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Study on Seismotectonic b-value and Dc Value for Dolakha after Gorkha Earthquake 2015

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Abstract

Fractal correlation dimension (Dc) and the b-value methods are being used in this study with the earthquakes ($m_l \geq 4.0$) for the period 2015/4/25 to 2016/10/7 in Dolakha district after Gorkha Earthquake, 2015. The entire data have been divided into 3 windows each with consecutive fifty events for observing temporal variation of Dc value and b value. Low b value of 0.87± 0.05 is found during the period between 2015/4/25 to 2015/5/14 (window 1), indicates the large earthquakes of the period. The large earthquake of magnitude (m_l) of 6.8 is seen to occur 2015/5/12 in the study region in window 1. High b value of 1.53± 0.14 is found during the period from 2015/6/22 to 2016/10/7. The Dc value varies from 1.10 to 1.17 indicating the clustering phenomena of the events during the period. Thus, this kind of clustering pattern study by using local station data for Dolakha can help in the preparedness and mitigation of earthquake hazard.

Key Words: b-value, correlation dimension, Dc value, earthquake, magnitude

Introduction

Earthquake is a suddenand sometimes violent movement of the earth's surface usually caused by the release of built-up energy in the earth's crust within limited region of the rocks. It can be a slow release of energy occurring over a longer time interval - on the order of days, weeks, months, or years. Earthquakes are usually caused by ruptures along geological fault lines in the earth's crust, resulting in the sudden release of strain energy in the form of seismic waves (body wave and surface wave)[1].The classical understanding of earthquakes was quite different from modern scientific interpretations. As explained in myths and legends, early civilizations had either gods or mythological creatures to explain major natural disasters such as thunder, lightning and earthquakes [2].Today, it has been proven that earthquakes are not because of god and mythological creatures,but are due to the sudden slip of the fault plane. Little was understood about earthquakes until the emergence of seismology at the beginning of the 20th century. Seismology involves the scientific study of all aspects of earthquakes, and has yielded answers to such long-standing questions as why and how earthquakes occur. **E**arthquake is sudden shaking of the ground caused by the passage of seismic waves through Earth's rocks. Tectonic

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earthquakes are explained by elastic rebound theory, formulated by the American geologist, Harry Reid, after the 1906, San-Francisco earthquake. According to the theory, a tectonic earthquake occurs when strains in rock masses accumulated to a point where the resulting stresses exceed the strength of the rocks [3,4]

The fractures propagate rapidly through the rock, extending many kilometers along a local zone of weakness. The release of elastic strain energy that is accumulated in the fault zone because of interlock of the rough fault plains (mostlynear the tectonic plate boundaries). The region where the Himalaya is standing at present was once covered with Tethys Sea (ancient sea) around 200 million years ago.Thus, the formation of the Himalaya range is the consequence of the continuous continental-continental collision of Indian plate and Eurasian (Tibetan) plate. The Indian plate is under-thrusting the less dense Eurasian plate since last 65 million years ago after collision. [5]. The four major large-magnitude earth quack events are in 1905at Kangra of Mw 7.8, in 1934 in Bihar of Mw 8.1 and in 1950 in Upper Assam of Mw 8.4 earthquakes and in 2015 at Gorkha of Mw 7.8 in last 110 year's history [6] has also revealed the seismically active tectonic networks of Himalayas.

Nepal lies between 80^o 4'E and 88^o12' E longitude, and from 26^o 22'N to 30^o 27'N latitude, covering a territory of approximately 147,181 km^2 that extends roughly 885 km from east to west and 200km north to south[7]. It is a landlocked country surrounded by India to the east, west and south, and China in the north. Nepal is lying at the center of the 2500 km long Himalayan range.We have a long history major earth quacks happened in Nepal lyinglong Himalayan range since 12^{th}century. Major earthquakes were in June 7,1260; 1260; 1408; 1681; June and July of 1767, August 26, 1833; August 26, 1833; 16 January 1934 and 25 April 2015.On 25 April 2015 magnitude Mw 8.1 occurred at 11:56 local time with epicenter Barpak, Gorkha district[8].The damages were mainly concentrated on districts like Dhading, Dolakha, Nuwakot, Rasuwa and Sindhupalchowk. Relatively, Sindhupalchowk area was highly affected [9]. Gorkha earthquakes were attributed to toll of more than 8500 human lives in Nepal, injuries to about 20,000 persons, collapse of 498,852 buildings, 446 public health facilities and partial damage of 256,697 buildings, 765 health facilities as well as severely affected 2900 cultural and historical sites [10,11]

Materials and Methods

Different magnitude scalesare used to express magnitude of earth quake.The Richter magnitude scale was developed in 1935 by the U.S. seismologist Charles Francis Richter (1900–1985) .The Richter scale assigns a magnitude number to quantify the energy released by an earthquake. This scale is a base-10 logarithmic scale, which defines magnitude as the logarithm of the ratio of amplitude of the seismic waves to arbitrary, minor amplitude. Earthquake frequency-magnitude relationship is a way to examine seismic activity in an area. There are some other scales like local magnitude scale (m_l), body wave magnitude scale (M_b), surface wave magnitude scale (M_s) and moment magnitude scale (M_w) that are also used in the study Earthquake. The b-Value describes the ratio of occurrence of small to large earthquakes, and its global value is 1, meaning a

10-fold decrease in seismic activity associated with increase in each subsequent unit magnitude (m). The b-Value has been estimated using most widely used empirical relation between magnitude and frequency of earthquake occurrence in a region given by Gutenberg and Richter (1944) [12]as

$$logN = a - bm \quad (1)$$

Where N represents the number of earthquakes of magnitude m or greater than m per unit time, a and b are constant for a given region representing seismic character that may varies in space and time. The parameter 'a' characterizes the general level of seismicity in a given area during the study period i.e. higher the 'a' value, higher the seismicity. Similarly, 'b' value is a characteristic of the region and has been defined as measurement of seismicity. The low b- Value implies that the majority of earthquakes are of higher magnitude, and a higher b- value implies that the majority of earthquakes are of lower magnitude. The variation of b-value has been seen to be inversely related to stress distribution and also large material heterogeneities have been reported with higher b-Value [13]. Earthquake distribution spatial patterns and temporal patterns of occurrence were demonstrated to be fractal using a two-point correlation dimension (Dc). Analyzing correlation dimension is a powerful tool for quantifying a geometrical object's self-similarity. Grassberger and Procaccia (1983) defined Dc, fractal dimension (more strictly, the correlation dimension) and correlation sum C(r) as follows: [14]

$$Dc = \lim_{r \to 0} \frac{\log(c(r))}{\log(r)} \quad (2)$$

Where ' r' is the length scale.

The fractal correlation dimension is derived from the correlation integral [15,16], which is a cumulative correlation function that measuresthe fraction of points in the 2-dimensional space[14]

$$c(r) = \frac{2}{N(N-1)} \sum_{i=1}^{n} \sum_{j=i+1}^{n} H(r - r_{ij}) \quad (3)$$

For 50 events window, N will be ${}^{50}C_2$i.e 1225), r_{ij} the distances between the points of a set, H is the Heaviside step function.

$$r_{ij} = R\cos^{-1}\lfloor \cos\theta_i \cos\theta_j + \sin\theta_i \sin\theta_j \cos(\emptyset_i - \emptyset_j) \rfloor \quad (4)$$

where R is radius of Earth. θ_i, ϕ_i and θ_j, ϕ_j are the latitudes and longitudes of i^{th} and j^{th} events respectively [17]. Here c(r) is proportional to the number of pairs of points of the fractal set separated by a distance less than r. If the system of points examined belongs to a fractal set, the graph of c(r) versus r in logarithmic coordinates must be a linear function with slope DC equaling to the fractal dimension of the system. The DC value is inversely related to the degree of clustering and it requires higher degree of accuracy in both space and time of occurrence of events as the present analysis depends on the spatio-temporal distribution of earthquake sequences. Thus, it is utmost important to use well constrained catalog.

Dolakha district($27^{o}47'$ N, $86^{o}11'$ E and altitude 762 m to 7183 m) is part of Bagamati Pradesh in central and mid-hills of Nepal. The district, with Charikot as its district headquarters is 133 km east of Kathmandu. The Dolakha covers an area of 2,191 km^2 with population of 186,557

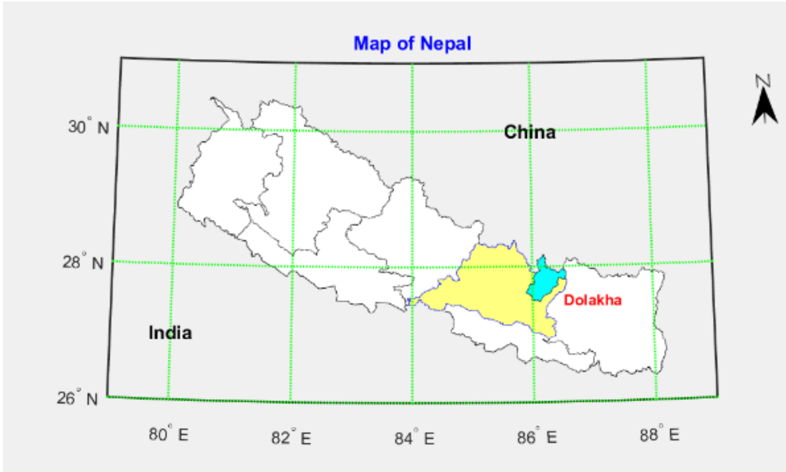

Figure 1: Map of Dolakha [source: Survey Department, 2020

The earthquake data base ($m_l \geq 4.0$) is prepared from Department of Mines and Geology (DMG), Ministry of Industry, government of Nepal[www.seismonepal.gov.np] from 25th April 2015 to 7th Oct 2016. The total 150 events are divided into three windows containing fifty events in each as shown in Table1.

Table 1: Distribution of window

Window	Time duration for 50 events	Time(days)
1	2015/4/25 to 2015/5/14	23
2	2015/5/14 to 2015/6/21	48
3	2015/6/22 to 2016/10/7	474

Open source software Python 3.7 software is used to analysis and to plot graph. Least square method is used to fit data in straight line (y = a + bx). The coefficient of determination (R^2) is necessary to indicate at what extent the observed result is close to the predicted one so in this study the R^2 value for the linear fit is calculated with formula.

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \quad (5)$$

where, y_i and $\hat{y}_i$ are the observed value and the predicted value of i^{th} data. $\bar{y}$ is mean of data.

Results and Discussion

Spatial and temporal variation of Earthquake in Dolakha is shown in figure2 of 150 events from 2015/4/25 to 2016/10/7. Figure2 (a) shows variation of magnitude of earthquake with longitude and latitude. Magnitude of 6.8 is occurred on 2015/5/12 at 12:50 PM in NST with Sunkhola epicenter. It is greatest magnitude of aftershock of Gorkha Earthquake 2015. Figure 2(b) represents variation in magnitude with number of days. Out of 150 events, 31 events are magnitudes of 4.1. During study period, 138 Earthquakes are occurred in 2015 and 12 in 2016. Figure2(c) shows monthly variation of earthquake. Out of 150 Earthquake, 81 events occurred in May and no Earth quake occurred in February, March and November. Figure2d shows variation of number of earthquake with time in hour. During study period, 14 Earthquakes occurred in 2 PM. One Earthquake occurred on 1 AM and 2 AM.

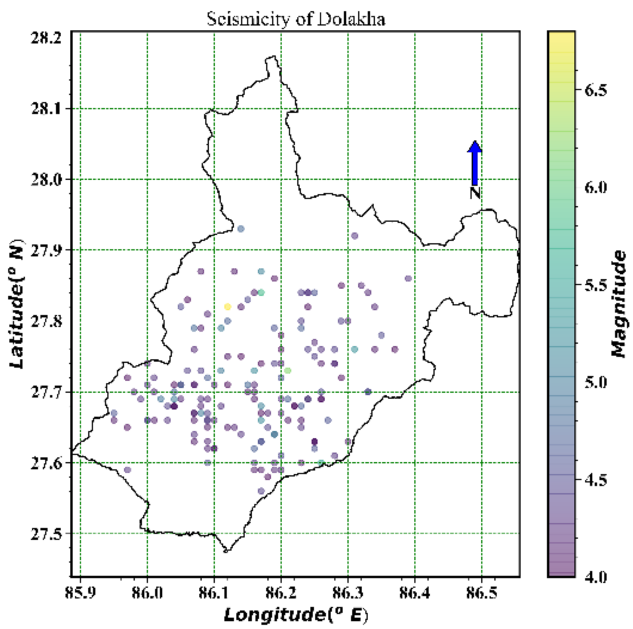

Figure 2 a: Locations of Earthquakes of different magnitudesin Dolkha district.

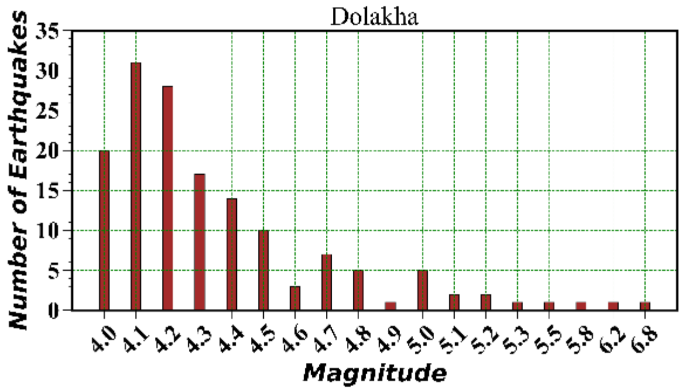

Figure2b: Frequencies of Earthquakes having particular magnitudes in Dolkha district.

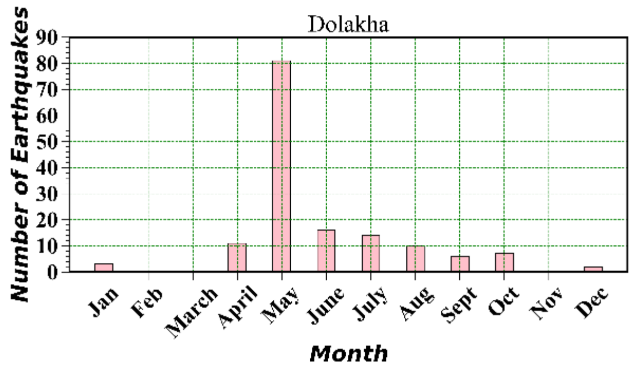

Figure 2c: Frequencies of Earthquakes in particular month in Dolkha district.

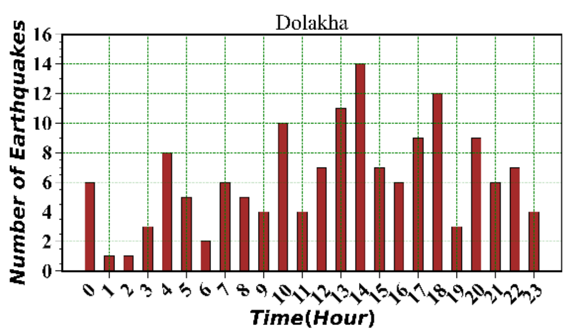

Figure2d: a: Frequencies of Earthquakes atparticular day hour in Dolkha district.

Figure2: Spatial and temporal variation of Earthquakes for 150 events from 25th April 2015 to 7th Oct 2016. Energy released during earthquake in erg is calculated by using equation

$E = 10^{1.5ml + 11.8}$ (6)

Where*ml* is local magnitude.Energy is represented in TJ(1 TJ = 10^{19} erg). Cumulative frequency 'N' with magnitude greater than *m* is calculated. Straight line is fitted between $\log_{10}N$ and m according to equation (1) for three windows.

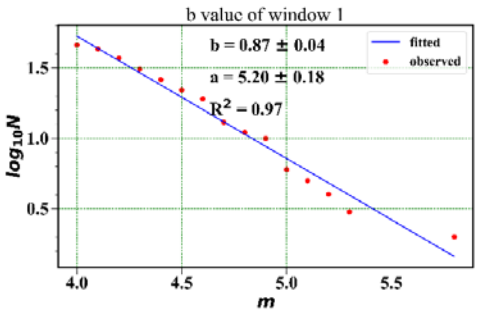

Figure 3 a. Window 1 represents frequency of Earthquakes against magnitude first 23 days.

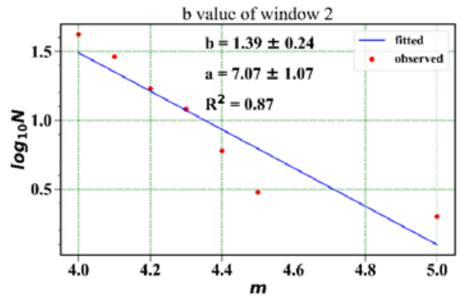

Figure3b.Window2represents frequency of Earthquakes with magnitude in nest 48 days.

The b-value is slope of the straight line. Plot between $\log_{10}N$ versus *m* for three windows are shown in Figure 3. Figure 3(a) represents windows 1 of 23 daysfrom 25th April2015to 14th May 2015. From equation (6), total energy released is 1192 TJ. From the above graphthe b-value and a-Value obtained are 0.87 ± 0.04 and 5.20 ± 0.18 respectively with coefficient of determination, R^2 = 0.97. Figure 3(b) represents windows2 of 48 daysfrom 14 May 2015 to 21th June 2015. In the same way energy released is 24 TJ. The b-value and a-value obtained are 1.39 ± 0.24 and 7.07 ± 1.07 respectively with coefficient of determination, R^2 = 0.87. Here the b-Values predicts about Earthquakes happening in future.

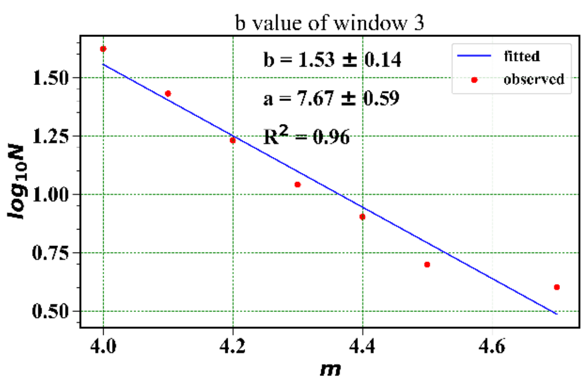

Figure 3(c) is for windows 3 of 474 daysfrom 22th June 2015 to 7th Oct 2016. Total energy released is 12 TJ. The b-Value and a-Value obtained are 1.53 ± 0.14 and 7.67 ± 0.59 with R^2 = 0.96. During 545 days of the study period, 1228 TJ energy released.

Figure 3c. Window 3 represents frequency of Earthquakes magnitude for 474 days

Figure. 3: Plots of the log N versus *m*for the threeconsidered windows of Dolakha, where the slope gives b-Value

The C(r) values are calculated by using equations (3) and (4). Straight line is fitted between $\log_{10}(C(r))$ and $\log_{10}(r)$. Slope of the line is Dc value. Plot between $\log_{10}(C(r))$ versus $\log_{10}(r)$ for three windows are shown figure 4.

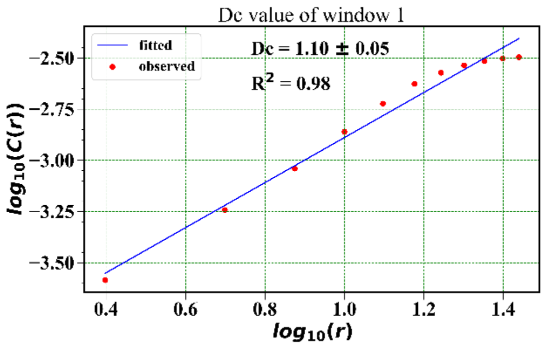

Figure 4a. Window 1

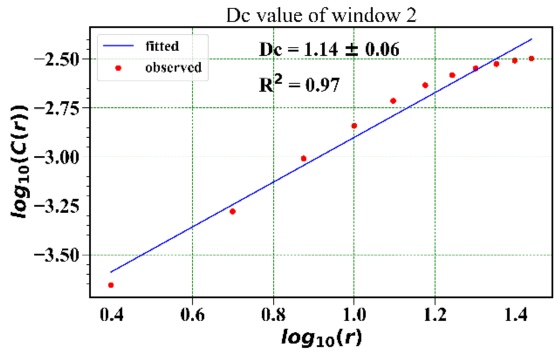

Figure 4b. Window 2

Figure 4(a) is for windows 1.The Dc-value obtained from the above graph is 1.10 ± 0.05 with coefficient of determination, R^2 = 0.98. Figure 4(b) is for windows 2.The Dc-value obtained is 1.14 ± 0.06 with coefficient of determination, R^2 = 0.97. Figure 4(c) is for windows 3. The Dc-value obtained is 1.17 ± 0.06 with coefficient of determination, R^2 = 0.98.

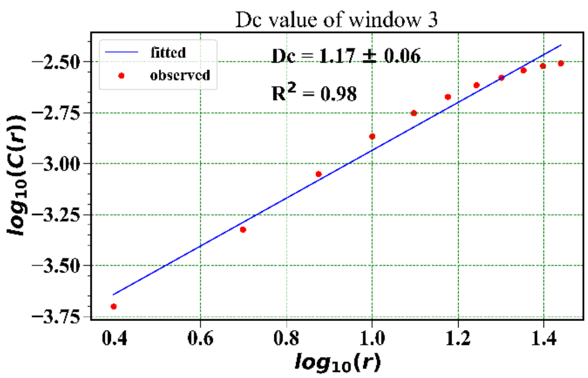

Figure 4c. Window 3

Figure. 4: Plot of the log C(r) versus log r is shown for the three windows for Dolakha, the slope gives Dc

Conclusion

The correlation dimension value (Dc value) and b-value of the Dolakha bounded by 27.52°N to 28.18°N latitude and85.92°E to 86.56°E longitude are calculated from earthquake data base are prepared from Department of Mines and Geology (DMG), GoV of Nepal. Three windows with 50 events were used to analyze the Dc value and the b-value. b value is ranging from 0.87 to 1.53 during the study period. b value is less than 1 in windows 1. This indicates the large earthquakes of the period. The large earthquake of magnitude of 6.8 occurred on 12 May 2015in the study region of window 1. Window 2and window 3 have b-Value greater than 1 which indicates that majority of earthquakes are of less magnitude. Dc value are ranging from 1.10 to 1.17 during the study period. All three windows have Dc value greater than 1 indicating the clustering phenomena of the events during the period.

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