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Earthquakes in Upper Mandakini River Basin: A Spatio-temporal Analysis

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Abstract

Himalayan region is highly prone to earthquakes due to its complex geological setting and plate movements. Upper Mandakini river basin located in the western Himalayan belt is not exempted from ever looming threat of earthquakes and falls underearthquake risk zone V category. Various thrusts such as MCT and MBT thrust pass through this region. This paper seeks to shed light on the spatial and temporal occurrence of earthquakes and their impact in the region. Present study was carried out using various secondary data sources and newspaper reports. Time period of 201 years from the year 1816 to 2017 was taken for the study depending on the availability of data sources. A total of 116 earthquake events have been in and around the study area.

Keywords: : Earthquakes, Mandakini, Rudraprayag, Himalayas, Disaster.

Introduction

Earthquake is one of the most destructive forces of nature that causes huge loss to life and property. The problem with earthquakes is their unpredicted occurrence and it is this surprise element which makes earthquakes most fatal. Himalaya is one of the most seismically active regions where collision between Indian and Eurasian plates has created massive structural deformations and produced faults and folds (Chandra 1992 and Rastogi 1992).It is no wonder then that the Himalayan state of Uttarakhand is highly prone to earthquakes. Occurrence of earthquakes in this region is very frequent and the area is subjected to both major and minor earthquakes.Tectonic movements happening in the entire Himalayan belt trigger the earthquakesin the entire region. Earthquake is one of the most devastating natural disasters which not only causes damage to life and property but also triggers landslides in many cases (Lodhi 2011). It becomes very important to study about earthquakes for the areas like Upper Mandakini river basin where the terrain in very rugged and there is large amount of population movement because of the *char dham yatra* thus making the people highly vulnerable. Other things which add to the population vulnerability are limited road network and lack of medical infrastructure.

Study Area

The study area comprises of upper Mandakini River basin which forms a part of the Ukhimath tehsil of district Rudraprayag in higher Garhwal Himalaya in the state of Uttarakhand. The area is characterized by highly rugged topography and high relief having sharp ridges with prominent deep slopes. The upper Mandakini River basin lies between latitude 30°29’N and 30°48´N and longitude 78°54´E and 79°21´E comprising an area of 927.40 km². The elevation ranges from 948 to 6968 meters above mean sea level.The basin has complex topography having high mountain chains with glaciers in the north and fluvial terraces in the lower part. Tectonically active lineaments such as faults and thrusts control the relief of the region.There are 111 settlements in the basin, out of which six are un-inhabited. Total population of the basin comprises of 45,278 people.

Objectives of the Study

The present study is aimed at the following objectives:

1. To study the spatio-temporal pattern of the seismic activity in the region.
2. To study the damage that has been cause by various earthquake events in the region.

Methodology

This study was carried out for the time period of 201 years and is based on three types of data i.e.the location, temporal data of earthquake events and the damage caused by earthquake event. For the location and temporal data various data sources such as India Metrological Department (IMD), United States Geological Survey (USGS), International Seismological Centre(ISC), Peking (PEK), National Centre for Seismology of the Ministry of Earth Sciences of India (NDI) were used. The data on damage that occurred during an earthquake event was collected from newspapers and state reports of Uttarakhand. Data obtained from these sources was then plotted and analysed through the ArcGIS software for better analysis and interpretation.

Earthquakes in Upper Mandakini River Basin

Seismic History of the Region

The Western Himalayan state of Uttarakhand being tectonically very active is prone to earthquakes. Seismically, Uttarakhand can be divided into Zone IV and V representing high and very high risk regions, respectively. The regional tectonic features include the Main Boundary Thrust (MBT) and Main Central Thrust (MCT) that runs parallel to the Himalayan ranges(Gautam et. al. 2017). Apart from these,several other active local faults also contribute towards seismic risk in this part of western Himalayas.

The Upper Mandakini River basin falls in seismic Zone V, i.e. the highest earthquake risk category. This precarious situation is the result of tectonically active lineaments such as faults and thrusts that control the geological structure and relief characteristics of the region. Since the beginning of 19th century, the study region and its surrounding areas in Chamoli, Uttarkashi, Tehri-Garhwal and the lower Mandakini River valley have witnessed a total of 116 earthquakes of various magnitudes (Table 1.1). The chronological information available suffers from temporal inconsistency due to changes in the methods of seismic observation, tools, techniques and the scales of seismic measurement. Reconstructing a comparable orderly temporal narration on earthquakes occurrence is hence not possible.

The oldest record on seismic activity in the study area and its immediate surroundings dates back to the year 1816 when an event of intensity between VII to VIII on Modified Mercalli scale (MM) and two other similar intensity earthquakes occurred on May 26, 27 and 28 in Garhwal area. Describing the event, Oldham (1883, p.16) wrote that *'Upper valley of Ganges two shocks, rocks hurled in every direction from the peaks, Smartly felt in all parts of the mountains as well as in the plains of the North Western Provinces… Slight shocks recurred frequently. Huge land slips resulted. One said to be extend for half a mile…'.* Since no instrumentally measured earthquake scale had been invented by this time, the magnitudes for these events were rough estimation based on the damage descriptions and hence do not have the accuracy in epicenter location and magnitude of the event. After these events, no information was found for any kind of seismic activity in the region till about early 1900.

In the early parts of twentieth century, three earthquake events of significant magnitude (~ 5.0-6.0 Mb on Richter scale) were recorded in 1902, 1906 and 1908 with probable epicenter located around northern parts of the study area. The detailed information is not available for the first half of this century as well. It was only after 1960 when International Seismological Centre (ISC) started publishing good quality instrumentally recorded seismic data on earthquake locations, we have detailed information of seismic activities in the region. Around this time, many organizations installed their seismological observatories in various parts of India that helped in creating a detailed and more accurate database on earthquakes. The same is reflected in increased number of seismic events observed since 1960s; the sophisticated instrumentation enabled precise recording of lower magnitude events as well.

From 1960 onwards, over 100 earthquakes of varying magnitude occurred in the region and since most of these events were of smaller magnitude, no damage to life and property was reported. The occurrence of moderate and higher intensity earthquakes remained largely random with no major temporal concentration except for two occasions. The region experienced two major damaging earthquakes preceded and succeeded by several low magnitude earthquakes in the recent past in 1991 and 1999. The first events occurred on October 19th, 1991 at 30.78° N latitude and 78.77° E longitude with its epicenter in Uttarkashi district. This was the highest magnitude earthquake (6.8 Mb on Richter scale) recorded in study region during the last century. A lot of damage was reported from this event… '*Major earthquake occurred in India in mountainous area… magnitude and position to 7.1 on Richter scale, latitude 30.8 degree north, longitude 78.9 degrees east… early reports Indicate worst damage in Uttarkashi and Tehri districts'* (UNDRO, Information Report No. 1, 21 October 1991). The reports further recorded that, *'More than 500 villages destroyed… people died in collapsed houses and landslides. Total death toll presently feared to exceed 1,000 with higher number of people injured'*, (UNDRO, Information Report No. 2, 21 October 1991). This event caused strong ground shaking and destruction in Uttarkashi, Tehri and Chamoli area. Nearly 3, 07,000 people in 1294 villages were affected; 768 persons died and 5066 injured while 42,400 houses were damaged (Jain et al. 1992). Following this major earthquake event, more than 40 aftershocks were experienced in Uttarakhand, some with magnitude four and above on Richter scale.

The second major event of magnitude 6.6/6.8 Mb on Richer scale that occurred in the year 1999 had its epicenter in Chamoli district (Table 1.1). This event not only caused extensive damage in the immediate vicinity of epicenter in Chamoli and Gopeshwar areas but other surrounding areas like Rudraprayag, Tehri Garhwal, Bageshwar and Uttarkashi also felt the strong shock waves and underwent substantial damage due to seismic waves. Over 100 people died and more than 300 were injured in this event; Chamoli and Rudraprayag were the most affected. An extensive damage to houses and roads was reported from the study area...'*In Rudraprayag district 750 houses were completely razed to the ground, while 3160 houses were partially damaged… Many roads were blocked or*

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damaged'(The Tribune, 2nd May 1999).Since then, only four events of significant earthquakes (≥5.0 Mb) have occurred, one in 2005, another in 2009 and two events in 2017 (Table 1.1).

Table 1.1
Earthquakes In Upper Mandakini River Basin And Its Surroundings

S. No.	Date	Latitude (DD)	Longitude (DD)	Magnitude (Mb)	Depth (KM)	Source
1	26-05-1816	30.900	79.000	5.5	NA	OLD
2	27-05-1816	30.900	79.000	5	NA	OLD
3	28-05-1816	30.900	79.000	5	NA	OLD
4	16-06-1902	31.000	79.000	6	NA	IMD
5	13-06-1906	31.000	79.000	6	NA	IMD
6	11-12-1908	31.000	79.000	5	NA	IMD
7	13-07-1962	30.640	79.480	4.5	NA	MOS
8	14-07-1962	30.640	79.320	4.5	17	PEK
9	14-07-1963	30.700	79.400	4.8	33	CGS
10	27-11-1963	30.800	79.100	5.1	33	USGS
11	02-01-1967	30.644	79.279	4.8	25	USGS
12	05-01-1968	30.400	79.100	5.4	7	USGS
13	22-06-1969	30.500	79.400	5.3	15	ISC
14	30-01-1971	30.485	79.058	4.6	56	USGS
15	23-08-1975	30.614	79.453	4	33	USGS
16	20-04-1977	30.519	79.352	4.8	33	USGS
17	07-01-1978	30.565	79.380	4.7	33	USGS
18	19-06-1981	30.541	79.217	4.4	63.6	USGS
19	16-10-1982	30.326	79.129	4.5	71.2	USGS
20	26-11-1984	30.489	79.252	4.5	33	USGS
21	28-03-1986	30.801	79.166	4.2	33	USGS
22	06-06-1987	30.555	79.267	4.7	33	USGS
23	06-06-1987	30.470	79.202	4.9	44.4	USGS
24	09-06-1988	30.654	79.216	4.8	25.2	USGS
25	18-12-1990	30.336	79.117	4.9	18.7	USGS
26	12-02-1991	30.614	79.288	4.1	33	USGS
27	04-03-1991	30.810	79.215	3.2	33	USGS
28	15-10-1991	30.565	79.311	4.5	33	USGS
29	19-10-1991	30.780	78.774	6.8	10.3	USGS
30	20-10-1991	30.945	78.922	4.3	33	USGS
31	20-10-1991	30.899	78.832	4.5	33	USGS
32	20-10-1991	30.847	78.777	4.2	33	USGS
33	21-10-1991	30.777	78.800	4	33	USGS
34	14-03-1992	30.664	78.829	4.8	30.3	USGS
35	12-06-1992	30.779	78.764	4.7	22.3	ISC
36	16-08-1993	30.955	78.955	4	33	USGS
37	15-08-1993	30.764	78.870	4.2	45.8	ISC
38	29-03-1994	30.583	79.394	4	43.2	ISC
39	27-11-1995	30.693	79.232	4.6	37.5	USGS
40	23-01-1996	30.483	79.413	4.3	33	USGS
41	26-03-1996	30.651	79.102	4.8	47.4	USGS
42	18-06-1996	30.525	79.266	4	33	USGS
43	03-08-1996	30.761	79.029	3.9	33	USGS

44	19-11-1998	30.566	79.389	3.9	33	USGS
45	19-11-1998	30.420	79.163	4.5	33	USGS
46	25-02-1999	30.657	78.878	4	33	USGS
47	28-03-1999	30.512	79.403	6.6	15	USGS
48	28-03-1999	30.315	79.387	5.4	10	USGS
49	28-03-1999	30.342	79.310	4.7	10	USGS
50	28-03-1999	30.357	79.481	4.4	10	USGS
51	28-03-1999	30.385	79.494	4.5	10	USGS
52	28-03-1999	30.415	79.451	2.7	16.4	NDI
53	28-03-1999	30.413	79.164	3.3	1	NDI
54	28-03-1999	30.469	79.377	2.6	4.3	NDI
55	28-03-1999	30.406	79.429	3.5	4.6	NDI
56	28-03-1999	30.347	79.274	3	12.2	NDI
57	28-03-1999	30.285	79.386	2.3	28.2	NDI
58	28-03-1999	30.458	79.407	2.9	11.1	NDI
59	28-03-1999	30.508	79.362	3.1	3.4	NDI
60	28-03-1999	30.648	79.403	3.9	1.9	ISC
61	28-03-1999	30.469	79.455	3.3	11.2	NDI
62	28-03-1999	30.426	79.341	2.6	2.9	NDI
63	29-03-1999	30.502	79.443	2.8	4.6	NDI
64	29-03-9199	30.338	79.358	3.1	1.8	NDI
65	29-03-1999	30.433	79.366	3.3	23.1	NDI
66	29-03-1999	30.304	79.294	3	2.1	NDI
67	29-03-1999	30.286	79.286	4.6	10	USGS
68	30-03-1999	30.411	79.422	3.3	4	NDI
69	30-03-1999	30.314	79.331	2.8	2.9	NDI
70	30-03-1999	30.389	78.821	3.5	3.9	NDI
71	30-03-1999	30.346	79.491	3.2	3.7	NDI
72	30-03-1999	30.262	79.359	2.5	18.1	NDI
73	30-03-1999	30.393	79.429	3.7	44.9	ISC
74	30-03-1999	30.341	79.348	5.2	40.7	ISC
75	31-03-1999	30.289	79.393	3.5	3	NDI
76	31-03-1999	30.352	79.486	3.1	1	NDI
77	31-03-1999	30.262	79.365	3	1	NDI
78	01-03-1999	30.497	79.344	4	51.8	ISC
79	01-04-1999	30.528	79.409	4.5	10	USGS
80	06-04-1999	30.414	79.321	5.1	10	USGS
81	06-04-1999	30.330	79.343	4.6	10	USGS
82	07-04-1999	30.257	79.295	4.7	40.3	USGS
83	07-04-1999	30.449	79.368	4.4	42.4	ISC
84	12-04-1999	30.522	79.410	4.8	28	ISC
85	14-04-1999	30.256	79.305	4.9	10	USGS
86	18-04-1999	30.401	79.339	4.8	38	ISC
87	14-05-1999	30.306	79.297	3.9	45.3	ISC

88	02-06-1999	30.273	79.280	3.6	33	ISC
89	21-06-2000	30.581	79.196	3.5	33	USGS
90	01-10-2000	30.471	79.054	2.6	33	NDI
91	12-03-2001	30.406	79.022	4.5	33	USGS
92	09-08-2001	30.486	79.167	4.3	39.3	USGS
93	27-05-2003	30.547	79.293	4.9	33	USGS
94	27-05-2003	30.383	79.087	4.1	33	USGS
95	27-05-2003	30.444	79.283	3.7	3.1	USGS
96	30-11-2003	30.614	79.219	3.6	31.1	ISC
97	12-12-2003	30.784	79.349	4.1	14.5	USGS
98	14-01-2004	30.295	78.958	3.1	3.1	NDI
99	18-01-2005	30.547	79.401	2.7	15	NDI
100	05-09-2005	30.406	79.151	4.6	10	USGS
101	05-09-2005	30.432	79.114	3.8	35	USGS
102	14-12-2005	30.476	79.255	5.1	44	USGS
103	14-12-2005	30.610	79.386	3	32.3	NDI
104	16-12-2005	30.464	79.142	3.7	23.1	USGS
105	25-01-2008	30.676	79.439	3.4	27.4	ISC
106	03-01-2009	30.566	79.245	3.8	10	NDI
107	15-05-2009	30.588	79.318	3.6	31.5	ISC
108	21-09-2009	30.879	79.057	5	52.3	USGS
109	14-03-2011	30.542	79.176	3.9	24	ISC
110	20-06-2011	30.610	79.338	4.9	14.3	USGS
111	06-04-2013	30.704	78.939	3.6	16.3	ISC
112	16-02-2014	30.443	79.279	3.5	17.3	ISC
113	24-02-2014	30.533	79.294	3.5	24.2	NDI
114	18-07-2015	30.448	79.154	4.4	10	USGS
115	06-02-2017	30.654	79.165	5.1	16.1	USGS
116	06-12-2017	30.634	79.160	5.1	10	USGS

Source: Oldham (1883), IMD, USGS, ISC, PEK, NDI and The Tribune (1990-2015)

Distribution and Concentration Patterns of Seismicity

The majority of the earthquakes reported from study region were minor (Table 1.2); the magnitude of earthquakes ranged between 2.3 to 6.8 mb on Richter scale (Map 1.1). There were 10 events of magnitude 2.3-2.9 mb which accounts for 8.62 percent of the total occurrence while 35 events (30.17 per cent) had earthquakes magnitude between 3.0-3.9 mb. Events recorded with the magnitude between 4.0-4.9 mb were 53 which makes for 45.68 percent of the total events. There were only 18 events of significant force, i.e. magnitude ≥ 5.0 mb on Richter scale, out of which 14 events had earthquake magnitude between 5-5.9 mb while magnitude exceeded 6.0 Mb in case of 4 only. The regional distribution of earthquakes is shown in Figure 1.1.

Table 1.2
Upper Mandakini River Basin, Uttarakhand
Earthquake Intensity And Frequency (1800-2017)

Magnitude (Mb)	Number of Events	Per cent Events
Below 2.9	10	8.62
3.0-3.9	35	30.17
4.0-4.9	53	45.69
5.0-5.9	14	12.07
6.0-6.9	4	3.45
Total	**116**	**100**

Source: Oldham (1883), IMD, USGS, ISC, PEK, NDI and The Tribune (1990-2015).

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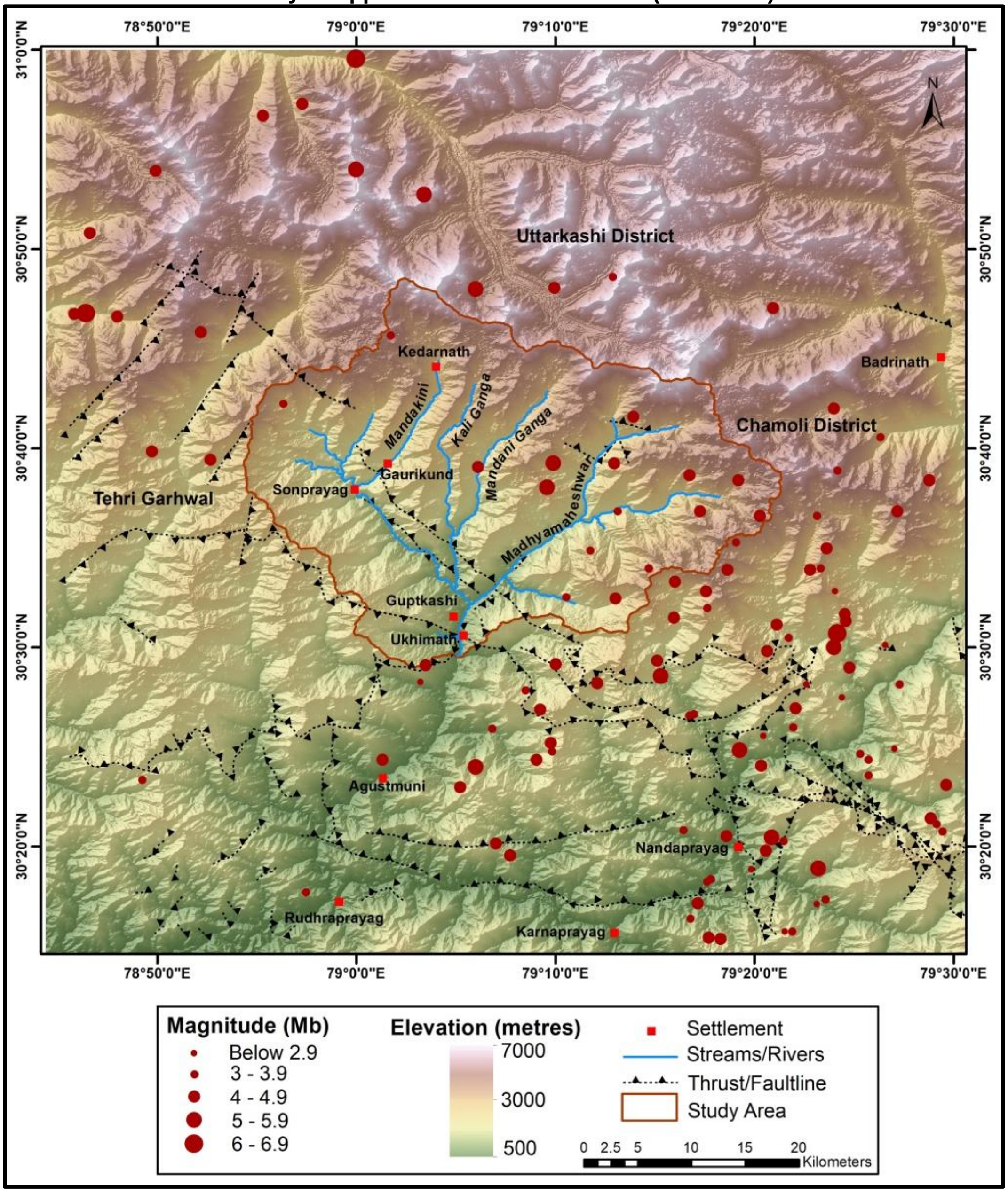
Map 1.1
Seismicity in Upper Mandakini River Basin (1800-2017)



Source: Oldham (1883), IMD, USGS, ISC, PEK, NDI and The Tribune (1990-2015).

The spatial distribution of seismicity in study region demonstrates a higher concentration around southeastern and southern parts. The areas in southeastern parts of Chamoli district shows higher concentration of earthquakes (Map 1.1) while their occurrence in upper Mandakini River valley is relatively less with fewer significant earthquakes incidences. Seismicity in the region reflects influence of tectonics and associated faults/thrusts and geological lineaments. There are four prominent tectonic alignments i.e. the Ramgarh Thrust, the Munsiari Thrust, the Vaikrita Thrust and the Pindari Thrust which traverse through the region and are aligned in northwest-southeast direction parallel to the Himalayas. The Main Central Thrust is major structural discontinuity of Himalaya that traverses through central portion of the study area in northwest to southeast direction. Besides these major thrusts/faults, the region also has several localized lineaments or weak planes that can be seen in the southern parts of study region (Figure 1.1). These thrusts and fault lines make study region tectonically very active. These tectonic features has led to evolution of a highly rugged topography which comprises of high elevation, cliffs, steep slopes, deep and narrow valleys where river channels are controlled by the lithological and structural characteristics. As a result, the seismicity in conjunction with highly rugged terrain adds to region's physical risk and enhances the vulnerability potential.

Conclusion

Upper Mandakini River basin and disaster occurrence represents an extremely despicable interplay between natural processes and human actions. The last 20 years or so has been bizarrely catastrophic for the area and people have suffered unbearable losses. The area has a natural propensity for earthquakes; their occurrence is a common phenomenon in and around the Upper Mandakini River basin. The occurrence of 116 events of earthquakes with various magnitudes is attributed to region's complex geological setting and weaker structure dissected by a number of thrusts and faults. The entire study area is a part of very high seismic risk zone V; the areas of Chamoli and Uttarkashi are the most vulnerable as these have faced massive destruction due to earthquakes in the past.

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