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Spatial spread of earthquakes around a portion 23.5^0N and 121^0E in Taiwan Island

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Abstract

This study investigated the spatial spread of earthquakes around a portion in Taiwan Island. The data used for this study were acquired from earthquake catalogue of International Seismological Centre (ISC), Pipers Lane, Thatcham, Berkshire, United Kingdom. Earthquake events with body magnitude $M_b \geq 2.4$ for the period 1st January 1941 to 31st December 2010 (70years) and of focal depth 0–700km. The region of study is situated within the coordinates; 23.5^0N, 121^0E.32,745 earthquake events were employed in the study. The data were analyzed using Least Regression (LS) method with the aid of Origin Program Software Version 5.0. The findings of this study revealed a general trend of increasing activity for each radius showing that the activity in the whole region of study is increasing. Also earthquakes in the magnitude range 4.0 - 4.9 had the highest distribution and 7.0-7.9(0.00)% the least distribution. This indicates that earthquakes of magnitude 4.0-4.9 are more predominant in the study area. Also as the radius is increasing the number of earthquake events is also increasing. The magnitude shifts from 1941-2010 revealed an overall increment for each radius indicating that the region is under increasing stress and more devastating events are inevitable in the near future, the highest magnitude in 70years is 7.2. Also the value of b varies from 0.74 to 0.85 and a-value varies from 5.86 to 6.98. The implication of this study is that the probability of occurrence of large earthquakes in Taiwan Island region is low but earthquakes are naturally unpredictable due to sensitivity of earthquake catalogues to small events, saturation of earthquake magnitudes and variation in seismic data collection by different seismic stations and networks.

Keywords: Spatial spread, earthquakes, a-value, b-value, Taiwan Island, Least Square.

Introduction

Taiwan is a very active region with high level of seismicity. It lies on the Ring of fire and at the western side of the Philippine Sea plate. Forty two cracks in the geologic formation (faults) have been identified by geologists on the island. In Taiwan Island, there is collision between Philippine Sea plate and Eurasian plate at a convergence speed of 8.0cm/year Yu et al[1]. About 18,000 earthquakes happen in Taiwan region and its surroundings annually Wu et al[2]. Findings by Wu et al[3] revealed that most of the disastrous earthquakes have resulted in many deaths and losses. For example, the 1906, M_L = 7.1 Meishan earthquake claimed 1,258 lives; the 1935, M_L=7.1 Hsinchu-Taichung earthquake claimed 3,276 lives; and the 1999, M_L=7.3 Chi-Chi earthquake killed 2,455 people. Earthquake is the major disaster in Taiwan region. High rate of strong seismicity and crustal deformation are common in Taiwan Island. It is against this backdrop that this study is carried out to investigate spatial spread of earthquakes around a portion in Taiwan Island.

The b-value is the most important parameter in seismicity studies. Several studies have been conducted globally by seismologists. Abong[4] evaluated the variation of b-value of earthquakes in Papua New Guinea. His findings classified b-value into three groups: high, moderate and low with high b-values varying from 1.01 to 1.35; moderate b-value from 0.80 to 1.00 and low b-value from 0.63 to 0.81 and the overall b-value of 0.91.

Some researchers are of the opinion that b-value does not vary systematically in different tectonic regime Bayrak et al[5]. But Schorlemmer et al[6] and many other researchers found that *b*-value varies significantly between individual fault zones Schorlemmer and Wiemer[7] and even within a given space and time range Nuannin et al[8].

Schorlemmer et al[9]; and Wiemer and McNutt[10] in their study in volcanic areas in Washington, Alaska and Italy found high b-value is 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. Schorlemmer and Wiemer[7] found low b-value within the rock volume of the 2004 Mw 6.0 Parkfield. Similarly, a study of the Sumatra subduction zone showed that the area around the epicentre of two giant earthquakes, 2004 Mw 9.0 and 2005 Mw 8.7 events happened within the zones of low *b*-values Nuannin et al[8].

Abong et al[11] investigated time scale dependence of frequency-magnitude of Gutenberg-Richter's relationship in South Africa. Their findings revealed that b-value varies from 0.67 to 1.11.

Awoyemi et al[12] 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[13] 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. However, there is no consensus on the universal value of b.

Seismicity of Taiwan Island: According to Wang[14] and Wu and Chen[15], the Taiwan region is divided into four different seismic zones. i. Western seismic zone: This is situated within the Eurasian plate. Majority of earthquakes in this area are characterized by active faults on the Taiwan Island. This zone has experienced the most disastrous earthquake in history, for example, the Chi-Chi earthquake of 1999. ii. Southwestern seismic zone: This is situated majorly in the South China Sea block of the Eurasian plate. It is the least active zone. iii. Northeastern seismic zone: This area houses the Ryukyu subduction system and shows high level of seismicity with few disastrous earthquakes. iv. Southeastern seismic zone: The collision between Eurasian plate and the Luzon island arc on the Philippine Sea plate takes place in this zone. This zone has witnessed many destructive earthquakes and other seismic activities.

Methodology

Source of data: The data were acquired from the earthquake catalogue of International Seismological Centre (ISC), Pipers Lane, Thatcham, Berkshire, United Kingdom (http://www. isc.ac.uk/). Earthquake events with body magnitude, $M_b \geq 2.4$ from 1st January, 1941 to 31st December, 2010 (70years) and of focal depth 0–700km. The region of study is situated within the coordinates; 23.5^0N, 121^0E (Figure-1). A total of 32,745 events were employed in the study.

Spatial variation: The region of study was varied in the following radii in km: 100, 200, 300, 400 and 500, all having the coordinate 23.5^0N, 121^0E.

Magnitude variation: The magnitude was grouped as follows: 2.0-2.9, 3.0-3.9, 4.0-4.9, 5.0-5.9, 6.0-6.9 and 7.0-7.9 for each radius.

Gutenberg-Richter Relationship: Ishimoto and Iida proposed the relationship in Japan in 1939 with the aid of maximum trace amplitude of earthquakes. Then Gutenberg and Richter in 1944 established the relationship in California. Their purpose was to enhance the estimation of the frequency of disastrous earthquakes in California by statistical techniques instead of relying only on historical records.

The Gutenberg-Richter's relationship is given by:

$$\text{Log } N = a - bM \quad (1)$$

Where, N is the number of earthquakes of magnitude ≥ M that happened in the region over a period of time. a and b are regression constants. a is the total number of earthquakes with magnitude >0 and it depends on the location, time window and sample used. It also describes the level of seismicity in a given region. b is the proportion of earthquakes of small and large magnitudes.

Results and discussion

The statistics in Table-1 and Figure-2 reveal a general trend of increasing activity for each radius showing that the activity in the whole region of study is increasing with 50 events in the time range 1941-1950; 287 events in 1951-1960; 890 events in 1961-1970; 2092 events in 1971-1980; 6147events in 1981-1990; 10731 in 1991-2000 and 12548 events in 2001-2010.

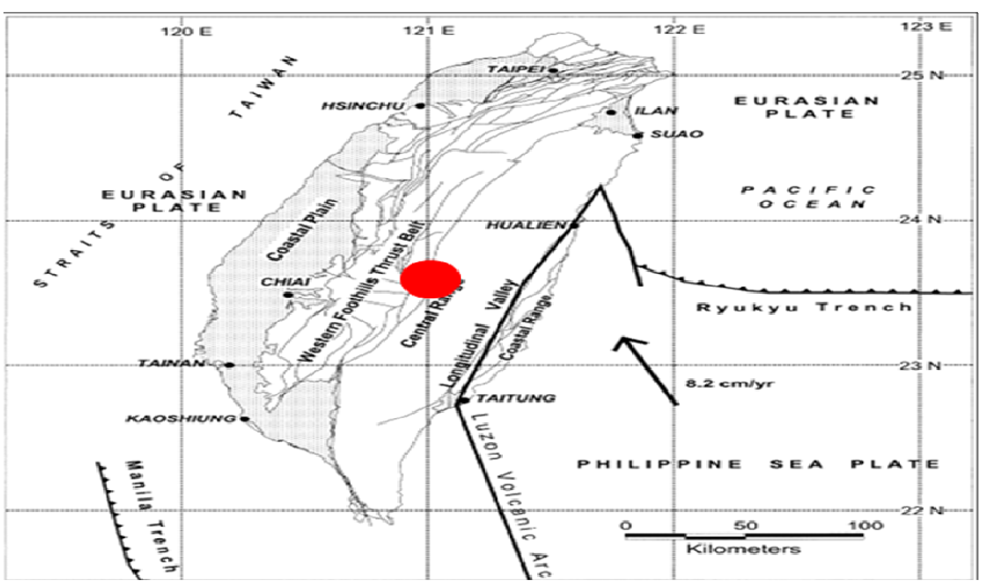

Figure-1: Map of Taiwan Island with the red circle showing the study area Modified from Obi et al[16].

Table-1: Statistics of earthquakes with Mb ≥ 2.4 in the study area.

Radius(Km)	Magnitude	1941-1950	1951-1960	1961-1970	1971-1980	1981-1990	1991-2000	2001-2010	Total
100	2.0-2.9	0	0	0	0	0	0	0	0
	3.0-3.9	0	0	0	7	66	326	348	747
	4.0-4.9	0	0	13	64	178	367	177	799
	5.0-5.9	2	22	22	44	44	40	28	202
	6.0-6.9	2	8	2	2	3	9	4	30
	7.0-7.9	0	0	0	0	0	0	0	0
200	2.0-2.9	0	0	0	1	0	6	0	7
	3.0-3.9	8	0	0	21	197	771	1107	2104
	4.0-4.9	0	0	57	174	521	756	535	2043
	5.0-5.9	0	43	91	123	114	82	88	541
	6.0-6.9	2	9	7	9	5	13	10	55
	7.0-7.9	0	0	0	0	0	0	0	0
300	2.0-2.9	0	0	0	1	0	9	1	11
	3.0-3.9	0	0	0	27	275	1165	1693	3160
	4.0-4.9	0	0	72	259	1014	1082	775	3202
	5.0-5.9	10	50	120	168	183	115	113	759
	6.0-6.9	2	9	9	11	6	14	13	64
	7.0-7.9	0	0	0	0	0	0	0	0
400	2.0-2.9	0	0	0	1	0	10	2	13
	3.0-3.9	0	0	0	30	300	1328	2161	3819
	4.0-4.9	0	0	83	295	1128	1252	1103	3861
	5.0-5.9	10	59	134	186	206	131	148	874
	6.0-6.9	2	11	8	11	9	14	18	73
	7.0-7.9	0	0	0	0	0	0	0	0
500	2.0-2.9	0	0	0	1	0	10	2	13
	3.0-3.9	0	0	0	34	316	1598	2668	4616
	4.0-4.9	0	0	105	382	1325	1473	1354	4639
	5.0-5.9	10	64	158	230	247	143	180	1032
	6.0-6.9	2	11	9	11	10	17	20	80
	7.0-7.9	0	1	0	0	0	0	0	1
TOTAL		50	287	890	2092	6147	10731	12548	32745

Table-2 shows that earthquakes in the magnitude range 4.0 - 4.9 had the highest distribution (44.42%), 3.0-3.9(44.12%), 5.0-5.9(10.41%), 6.0-6.9(0.92%), 2.0-2.9(0.13%) and 7.0-7.9(0.00)%.

This indicates that earthquakes of magnitude 4.0-4.9 are more predominant in the study area. Similar results were observed by Obi et al.[16]. Also as the radius within which earthquakes occur is increasing the number of earthquake events is also increasing.

Table-3 and Figure-3 indicate that the magnitude shifts from 1941-2010 reveal an overall increment for each radius. This indicates that the region is under increasing stress and more devastating events are inevitable in the near future, the highest magnitude in 70 years is 7.2.

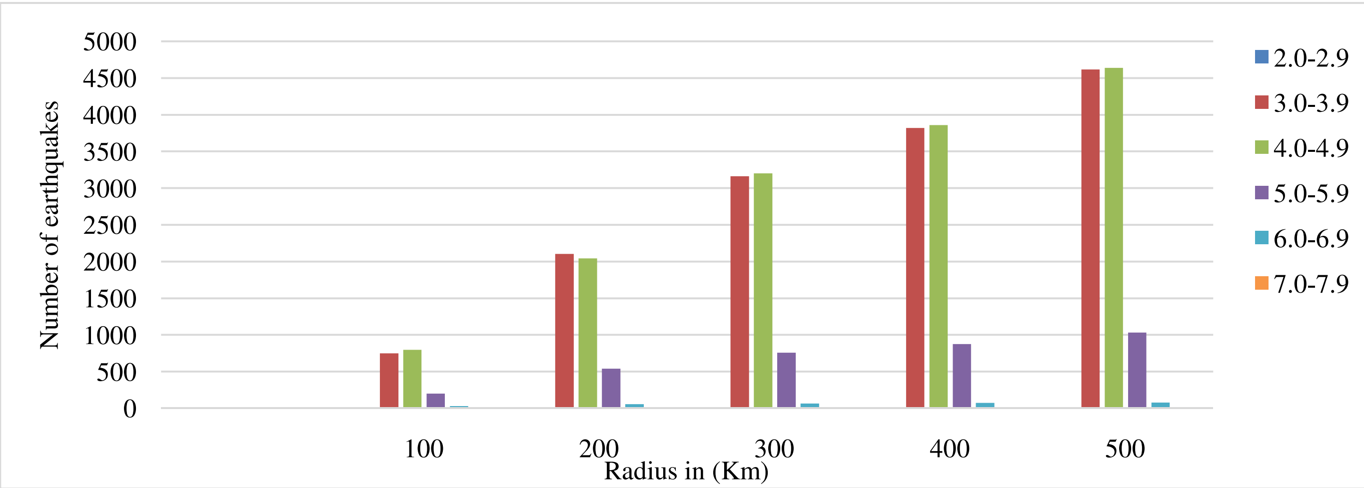

Figure-2: Graph showing earthquakes distribution in the study area from 1941 – 2010.

Table-2: Earthquakes distribution in the study area from 1941 to 2010.

Radius(Km)/Magnitude	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	Total
100	0	747	799	202	30	0	1878
200	7	2104	2043	541	55	0	4950
300	11	3160	3202	759	64	0	7496
400	13	3819	3861	874	73	0	9040
500	13	4616	4639	1032	80	1	10880
Total	44	14446	14544	3408	302	1	32745
Percentage (%)	0.13	44.12	44.42	10.41	0.92	0.00	100.0

Table-3: Magnitude shifts from 1941 – 2010 in the study area.

Year/Radius(Km)	100	200	300	400	500
1941-1950	6.2	6.2	6.2	6.2	6.2
1951-1960	6.5	6.5	6.5	6.5	7.2
1961-1970	6.5	6.6	6.7	6.6	6.6
1971-1980	6.3	6.6	6.6	6.6	6.6
1981-1990	6.1	6.1	6.1	6.1	6.2
1991-2000	6.3	6.3	6.4	6.4	6.4
2001-2010	6.2	6.4	6.4	6.4	6.4

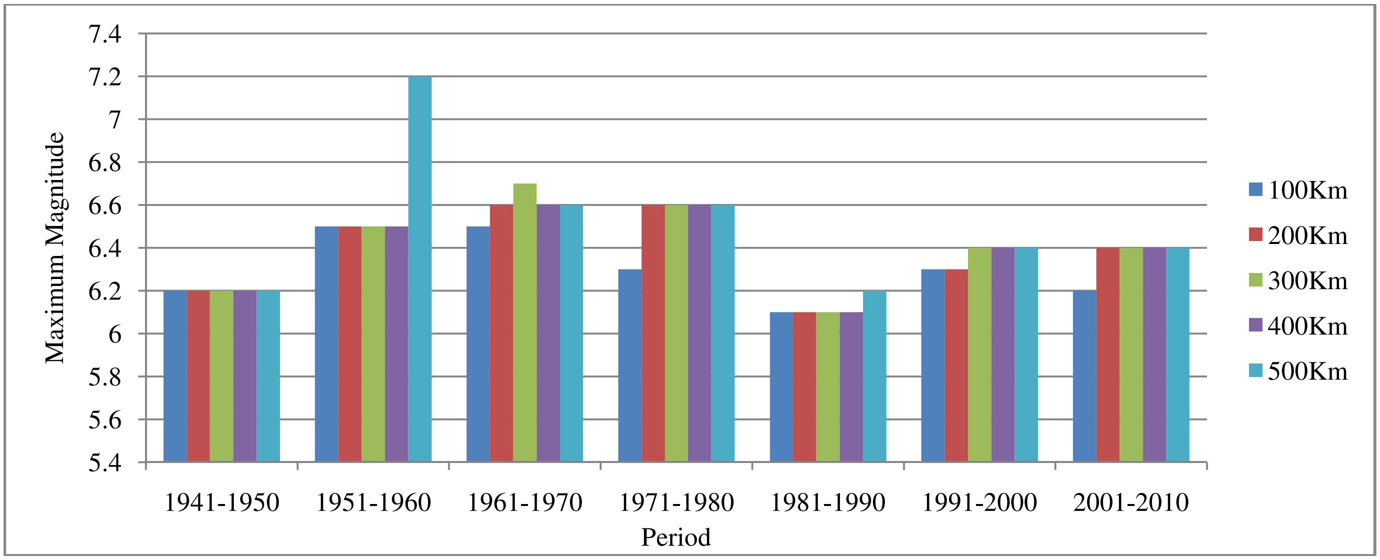

Figure-3: Bar chart showing magnitude shifts from 1941 – 2010.

Table-4: **a**-and **b**-values in the study area.

Radius (Km)	b	a
100	0.74	5.86
200	0.76	6.25
300	0.80	6.58
400	0.80	6.65
500	0.85	6.98

Table-5: b-values and its represented seismic activity and regions Miyamura[19].

b-values	Type of seismicity and region
0.4-0.6	Very low=Old shield zone
0.6-0.7	Low = Continental rift zones
0.7-1.0	Moderate = Circum-Pacific and Alphine Orogenic zones
1.0-1.8	High = Oceanic zones

Table-4 show the a- and b- values. Figure-4 to Figure-8 show the graph of cumulative number of earthquake events and magnitude in the study area. The value b varies from 0.74 to 0.85 and a-value varies from 5.86 to 6.98. The b-values obtained are moderate and fall within the range for Circum-Pacific and Alphine Orogenic zone (Table-5). The values of b-and a indicate that as the radius is increasing the values of b and a increase with it. The trend is as shown in Figure-9 and Figure-10. High b-and a-values were observed in radius 500km while low b-and a-values were observed in radius 100km to 400km. The radii with smaller value of b indicate that such areas are probably under the influence of greater applied shear stress, whereas radii that have larger values of b are areas that have been subjected to strike-slip after the major earthquake Enuscu and Ito[17]. Also it was found by Obi et al[16] that when value of b is low, there is an indication that the stress is high which serves as a sign for rupture in the future. The reason for this is that within the layers the rocks are not strongly cracked. According to Shaik and Srivastava[18], the value of b is dependent on the mechanical components of the rock mass which increases with the increase in heterogeneity (heavily cracked rocks).

Conclusion

This study investigated the spatial spread of earthquakes around a portion in Taiwan Island. The findings of this study revealed a general trend of increasing activity for each radius showing that the activity in the whole region of study is increasing. Also earthquakes in the magnitude range 4.0 - 4.9 had the highest distribution and 7.0-7.9(0.00)% the least distribution. This indicates that earthquakes of magnitude 4.0-4.9 are more predominant in the study area. The magnitude shifts from 1941-2010 revealed an overall increment for each radius indicating that the region is under increasing stress and more devastating events are inevitable in the near future, the highest magnitude in 70years is 7.2.

The implication of this study is that the probability of occurrence of large earthquakes in Taiwan Island region is low but earthquakes are naturally unpredictable due to sensitivity of earthquake catalogues to small events, saturation of earthquake magnitudes and variation in seismic data collection by different seismic stations and networks.

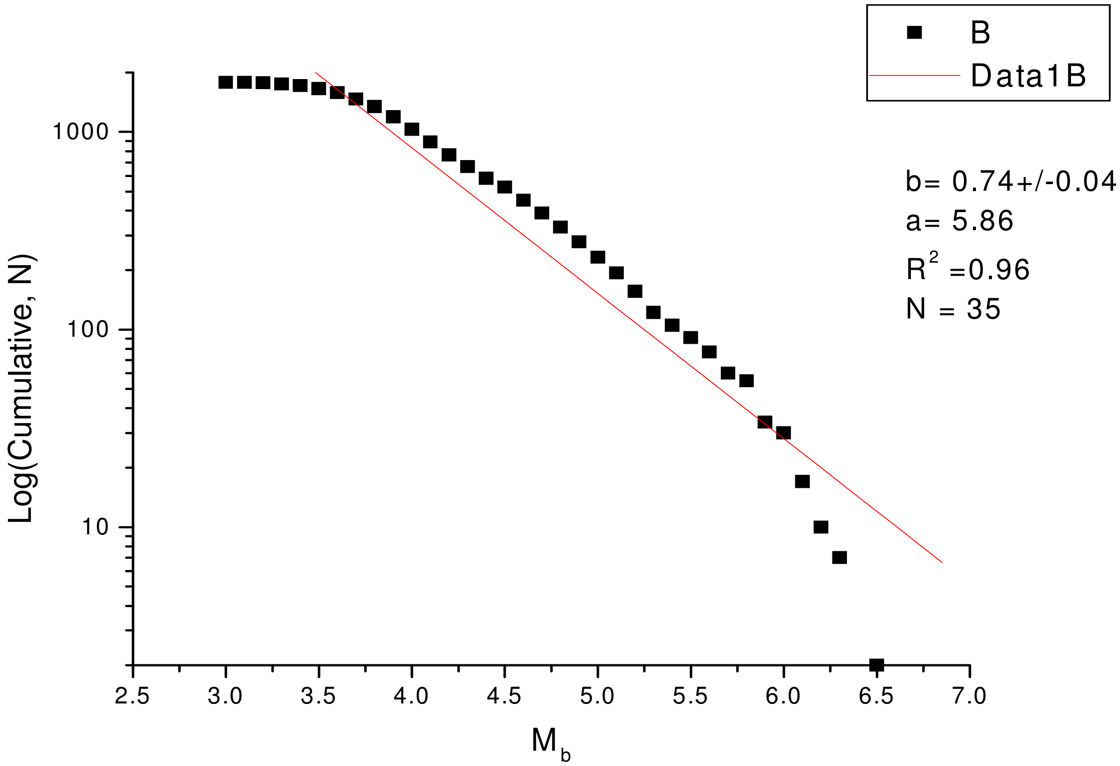

Figure-4: Cumulative frequency-magnitude graph for 100km radius.

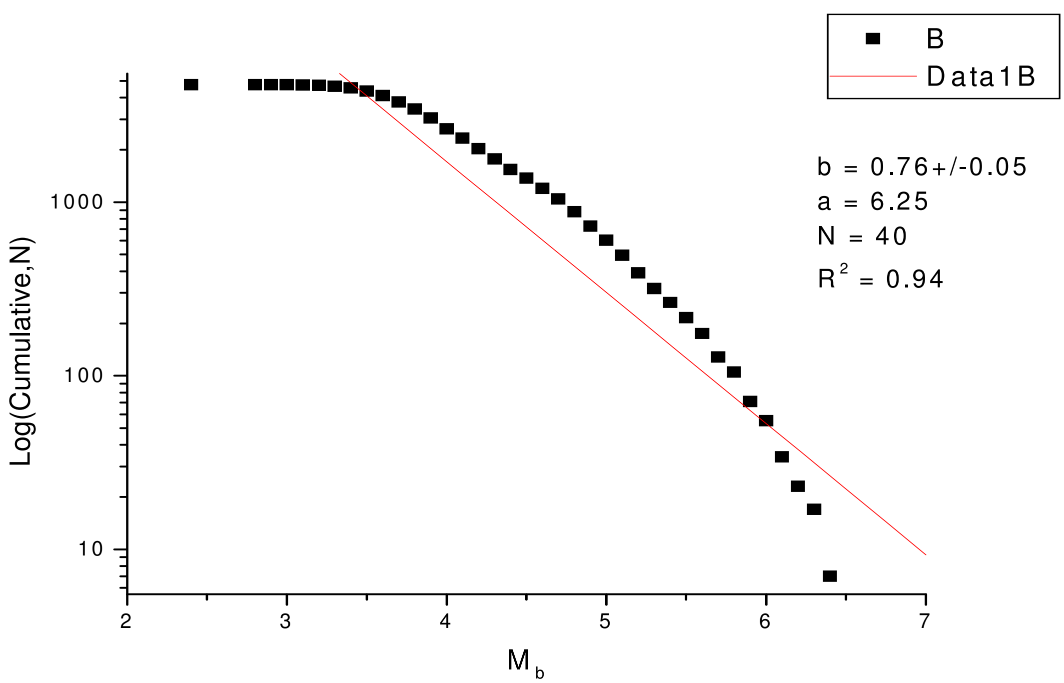

Figure-5: Cumulative frequency-magnitude graph for 200km radius.

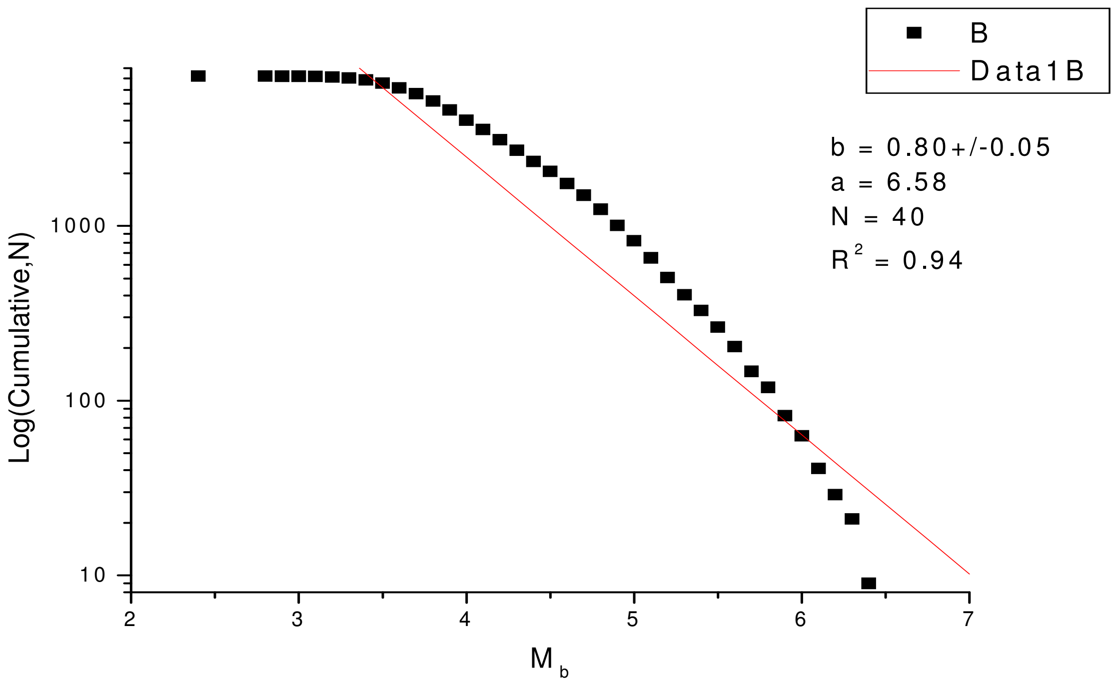

Figure-6: Cumulative frequency-magnitude graph for 300km radius.

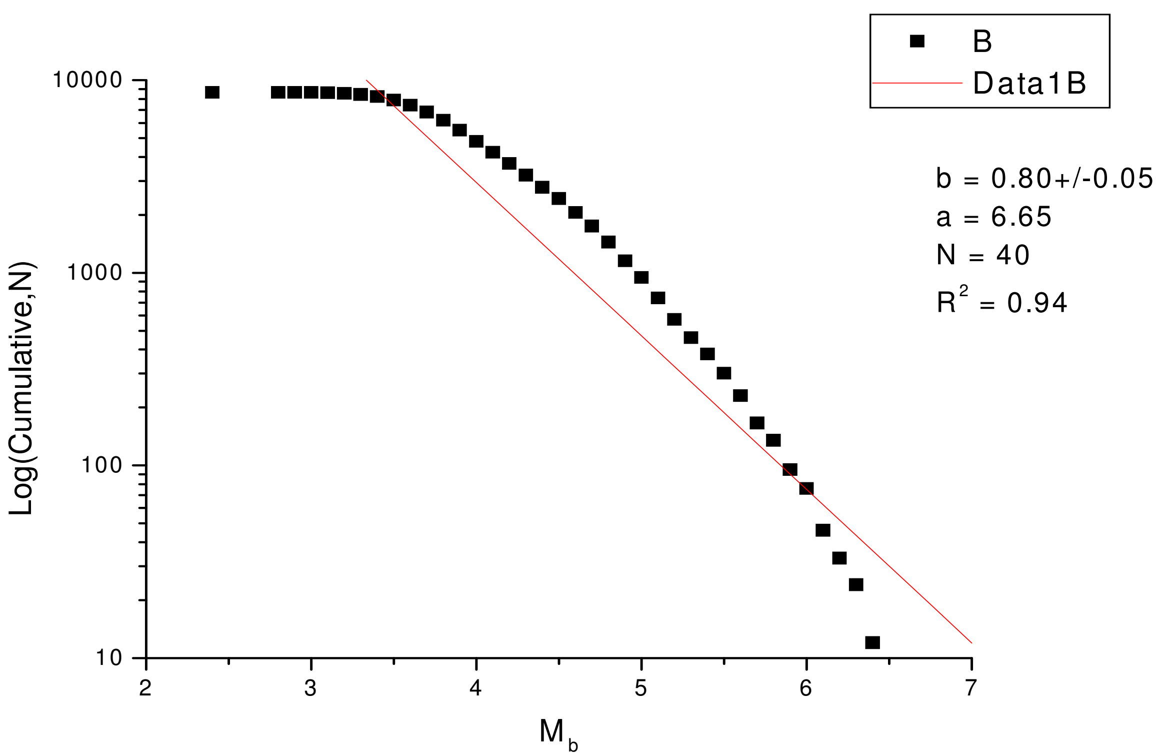

Figure-7: Cumulative frequency-magnitude graph for 400km radius.

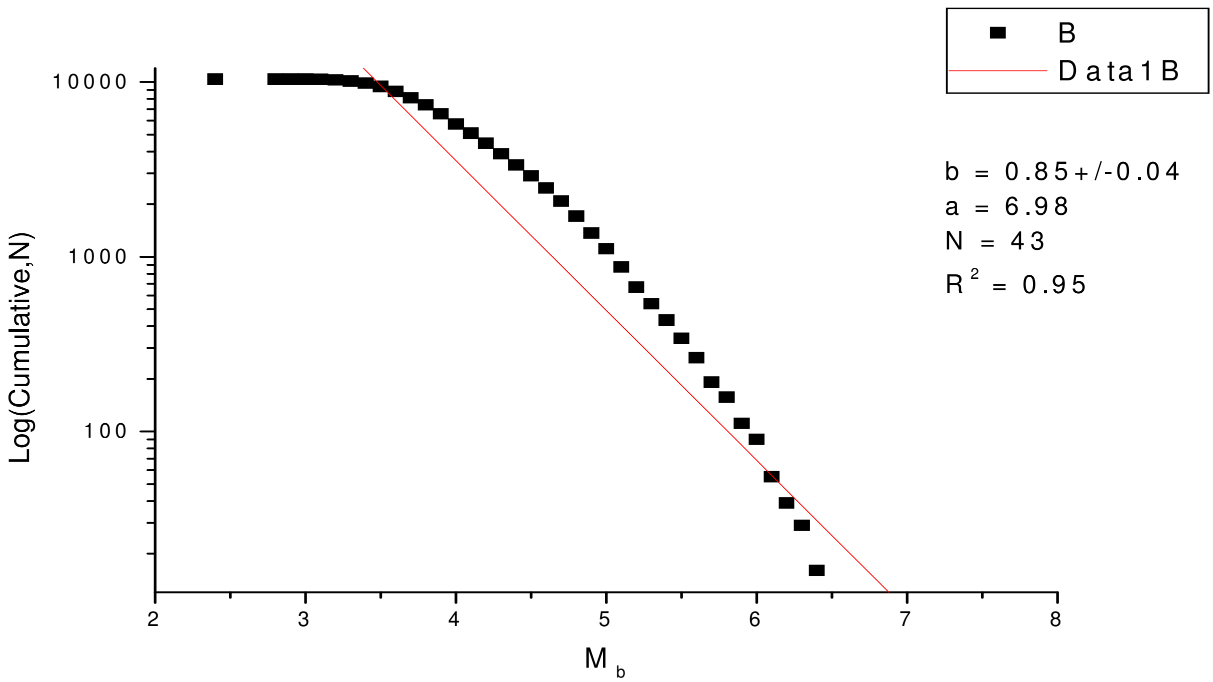

Figure-8: Cumulative frequency-magnitude graph for 500km radius.

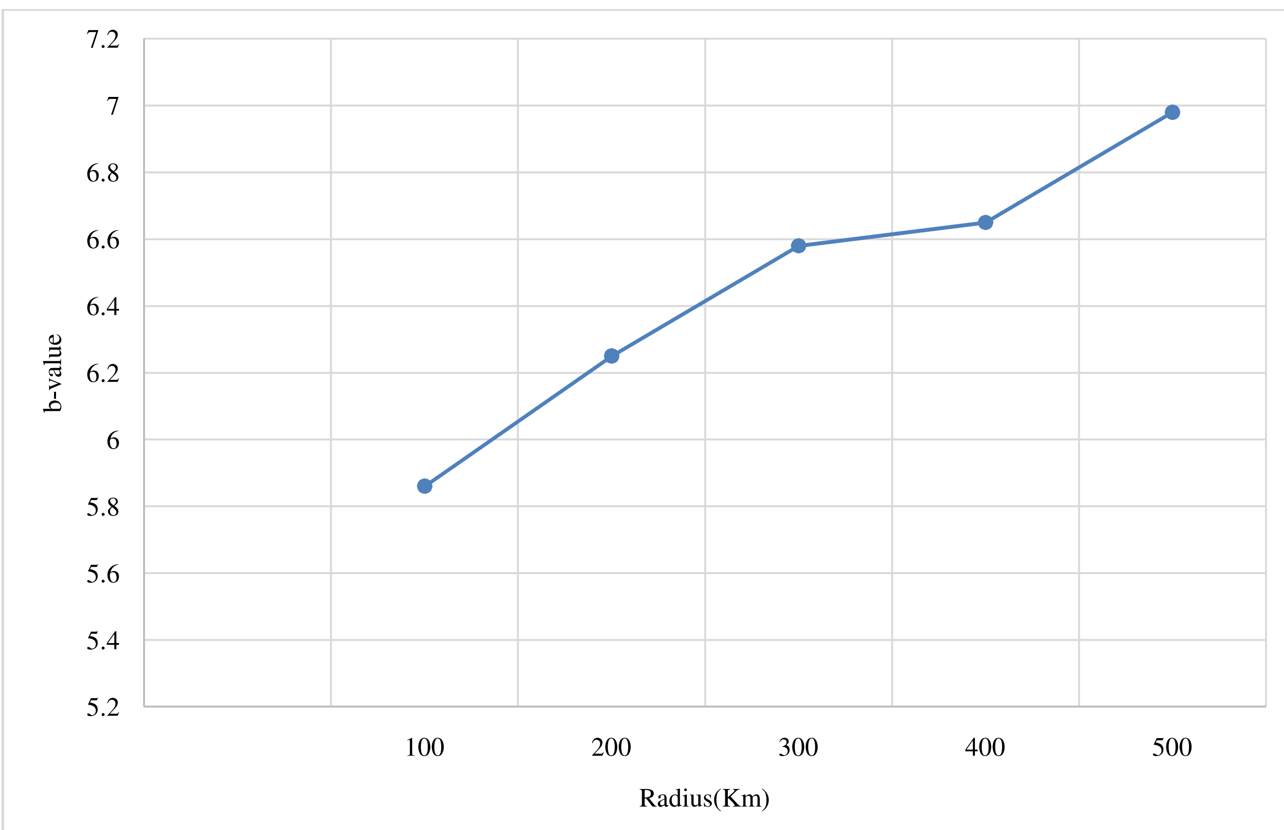

Figure-9: Variation of b-value with radius (km).

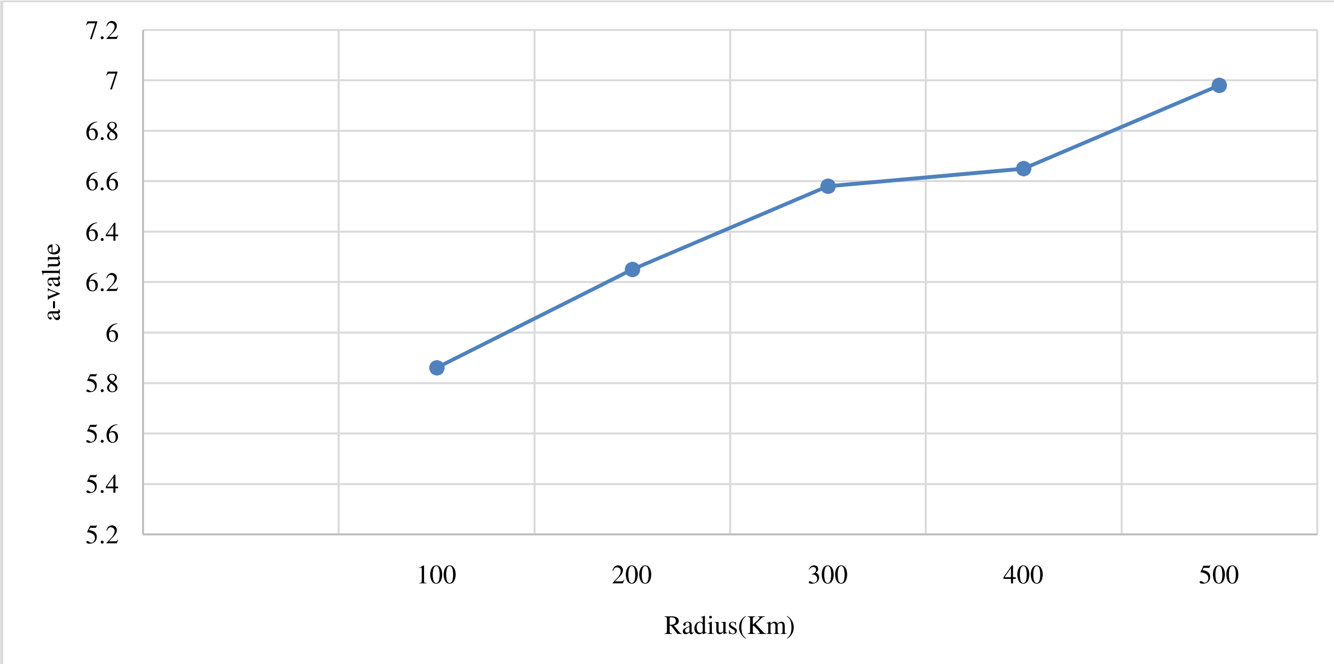

Figure-10: Variation of a-value with radius.

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