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Variability of b-value before and after the Gorkha earthquake in the central Himalaya and vicinity

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ABSTRACT

This study computes the b-value of Gutenberg-Richter relation associated with the 25 April 2015 Gorkha earthquake and its aftershock sequences. For this the homogeneous catalogue of 769 earthquakes that occurred in the Himalayan compressed belt and its vicinity was analyzed by three different approaches. The minimum b-values 0.60 ± 0.07 and 0.63 ± 0.06 were observed for windows containing Gorkha earthquake. For time window before Gorkha earthquake, the b-value was noted as 0.89 ± 0.12 . It was noted 0.81 ± 0.04 for time window between Gorkha earthquake and Dolakha earthquake and 0.78 ± 0.08 for time window after Dolakha earthquake. The results revealed the fact that b-value starts to decrease for strong earthquake. About 17% jumps of the b value were observed within 17 days between Gorkha earthquake and its largest aftershock, the Dolakha earthquake. The b-value 1.16 ± 0.09 was obtained for the depth range of 0-10 km, 0.89 ± 0.4 for the depth range 10-20 km and 0.65 ± 0.08 for the depth range of 20-30 km. The results strongly support the global trends of decreasing b-value with depth in the continental crust and subduction zones. The low b-value patch observed in the west of Gorkha from contour map depicts the region as the potential zone of future strong seismic activity.

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1. Introduction

The entire Himalayan terrain and its surroundings is a highly active seismic zone on the earth. Nepal lying at the center of the 2500 km long Himalayan range, has encountered 19 devastating earthquakes since the twelfth century. A catastrophic earthquake (7.8 Mw) on 25 of April 2015 has left the entire nation stunned with the casualty of about 8900 people. The effect was felt in some adjoining parts

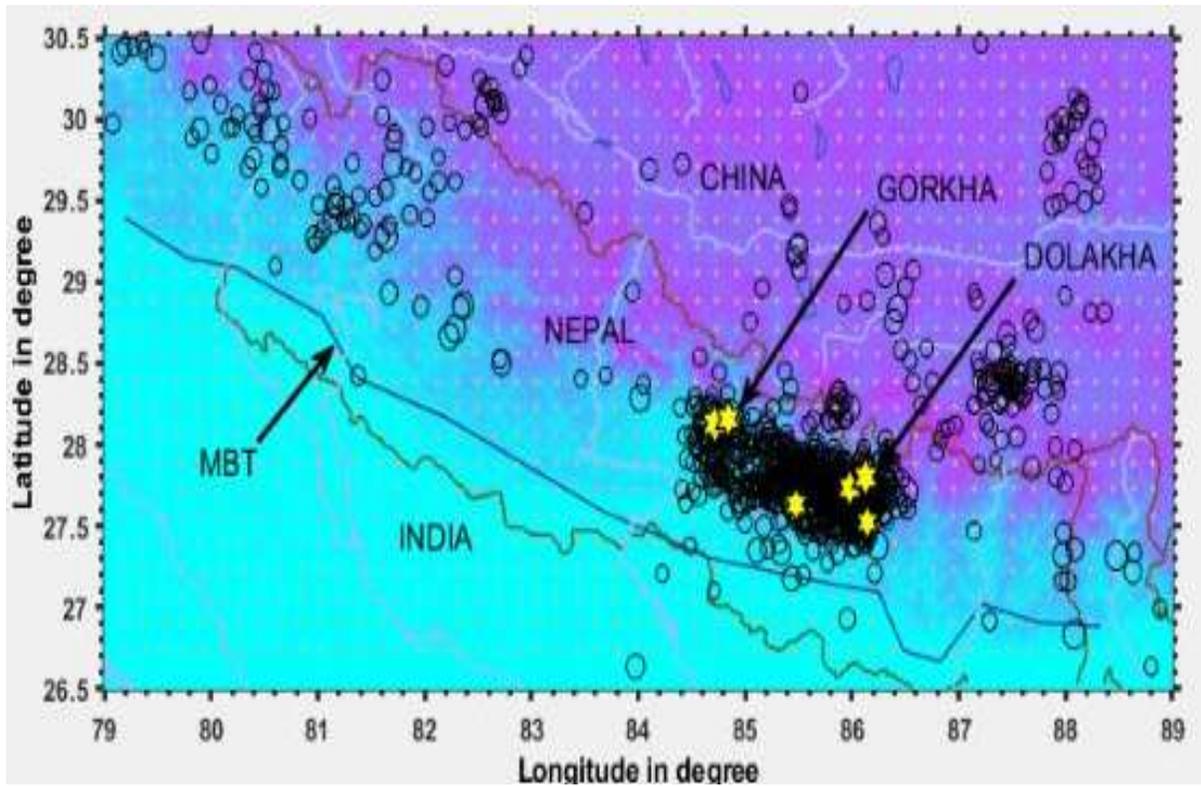


Fig. 1: Map of Central Himalaya and adjoining region showing location of earthquake epicenter from 1 Jan. 2013 to 31 Dec. 2016. Events with magnitude 6 and above are depicted by yellow stars.

of India, Bangladesh and the Tibet [1]. The event was followed by hundreds of aftershocks throughout Nepal, with one shock reaching a magnitude of 6.6 mb on 26 April and the major aftershock of 6.7 mb (7.3 Mw) on 12 May 2015. The Gorkha earthquake ruptured $\sim 150 \times 60$ km patch of the Main Himalayan Thrust (MHT), the decollement defining the plate boundary at depth and locations of aftershocks are at or below the mainshock rupture plane [2]. The seismicity distribution and the cumulative number of events are depicted in Fig. 1 and Fig. 2.

The fundamental seismic parameter used to describe the ensemble of earthquakes is b value of the Gutenberg-Richter distribution which is power law

size distribution described in terms of magnitude [3]. The distribution is

$$\log N(M) = a - bM$$

where $N(M)$ is the number of earthquakes in the group having magnitudes $\geq M$. A constant parameter a is the logarithm of the total number of earthquakes with magnitudes greater than or equal to completeness magnitude that depends on the seismicity rate and the length of the observation time. The b value can be obtained from the slope of frequency magnitude distribution of the earthquakes. The spatial and temporal variation of b value is regarded as key clues for the future large earthquake precursors [4].

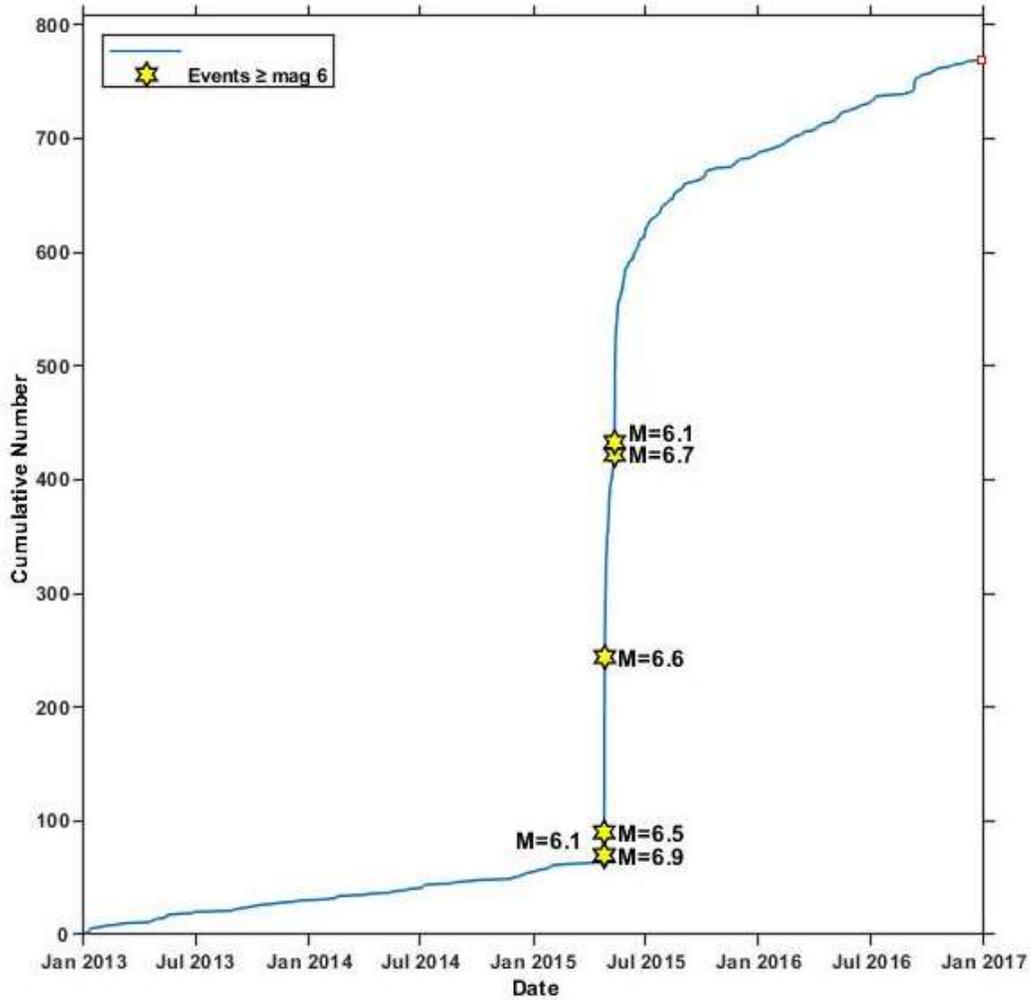


Fig. 2: Time series analysis of 769 earthquake occurred in Central Himalayan compression zone showing events (>6 mb) for the study period.

A high b value means a predominance of small earthquakes while a low b value means that the large earthquake dominates over smaller earthquakes. The b value is also associated with geotectonic features of an area so it has important value in seismology. A decreased in stress results in high b values whereas the increase in applied stress decreases b value [5-7] thus it decreases laterally with depth possibly because of increased stress [8], [9]. Large heterogeneity present in material corresponds to higher b value [10]. Aftershocks have large b values while foreshocks on the other hand show low b -

value [11], [12]. Numerous workers have disclosed that foreshocks before strong earthquakes often have low b -value. The variation of b values before the mainshock usually experience three stages, an increase in the first, followed by a drop and another increase prior to the major event. [13-15]. A decrease in b value is interpreted because of stress increase prior to a seismic event [12], [16]. So, it is especially important to understand the b value of the frequency magnitude distribution. The objective of the study is to examine temporal and spatial variation of b value to understand the stress condition before and after the earthquake.

2. Data and method

A homogeneous earthquake catalogue is a prerequisite for the study of seismic activity of any region. We get 881 earthquake data (≥ 3.2 mb), for the period 1 Jan. 2013 to 31 Dec. 2017) from the catalogue of International Seismological Centre (ISC) for the region 26.5°N - 30.5°N and 79°E - 89°E . Out of these earthquakes, 112 are found to occur in adjoining Tibetan normal faulting environment. Since this study is limited to Himalayan compressive zone, these 112 earthquakes are removed from the catalogue for further study. Thus, the subset of catalogue including 769 events is prepared by considering the earthquake data within central Himalaya and its closed surrounding for the period of 2013-01-01 to 2016-12-31. Gardner and Knopoff [17] algorithm was used for declusterising the catalogue. The catalogue is analyzed by three different approaches. First one is by dividing the catalogue into fixed event window; the second

approach is by dividing catalogue into three different time window and, the third approach is by dividing the catalogue into subsets of depth ranges. The event time windows were prepared by taking 100 events with overlapping of 60 events. The magnitude of completeness (M_c) is computed by the maximum curvature [18] approach using ZMAP-7.1 software [19]. The b-value is calculated by maximum likelihood estimation (MLE) method which is not affected by large magnitude earthquake. The formula [20] for b-value estimation is

$$b = \frac{\log_{10} e}{M_a - \left(M - \frac{\Delta M}{2}\right)}$$

where M_a is average of all magnitudes, M is minimum magnitude in the catalogue and ΔM is binning width of the catalogue. The b-value of all the 769 events is computed as 0.77 ± 0.09 as depicted in Fig. 3.

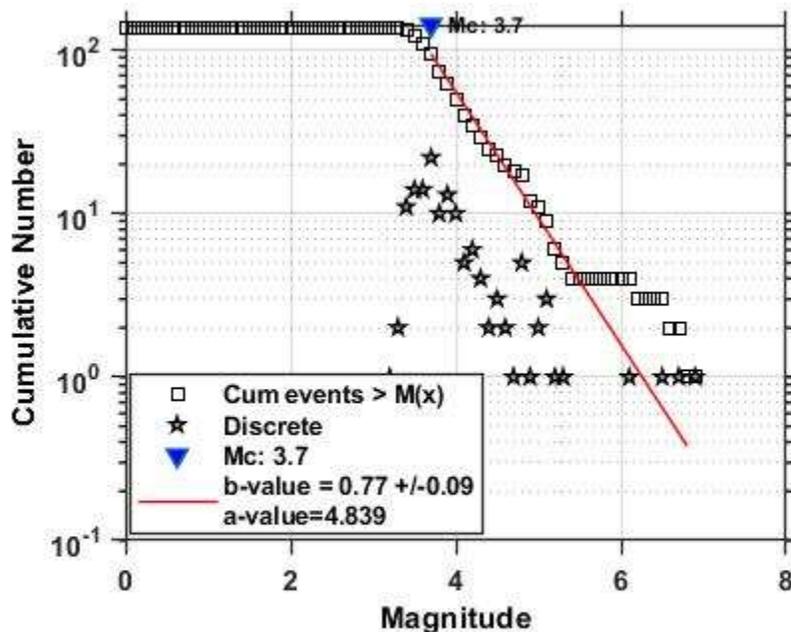


Fig. 3: Frequency magnitude distribution of GR (Gutenberg Richter) relationship for the earthquake sequences for the period Jan. 2013 to Jan. 2017 where cum events in legend is for cumulative number of events and discrete is for discrete events.

Frequency magnitude distribution of GR and after Dolakha earthquake (from 12 May 2015 to 31 Dec. 2017) are shown in Figs. 4, 5 and 6 respectively. The b-value is observed to increase ~ 17% within 17 days between the Gorkha earthquake and Dolakha earthquake (Fig. 7).

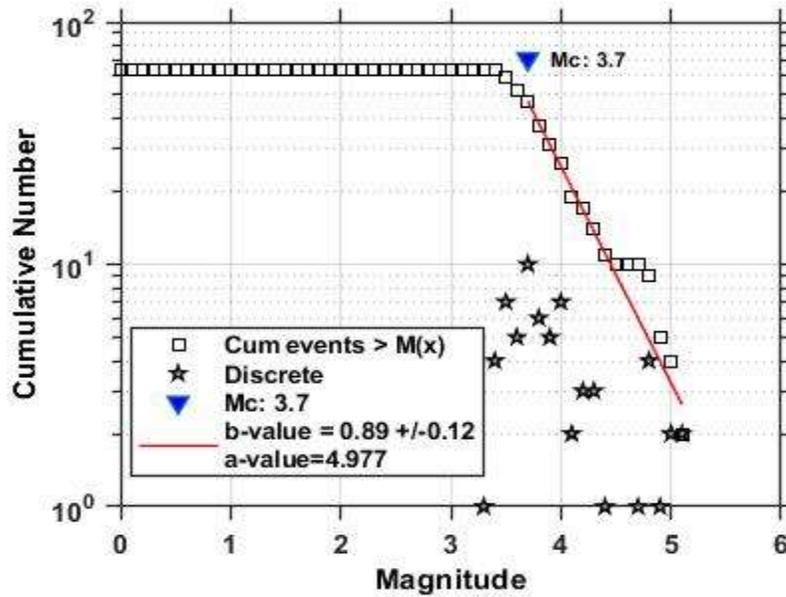


Fig. 4: Frequency magnitude distribution of GR relationship for the earthquake sequences (from 1 Jan. 2013 to 25 April 2015) before the Gorkha earthquake of Mw 7.8 where cum events in legend is for cumulative number of events and discrete is for discrete events.

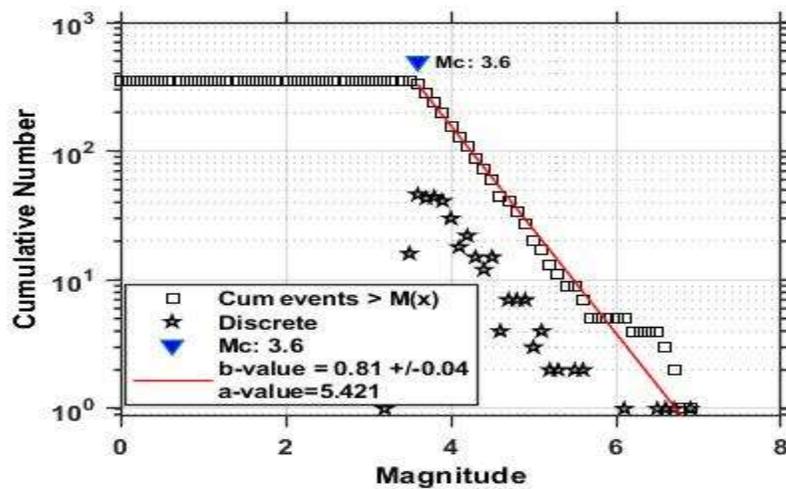


Fig. 5: Frequency magnitude distribution of GR relationship for the earthquake sequences (from 25 April to 12 May 2015) between Gorkha earthquake and Dolakha earthquake where cum events in legend is for cumulative number of events and discrete is for discrete events.

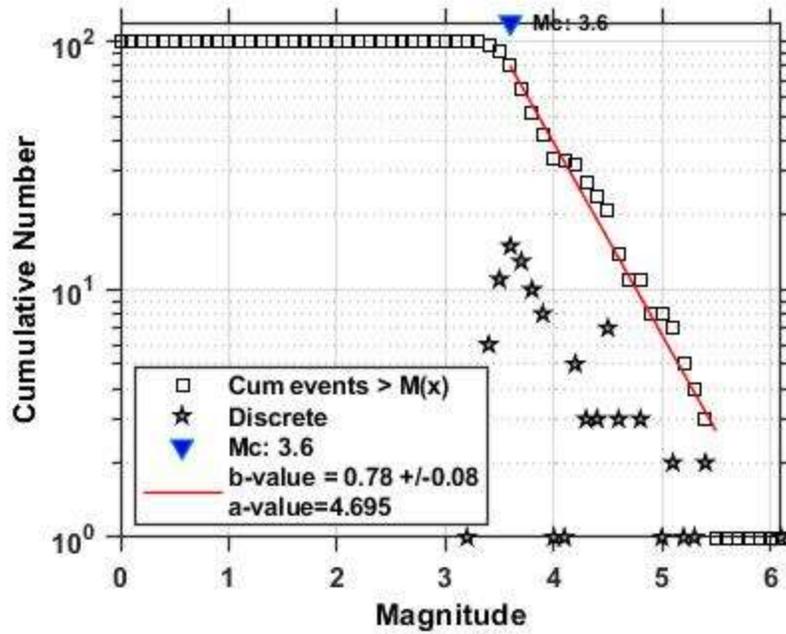


Fig. 6: Frequency magnitude distribution of GR relationship for the earthquake sequences (from 12 May 2015 to 31 Dec. 2017) after Dolakha earthquake where cum events in legend is for cumulative number of events and discrete is for discrete events.

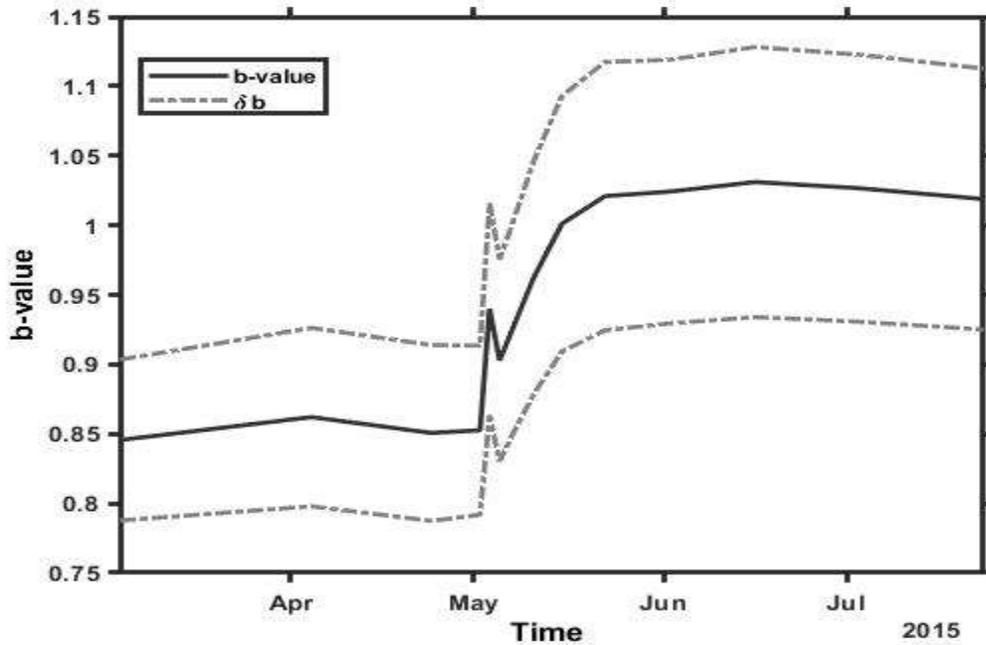


Fig. 7: Time series analysis of b-value over the study period showing sudden jumps of b-value after the 25 of April 2015 Gorkha earthquake.

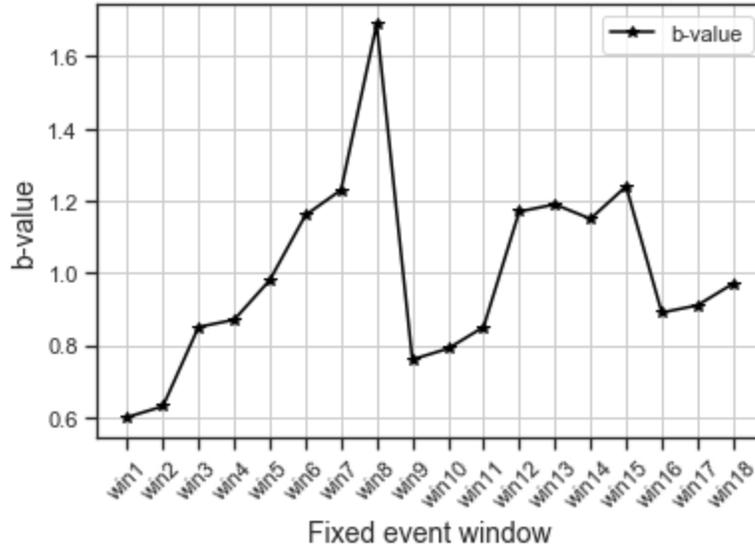


Fig. 8: Variation of b-value with time window. For time window 1 (2013/01/01 - 2015/04/25) b-value is lowest indicating the accumulation of stress and for time window 8 (2015/04/26 - 2015/05/03) b-value rises to 1.69 indicating release of stress after the large earthquake.

3. Results and Discussion

Seismic b-value for fixed 100 events window with overlapping of 60 events is given in Table 1. The lowest b-value was observed as 0.60 ± 0.07 and 0.63 ± 0.06 for first and second windows, prior to and during the Gorkha earthquake (6.9 mb). It was 0.79 ± 0.08 for the period 2015/05/01-2015/05/12 during which 6.7 mb Dolakha earthquake occurred in the region. After the Gorkha earthquake, the b-value was increased to 0.85 ± 0.08 and further up to 1.69 ± 0.23 . The b-value was found increased even after the Dolakha earthquake up to 1.19 ± 0.14 (Table 1). Thus, the results agree with hypotheses that b-value decreases before a strong event and increases after the event (Fig. 8). The increase in b-value indicates the releasing of the accumulated strain in the region. The frequency magnitude distribution (FMD) plots for the earthquake sequences are depicted in the Figs. 3, 4, 5 and 6. The b-value is 0.77 ± 0.09 for the entire study period. It was 0.89 ± 0.12 before the earthquake (2013/01/01-2015/04/23). It was computed 0.81 ± 0.04 between the Gorkha earthquake and Dolakha earthquake (2015/4/25-2015/5/12) and 0.78 ± 0.08 after the

earthquake (2015/05/12-2016/12/31). The most dominant range of earthquake magnitude in this period is indicated by a-value variation of 4.977 to 5.421 (Table 2). The low b-value for aftershock sequences may correspond to the generation of enormous size asperities in the hypocentral area of the MHT [21] by the mainshock. These observed b-values indicate that it is increasing after the Dolakha earthquake showing the gradual release of stress in the region. The b-value variation with the depth range is given in Table 3. By dividing the full depth range (0 km-100 km) into two groups (0-40 km and 30-100 km), the b-value estimation shows variation from 0.83 ± 0.03 to 1.29 ± 0.16 respectively, indicating high strain accumulation in the crust. It is also the indication of more heterogeneous stress distribution in the depth range 0-40 km compared to the depth below 30 km. For the depth ranges of 10 km, the smallest b-value is 0.65 ± 0.08 for the depth range 20 km to 30 km and the highest b-value is 1.42 ± 0.17 for the depth range 30 km to 40 km. The lowest b-value for the depth range 20-30 km may be because of increased applied stress at greater depth [8], [9]. The higher b-value (1.16 ± 0.09) for the 0-10

km range suggests higher heterogeneity. It may also indicate the low strength of rock's that are present in the crust [22]. The depth versus b-value analysis for the region shows a continuous decrease from 0 km to 30 km (Table 3). The b-value observed lower than the global b value of 1.0 from 10 km to 30 km reveal a highly differential stressed regime [9]. These observations also indicate the reverse relationship

between b-value and differential stress in the crust. The Gorkha earthquake exposed an asymmetric fault rupture scattering eastward from the epicenter [23]. The observed low b-value patch in the region (Fig. 9) in conjunction with asymmetric fault rupture indicates the possibility of future earthquakes in the west of epicenter of the Gorkha earthquake.

Table 1: Seismic b-value for fixed 100 events window with overlapping of 60 events.

Window	No. of events	Time period	Depth range (km)	Magnitude range	M _c	b-value
1	100	2013/01/01 - 2015/04/25	2.70 - 99.0	3.3 - 6.9	4.0	0.60±0.07
2	100	2014/07/03 - 2015/04/25	3.50 - 99.0	3.3 - 6.9	4.0	0.63±0.06
3	100	2015/04/25 - 2015/04/25	3.50 - 28.7	3.4 - 6.5	4.0	0.85±0.08
4	100	2015/04/25 - 2015/04/25	3.50 - 28.7	3.2 - 5.2	3.7	0.87±0.08
5	100	2015/04/25 - 2015/04/26	7.90 - 28.7	3.2 - 6.6	3.7	0.98±0.12
6	100	2015/04/25 - 2015/04/27	4.50 - 22.8	3.2 - 6.6	3.9	1.16±0.21
7	100	2015/04/26 - 2015/04/29	4.50 - 22.8	3.4 - 6.6	3.8	1.23±0.19
8	100	2015/04/26 - 2015/05/03	7.60 - 35.0	3.4 - 4.8	3.8	1.69±0.23
9	100	2015/04/28 - 2015/05/11	4.50 - 19.60	3.4 - 5.2	3.8	0.76±0.22
10	100	2015/05/01 - 2015/05/12	2.20 - 35.0	3.5 - 6.7	3.6	0.79±0.08
11	100	2015/05/07 - 2015/05/12	2.20 - 20.30	3.4 - 6.7	3.9	0.85±0.11
12	100	2015/05/12 - 2015/05/15	0.70 - 35.0	3.4 - 5.2	3.9	1.17±0.14
13	100	2015/05/12 - 2015/05/27	0.70 - 35.0	3.4 - 5.6	3.9	1.19±0.14
14	100	2015/05/13 - 2015/07/01	4.50 - 35.0	3.4 - 5.6	3.9	1.15±0.15
15	100	2015/05/21 - 2015/09/02	4.50 - 35.0	3.4 - 5.1	3.9	1.24±0.14
16	100	2015/06/15 - 2016/02/23	5.70 - 100.0	3.2 - 5.3	3.6	0.89±0.08
17	100	2015/07/30 - 2016/08/27	5.70 - 100.0	3.2 - 5.3	3.7	0.91±0.09
18	89	2015/11/29 - 2015/12/31	0.70 - 68.0	3.2 - 5.4	3.6	0.97±0.12

Table 2: Seismic b-value and a value comparison for different period

SN	No of events	Time duration	M _c	b-value	a-value
1	769	2013-01-02 - 2016-12-28	3.7	0.77±0.09	4.839
2	68	2013/01/02 - 2015/04/23 (Before Mainshock)	3.7	0.89±0.12	4.977
3	354	2015/4/25-2015/5/12 (Between mainshock and largest aftershock)	3.6	0.81±0.04	5.421
4	430	2015/05/12 - 2016/12/31 (After Dolakha earthquake)	3.6	0.78±0.08	4.695

Table 3: Seismic b-value at different depths

Depth	Mean Longitude	Mean Latitude	No. of events	M_c	b-value
0-10	84.95	28.00	345	3.8	1.16 ± 0.09
10-20	85.21	27.95	713	3.7	0.89 ± 0.04
20-30	83.42	28.78	55	3.6	0.65 ± 0.08
30-40	84.33	28.55	123	3.5	1.42 ± 0.17
0-40	85.07	28.02	957	3.6	0.83 ± 0.03
30-100	84.65	28.49	143	3.5	1.29 ± 0.16

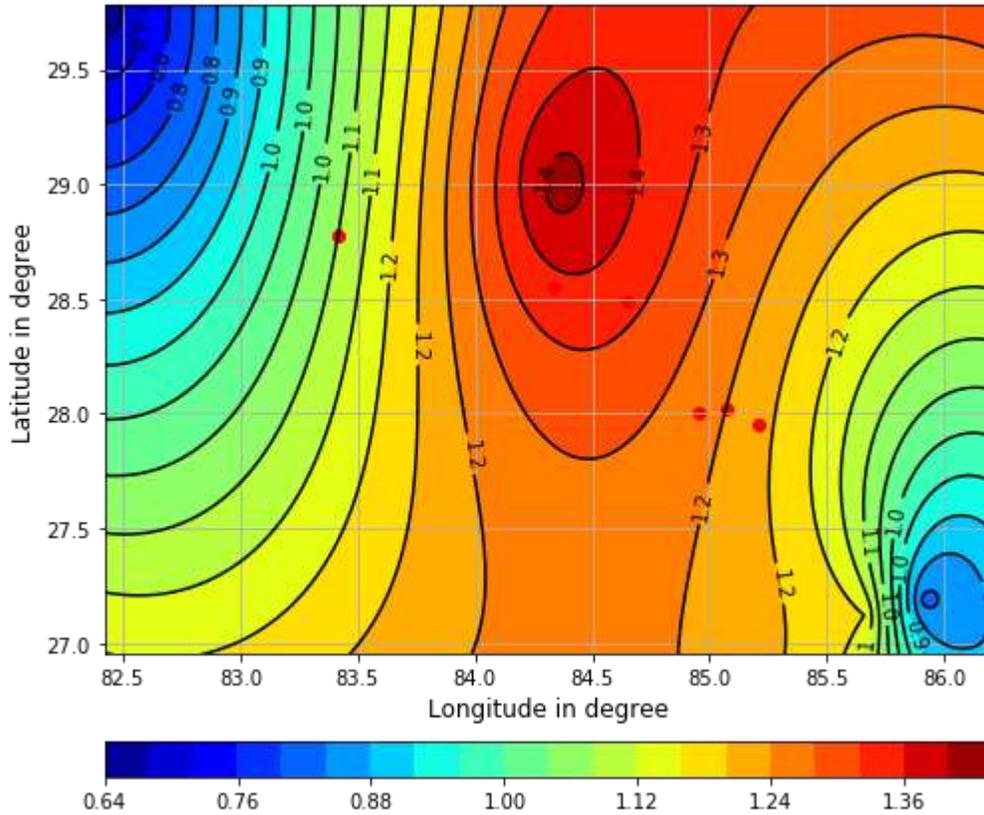


Fig. 9: Contour map for b-value variation with depth. Solid dots are b-value plotted for mean longitude and latitude (Table 3)

4. Conclusion

The statistical parameter b-value of GR relation has been investigated. The b-value for the overall study period was found to be 0.77 ± 0.09 . Before the Gorkha earthquake, it was computed as 0.89 ± 0.12 . The b-value for the period between the Gorkha earthquake and the Dolakha earthquake was noted as 0.81 ± 0.04 . It was found decreasing even after the Dolakha earthquake as 0.78 ± 0.08 . The distinct drop

of b-value before two strong events is the exhibition of rupture nucleation points of stressed region of Himalaya. The analysis of b-value based on fixed event window shows gradual increase after the Gorkha earthquake and reaches the maximum value of 1.69 ± 0.23 and again drops to the low value of 0.76 ± 0.22 . Thus, there is a sudden variation of b-value within a noticeably brief period of 17 days.

The b -value for depth range indicates the presence of heterogeneous crust with differential stress in the region. This observation of variation of b -value with depth agrees with other studies in various parts of the world. The contour map (Fig. 9) shows low b -value patch west of Gorkha region which could be the region of future seismic activity. This study presents the stress level in the region before and after the Gorkha earthquake in terms of earthquake

precursor parameter b -value of earthquake frequency magnitude distribution.

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