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Seismic Study and Spatial Variation of b-value in Northeast India

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Abstract: *Study of recent seismicity and b-value estimation by Least Square and Maximum Likelihood Estimation methods in five tectonic blocks of Northeast India demarcates indo Burma Belt, Main Central Thrust, Main Boundary Thrust, Shilling Plateau, Mikir Hills and Kopili Lineament as active seismic source of the region. Spatial variation of b-value is observed by dividing the study area into $1^0 \times 1^0$ grids. Higher b-value contours depict the highly seismic area with structural heterogeneity, while lower b-value contours indicate the areas under high stress. b-values are observed in the range of 0.437 - 0.908 and mostly concentrated around 0.7, indicating high stress accumulation.*
Keywords: *Seismicity, b-value, Contour.*

I. Introduction

Northeast India and its surrounding regions are seismically one of the six most active regions of the world. It falls in zone V (presently zone IV) of the Seismic zonation map[1] of India, the highest vulnerable zone of the country. The higher level and diffused seismicity in this area which is possibly due to the complicated tectonics resulted from the collision and continued north south and east west convergence of the Indian plate towards the Himalaya[2-4] and Burmese arc[5-7] have been drawn attention of several Geoscientists over decades. Different studies pertaining to seismicity are available for this region where tools like seismic *b*-value[8-11] and seismic 'a' value[12] are used. *b*-value is one of the basic seismological parameters applied to describe an ensemble of earthquakes in the magnitude frequency relation. Gutenberg-Richter's[13] Magnitude-Frequency relation is:

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

Where N (M) is the number of earthquakes having magnitude ≥ M and occurred over a finite duration. The parameter 'a' is an index of seismic activity level of the given region. It depends on the size of the area, the time interval, number of earthquakes occurring in the region, largest seismic magnitude and also on the *b*-value. The *b*-value is the slope of the cumulative number- magnitude trend line. It varies both spatially and temporally. *b*-value is generally used for quantifying seismicity[14] . An Increased heterogeneity or crack density results in high *b*-values[15] whereas an increase in applied shear stress[16, 17] or an increase in effective stress[18] decreases the *b*-value. *b*-value decreases with depth[19,20] possibly because of the increase in applied stress at greater depth. A low *b*-value implies that majority of earthquakes are of higher magnitude that can be expected to occur in regions of high resistance and homogeneity[21-23] and a high *b*-value implies that the majority of earthquakes are of lower magnitude usually occur in a region of low strength and large heterogeneity. High *b*-values are associated with aftershocks and low *b*- values are associated with foreshocks[24, 25].

II. Data source and seismic surveillance

To study the seismicity and seismotectonics of any region a large volume of earthquake data covering a comparatively long period is necessary. But systematic and scientific record of earthquakes occurred in this region are available only from the later half of the 20th century and that also compiled by different organization in different format. For the present study data sources considered are USGS (United States Geological Survey) and ISC (International Seismological Center) Catalogs. Data for the study pertains to the rectangular area from 21^0N to 29.5^0N latitude and 88^0E to 97.5^0E longitude. To prepare a comprehensive database the sources are compared with each year record. The record of the particular year with the maximum number of earthquakes is selected to construct the database of the specific year. This is done for each year till the database is completed and duplication is carefully avoided by comparing the time and location of the events. Surface wave magnitude (M_s) and body wave magnitude (M_b) are adopted. To convert the data into one from the other the Richter[26] relation $M_b = 2.5 + 0.63\ M_s$ is used. Data completeness of the catalog is done by Stepp's method[27]. Catalog completeness (threshold) magnitude is 4 M_b. For the present study a total number of 1571 events occurring in the area are taken for the time window 1964 - 2011, since it has been noted that there is a marked difference in the clustering of earthquakes for the period before and after 1964. This difference may be due to the lack of seismic surveillance in the region. Shillong was the only seismic station in this region operated by the Indian Meteorological Department, New Delhi (IMD), till recent years. In the decade of 1960, Indian Meteorological Department added new station at Tura, Imphal and Lekhapani. At present the region is monitored by more than twenty numbers of digital seismic stations being operated by various organizations like RRL-J, NGRI-Tezpur, IMD, Guwahati University and Manipur University[28].

III. Seismicity and Seismotectonics

The northeast India has experienced 19 large Earthquakes ($M \geq 7$) including the great earthquakes of Shillong (1897, M=8.7), Burma (1912, M=8) and Assam-Tibet border (1950, M=8.7). Moreover several hundred small and micro earthquakes have also been recorded in the region. The region has collision tectonics between the Indian plate and the Eurasian plate in the north and subduction tectonic along the Indo-Burma range in the east[5, 29-33]. The shallow seismic activity is the effect of continental-continental collision and the subduction which is still continuing in the Indo-Burma region is evidenced by the intermediate to deep focus earthquake in this range[28]. Depending upon the tectonic setting, the study area is divided into five blocks: Block – A (26. 8^0N to 29.5^0N and 88^0 E to 95^0 E), Block– B (26. 8^0N to29.5^0N and 95^0 E to 97.5^0E), Block –C (21^0 N to 26.8^0N and 93.5^0 E to 97.5^0 E), Block–D (25^0 N to 26.8^0 N and 88^0 E to 93.5^0 E) and Block–E (21^0N to 25^0N and 88^0 E to 93.5^0 E). Block-A is the eastern Himalayan range which is characterized by a series of north heading thrusts.

Amongst these the important thrusts are the Main Boundary Thrust (MBT), Main Central Thrust (MCT) and Main Frontal Thrust (MFT). Block-B is also known as the Syntaxis Zone which is the meeting place of Himalayan and Burmese Arc. The main fracture of this zone is Mishmi Thrust, Lohit Thrust and a part of Disang Thrust. Block-C, the Indo-Burma range is characterized by Arakan Yoma, Chin Hills, Sagaing Fault and Schuppon Belt which is mainly infested by Naga and Disang Thrust. Block-D comprises Shillong Massif, Mikir Hills, Tista Fault, Dhubri Fault, Kopili Lineament, Dapsy Thrust, a part of Naga Thrust and a part of Brahmaputra Fault. The southern margin of the Shillong Massif is characterized by the Dauki Fault which has been interpreted to have strike slip displacement by Evans[34]. Murthy et al.[35] considered it as a reverse fault whereas Molnar[36] interpreted it as a north heading thrust. The western margin is demarcated by the NS Yamuna Fault. There is a NS Grabben between the Shillong Massif and Mikir Hills in the east along which the Kopili River flows north. Block-E comprises Bengal Basin and Tripura-Mizo Fold Belt. The main fractures of this zone are Padma Fault, Yamuna Fault, Kaladan Fault and Tapu Thrust. Evans[34] and Krishnan[37] prepared a map suggesting the tectonic setting of northeast India. A seismotectonic map of the study area with different blocks is shown in **Fig.1.**

IV. b-value estimation and mapping

The least square (LS) fit method and the maximum likelihood estimation (MLE) method are adopted in the present study to find out the *b*-value. In the least square fit method the log values of cumulative number of earthquakes are plotted against the different magnitudes of the events and the best fitted line is drawn. In the MLE method *b*-value is estimated using the relation given by Aki[38], which based on theoretical considerations. The relation given by Aki is –

$$b = \frac{\mathrm{Log\ e}}{\bar{\mathrm{M}} - \mathrm{M}_0}$$

Where, $\bar{\mathrm{M}}$ is the average magnitude and M_0 is the lower limit of magnitude or threshold magnitude. Estimating the b-values in each tectonic block and using these in magnitude-frequency relationship a Log N (M) ~M regression line for each block is obtained.

Regression lines for both LS and MLE method are depicted in **Fig. 2.** The estimated *b*-values along with a-values are given in **table 1.** A bar diagram comparing the *b*-values in both methods are depicted in **Fig. 3**. To visualize the spatial variation of *b*-values, the study area is divided into square grids having dimension of $1^0 \times 1^0$ each with overlapping windows of dimension $.5^0 \times .5^0$. Grids having 21 and more samples are only included for the analysis. And thus a total number of 91 grids are found. The estimated *b*-value of each grid is shown in the **table 2.** The values are plotted at the centre of each grid and the iso- lines are drawn for computing the map of *b*-value as shown in **Fig.4.**

V. Result and Discussion

In each tectonic block *b*-values for earthquake range $\geq 4M_b$ are estimated using LS and MLE method. The values obtained by these two methods are comparable. For the five blocks the values in MLE method are steadier and vary from 0.71 to 0.57 in comparison to LS method which shows a greater variation from 1.02 to 0.66. In the entire region *b*-values are found to be higher in LS method. Values are observed maximum in block C and minimum in block A in both the methods. Structural heterogeneity, stress distribution in space and subduction tectonics may be the probable cause of high *b*- value in block C.

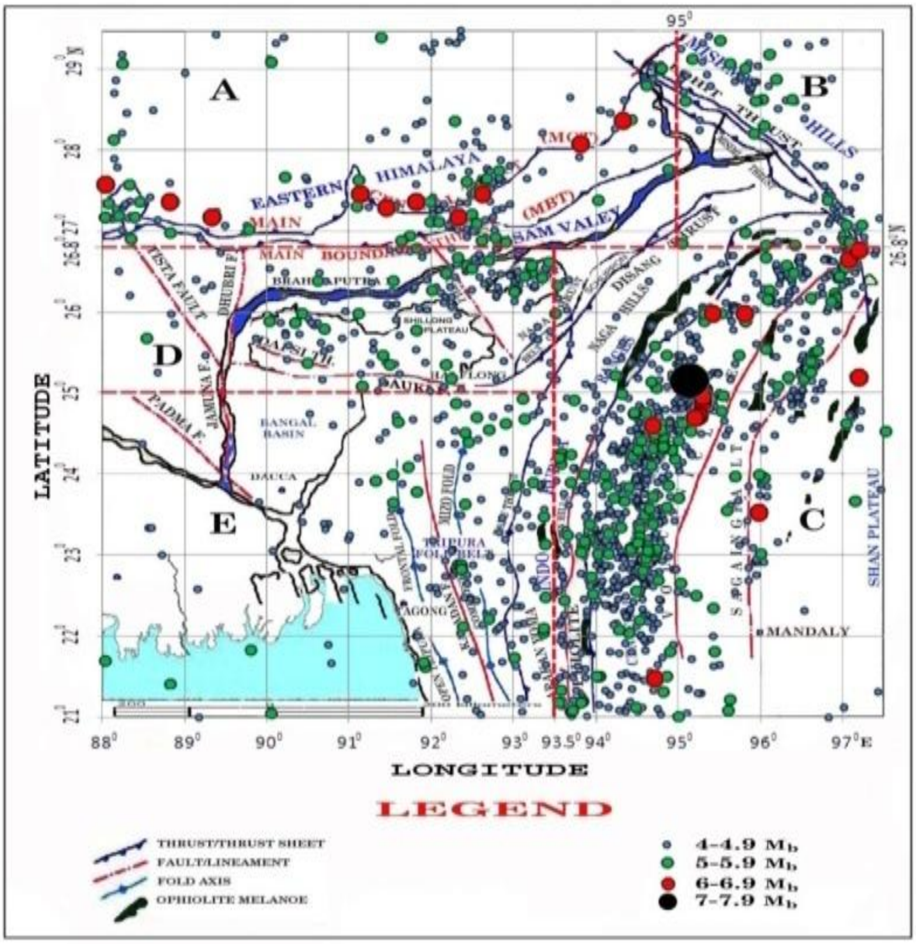
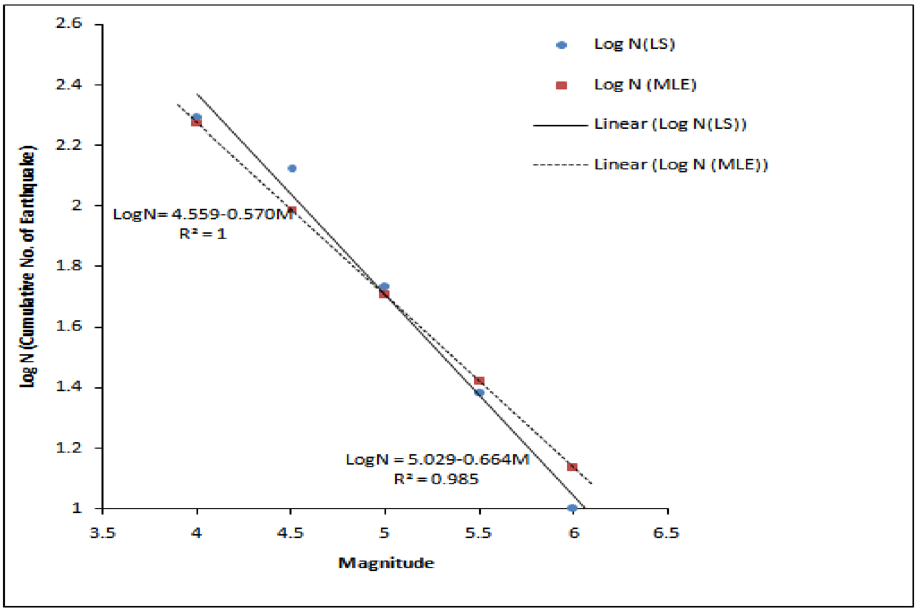
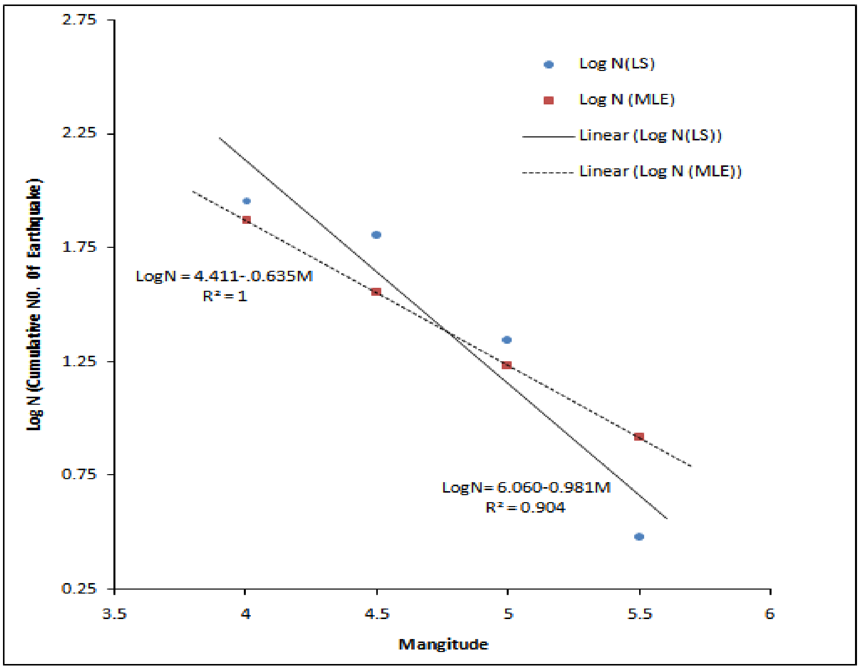


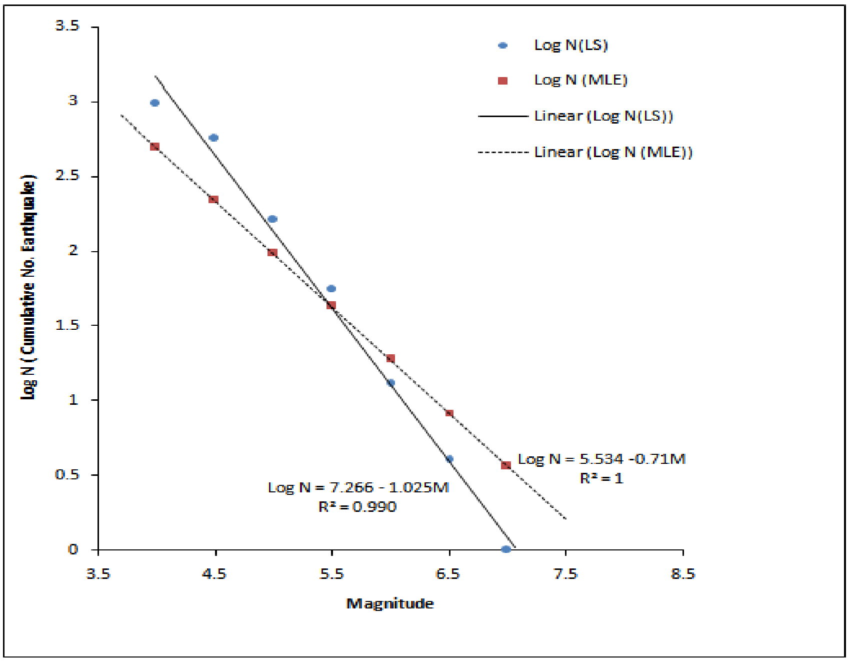
Fig.1:- Seismotectonic map of Northeast India with Block division (1964-2011)
(Tectonic features of NE India: after Evans[34] and Krishnan[37])



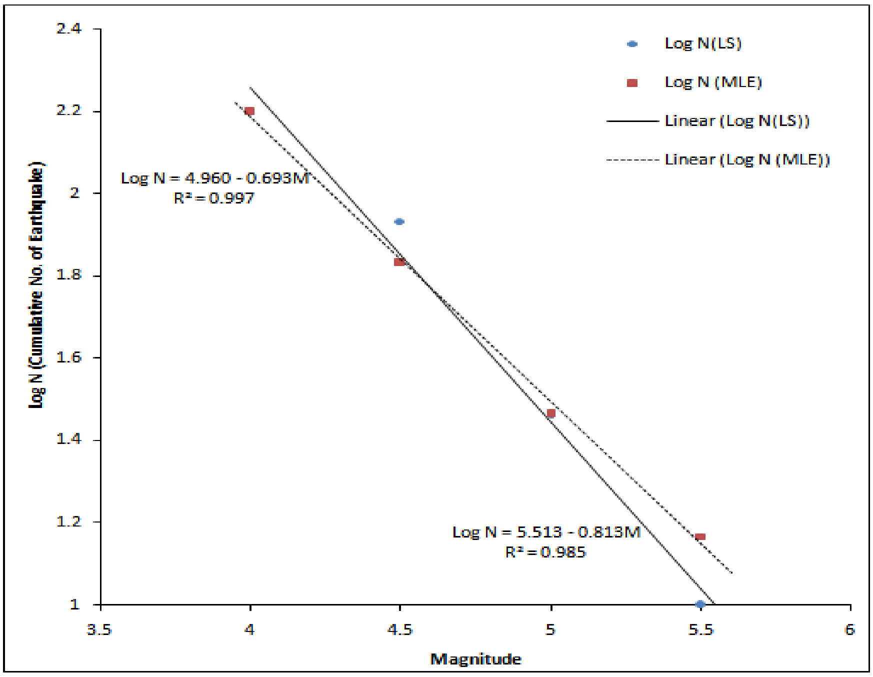
2(a)


Log N(LS)
Log N (MLE)
Linear (Log N(LS))
Linear (Log N (MLE))
LogN = 4.411-.0.635M
R² = 1
LogN= 6.060-0.981M
R² = 0.904
Log N (Cumulative N0. 0f Earthquake)
Mangitude
2.75
2.25
1.75
1.25
0.75
0.25
3.5
4
4.5
5
5.5
6

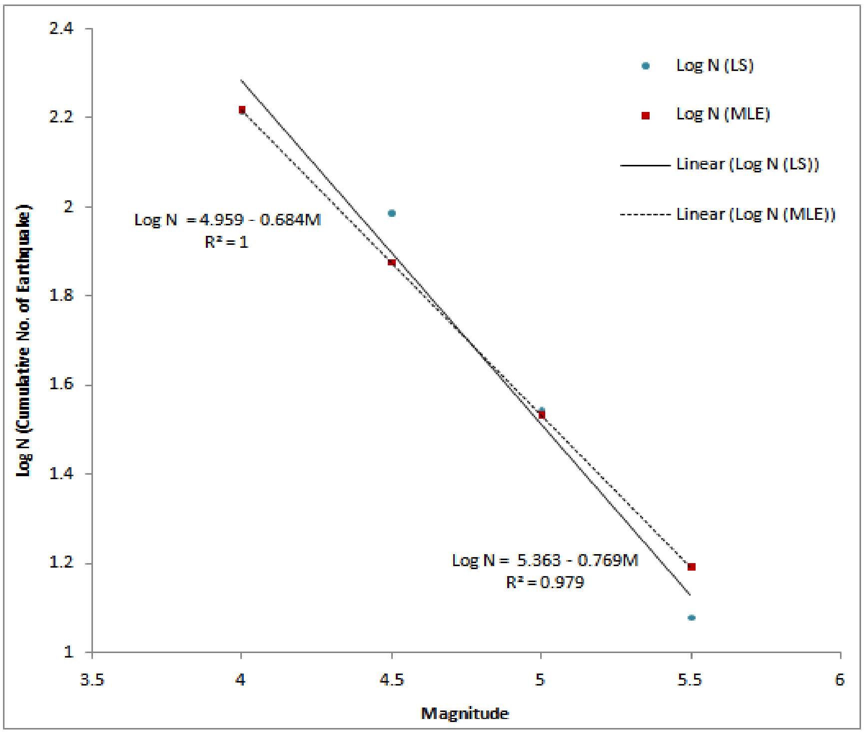
2(b)


Log N(LS)
Log N (MLE)
Linear (Log N(LS))
Linear (Log N (MLE))
Log N = 5.534 -0.71M
R² = 1
Log N = 7.266 - 1.025M
R² = 0.990
Log N (Cumulative No. Earthquake)
Magnitude
3.5
3
2.5
2
1.5
1
0.5
0
3.5
4.5
5.5
6.5
7.5
8.5

2(c)



2(d)



2(e)

Fig. 2.-a, b, c, d and **e** show cumulative number of earthquake versus magnitude for Block A, B, C, D and E respectively. The LS and MLE best fit lines with equations are showed.

Table- 1: Showing estimated *b*-values and a-values in different Blocks.

Blocks	*b*-value		a-value	
	LS	MLE	LS	MLE
Block A	0.66	0.57	4.55	5.02
Block B	0.98	0.63	6.06	4.41
Block C	1.02	0.71	7.26	5.53
Block D	0.81	0.69	5.51	4.96
Block E	0.76	0.68	5.36	4.95

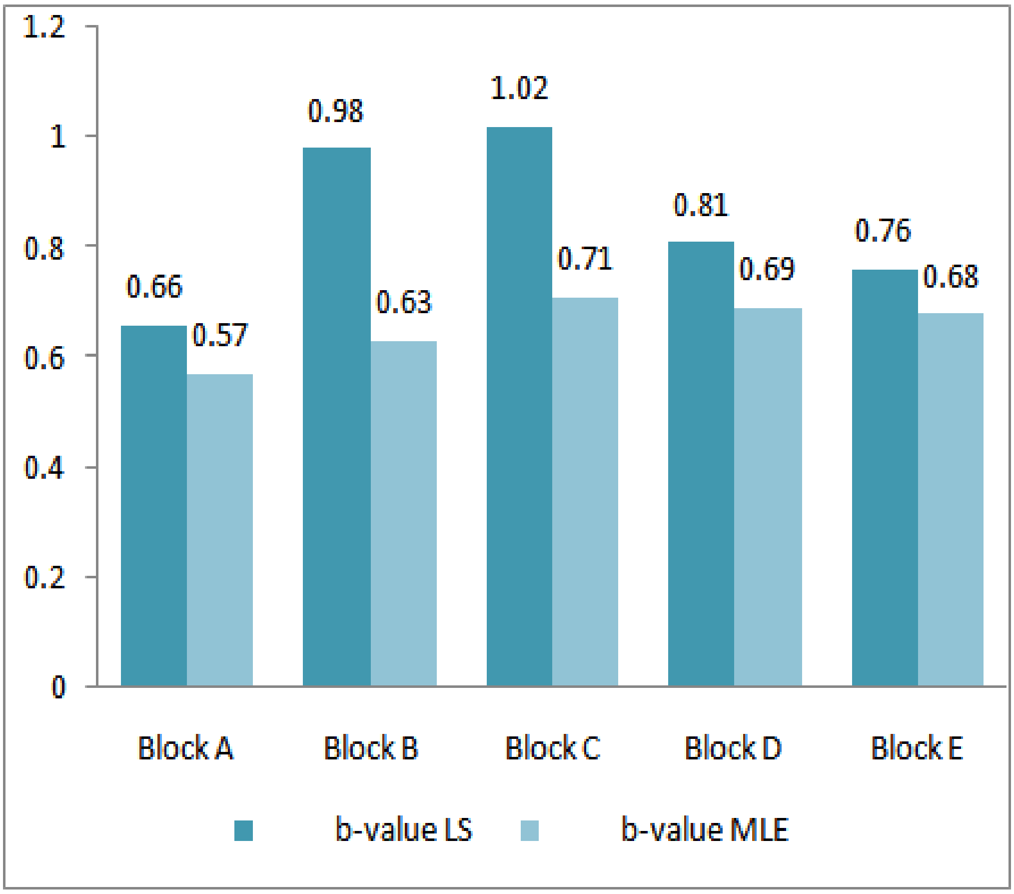


Fig.3: Bar diagram comparing the *b*-values in LS and MLE methods

Table-2. *b*-value of the grids with Latitude and Longitude

Latitude	**Longitude**	***b*-value**
21.5	93.5	0.652
21.5	94	0.694
21.5	94.5	0.761
21.5	95	0.727
22	93	0.718
22	93.5	0.782
22	94	0.8
22	94.5	0.891
22	95	0.836
22.5	92	0.702
22.5	92.5	0.729
22.5	93	0.811
22.5	93.5	0.833
22.5	94	0.886
22.5	94.5	0.908
22.5	95	0.854
23	92	0.718
23	92.5	0.733
23	93	0.82
23	93.5	0.739
23	94	0.769
23	94.5	0.765
23	95	0.724
23.5	93	0.74
23.5	93.5	0.691
23.5	94	0.698
23.5	94.5	0.722
23.5	95	0.752
23.5	96	0.625
24	93.5	0.674
24	94	0.749
24	94.5	0.764
24	95.5	0.769
24	96	0.587
24.5	93.5	0.579
24.5	94	0.698
24.5	94.5	0.704
24.5	95	0.657
24.5	95.5	0.631
24.5	96	0.83
25	90.5	0.723
25	91	0.671
25	94.5	0.595
25	95	0.595
25	95.5	0.625

Latitude	**Longitude**	***b*-value**
25	96	0.639
25	96.5	0.751
25	97	0.613
25.5	90.5	0.723
25.5	91	0.671
25.5	94.5	0.595
25.5	95	0.654
25.5	95.5	0.625
25.5	96	0.639
25.5	96.5	0.751
25.5	97	0.613
26	90.5	0.705
26	91	0.714
26	91.5	0.696
26	92	0.702
26	92.5	0.613
26	93	0.828
26	93.5	0.748
26	95	0.577
26	95.5	0.749
26	96	0.66
26	96.5	0.697
26	97	0.678
26.5	91.5	0.735
26.5	92	0.679
26.5	92.5	0.85
26.5	93	0.686
26.5	93.5	0.679
26.5	95.5	0.536
26.5	96	0.611
26.5	96.5	0.68
26.5	97	0.663
27	88.5	0.449
27	92.5	0.625
27	93	0.543
27	96.5	0.699
27	97	0.65
27.5	88.5	0.437
27.5	92	0.647
27.5	92.5	0.653
27.5	93	0.602
27.5	97	0.721
28	92.5	0.568
28	93	0.586
29	95.5	0.625
29	96	0.558

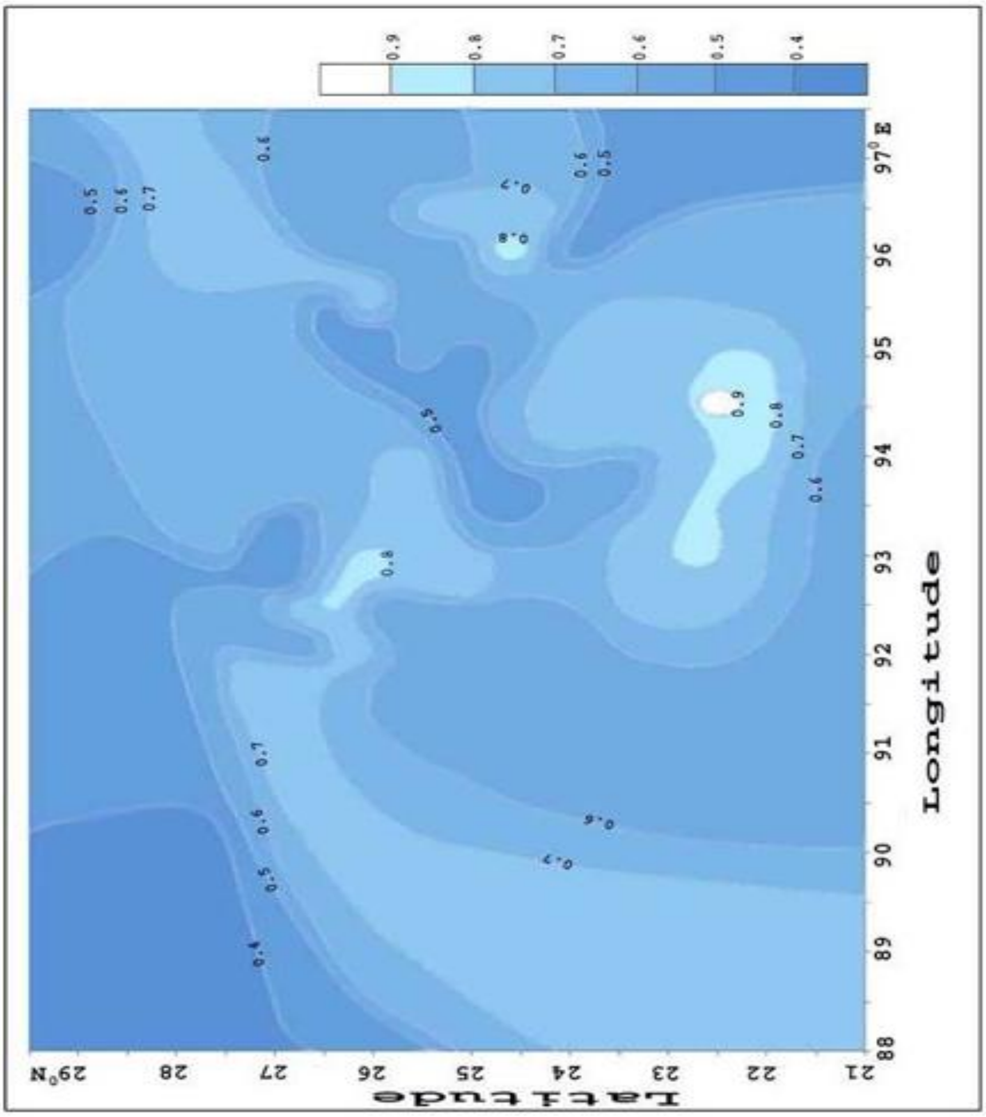


Fig.4: *b*-value map of the study region. Contour difference is 0.1.

To study the spatial variation through the region *b*-values estimated by the MLE method which is more reliable estimate[38] are taken. The values obtained are widely spread over the study region **(Fig.4)** including maximum of 0.908 and minimum of 0.437 and mostly concentrated around 0.7, which is lower than the normal value(b=1) indicating the entire area under high stress. Singh et al.[39] observed the *b*-values as 1.36 and 0.61 in the region while Bhattacharya et al.[40] found to vary *b* value from 0.6 to 1.0 and these are comparable to the present study. In block A, the Eastern Himalayan region, *b*-values vary from 0.437 to 0.653. Low *b*-value in the area perhaps suggests high stress accumulation. In the Eastern Syntaxis of Himalaya (block B) *b*-value shows a variation from 0.558 to 0.721. In block C, the Indo-Burma range, the maximum *b*-value is 0.908 and minimum is 0.536. In this range relatively higher *b*-values are predominant in the southern part of the central Burma Basin as well as around the Arakan Yoma and Chin Hills. This indicates that the region is seismically active and a large amount of strain energy gets dissipated in form of earthquakes. *b*-value decreases towards the Assam valley and Schuppon belt indicating high stress accumulation in the area. The area comprising upper Assam valley, NE extremities of Naga and Disang Thrust between Mikir Hills and Syntaxis zone is found to be aseiemic comparing to surrounding area where *b*-value can't be estimated. Khattri and Wyss[41] termed this area as 'Assam Gap'. Around this region a seismically active area is obtained comprising Mikir Hills, SW extremity of Naga Thrust and upper Burma Belt. In block D, comprising Shillong Plateau, Mikir Hills and a part of Assam valley *b*-value shows a variation from 0.666 to 0.850. In Shillong Plateau the maximum observed *b*-value is 0.723. Verma et al.[9] reported the value in this area as 1.29. The cause of decreasing *b*-value of the area may be accumulation of new stress during the last 20 years. In block A and D an increasing trend in *b*-value is observed along the Kopili Lineament which is suggested to be an active lineament[42]. This trend was also revealed by Bhattacharya et al.[11]. In block E, *b*-values cannot be estimated in the area of Bengal Basin due to lack of recorded events. The maximum *b*-value estimated in Tripura and Mizoram fold belt is 0.733. Relatively higher *b*- values (0.7-0.8) along the Tapu Thrust may indicate that the thrust is active.

The *b*-value map clearly depicts the spatial variation of earthquake frequency. Relatively higher *b*-value contours (~0.9) are observed in lower part of central Burma Basin, Around Arakan Yoma (~0.8) and along Kopili Lineament (~0.8). Lower *b*- value contours are observed around Naga Thrust (~0.5) and Assam Valley (~0.6).

VI. Conclusion

The spatial distribution of *b*-values suggests that tectonic discontinuities are spread over the whole region. The area comprising Assam Valley, Mikr Hills, SW extremities of Disang and Naga Thrust are of low *b*-value indicating under high stress accumulation. The increasing trend of *b*-value indicates that the Indo-Burma Belt is the most active zone whereas the Kopili Lineament is the most active lineament of Assam Valley.

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