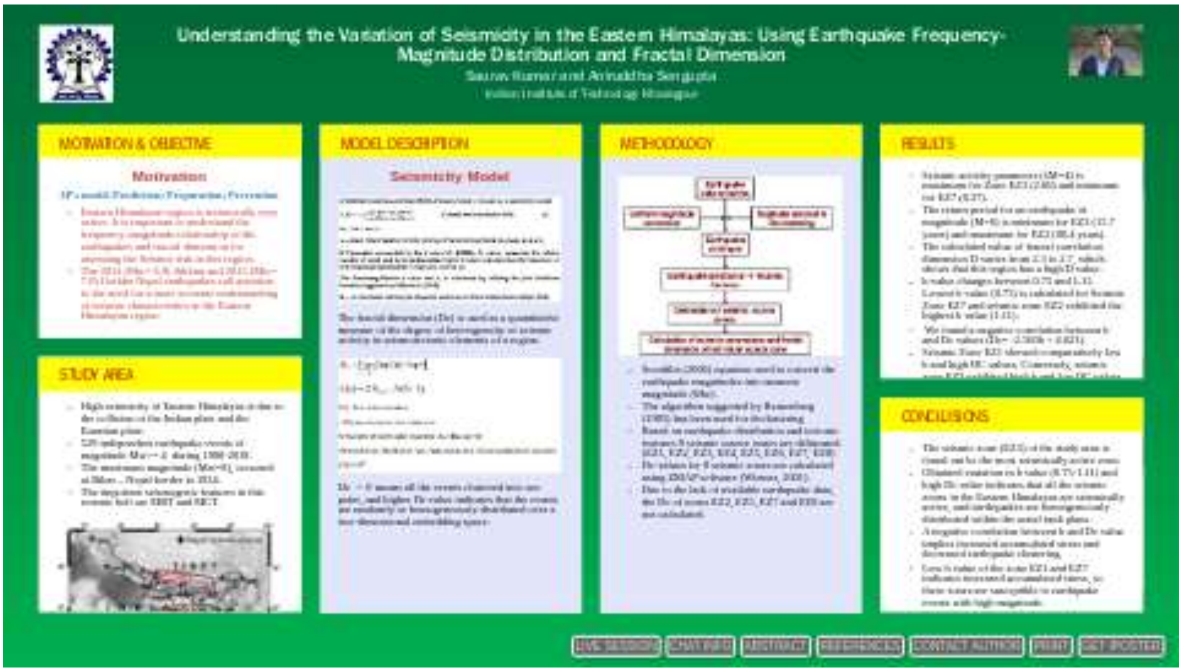
Understanding the Variation of Seismicity in the Eastern Himalayas: Using Earthquake Frequency-Magnitude Distribution and Fractal Dimension



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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 (λ_o), 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

MOTIVATION & OBJECTIVE

Motivation

3P's Model-Prediction; Preparation; Prevention

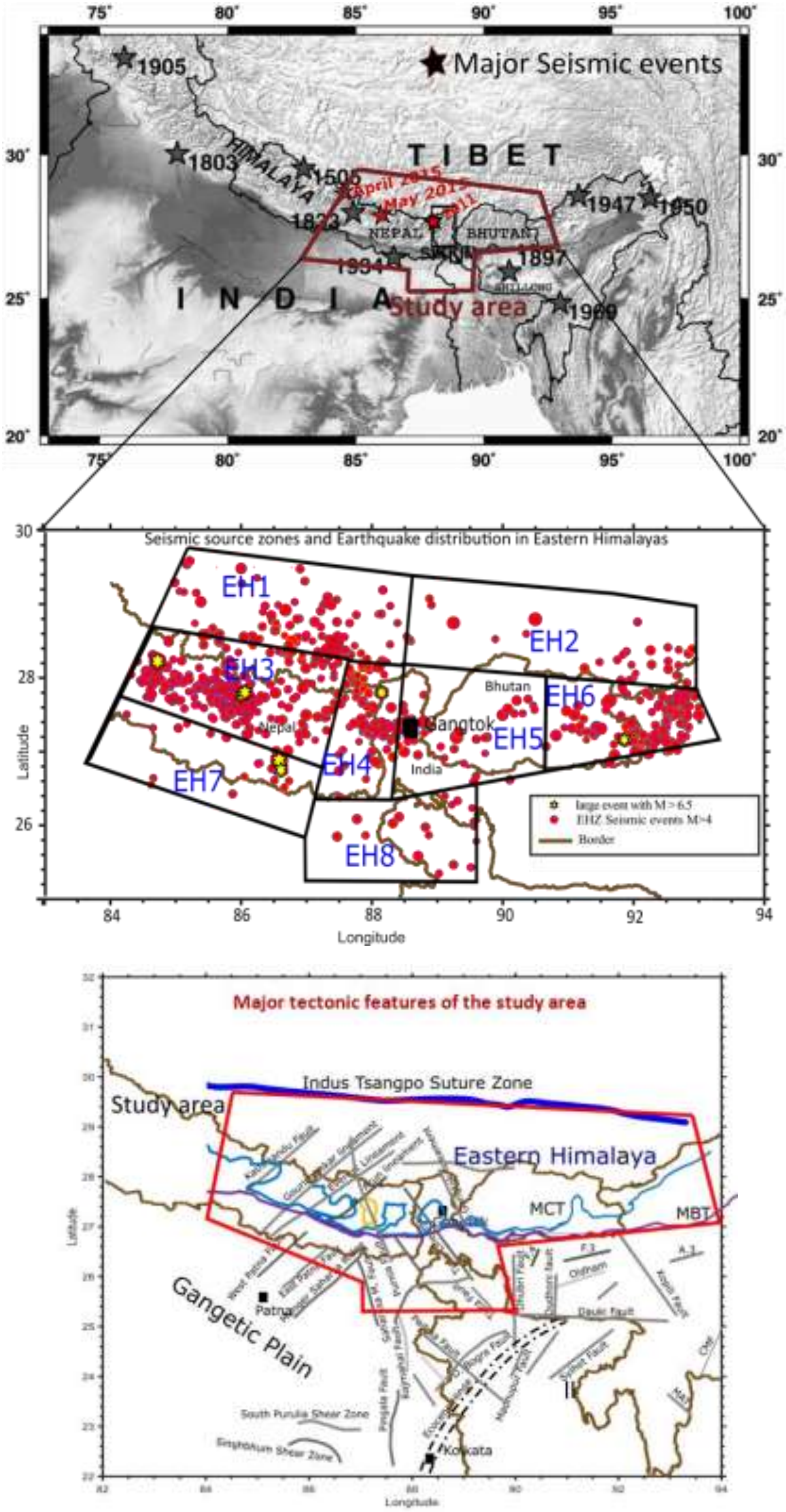
- Eastern Himalayan region is tectonically very active. It is important to understand the frequency–magnitude relationship of the earthquakes and fractal dimension for assessing the Seismic risk in this region.
- The 2011 (Mw= 6.9) Sikkim and 2015 (Mw= 7.8) Gorkha Nepal earthquakes call attention to 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 Mw>= 4 during 1900-2018.
- The maximum magnitude (Mw=8), occurred at Bihar – Nepal border in 1934.
- The important seismogenic features in this seismic belt are MBT and MCT.


Major Seismic events
TIBET
HIMALAYA
NEPAL
BHUTAN
INDIA
Study area
April 2015
May 2015
2011
1905
1803
1505
1833
1934
1897
1947
1950
1969
SHILLONG
Seismic source zones and Earthquake distribution in Eastern Himalayas
EH1
EH2
EH3
EH4
EH5
EH6
EH7
EH8
Gangtok
Bhutan
Nepal
India
large event with M > 6.5
EHZ Seismic events M>4
Border
Latitude
Longitude
Major tectonic features of the study area
Indus Tsangpo Suture Zone
Study area
Eastern Himalaya
MCT
MBT
Gangetic Plain
Patna
Kolkata
Dauki Fault
Oldham
South Purulia Shear Zone
Singhbhum Shear Zone
Latitude
Longitude

MODEL DESCRIPTION

Seismicity Model

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

$$\lambda(M) = \lambda o \frac{\exp(-\beta M)-\exp(-\beta Mmax)}{\exp(-\beta Mo)-\exp(-\beta Mmax)} \quad \text{(Cornell and Van Marke 1969)} \quad (1)$$

$Mo \leq M \leq Mmax$

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

β- Parameter comparable to the b value (β= 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 λ_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 (Dc) is used as a quantitative measure of the degree of heterogeneity of seismic activity in seismotectonic elements of a region.

$$D_C = \lim_{r \to 0} [\log C(r) / \log r]$$

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

C(r) - Correlation function

r - Distance between two epicenters

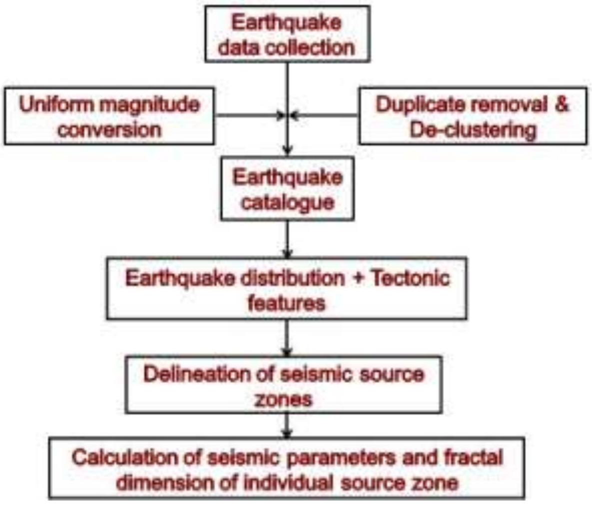
N - Number of event pairs separated by a distance R<r

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

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

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

METHODOLOGY

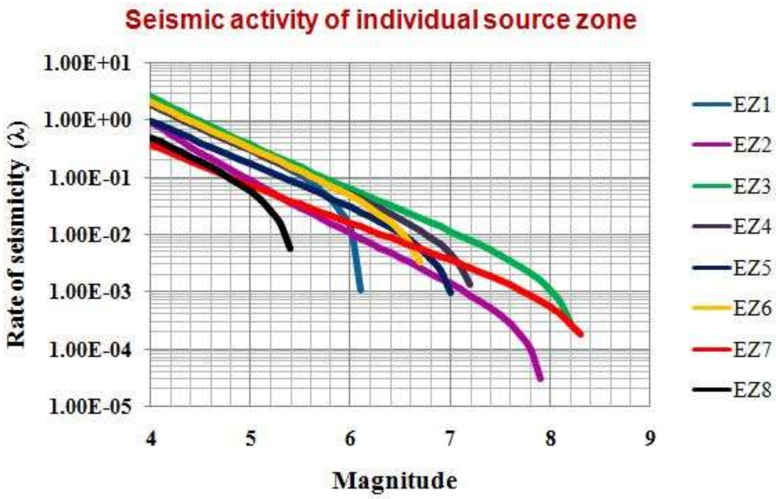


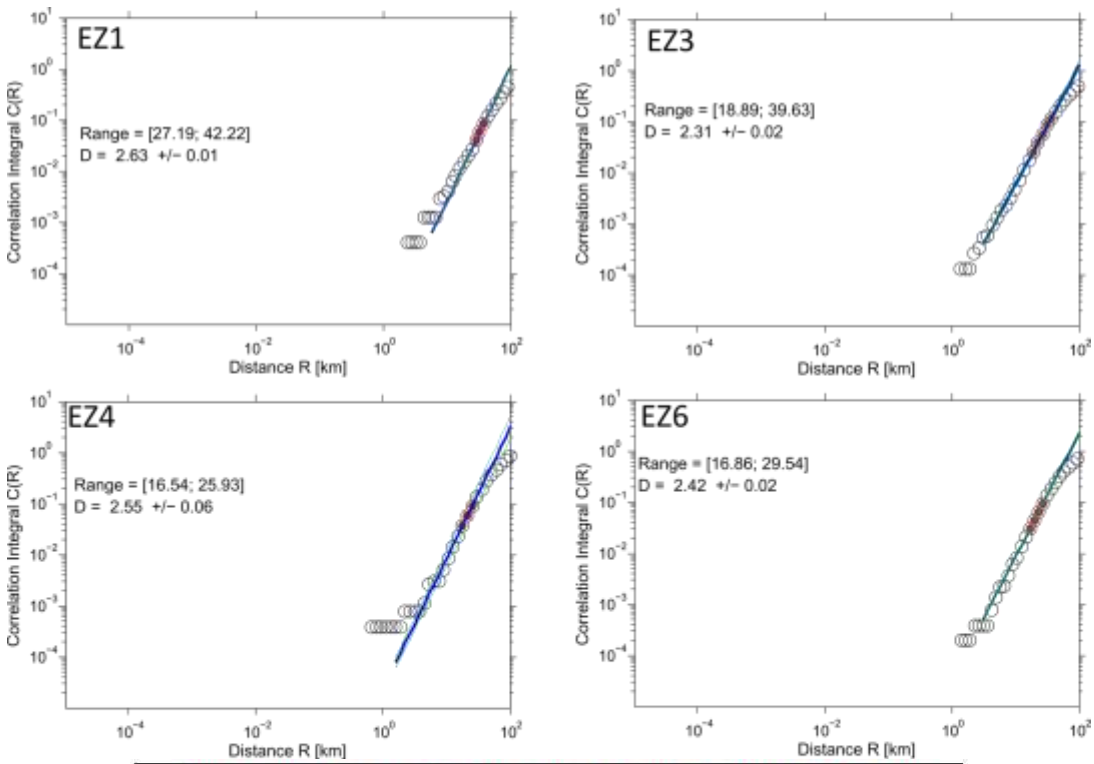
- Scordilis (2006) equation used to convert the earthquake magnitudes into moment magnitude (Mw).
- The algorithm suggested by Reasenberg (1985) has been used for declustering

- 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 Dc values (Dc= -2.560b + 4.621).
- Seismic Zone EZ1 showed comparatively low b and high DC values. Conversely, seismic zone EZ3 exhibited high b and low DC values.

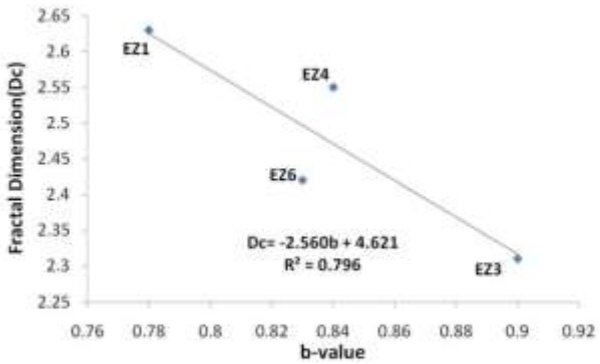




Seismic parameters of source zones considered in the Eastern Himalayas

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
EZ7	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

D_c versus b-value plot



CONCLUSIONS

- The seismic zone (EZ3) of the study area is found out 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.

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