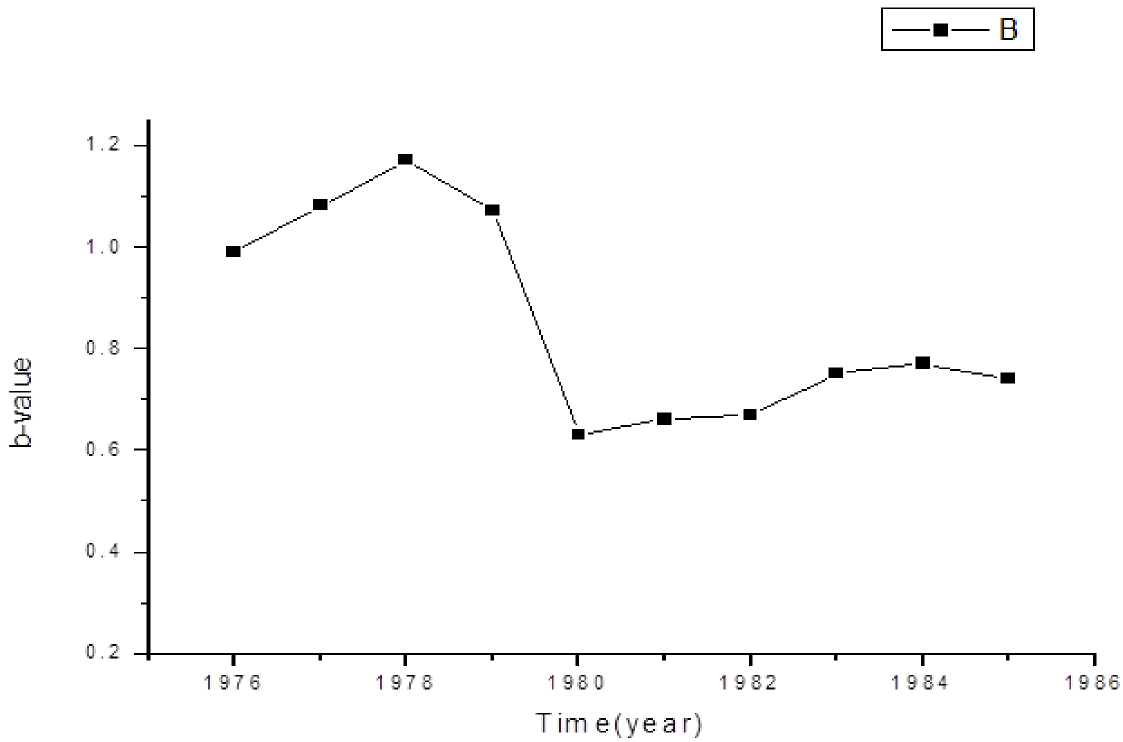

Figure 5. Temporal variation of b-value from 1st January 1976 to 31st December, 1985

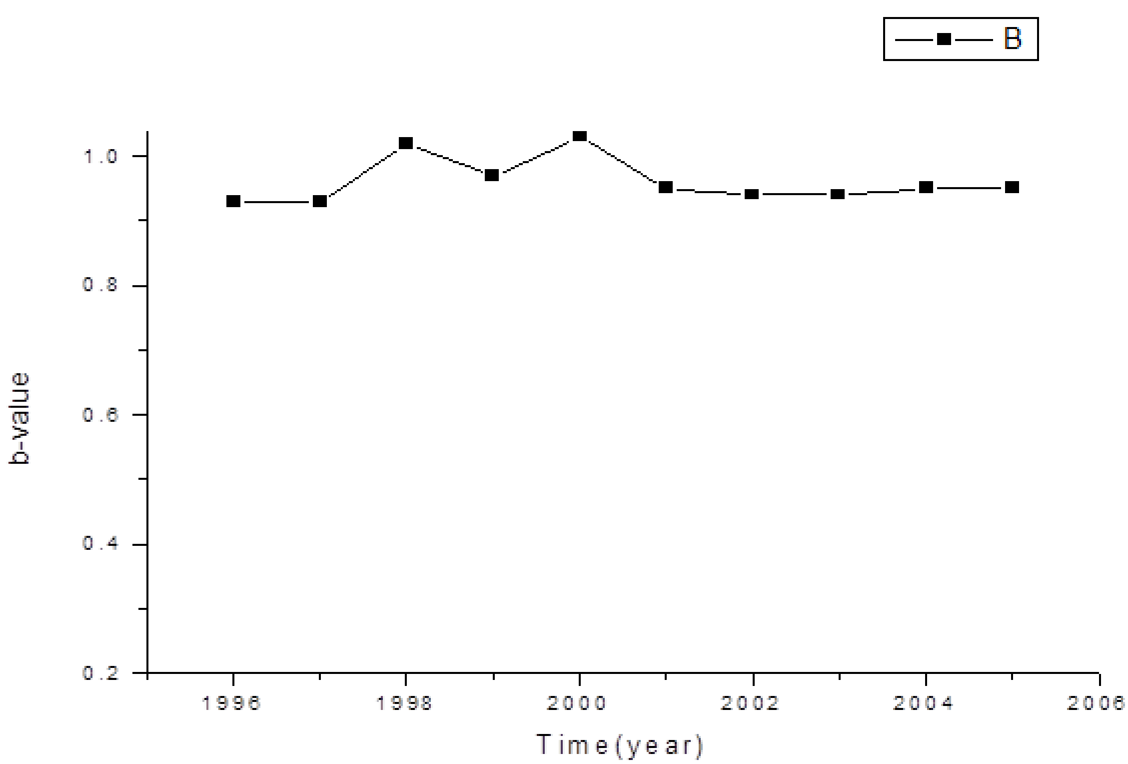

Figure 6. Temporal variation of b-value from 1st January 1986 to 31st December, 1995

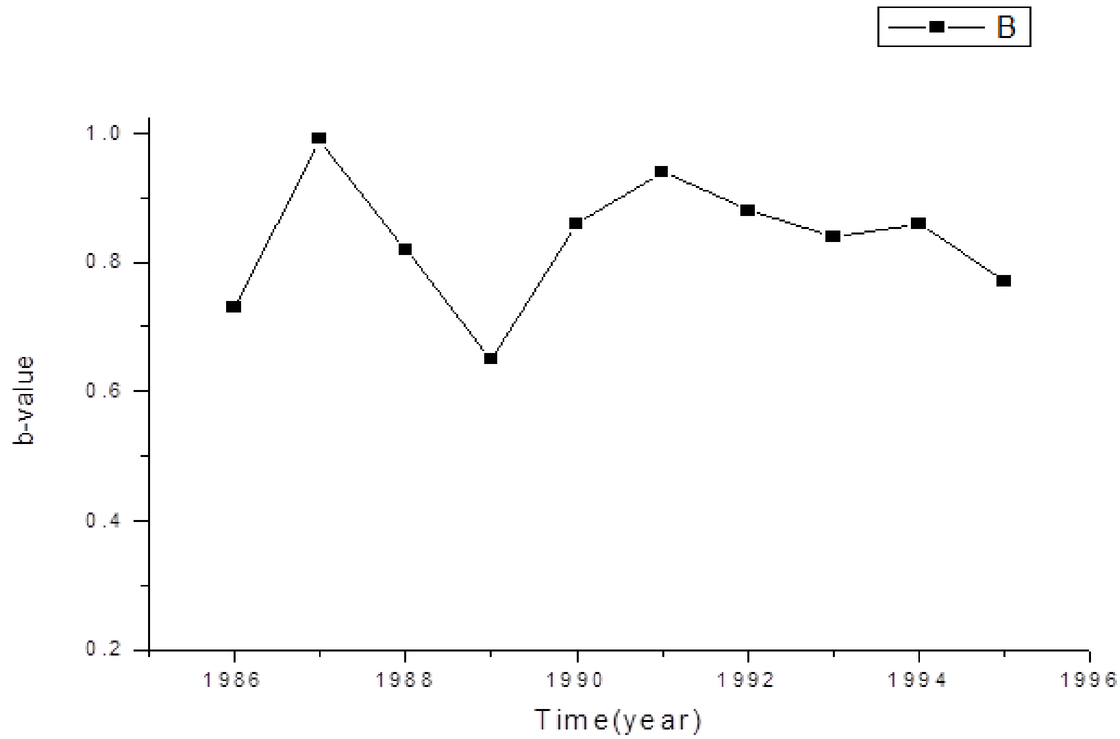

Figure 7. Temporal variation of b-value from 1st January 1996 to 31st December, 2005

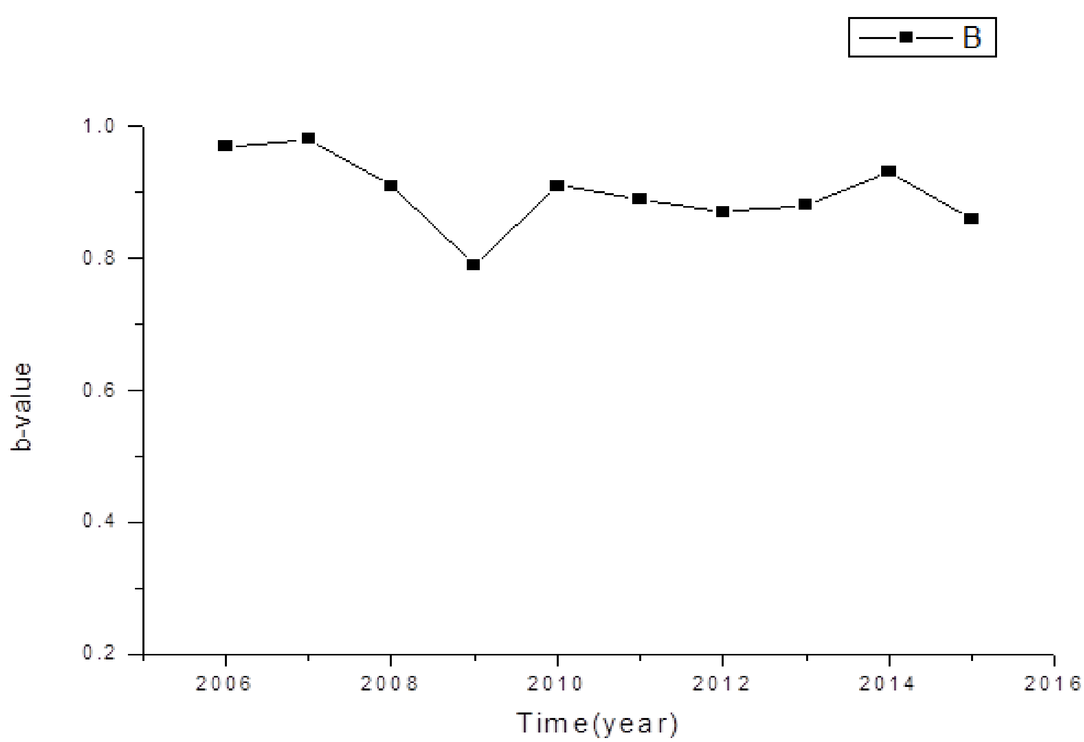

Figure 8. Temporal variation of b-value from 1st January 2006 to 31st December, 2015

3. 1. Research hypothesis

H_O: There is no significant difference in the b-value between the decade groups from 1966 to 2015

$H_{A:}$ There is a significant difference in the b-value between the decade groups from 1966 to 2015.

This hypothesis was tested at 0.05 level of significance using Analysis of Variance (ANOVA).

The results are as shown Table 4.

Table 3. Descriptive Statistics of b-value in the decade group from 1966 to 2015.

Group	Mean	Std. Deviation	N
1966-1975	1.0220	.15845	10
1976-1985	.8530	.20238	10
1986-1995	.8340	.09891	10
1996-2005	.9610	.03573	10
2006-2015	.8990	.05527	10
Total	.9138	.14025	50

Dependent Variable: b-value

Table 4. ANOVA results of b-values between the decade groups from 1966 to 2015.

Tests of Between-Subjects Effects					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.242[a]	4	.061	3.776	.010
Intercept	41.752	1	41.752	2603.720	.000
Decade group	.242	4	.061	3.776	.010
Error	.722	45	.016		
Total	42.715	50			
Corrected Total	.964	49			

Dependent Variable: b-value

a. R Squared = .251 (Adjusted R Squared = .185)

Table 4 shows that the P-value of 0.010 is less than 0.05. With this result it is sufficient to reject the null hypothesis and accept the alternative hypothesis. Hence, there is a significant difference in the b-value between the decade groups in the study area from 1966 to 2015. This implies that the b-value in each decade is different from each other.

The b-value obtained in this study is in disagreement with similar studies in other regions (Awoyemi *et al*., 2017). Since the P-value of the b-value is significant, the Post Hoc test was carried out using Least Significant Difference (LSD) to separate the means. The results are as shown (Table 5). The mean difference of the b-value between the decade 1966-1975 and other decades was significant in 1976-1985, 1986-1995, 2006-2015; between 1976-1985 and other decades was significant in 1966-1975; between 1986-1995 and other decades was significant in 1996-2005; between 1996-2005 and other decades was significant in 1986-1995, 1966-1975; between 2006-2015 and other decades was significant in 1966-1975.

Table 5. Post Hoc Tests of the b-values in the decade groups from 1966 to 2015

(I) Group	(J) group	Mean Difference (I-J)	Std. Error	Sig.
1966-1975	1976-1985	.1690*	.05663	.005
	1986-1995	.1880*	.05663	.002
	1996-2005	.0610	.05663	.287
	2006-2015	.1230*	.05663	.035
1976-1985	1966-1975	-.1690*	.05663	.005
	1986-1995	.0190	.05663	.739
	1996-2005	-.1080	.05663	.063
	2006-2015	-.0460	.05663	.421
1986-1995	1966-1975	-.1880*	.05663	.002
	1976-1985	-.0190	.05663	.739
	1996-2005	-.1270*	.05663	.030
	2006-2015	-.0650	.05663	.257
1996-2005	1966-1975	-.0610	.05663	.287
	1976-1985	.1080	.05663	.063
	1986-1995	.1270*	.05663	.030
	2006-2015	.0620	.05663	.279

2006-2015	1966-1975	-.1230*	.05663	.035
	1976-1985	.0460	.05663	.421
	1986-1995	.0650	.05663	.257
	1996-2005	-.0620	.05663	.279

Based on the observed means.
The error term is Mean Square (Error) = .016
*. The mean difference is significant at the .05 level

4. CONCLUSIONS

The findings of this study have classified b-value into three groups: high b-values predominantly consist of many earthquakes of moderate magnitudes. And a slight decrease in b-values are made up of earthquakes of large magnitudes. Low b-values are dominated by earthquakes of small magnitudes. The b-value for the whole study area was calculated to be 0.91. The research hypothesis revealed that there is a significant difference in the b-value between the decade groups from 1966 to 2015.

The F-ratio between the decade groups was found to be 3.776 with significant value of 0.010. The implication of this study is that temporal variation and monitoring of b-values will serve as one of the reliable ways of earthquake prediction in Papua New Guinea.

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