



# Understanding the Variation of Seismicity in the Eastern Himalayas: Using Earthquake Frequency-Magnitude Distribution and Fractal Dimension



Understanding the Variation of Seismicity in the Eastern Himalayas: Using Earthquake Frequency-Magnitude Distribution and Fractal Dimension

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MOTIVATION & OBJECTIVE

Motivation

3P's model: Prediction, Preparation, Prevention

- 1. Eastern Himalayas region is tectonically very active. It is important to understand the frequency-magnitude relationship of the earthquakes and fractal dimension for assessing the seismic risk in this region.
- 2. The 2011 (Mw=6.3), Mikin and 2015 (Mw=7.3) Gorkha Nepal earthquakes call attention to the need for a more accurate understanding.

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MODEL DESCRIPTION

Seismicity Model


The fractal dimension (D<sub>f</sub>) is used as a quantitative measure of the degree of heterogeneity of seismic activity in sub-tectonic elements of a region.

$D_f = \frac{\log(N)}{\log(R)}$

$N = 2N_{max} - 1$

N = Number of events clustered into one point, and higher D<sub>f</sub> value indicates that the events are randomly or homogeneously distributed over a two-dimensional confining space.

METHODOLOGY



- Inverted (2008) equation used to convert the earthquake magnitudes into moment magnitudes (M<sub>w</sub>).
- The slope then suggested by Benettung (1982) has been used for de-clustering.
- Based on earthquake observations and seismic features, 8 seismic zones were delineated (EZ1, EZ2, EZ3, EZ4, EZ5, EZ6, EZ7, EZ8).
- The values for 8 seismic zones are calculated using MATLAB software (Wolmer, 2005).
- Due to the lack of available earthquake data, the D<sub>f</sub> of zones EZ2, EZ5, EZ7 and EZ8 are not calculated.


RESULTS

- Seismic activity parameters (M<sub>w</sub>-t) is maximum for Zone EZ3 (2.80) and minimum for EZ7 (0.37).
- The return period for an earthquake of magnitude (M=5) is minimum for EZ3 (13.7 years) and maximum for EZ1 (36.4 years).
- The calculated value of fractal correlation dimension D<sub>f</sub> varies from 2.33 to 2.37, which shows that this region has a high D<sub>f</sub> value.
- D<sub>f</sub> value changes between 0.75 and 1.11. Lower D<sub>f</sub> value (0.75) is calculated for seismic zone EZ7 and seismic zone EZ2 exhibited the highest D<sub>f</sub> value (1.11).
- We found a negative correlation between b and D<sub>f</sub> values (R<sub>s</sub> = -0.7026 > 0.821).

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STUDY AREA

- High tectonicity of Eastern Himalayas is due to the collision of the Indian plate and the Eurasian plate.
- 525 independent earthquake events of magnitude M<sub>w</sub> > 2 during 1989-2015.
- The maximum magnitude (M<sub>w</sub>=7.3), occurred at Mikin - Nepal border in 2015.
- The important tectonic features in this seismic belt are MBT and NCT.



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CONCLUSIONS

- The seismic zone (EZ2) of the study area is found out to be the most seismically active zone.
- Obtained variation in b value (0.75-1.11) and high D<sub>f</sub> value indicates that all the seismic zones in the Eastern Himalayas are seismically active, and the depths are homogeneously distributed within the actual tect plane.
- A negative correlation between b and D<sub>f</sub> value implies increased accumulated stress and distributed earthquake clustering.
- Low b value of the zone EZ1 and EZ7

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ABSTRACT
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# MOTIVATION & OBJECTIVE

## Motivation

### **3P's model-Prediction; Preparation; Prevention**

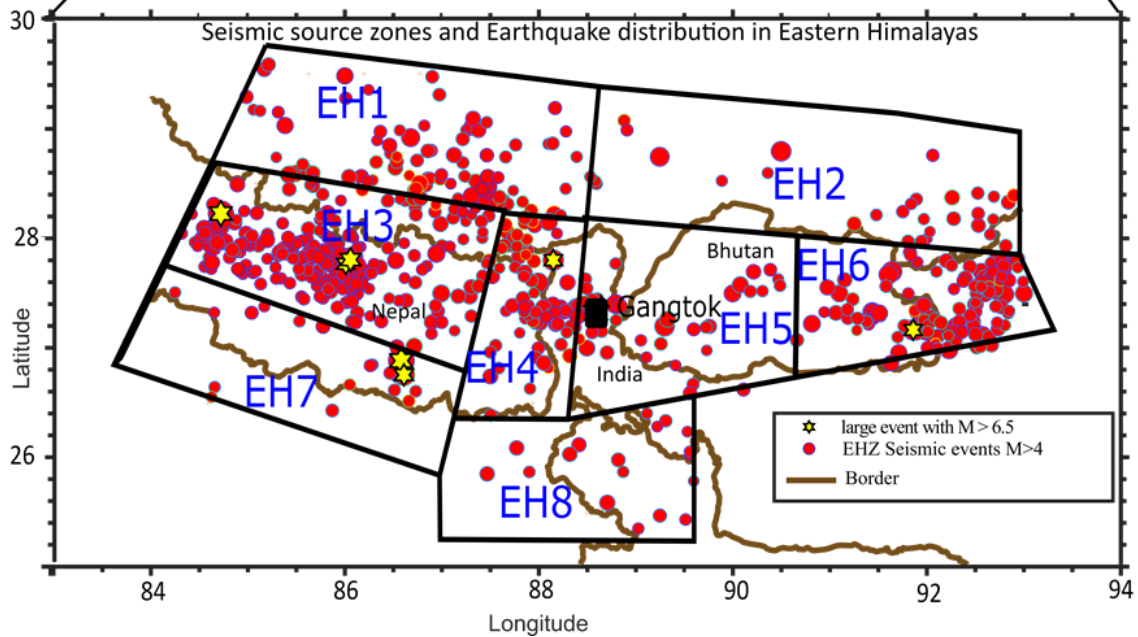
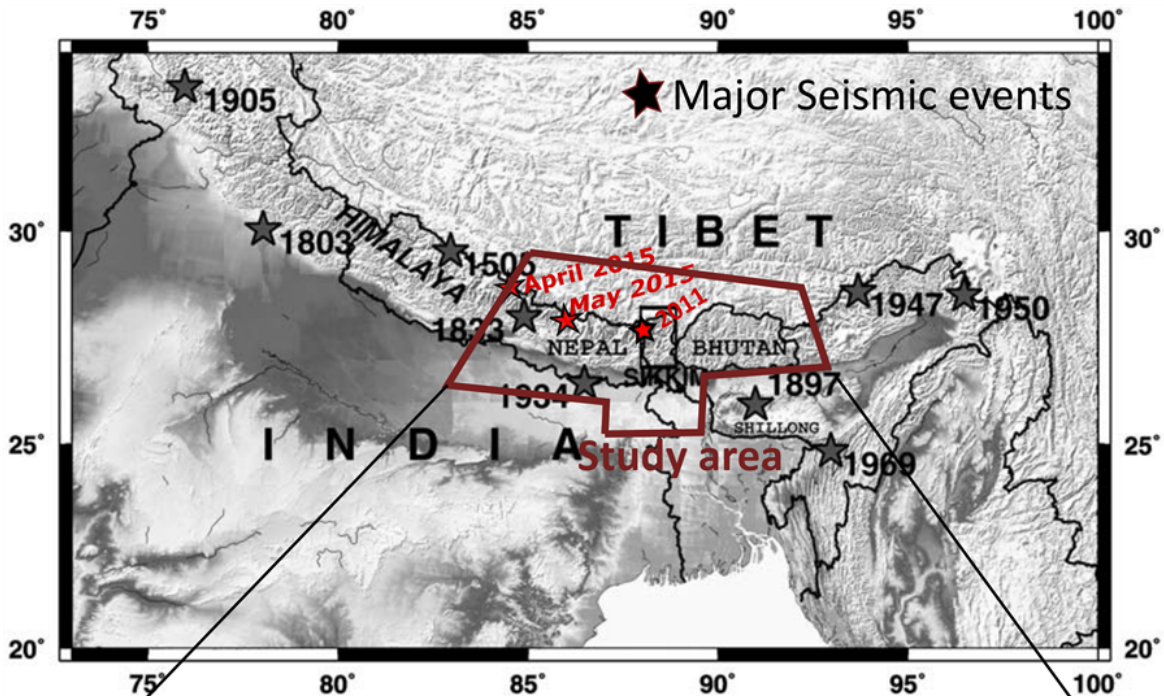
- Eastern Himalayan region is tectonically very active. It is important to understand the frequency–magnitude relationship of the earthquakes and fractal dimension for assessing the Seismic risk in this region.
- The 2011 (Mw= 6.9) Sikkim and 2015 (Mw= 7.8) Gorkha Nepal earthquakes call attention to the need for a more accurate understanding of seismic characteristics in the Eastern Himalayan region.

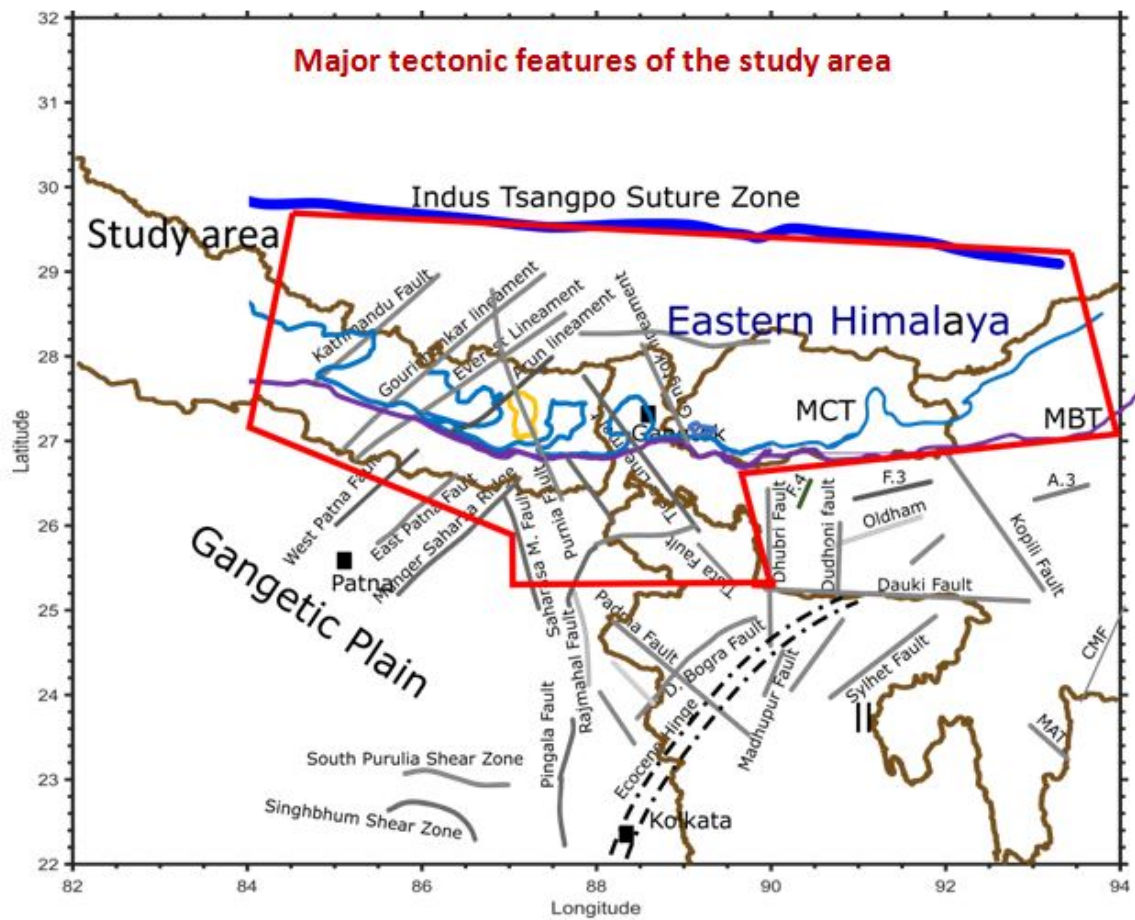
## Objective

- Delineation of Seismic Source Zone.
- FMD Coefficients calculation.
- Fractal Dimension (Dc) Calculation.
- Calculation of seismic parameters required for hazard analysis.

# STUDY AREA

- High seismicity of Eastern Himalayas is due to the collision of the Indian plate and the Eurasian plate.
- 529 independent earthquake events of magnitude  $M_w \geq 4$  during 1900-2018.
- The maximum magnitude ( $M_w=8$ ), occurred at Bihar – Nepal border in 1934.
- The important seismogenic features in this seismic belt are MBT and MCT.





# MODEL DESCRIPTION

## Seismicity Model

A Modified Gutenberg–Richter (MGR)–Poisson model is chosen as a seismicity model.

$$\lambda(M) = \lambda_0 \frac{\exp(-\beta M) - \exp(-\beta M_{\max})}{\exp(-\beta M_0) - \exp(-\beta M_{\max})} \quad (\text{Cornell and Van Marke 1969}) \quad (1)$$

$$M_0 \leq M \leq M_{\max}$$

$\lambda_0$  - Mean rate of seismic activity having a threshold magnitude,  $M_0$  (here,  $M_0 = 4.0$ ),

$\beta$ - Parameter comparable to the b value ( $\beta = 2.303b$ ), 'b' value represents the relative number of small and large earthquakes. Higher b-value indicates that the frequency of low-magnitude earthquakes is high and vice-versa.

The Gutenberg–Richter b value and  $\lambda_0$  is calculated by utilizing the joint likelihood function suggested by Kijko et al. (2016).

$M_{\max}$  is calculated utilizing the Bayesian extension of the K-S-B estimator (Kijko 2004).

The fractal dimension ( $D_c$ ) is used as a quantitative measure of the degree of heterogeneity of seismic activity in seismotectonic elements of a region.

$$D_c = \lim_{r \rightarrow 0} [\log C(r) / \log r]$$

$$C(r) = 2 N_{R < r} / N(N-1)$$

$C(r)$  - Correlation function

$r$  - Distance between two epicenters

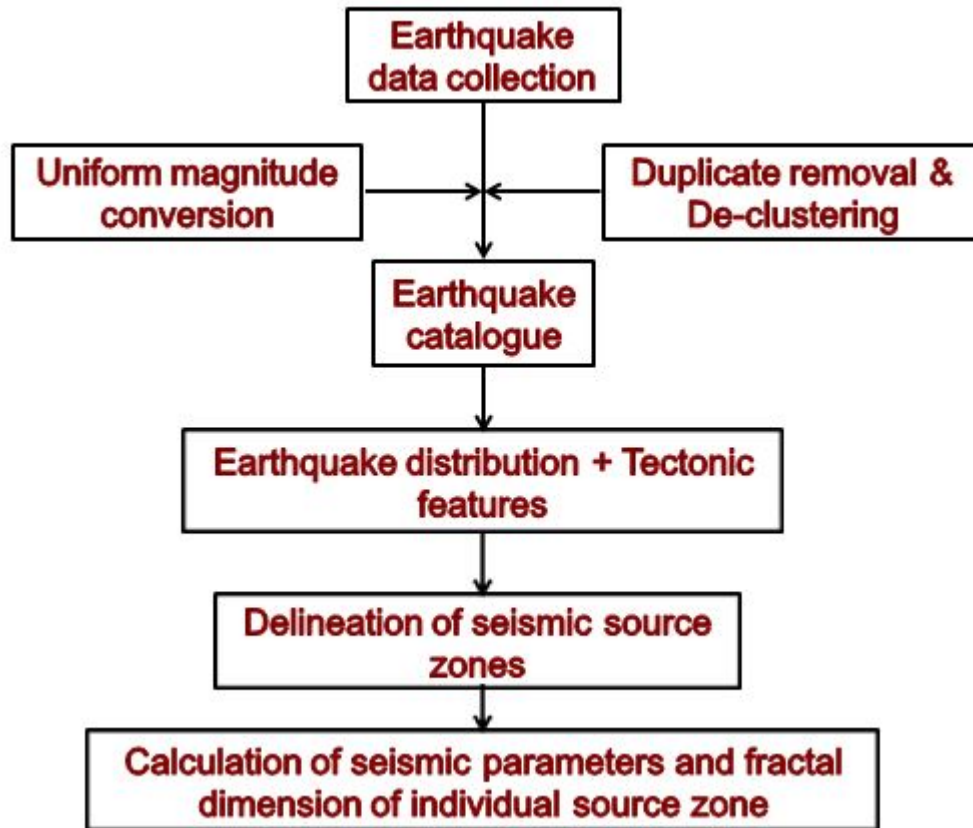
$N$  - Number of event pairs separated by a distance  $R < r$

If the epicenter distribution has a fractal structure, following relation is obtained

$$C(r) \sim r^{D_c}$$

$D_c \rightarrow 0$  means all the events clustered into one point, and higher  $D_c$  value indicates that the events are randomly or homogeneously distributed over a two-dimensional embedding space.

## METHODOLOGY

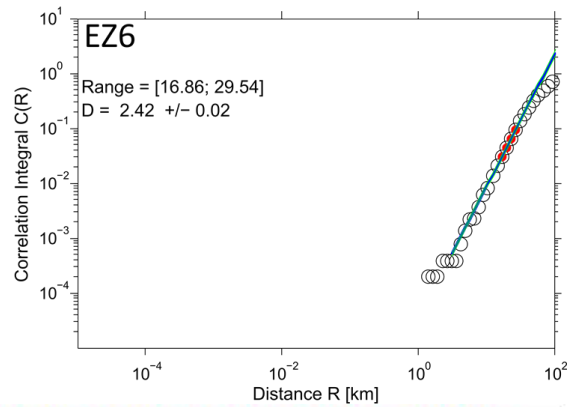
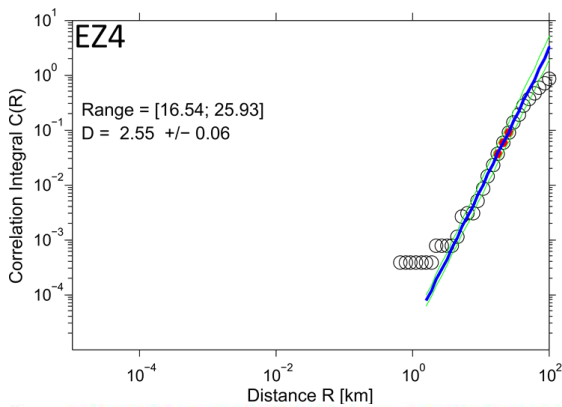
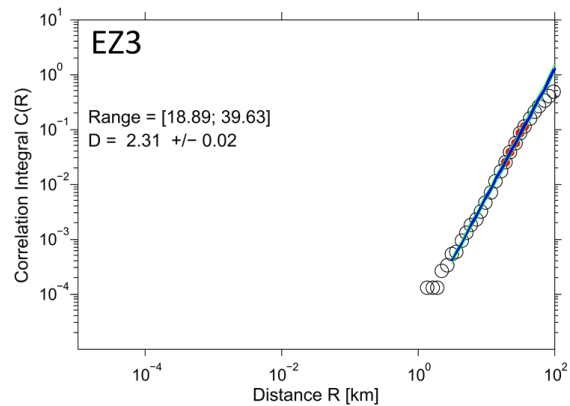
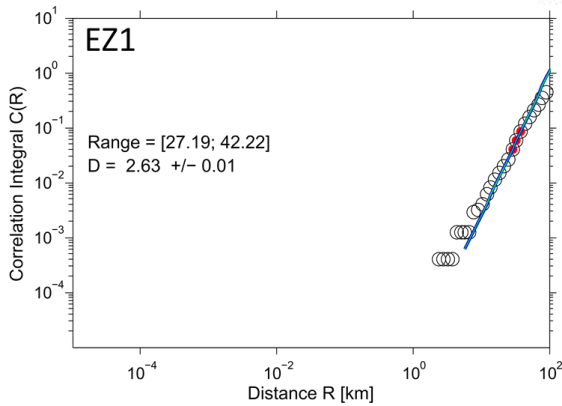
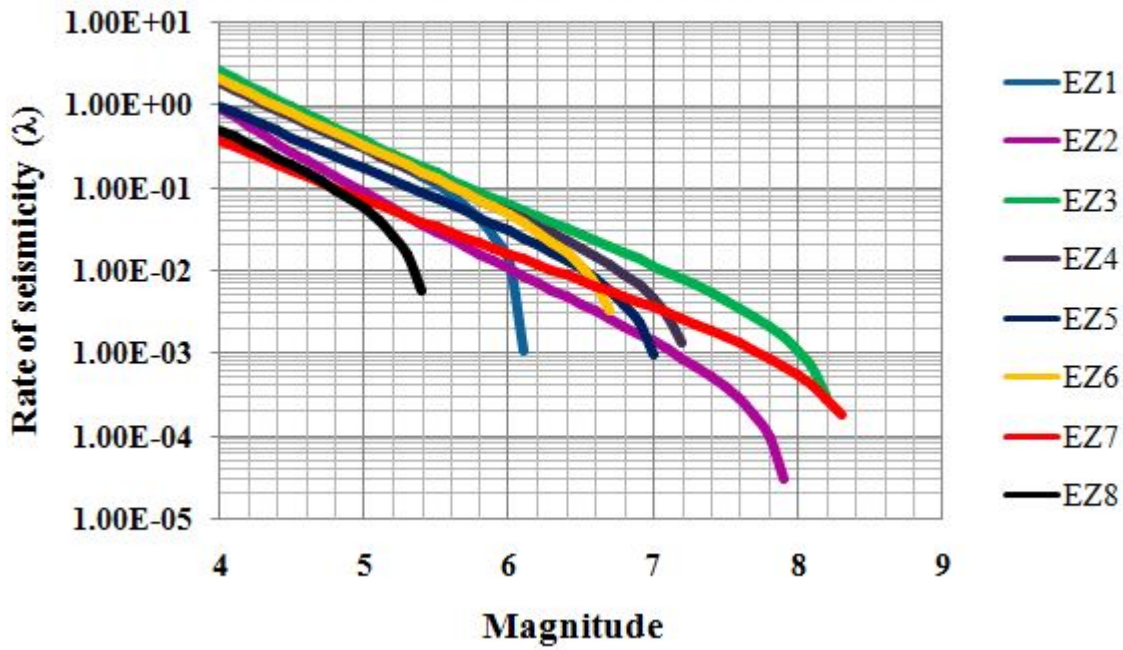


- Scordilis (2006) equation [used](#) to convert the earthquake magnitudes into moment magnitude ( $M_w$ ).
- The algorithm suggested by Reasenberg (1985) has been used for declustering
- Based on earthquake distribution and tectonic features 8 seismic source zones are delineated (EZ1, EZ2, EZ3, EZ4, EZ5, EZ6, EZ7, EZ8)
- Dc-values for 8 seismic zones are calculated using ZMAP software (Wiemer, 2001).
- Due to the lack of available earthquake data, the Dc of zones EZ2, EZ5, EZ7 and EZ8 are not calculated.

## RESULTS

- Seismic activity parameter ( $\lambda M=4$ ) is maximum for Zone EZ3 (2.60) and minimum for EZ7 (0.37).
- The return period for an earthquake of magnitude ( $M=6$ ) is minimum for EZ3 (15.7 years) and maximum for EZ2 (90.4 years).
- The calculated value of fractal correlation dimension  $D$  varies from 2.3 to 2.7, which shows that this region has a high  $D$  value.
- $b$ -value changes between 0.75 and 1.11. Lowest  $b$  value (0.75) is calculated for Seismic Zone EZ7 and seismic zone EZ2 exhibited the highest  $b$  value (1.11).
- We found a negative correlation between  $b$  and  $D_c$  values ( $D_c = -2.560b + 4.621$ ).
- Seismic Zone EZ1 showed comparatively low  $b$  and high  $D_c$  values. Conversely, seismic zone EZ3 exhibited high  $b$  and low  $D_c$  values.

## Seismic activity of individual source zone

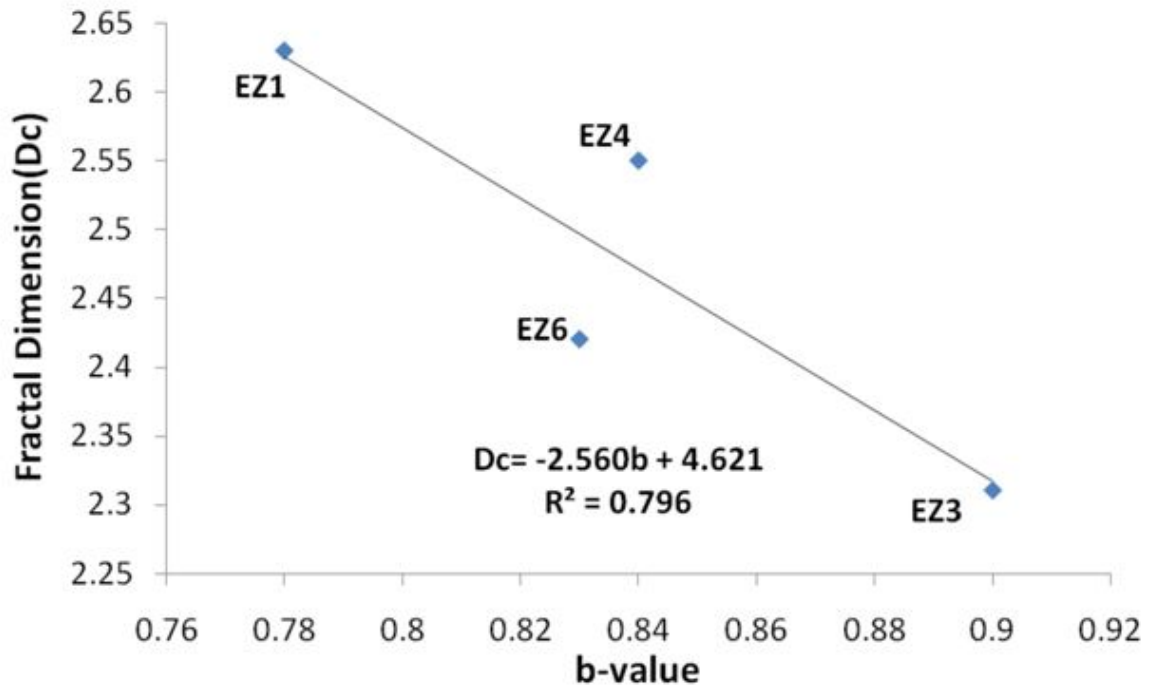


<b>Seismic parameters of source zones considered in the Eastern Himalayas</b>									
Seismic Zone	No. of EQ	Return Period (Yrs) M=6	$\lambda_{M=4}$	Dc	SE of Dc	b	SE of b	$M_{max}^{obs}$	$M_{max}$
EZ1	71	79.2	2.09	2.63	0.01	0.78	0.09	6	6.11
EZ2	34	90.4	0.94	NA	NA	1.11	0.17	6.43	7.95
EZ3	175	15.7	2.60	2.31	0.02	0.9	0.06	7.8	8.3
EZ4	73	19.7	1.86	2.55	0.06	0.84	0.07	6.7	7.3
EZ5	38	32.9	1	NA	NA	0.78	0.14	6.5	7.08
EZ6	102	21.1	2.1	2.42	0.02	0.83	0.09	6.2	6.8
F77	18	63	0.37	NA	NA	0.75	0.23	8	8.5



EZ8	18	NA	0.51	NA	NA	0.79	0.3	5.29	5.47
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### D<sub>c</sub> versus b-value plot



## CONCLUSIONS

- The seismic zone (EZ3) of the study area is found out to be the most seismically active zone.
- Obtained variation in b value (0.75-1.11) and high Dc value indicates that all the seismic zones in the Eastern Himalayas are seismically active, and earthquakes are homogeneously distributed within the aerial fault plane.
- A negative correlation between b and Dc value implies increased accumulated stress and decreased earthquake clustering.
- Low b value of the zone EZ1 and EZ7 indicates increased accumulated stress, so these zones are susceptible to earthquake events with high magnitude.
- Seismic parameters calculated (table 1) for each source zone may be used seismic hazard analysis of the study area.

# ABSTRACT

The Eastern Himalayan region, along with its neighboring area is known to be the part of the 'Alpine-Himalayan global seismic belt', a seismically active area of the world. In the past (1897, 1905, 1934, and 1950) four great earthquakes have triggered in this region with a magnitude higher than  $M_w=8.0$ . The 2011 ( $M_w=6.9$ ) Sikkim and 2015 ( $M_w=7.8$ ) Gorkha Nepal earthquakes call attention to the need for a more accurate understanding of seismic characteristics in the Eastern Himalayan region. In the present study, analysis of spatial variation of seismic activity in the Eastern Himalayas and its surroundings is done by analyzing the variation of seismic parameters and fractal dimension ( $D_c$ ). Considering the seismicity data and tectonic features, the eastern part of the Himalayas is divided into eight seismic source zones. For the comparison of the seismicity between each seismic source zone, seismic parameters like average seismic activity rate at threshold magnitude ( $\lambda_0$ ), maximum possible earthquake magnitude ( $M_{max}$ ), and 'b-value' are calculated. Seismic parameters of seismic zones are calculated by considering the incompleteness of earthquake catalogue, for that sub-catalogue is prepared for each seismic zone, which is complete to the different threshold of magnitude. The seismotectonic stress variations in Eastern Himalayas are indicated by the estimated values of b and  $D_c$ . The calculated seismic parameters can be used directly for seismic hazard analysis of the study area.

*Keywords:* Eastern Himalayas; Seismicity; Fractal dimension; Seismic source zone

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