Prolongation of Precursory Swarm and Future Earthquake estimate in Indo-Nepal Himalaya

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Research Background

Are earthquakes predictable?

**NO!**  (Problem)

**Solution**

EARTHQUAKE PREDICTION

SHOULD BE CONSIDERED TO BE AS

STAGE - BY - STAGE SEISMIC HAZARD ASSESSMENT
To predict an earthquake means to indicate the possibility that an earthquake will occur in a given range of space, time, and magnitude.
How we can predict earthquakes?

**Deterministic prediction?**

**NO**

For complex or chaotic system; Even an accurate modelling

Would not allow for prediction

**Statistical prediction?**

**NO**

Time scales involved in the seismogenic process are too long

and observation too limited

**Possibility**

Identification of Precursory Phenomena
Earthquake precursors

Possible precursors are those phenomena that may take place in the lithosphere during the accumulation of stresses.

**Difficulty:**

to establish a clear precursory connection, i.e.
to separate the precursory signal from natural fluctuations. This is due to the lack of sufficiently prolonged and systematic records.
Seismicity patterns

Various seismic precursors are known to be preceded to small to large earthquakes such as:

• Changes in b-values

• Anomalous seismicity fluctuations (Ishida Kanamori, 1977; Sekiya, 1977)

• Precursory Swarm (Evison, 1977, 1982)

Sekiya (1977) observed 10 cases of swarm like – activity preceding small to large earthquakes in the magnitude range 4.1-7.9, and indicated that anomalous activity is first to take place as compared to other precursory phenomena due to formation of various ruptures where considerable strain energy are accumulated. He also pointed out that such activity are of special interest and would be employed for Earthquake Prediction.
Precursory Swarm

• The swarms are a set of events occurring in an area over an interval of time which may continue to several months without any outstanding principal earthquake (Bullen, 1965)

• The level of magnitude of events constituting the swarm is generally lower and of comparable sizes as compared to Mainshock (Evison, 1977)

• The importance of precursory swarm sequence for long-range earthquake prediction demands for its identification in real sense of space and time domain.

• Identification of precursory swarm requires spatial and temporal clustering of approximately similar magnitude events.
The entire preparatory phenomena of seismicity fluctuation can be classified in four episode:

N—Normal seismicity Episode (or background)
- measured from the onset of swarm activity,
A—Anomalous seismicity Episode (or Precursory swarm Episode)
- period from the onset to end of swarm sequence
G—Precursory Gap Episode (or seismic quiescence)
- From the date of termination of swarm activity to the onset of the mainshock sequence
M—Mainshock Episode
- Duration of main shock and its associated aftershocks.

Within the preparatory area, the episodes of

N low, A high, G low and M high sequences represents Anomalously seismic activities, respectively
Identification of Seismicity patterns

A gradual increase in seismic activity in a region has been explained by slow increase of tectonic stress through dilatancy hypothesis; (Scholz et al., 1973).

Burst of seismic activity whereas a decrease in seismic activity was observed in the dilatancy hardening stage reflects the onset of the precursory sequence that follows a period of abnormal quiescence which continues till the occurrence of the major event (Evison, 1977a)
Map of the Central Himalaya and its adjoining region (modified after Ni and Barazangi, 1984). The map includes the **Himalayan arc**, **Tibetan plateau and surrounding regions** showing major tectonic–structural features. MCT (Main Central Thrust); MBT (Main Boundary Thrust); MFT (Main Frontal Thrust).
Study Area

Western Nepal and its adjoining region (Region A)

Main central thrust (MCT), Main boundary thrust (MBT), Main frontal thrust (MFT) and Indus Suture (ITS) are the major tectonic features in the region. The great earthquake of 1934 is located to the south of the MFT. A, B, C and D represent seismic regions that have been delineated based on spatial distribution of distinct seismicity as compared to the surrounding region.
Analyses

Three medium size earthquakes of

**Bajhang** earthquake of 29 July 1980 ($m_b$ 6.1)

**Bajura** Mainshock of 18 May 1984 ($m_b$ 5.6)

**Chamoli** earthquake of 28 March 1999 ($m_b$ 6.6)

occurred in the Western Nepal and its adjoining Indian region were preceded by well defined patterns of anomalous seismicity/precursory swarm.
Study the anomalous seismicity preceding the Bajhang earthquake of 29 July 1980,

Fig. 4.1: Spatial, focal depth and temporal distribution of events (mb ≥ 4.3) for the period 1967-1981 associated with Bajhang earthquake of 29 July 1980 (mb 6.1). The dotted elliptical area in Figs. a and b is the preparatory area for Bajhang earthquake on the surface and with focal depth respectively. The Fig. b represents the foci distribution of events within the preparatory area with longitudes and Fig. c shows relation between the magnitudes and the cumulative number of events. The four identified anomalous seismic phases with their seismic activity using spatial and temporal distributions of events are: Normal/ background seismicity (N); Anomalous seismicity/ swarm (A); Gap or quiescence (G); and Mainshock and its associated aftershocks (M).

Table 4.1: Seismic characteristics in the identified seismic episodes in the preparatory area of Bajhang earthquake of 29 July 1980 (mb 6.1) in the Western Nepal Himalaya.

<table>
<thead>
<tr>
<th>Seismic episodes</th>
<th>Duration</th>
<th>Days</th>
<th>Total events</th>
<th>Level of activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precursory gap (G)</td>
<td>01 Mar. 1978 – 28 July 1980</td>
<td>881</td>
<td>0</td>
<td>Extremely low</td>
</tr>
<tr>
<td>Mainshock sequence (M)</td>
<td>29 July 1980 – 10 Oct. 1980</td>
<td>74</td>
<td>8</td>
<td>-</td>
</tr>
</tbody>
</table>

The event of 29 July 1980 with magnitude 5.7 that occurred about two hours before the mainshock, probably a foreshock, is located within the preparatory area. The Bajhang earthquake of 29 July 1980 has occurred after a quiescence period of 881 days from the termination of the anomalous seismicity episode at a focal depth of 18 km and was located at 29.6° N, 81.09° E close to the northern boundary of the preparatory area (Fig. 4.1.a). This suggests that the Bajhang earthquake was preceded by a well defined anomalous seismic activity persisting for about 5-months followed by a gap of 2-years and 10- months prior to the mainshock.
Study the anomalous seismicity preceding the Bajura Mainshock of 18 May 1984 ($m_b$ 5.6)

Fig. 4.2: Spatial, focal depth and temporal distribution of events ($mb \geq 4.3$) for the period 1981-1984 associated with the mainshock of 18 May 1984 ($mb$ 5.6). The dotted elliptical area in Figs. a and b is the preparatory area for this mainshock on the surface and with focal depth respectively. The Fig. b represents the foci distribution of events within the delineated preparatory area with longitudes. Fig. c shows relation between the magnitudes and the cumulative number of events. N, A, G and M have their usual meaning as given in caption of Fig.4.1.

Table 4.2: Seismic characteristics in the identified seismic episodes in the preparatory area of 18 May 1984 mainshock ($m_b$ 5.6) in the Western Nepal Himalaya.

<table>
<thead>
<tr>
<th>Seismic episodes</th>
<th>Duration</th>
<th>Days</th>
<th>Total events</th>
<th>Level of activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal/ background (N)</td>
<td>01 Jan 1981 – 08 Sept. 1982</td>
<td>616</td>
<td>2</td>
<td>Very low</td>
</tr>
<tr>
<td>Mainshock sequence (M)</td>
<td>18 May 1984 – 22 Nov. 1984</td>
<td>179</td>
<td>3</td>
<td>-</td>
</tr>
</tbody>
</table>

The temporal pattern of events and their magnitude relationships within the elliptical preparation area depicted in Fig. 4.2c clearly show that the seismicity preceding mainshock fluctuated in the order as low-high-low. It is inferred here that the 18 May 1984 earthquake of the Western Nepal region was preceded by a well established earthquake swarms/anomalously high seismic activity that commenced about 1.7 years before the mainshock. The region has been quiet for the next two years from 23 November 1984, the date of termination of aftershock activity.
Study the anomalous seismicity preceding the **Chamoli** earthquake of 28 March 1999 (\(m_b 6.6\))

The continuing quiescence was terminated by the occurrence of Chamoli earthquake on 28 March 1999 (focal depth 23 km) to the north of the MCT and is close to the second swarm event (Fig. 4.3). The mainshock was followed by a series of aftershocks which continued till 02 June 1999 with seven aftershocks in the magnitude range of 5.0-5.5. The entire focal depth distribution pattern shows that events progressively have occurred at deeper level from east to west. In essence, the Chamoli earthquake was preceded by a well defined swarm of earthquakes which lasted for 205 days from November 1995. The mainshock was preceded by a precursory time period of 1217 days (onset of swarm activity to the occurrence of the mainshock). This is to be noted here that the region is quiet for the ensuing two years from the termination of the aftershock sequence on 03 June 1999 with the occurrence of only two small events since then.

Table 4.3: Seismic characteristics in the identified seismic episodes in the preparatory area of Chamoli mainshock (\(m_b 6.6\)) of 28 March 1999 in the Central Himalaya region.

<table>
<thead>
<tr>
<th>Seismic episodes</th>
<th>Duration</th>
<th>Days</th>
<th>Total events</th>
<th>Level of activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precursory gap (G)</td>
<td>19 Jun. 1996–26 Nov. 1996</td>
<td>1012</td>
<td>1</td>
<td>Extremely low</td>
</tr>
<tr>
<td>Mainshock sequence (M)</td>
<td>28 Mar. 1999–02 Jun. 1999</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 4.3: Spatial, focal depth and temporal distribution of events (\(m_b \geq 4.3\)) for the period 1981-1999 associated with Chamoli earthquake of March 28, 1999 (\(m_b 6.6\)). The dotted elliptical regions delineated in Figs. a and c are the preparatory areas on the surface and with focal depth respectively. Fig. b shows relation between the magnitudes and the cumulative number of events. N, A, G and M have their usual meaning as given in caption of Fig.4.1. The Fig. c represents the foci distribution of the events within the preparatory area with longitudes.
Study of Anomalous Seismicity for Future Earthquakes in Western Nepal

Seismic activity started concentrating in and around Chamoli area (India) since 27 November 1995 which was preceded by a quiet low seismicity in the region. After Chamoli earthquake in 1999, a low seismic activity was observed in the region which continued for the next two years till 14 April 2001.

The seismic activity again shifted towards southeast and started concentrating in the region east-northeast of Bajhang earthquake, since April 2001, in which anomalous pattern in seismicity is observed on two occasions.

On analyzing the seismicity data from 1999 to 2006, two additional cases of characteristic seismicity patterns were observed:

(1) 1999-2006, and
(2) 2003-2006.

In these two cases, though the anomalous seismicity exists, no mainshock has occurred so far. After critical analysis of the data, it is observed that the seismicity from 1999 onwards fluctuates in the order as low-high-low phases.

Following the similar procedure, as in previous cases, it could be delineated that there are three anomalous episodes in each of the sequence of 1999-2006 and 2003-2006.
In the Western Nepal, spurt in seismic activity has occurred from 15 April 2001 to 04 June 2002 which was preceded and followed by the abnormally low seismic phases (Fig. 4.4a, b; Table 4.4).

In the present case, clearly two anomalous phases could be identified i.e. the normal seismicity and the anomalous seismicity episodes; whereas the gap episode is still continuing since mainshock has not yet occurred in the delineated area.

Table 4.4: Characteristics of identified seismic phases in the preparatory area in Western Nepal and its adjoining region during 1999-2006 related to a future large earthquake. LPA (large preparatory area) and SPA (small preparatory area) represent the areas enclosed by solid and dotted curves in Fig. 4.4a respectively.

Fig. 4.4: Spatial, focal depth and temporal distribution of events (m≥ 4.3) for the period 1999-2006 which constitute a well defined anomalous seismicity/ precursory swarm pattern for a future seismic hazard. Figs. b & c represent temporal distribution of anomalous events in large and small preparatory areas respectively.

<table>
<thead>
<tr>
<th>Seismic episodes</th>
<th>Duration</th>
<th>Days</th>
<th>Number of events</th>
<th>Level of activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal/ background (N)</td>
<td>01 Jan.1999–14 Apr.2001</td>
<td>835</td>
<td>3</td>
<td>Extremely low</td>
</tr>
<tr>
<td>Anomalous/ swarm (A)</td>
<td>15 Apr. 2001–04 Jun.2002</td>
<td>416</td>
<td>8</td>
<td>Extremely high</td>
</tr>
<tr>
<td>Precursory gap (G)</td>
<td>05 Jun. 2002 to (continuing)</td>
<td>1671</td>
<td>14</td>
<td>Extremely low (continuing)</td>
</tr>
<tr>
<td>Mainshock sequence (M)</td>
<td>Not yet occurred</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Using these observations, it has been re-delineated a smaller preparatory area (\(\sim 1.3 \times 10^4 \text{ km}^2\)) with north-south orientation which falls totally within the large preparatory area (Fig. 4.4a) which encloses six out of eight swarm events. It is estimated that the seismic activity in the identified normal, anomalous and gap episodes are in the ratio 1:13:4 respectively. The temporal distribution of these events in three episodes within the smaller preparatory area shows low-high-low pattern of seismic activity (Fig. 4.4c, Table 4.4). The occurrence of the precursory swarm sequence from 15 April 2001 to 04 June 2002 followed by a significant decrease in seismicity (from 05 June 2002) which is still continuing is an indication of the existence of anomalous seismicity gap in the region.

It has been noticed that three swarm events having magnitude 5.6 occurred within 11 months during the anomalous episode and were confined in a north-south segment in the eastern portion of the large preparatory area. These large swarm events were not preceded by any type of seismic pattern but later two events were followed by a few aftershocks.
While examining the recent earthquake database of the Western Nepal and its adjoining region (28.5°-31° N and 79°-82.4° E) from 1999 onwards, it has been noticed here that the occurrence of two earthquake swarm cases during 2001-2002 and 2005 are almost in the overlapping areas but without any mainshock till date. It is to be noted that all the events constituting anomalous pattern for the earthquake swarm 2005 were occurred in the precursory gap period of the former earthquake swarm 2001-2002. and delineated the preparatory area (∼1.1 x 10⁴ km²) for the future seismic disturbances. Six events constitute the earthquake swarm sequence for the present case, which occurred in a short span of time of 47 days (Table 4.5), but distributed widely in the northwest-southeast trending preparatory area. This suggests that the events in all the identified episodes are probably caused by a single rupture zone and the expected mainshock could have occurred between 20-50 km focal depths. The occurrence of the earthquake swarm sequence followed by a quiescence with a significant low seismicity, which is still continuing, is an indication of the existence of the anomalous seismicity gap in the region.

Table 4.5: Characteristics of identified seismic phases in the preparatory area in Western Nepal and its adjoining region during 2003-March 2007 possibly related to a future large earthquake.
Orientation of preparatory areas of mainshocks from 1963-2006 that were preceded by anomalous seismic activity in (a) Western Nepal;

Such an anomalous pattern shows some kind of the causal relationship of the time of occurrence and the magnitude of the mainshocks.

In the Western Nepal and its vicinity, though all the three mainshocks were located close to the surface trace of the MCT in the northwest-southeast direction, their preparatory areas were oriented in different directions, e.g. NW-SE (1999), NE-SW (1984) and E-W (1980) with the mainshocks located in the northern part of the respective preparatory areas (Fig. 4.19a). In the case of the expected mainshocks, a large part of their preparatory areas is found to be common; however, they are oriented in the N-S and NW-SE.
It is observed here that during the preparatory phases of eleven mainshocks (Table 4.15), the seismic events showed clustering in space and time domains with a high annual frequency during the anomalous episode as compared to its preceding normal episode and the following gap episode as shown in Fig. 4.20. In some cases, e.g. the mainshocks of 1984 (M 5.6), 1988 (5.4), 1996 (M 5.9) and 1998 (M 5.8), the existence of an extremely high annual frequency is due to the spurt of events in short span of the anomalous episodes. In the remaining cases, a longer extent of anomalous episode was observed which provided comparatively lower level of annual frequency.
Table 4.15: Source parameters of the mainshocks that preceded by anomalous seismic activity in Himalayan (Sl. Nos. 1-16) and its adjoining Tibet (17-20) regions along with related precursory parameters. \( M_m \) and \( \bar{M}_p \) are the magnitude of mainshocks and the mean of two largest events in the anomalous (swarm) sequence respectively, and \( T_p \) is the preparatory time period measured from the onset of anomalous sequence to the occurrence of the mainshocks. The values of parameters \( M_m \), and \( T_p \) related to events 1-15 are used to establish predictive regression among these parameters for the Himalayan Frontal Arc.

<table>
<thead>
<tr>
<th>Sl. Nos.</th>
<th>Date</th>
<th>Location</th>
<th>Depth (km)</th>
<th>( M_m )</th>
<th>( T_p ) (days)</th>
<th>( \bar{M}_p )</th>
<th>Preparatory area (km(^2))</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27/03/1964</td>
<td>27.2</td>
<td>32</td>
<td>6.3</td>
<td>1769</td>
<td>5.0</td>
<td>( 1.2 \times 10^5 )</td>
<td>Gupta &amp; Singh (1986)</td>
</tr>
<tr>
<td>2</td>
<td>03/09/1972</td>
<td>35.94</td>
<td>45</td>
<td>6.2</td>
<td>1448</td>
<td>5.2</td>
<td>( 9.4 \times 10^3 )</td>
<td>Singh &amp; Singh (1984)</td>
</tr>
<tr>
<td>3</td>
<td>11/08/1974</td>
<td>39.34</td>
<td>7</td>
<td>6.2</td>
<td>1807</td>
<td>5.4</td>
<td>( 1.2 \times 10^4 )</td>
<td>Singh &amp; Singh (1984)</td>
</tr>
<tr>
<td>4</td>
<td>28/12/1974</td>
<td>35.06</td>
<td>24</td>
<td>5.9</td>
<td>845</td>
<td>5.0</td>
<td>( 7.9 \times 10^3 )</td>
<td>Singh &amp; Singh (1984)</td>
</tr>
<tr>
<td>5</td>
<td>19/01/1975</td>
<td>32.39</td>
<td>1</td>
<td>6.2</td>
<td>1064</td>
<td>5.1</td>
<td>( 6.8 \times 10^4 )</td>
<td>Singh &amp; Singh (1984)</td>
</tr>
<tr>
<td>6</td>
<td>05/12/1975</td>
<td>33.10</td>
<td>24</td>
<td>5.3</td>
<td>385</td>
<td>4.8</td>
<td>( 3.7 \times 10^3 )</td>
<td>Singh &amp; Singh (1984)</td>
</tr>
<tr>
<td>7</td>
<td>12/08/1976</td>
<td>26.7</td>
<td>27</td>
<td>6.2</td>
<td>440</td>
<td>5.3</td>
<td>( 3.9 \times 10^4 )</td>
<td>Gupta &amp; Singh (1986)</td>
</tr>
<tr>
<td>8</td>
<td>29/07/1980</td>
<td>29.60</td>
<td>18</td>
<td>6.1</td>
<td>1043</td>
<td>5.0</td>
<td>( 5.2 \times 10^3 )</td>
<td>This Study</td>
</tr>
<tr>
<td>9</td>
<td>19/11/1980</td>
<td>27.34</td>
<td>17</td>
<td>6.1</td>
<td>2127</td>
<td>5.2</td>
<td>( 3.6 \times 10^4 )</td>
<td>This Study</td>
</tr>
<tr>
<td>10</td>
<td>18/05/1984</td>
<td>29.58</td>
<td>33</td>
<td>5.6</td>
<td>617</td>
<td>4.8</td>
<td>( 7.4 \times 10^3 )</td>
<td>This Study</td>
</tr>
<tr>
<td>11</td>
<td>30/12/1984</td>
<td>24.6</td>
<td>22</td>
<td>5.6</td>
<td>1084</td>
<td>5.0</td>
<td>( 8.4 \times 10^4 )</td>
<td>Gupta &amp; Singh (1986)</td>
</tr>
<tr>
<td>12</td>
<td>20/04/1988</td>
<td>27.04</td>
<td>54</td>
<td>5.4</td>
<td>859</td>
<td>4.6</td>
<td>( 2.0 \times 10^4 )</td>
<td>This Study</td>
</tr>
<tr>
<td>13</td>
<td>06/08/1988</td>
<td>25.12</td>
<td>115</td>
<td>7.5</td>
<td>9199</td>
<td>6.6</td>
<td>( 1.3 \times 10^5 )</td>
<td>Singh et al. (2005a)</td>
</tr>
<tr>
<td>14</td>
<td>20/08/1988</td>
<td>26.75</td>
<td>57</td>
<td>6.4</td>
<td>3844</td>
<td>5.2</td>
<td>( 4.7 \times 10^4 )</td>
<td>This Study</td>
</tr>
<tr>
<td>15</td>
<td>28/03/1999</td>
<td>30.51</td>
<td>23</td>
<td>6.6</td>
<td>1217</td>
<td>5.0</td>
<td>( 4.0 \times 10^3 )</td>
<td>This Study</td>
</tr>
<tr>
<td>16</td>
<td>12/01/1965</td>
<td>27.40</td>
<td>23</td>
<td>6.1</td>
<td>346</td>
<td>5.0</td>
<td>( 6.1 \times 10^3 )</td>
<td>This Study</td>
</tr>
<tr>
<td>17</td>
<td>20/03/1993</td>
<td>29.08</td>
<td>12</td>
<td>6.1</td>
<td>455</td>
<td>4.9</td>
<td>( 2.2 \times 10^4 )</td>
<td>This Study</td>
</tr>
<tr>
<td>18</td>
<td>03/07/1996</td>
<td>30.15</td>
<td>9</td>
<td>5.9</td>
<td>113</td>
<td>4.9</td>
<td>( 7.9 \times 10^2 )</td>
<td>This Study</td>
</tr>
<tr>
<td>19</td>
<td>20/07/1998</td>
<td>30.13</td>
<td>33</td>
<td>5.8</td>
<td>310</td>
<td>4.5</td>
<td>( 1.3 \times 10^3 )</td>
<td>This Study</td>
</tr>
<tr>
<td>20</td>
<td>11/07/2004</td>
<td>30.69</td>
<td>13</td>
<td>6.2</td>
<td>3955</td>
<td>4.7</td>
<td>( 1.8 \times 10^4 )</td>
<td>This Study</td>
</tr>
</tbody>
</table>
A generalized precursory swarm hypothesis was introduced by Evison (1982) and we found that $\overline{M}_p$, $M_m$ and $T_p$ are correlated in the following forms as derived for Himalayan Frontal Arc:

\[
M_m = 1.05 \overline{M}_p + 0.69 \\
(R^2 = 0.80 \text{ for } M_m \text{ estimation})
\]

\[
\log T_p = 0.59 \overline{M}_p + 0.08 \\
(R^2 = 0.59 \text{ for } T_p \text{ estimation})
\]

\[
\log T_p = 0.52 M_m - 0.05 \\
(R^2 = 0.63 \text{ for } T_p \text{ estimation})
\]

or,

\[
M_m = 1.92 \log T_p + 0.10
\]

The expressions (1) and (3) are predictive regression equations which give the estimation of the magnitude of the mainshock ($M_m$), if $\overline{M}_p$ and $T_p$ are known from the anomalous seismic activity/earthquake swarm pattern well before the mainshock. These equations provide reliable results only if no earthquake with magnitude equal or greater than the magnitude of the largest swarm event ($M_p$) occurs during the gap episode (quiescence period) within the delineated preparation area.
On considering the second estimates, an earthquake with M 6 should occur by September 2008 in the same region. Evidently, this is the case of a repeated swarm sequence as pointed out by Evison (1982) in which the second activity has occurred in the gap episode of the first case which was continuing. Delay in the occurrence of an expected earthquake is probably due to the interruption in the continuing gap episode of the first sequence by the second one that has enhanced both the preparatory period and the magnitude. In view of the above and the inherent level of error in the magnitude estimation, the magnitude of the impending earthquake may be \( M_{6.5 \pm 0.5} \). In this condition, a precursory time period of 10.7 years for an earthquake with M 7 is estimated using the predictive equation (5). If so, the expected earthquake should occur at any time from now onwards till December 2011. Gupta and Singh (1986) have also made similar consideration to estimate the probable time of occurrence of 06 Aug. 1988 in Arakan Yoma. The same region of the Western Nepal was also considered as one of the seismogenic sources in which probability is estimated to be as 85% for the next 10 years from 2005 for an earthquake with magnitude \( 6.4 \pm 0.2 \) using the time and magnitude predictable model.
Estimated Earthquake very close to Occurred event

29.3°-30.5° N and 81.2°-81.9° E
M 6.5 ± 0.5, till December 2011

25/April/2015
28.2°N, 84.7°E

12/May/2015
27.8°N, 86.1°E
Summary and conclusion

- Anomalous seismic activity/earthquake swarm existed prior to the medium size earthquakes in the Nepal Himalaya and its adjoining Tibet region. The mainshocks were preceded by the quiescence period which is an indication for the occurrence of future seismic activity.

- In all the cases, the identified episodes of anomalous seismic activity were characterized by an extremely high annual earthquake frequency as compared to the preceding normal and the following gap episodes, and is the characteristics of the events in such an episode is causally related with the magnitude and the time of occurrence of the forthcoming earthquake. It is observed here that for the shorter duration of the preparatory time period, there will be the smaller mainshock, and vice-versa.

- The present study suggests that the parts of the Western Nepal and the adjoining Tibet region are potential for the future medium size earthquakes. Accordingly, it has been estimated here that an earthquake with $M \ 6.5 \pm 0.5$ should had occurred till December 2011 in the Western Nepal within an area bounded by $29.3^\circ$-$30.5^\circ$ N and $81.2^\circ$-$81.9^\circ$ E, in the focal depth range $10 \ -30 \ km$.

- The same region of the Western Nepal was also considered as one of the seismogenic sources in which probability is estimated to be as $85\%$ for the next 10 years from 2005 for an earthquake with magnitude $6.4 \pm 0.2$ using the time and magnitude predictable model.

- Delay in the occurrence of an expected earthquake is probably due to the interruption in the continuing gap episode of the first sequence by the second one that has enhanced both the preparatory period and the magnitude.
Thank you

Take a dip to get rid of all sin