The 2020 Mw 5.5 Mizoram earthquake and associated swarm activity in the junction of the Surma Basin and Indo-Myanmar Subduction Region

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ORIGINAL PAPER

The 2020 Mw 5.5 Mizoram earthquake and associated swarm activity in the junction of the Surma Basin and Indo-Myanmar Subduction Region

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Abstract
A severely felt earthquake of Mw 5.5 occurred on 22 June 2020, in the Champhai district of Mizoram, North East Region (NER) of India, in the vicinity of the Indo-Myanmar subduction zone. This earthquake was associated with a swarm type of activity; six earthquakes of Mw 4.0–5.1 and some 16 earthquakes of Mw 3.0–3.9 occurred almost within two months like a swarm which caused much panic in the Mizoram state and neighbouring region. The mainshock of Mw 5.5 was preceded by an earthquake of Mw 5.1 on the previous day, 21 June 2020, in the capital city Aizawl, ~ 70 km northwest of Champhai. All of these events originated at shallow depth (~ 10–30 km) and occurred in the intra-plate zone of the subducting Indian plate. Fault plane solution of the mainshock indicates strike-slip faulting that matches fairly well with the transverse Mat Fault in the Outer Indo-Burma Wedge (OIBW). Macroseismic investigation of the mainshock at some 46 sites shows the maximum intensity of VIII (MMI scale) at the epicentral track. An attenuation relation between intensity and hypocentral distance is derived, which may be helpful to assess seismic hazards in this region.

Keywords Swarm activity · Fault plane solutions · Active fault · Mizoram · Northeast India

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1 Introduction

The North East Region (NER) of India is one of the most seismically active regions in the world as the region is jawed in between the Himalayan collision zone in the north and the Indo-Myanmar subduction zone (Indo-Burmese subduction zone) in the east. The major tectonic features of the region are illustrated in Fig. 1. The earthquakes are mostly clustered in the Indo-Myanmar subduction zone and the Himalayan collision zone; but the intraplate zones, such as the Shillong plateau, the Assam valley and the Bengal basin are also active. Details on the regional seismicity, active faults, and tectonics are given by several authors (Nandy 2001; Kayal 2008).

The present study area comprises several major faults, like Churachandpur Mao Fault (CMF), Kaladan Fault (KF), Kabaw Fault (KBF), Chittagong-Coastal Fault (CCF), Gomati Fault (GF), Mat-River Fault (hereafter Mat Fault, MF) and numerous NW–SE trending lineaments associated with anticlinal-synclinal structures in the Mizoram Fold Belts (Fig. 1). Maurin and Rangin (2009) divided the Indo-Myanmar subduction zone into three divisions: Outer Indo-Burmese Wedge (OIBW), Inner Indo-Burmese Wedge (IIBW), and Core (CORE), each separated by faults. The OIBW between KF and CMF is seismically less active compared to the IIBW and Core part of the subduction zone. The OIBW is tectonically complex, with eastward movement of the subducting Indian plate beneath the Burmese microplate under NNW to NNE compressional stress (Maurin and Rangin 2009;

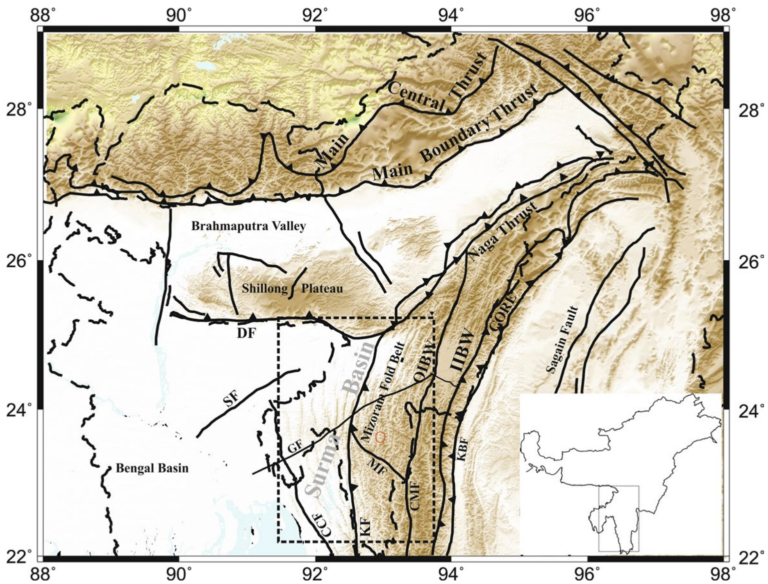


Fig. 1 Tectonic map of Northeast India region (NER) with the major faults and lineaments of the regions. Our study region is represented by dash lined rectangular shape in the southern part of NER. In the figure, the major structural features like Main Boundary Thrust, Main Central Thrust; Brahmaputra valley, Naga Thrusts, Shillong Plateau, DF: Dauki Fault, CCF: Chittagong Coastal Fault, MF: Mat Fault, KF: Kaladan Fault, GF: Gomati Fault, CMF: Churachandpur Mao Fault; KBF: Kabaw Fault, are shown. In the inset, NER is shown on the right-hand corner and our study area is represented in a rectangular shape region. Some specified regions like Surma Basin, OIBW: Outer Indo-Burmese Wedge, IIBW: Inner Indo-Burmese Wedge and CORE: Core of the subduction zone is also shown in the figure. The red colour circle represents the capital city, Aizawl of Mizoram state

Kundu and Gahalaut, 2012). The Core unit of the Indo-Burmese Wedge has approximately 50 km width in between the KBF and CMF and consists of undated high-grade metamorphic rocks.

Recently, in June–August, 2020, a series of small to moderate earthquakes (Mw 4.0–5.5), resembling swarm activity, occurred in the Mizoram within OIBW. OIBW is seismotectonically less active, but the sudden swarm activity created panic across the region. There were several reports of damages and landslides in different parts of the epicentre region. In this present work, we try to understand the tectonics of the swarm activity and the active fault(s). We also carried out a macroseismic investigation for the mainshock of Mw 5.5 on 22 June 2020, and prepared an isoseismal map. Further, we attempted to find a relation between ground-motion attenuation and observed intensity. These results are highlighted and discussed here.

2 Seismotectonic of the study region

It is primarily envisaged that earthquakes of the Surma Basin, the Mizoram Fold Belts (hereafter Mizo Fold Belts), and the western segment of Myanmar have the property of Benioff zone earthquake. The earthquakes clustered in the upper surface of the subducting Indian plate, among which, the 6.7 Mw, 4th January (04:35 IST) 2016 is noteworthy (Gahalaut et al. 2016). The tectonic components of the region are comprised of right-lateral strike-slip CMF, west-dipping thrust typs KBF and KF which are highly active and cause intense seismic activity in the region (Fig. 1). The seismicity in this atypical subduction zone is continued to a deeper depth, triggers earthquakes up to a depth of 150 km that extends from OIBW to the Central Myanmar Basin. Another prominent tectonic feature that runs across the Surma Basin and Mizo Fold Belts is the Mat Fault which is a right-lateral strike-slip fault, trending NW–SE across Mizoram. Due to such tectonic settings, earthquakes were not an uncommon feature in the area. However, no major earthquake was reported in near vicinity of the MF, but some localized seismicity was observed in this fault zone. Furthermore recent studies on the Mat Fault, extending upto a shallow depth of 4 km, shows little movement or slip (Tiwari et al. 2015).

Indo-Myanmar subduction region has frequently witnessed several small- to moderate-size earthquakes, but few significant and destructive earthquakes have been reported. Most recently, a strong earthquake of Mw 6.7 occurred at the Tamenglong district of Manipur; the epicentre falls to the northwest of the study area (Fig. 2a). In 1918, another remarkable earthquake of Mw 7.2 occurred in Bangladesh known as the Srimangal earthquake located in the western margin of Surma Basin (Stuart 1919; Bapat et al. 1983). The past seismic activity in Mizo Fold Belt region shows this region experienced moderate size earthquakes with maximum Mw 5.0–5.5. Al Zaman and Moinra (2017), however, argued that faults within Mizoram are capable of producing Mw 7.0 earthquake. The seismicity in the study area is mainly due to the active tectonic features like CMF, KF, MF and other associated lineaments (Fig. 2a). Most of the earthquakes are within a magnitude range of Mw 3.0–4.9, with some moderately felt earthquakes of magnitudes Mw 5.0–5.5. In the intra-plate region, OIBW bounded by the CMF to the east, the earthquakes are mostly within 50 km of depth. Beyond the CMF, in the IIBW, the earthquakes are deeper down to a depth of 50–75 km, and in the Core part, east to KBF, seismicity observes up to a depth of 100 km (Ni et al. 1989; Satyabala 2003; Kundu and Gahalaut 2013; Baruah et al. 2013; Saikia et al. 2019). The earthquakes are much deeper reaching down 150–180 km in the

Fig. 2 **a** Map showing the enlarged version of study region showing regional features and locations of earthquakes since 21st June 2020, 5.1 Mw, Aizawl earthquake and 22nd June 2020, 5.5 Mw earthquakes analysed by National Center for Seismology. The 5.5 Mw earthquake was recorded by all running seismic stations of the Northeast Telemetry Network System of NCS, although in the figure, we show 2 broadband stations, Saiha and Aizawl operated in Mizoram state. Local lineaments and major faults are shown in the map. Recent 6.7 Mw, 2016, Tamenglong earthquake occurred on the Northeast corner of the study region is also shown by the red star (Gahalaut et al. 2016). The USGS and other international agency recorded all those earthquakes of Magnitude 5 and above are shown by blue coloured beach ball solutions. The fault plane solutions of the 22nd June 2020, Mw 5.5 earthquake has been published in Harvard Global Centroid Moment Tensor (GCMT, https://www.globalcmt.org/CMTsearch.html) solution and is shown by brown colour beach ball notation. The dotted white colour EW profile across the study region is considered for the depth seismicity of the region. **b** Depth seismicity of Mizoram and Champhai region post 22nd June 2020, Mw 5.5 earthquake. Earthquakes are well relocated as mentioned on the NCS website. The subducting Indian plate has a low dip angle is represented by the dotted line following Maurin and Rangin 2009. The earthquakes of magnitudes M > 5.0 are represented by roman numerals corresponding to the epicentral parameters given in Table 1

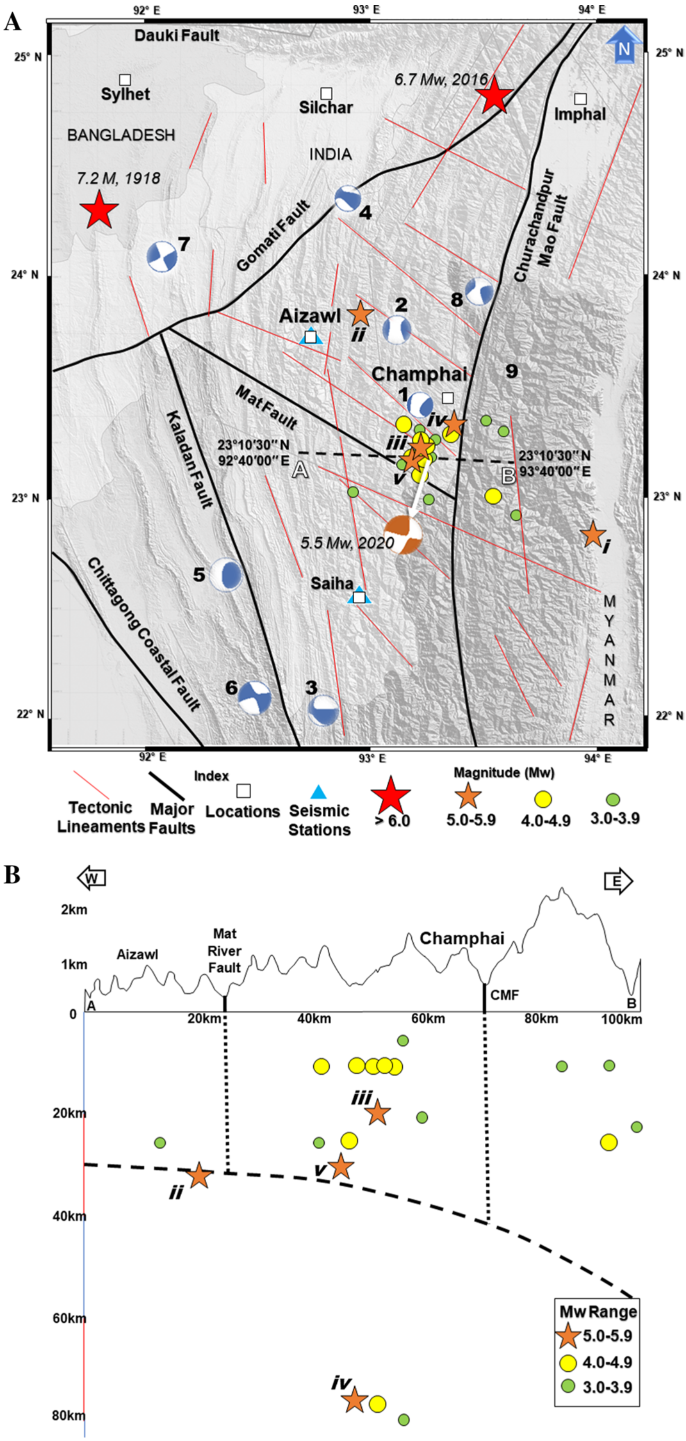
Central Myanmar Basin (Satyabala et al. 2003; Mishra and Zhao 2004, Maurin and Rangin 2009, Hurukawa et al. 2012). However, the recent seismicity in the Champhai area in the intra-plate zone of OIBW shows a depth range of 10–30 km (Fig. 2b). From the GCMT solutions, (https://www.globalcmt.org/CMTsearch.html), it appears that the earthquakes are mainly strike slip in nature, while some are associated with thrust and normal faults (Fig. 2a). Fault plane solutions of some earthquakes (earthquakes 1 & 8 in Fig. 2a) are pure strike-slip with an east dipping fault plane, which resembles the CMF. While fault plane solutions of some earthquakes (earthquakes 3, 5 & 6 in Fig. 2a) indicate thrust mechanism along KF with NW–SE trend, transverse and parallel faults of the region are showing oblique to strike-slip mechanism. Tiwari et al. (2015) reported some earthquake has NW–SE strike-slip component parallel to the Mat Fault.

Recently, a series of small to moderate earthquakes (Mw 4.0–5.5) occurred in the Mizoram state in OIBW and created panic in the whole region (Fig. 2a, Table 1). This earthquake series was initiated by a moderate felt earthquake of Mw 5.1 at a depth of 35 km in capital city Aizawl on 21 June 2020. This earthquake was recorded by more than 10 seismic stations of Northeast Telemetry Network of National Center for Seismology (NCS). Within 12 h, there was the intensified mainshock of Mw 5.5 on 22nd June 2020 near Tuipuiral locality in the Champhai district (hereafter named as the Champhai earthquake). The Champhai earthquake occurred at a depth of 25 km and was followed by two smaller earthquakes of Mw 4.5, and Mw 4.3 at a shallower depth of 10 km on June 25 and July 9, respectively (Table 1). From 21 June 2020, 5.1 Mw Aizawl earthquake to August 2020, there were 23 well-recorded earthquakes of Mw 3.0–3.9 and numerous smaller magnitude quakes M < 3.0 in the mainshock epicentral region. The 22nd June 2020, 5.5 Mw earthquake occurred in the juncture of Mat Fault and CMF, approximately 40 km west to the CMF and within 15 km periphery of the Mat Fault, the fault plane solution of which coincides with the right lateral strike-slip Mat Fault (Fig. 2a).

3 Data and methodology

3.1 Macroseismic data

We collected macroseismic pieces of evidence at 26 sites in and around Champhai district after the 22nd June 2020, Mw 5.5 mainshock. These observations are listed in Table 2. To


A
Dauki Fault
Sylhet
Silchar
Imphal
BANGLADESH
INDIA
6.7 Mw, 2016
7.2 M, 1918
Gomati Fault
Churachandpur Mao Fault
Aizawl
Champhai
Mat Fault
Kaladan Fault
Chittagong Coastal Fault
23°10'30" N 92°40'00" E
23°10'30" N 93°40'00" E
5.5 Mw, 2020
Saiha
MYANMAR
Tectonic Lineaments
Major Faults
Index Locations
Seismic Stations
> 6.0
Magnitude (Mw)
5.0-5.9
4.0-4.9
3.0-3.9
B
W
E
Aizawl
Mat River Fault
Champhai
CMF
Mw Range
5.0-5.9
4.0-4.9
3.0-3.9

estimate the degree of damages, media reports were collected from 20 published sources, enlisted in Table 3. These reports are cross verified and examined in the epicentral tracks. In order to know about the damages for assessing the intensity, some basic questionnaires were made and the responses of local people were incorporated. The Mw 5.1 earthquake of the 21st June 2020 also did some damages, like cracks on roads and walls of the old Church building and PHE pipelines (Fig. 3).

The mainshock of 22nd June 2020 earthquake was strongly felt in the settlements of the eastern parts of Mizoram in the Champhai district and other neighbouring districts like Serchhip and Khawzawl comprising of around 30 villages. This event seriously affected 360 residential and government/public buildings (Fig. 4, Fig. S1). Moderate level slope failures in 15 different areas were observed, and 10 retaining walls were damaged. However, no human casualties were reported, but mortalities in livestock were high and documented (Table 2). As the mainshock occurred in the early hours of the morning (04:10 IST), most inhabitants were asleep and startled by the sudden shaking and rumbling sound of the earthquake, that made them rush out to open places. Damages of structures such as Churches, weak buildings, a few newly constructed RCC buildings, and buildings on the hill slopes were reported (Fig. 4).

The severe shaking and damages were caused due to its shallow focus and sedimentary subsurface. We do not have accelerograms to calculate peak ground acceleration (g) and instrumental intensity data, however around 46 felt reports assisted us in compiling an isoseismal map. Following Stover and Coffman (1993), we assigned maximum MM intensity VIII in the epicentral area (Fig. 5). The maximum intensity region extends up to approximately 20 km^2 trending NNE–SSW, possibly indicating the direction of rupture propagation. The ground-shaking was felt in all nearby cities of the neighbouring states in NER like Silchar, Shillong, Imphal and Kohima. It was felt severly in the Lower Assam valley within the 300 km periphery; assigned Intensity IV, and felt mildly in the upper Assam valley within 500 km radius, assigned Intensity II. The isoseismal map clearly provides a fair picture of the distribution of ground-shaking impacts (Fig. 5).

Based on the field study, it has been observed that the affected buildings are semi-permanent type. These were built with structural loopholes due to which column-wall joint failure was common (Fig. 4, Fig. S1). Several open ground cracks were noticed in different localities in Champhai district, such as in the villages of Vanzau, Samthang, Dungtlang, E. Chawngtui, Farkawn and Thekte villages, which are within 5 km radius of the epicentre (Fig. 6). From the epicentral track, it was observed that there were 20 earthquake-induced small to medium-size landslides that occurred due to the mainshock (Fig. 7). Most of them occurred with strong jolts accompanied by a rumbling sound. As a result, people rushed out of their houses, fearing aftershocks. Although the intensely felt mainshock did not inflict significant devastation in terms of property loss or human lives, panic-stricken residents in the vicinity were living in a temporary shelter in open space for about a month (Fig. S2).

The 21st June 2020, Mw 5.1 earthquake caused panic throughout the Mizoram region as it was followed by several landslides (Fig. 7). Most of these landslides in this region were associated with slope failures along the steeply dipping beds. Some of the rockfalls and slumps were also reported during the field investigations. Because of the high degree of inclination and joint sets that occur at different angles to the bedding plane, the slope of the bedrock is unstable and prone to slide (Rakshit et al. 2021). The lithology of Surma Basin comprises primarily silty sandstone alternating with thinly bedded/layers of shale-siltstone associated with high proportion of clays and organic matters. As a result of climatic conditions and other anthropogenic activities, these rocks have undergone moderate

Table 1 Well-located earthquake parameters of near vicinity to Champhai region and its associated swarm activity of magnitude above M > 3.0 for 2 months starting from 18th June 2020

Serial No	Magnitude	Origin Time	Latitude	Longitude	Depth	Region	Location
1. Figure 2 *(i)*	5.0	2020–06–18 19:29:25	22.82	94.00	80	Myanmar	98 km SE of Champhai, Mizoram, India
2. Figure 2 *(ii)*	5.1	2020–06–21 16:16:24	23.80	92.96	35	Aizawl, Mizoram	10 km NE of Aizawl, Mizoram, India
3. Figure 2 *(iii)*	5.5	2020–06–22 04:10:52	23.22	93.24	20	Champhai, Mizoram	27 km SSW of Champhai, Mizoram, India
4	3.7	2020–06–23 19:17:37	23.01	93.03	25	Champhai, Mizoram	39 km SE of Thenzawl, Mizoram, India
5	3.2	2020–06–23 23:03:48	22.89	93.64	10	Champhai Mizoram	70 km SSE of Champhai, Mizoram, India
6	4.1	2020–06–24 08:02:36	23.18	93.25	10	Champhai, Mizoram	31 km SSW of Champhai, Mizoram, India
7	4.5	2020–06–25 01:14:44	23.26	93.34	136	Champhai, Mizoram	21 km S of Champhai, Mizoram, India
8	4.6	2020–07–03 14:35:41	23.02	93.53	25	Champhai, Mizoram	52 km SSE of Champhai, Mizoram, India
9	4.6	2020–07–05 17:26:37	23.24	93.24	77	Champhai Mizoram	25 km SSW of Champhai, Mizoram, India
10	4.3	2020–07–09 14:28:16	23.30	93.18	10	Champhai, Mizoram	23 km SW of Champhai, Mizoram, India
11	4.2	2020–07–17 15:56:42	23.17	93.22	10	Champhai, Mizoram	33 km SSW of Champhai, Mizoram, India
12. Figure 2 *(iv)*	5.1	2020–07–17 22:03:58	23.29	93.35	78	Champhai, Mizoram	18 km S of Champhai, Mizoram, India
13	3.7	2020–07–17 22:35:35	23.19	93.27	80	Champhai Mizoram	30 km S of Champhai, Mizoram, India
14	3.5	2020–07–18 20:31:36	23.31	93.48	10	Myanmar	22 km SE of Champhai, Mizoram, India
15	3.2	2020–07–20 03:39:38	23.24	93.29	20	Champhai, Mizoram	24 km S of Champhai, Mizoram, India
16	3.8	2020–07–24 11:16:00	23.27	93.53	10	Myanmar	29 km SE of Champhai, Mizoram, India
17	4.4	2020–07–28 20:08:52	23.22	93.26	10	Champhai, Mizoram	27 km SSW of Champhai, Mizoram, India
18	4	2020–08–14 06:38:10	23.12	93.24	10	Champhai, Mizoram	38 km SSW of Champhai, Mizoram, India
19. Figure 2 *(v)*	5.3	2020–08–27 17:37:18	23.16	93.20	30	Champhai, Mizoram	35 km SSW of Champhai, Mizoram, India
20	3.6	2020–08–27 18:16:10	23.16	93.18	25	Champhai, Mizoram	36 km SSW of Champhai, Mizoram, India
21	4.1	2020–08–27 18:47:23	23.17	93.21	25	Champhai Mizoram	34 km SSW of Champhai, Mizoram, India
22	3.3	2020–08–28 06:27:19	23.00	93.27	5	Myanmar	51 km S of Champhai, Mizoram, India
23	3.7	2020–08–29 00:44:45	23.27	93.24	10	Champhai, Mizoram	22 km SSW of Champhai, Mizoram, India

Table 2 Macroseismic report of 5.5 Mw, 22nd June 2020 Champhai earthquake and immediate aftershocks on Champhai region and all neighbouring locality in Eastern Mizoram

Sl. No	Name of village	GPS Coordinates	No. of affected building		Remarks
			Residential	Govt./Public	
1	Zokhawthar	23º21′55.86″ & 93º23′57.82”	19	12	Alluvial filled valley, thick loose colluvium, no proper rock bedding; Indo-Myanmar border
2	South Khawbung	23º10′20.11″ & 93º13′11.25”	30	3	People heard explosion sound before jolting
3	Farkawn	23º04′45.38″ & 93º17′37.57”	41	4	Cultural heritage site; People heard explosion sound before jolting
4	Samthang	23º09′40.10″ & 93º15′59.26”	18	8	People heard explosion sound before jolting; pond leakage; 7 small slides, 4 open ground cracks after 17th July 2020 earthquake
5	Vaphai	23º08′54.48″ & 93º19′32.16”	18	2	Cultural heritage site; People heard explosion sound before jolting; 4 small slides; damaged 9 television; 31 livestock (7 pigs and 24 poultry) killed
6	Dungtlang	23º11′38.65″ & 93º15′02.61”	19	3	Cultural heritage site; People heard explosion sound before jolting; 1 slide, and two ground cracks after 17th July 2020 earthquake
7	Zawlsei	23º09′25.51″ &93º12′29.39”	34	1	People heard explosion sound before jolting
8	Leithum	23º14′29.35″ & 93º16′09.45”	13	1	People heard explosion sound before jolting
9	Chawngtui East	23º07′39.76″ & 93º19′32.67”	9	4	People heard explosion sound before jolting; 2 small slides
10	Sazep	23º14′06.94″ & 93º18′01.55”	3	2	People heard explosion sound before jolting; 8 pigs killed
11	Khuangthing	23º05′42.08″ & 93º11′54.00”	31	5	
12	Khuangleng	23º18′26.21″ & 93º18′46.16”	15	3	Spring water turbidity was high
13	Vangchhia	23º12′12.52″ & 93º19′59.53”	4	1	Cultural heritage site
14	Kelkang	23º23′18.74″ & 93º18′27.94”	5	0	
15	Thekpui	23º03′39.79″ & 93º14′24.03”	0	1	
16	Thekte	23º02′45.47″ & 93º15′37.29”	4	3	
17	Bungzung	23º16′57.36″ & 93º14′08.03”	1	1	1 small slide and ground crack
18	Vanzau	23º14′40.77″ & 93º15′04.94”	3	1	11 pigs killed
19	Sesih	23º17′35.31″ & 93º20′09.92”	14	1	
20	Leisenzo	23º17′15.53″ & 93º19′25.73”	4	1	2 slides
21	Saikhumphai	23º08′18.03″ & 93º22′36.04”	0	1	

Table 2 (continued)

Sl. No	Name of village	GPS Coordinates	No. of affected building		Remarks
			Residential	Govt./Public	
22	Khankawn	23º06′38″ & 93º24′76”	4	0	1 pig killed
23	Khawkawn	24º01′08.77″ & 93º13′16.11”	0	1	
24	Lianpui	23º24′37″ & 93º32′85”	2		
25	Mualkawi	23º25′09.77″ & 93º19′57.73”	1	0	
26	Vaikhawtlang	23º89′10″ & 93º37′17”	0	2	

Table 3 Media-based reports on 5.5 Mw, 22nd June 2020 Champhai Earthquake

Sl. No	Location	Latitude (N)	Longitude (E)	Report	MMI	Source
1	Silchar and southern villages, Assam	24º49′59.25″	92º46′44.05″	Furniture and windows rattled Felt by many	VI	Northeast Now
2	Eastern part of Meghalaya	25º18′46.25″	92º37′09.51″	Felt by many	V	Republic World news
3	Imphal and Southern Manipur	24º49′01.25″	93º23′48.52″	Strongly felt, buildings and articles rattled	VI	Republic World
4	Shillong, Meghalaya	25º34′43.21″	91º53′35.05″	Tremor felt by many	VI	The Northeast Today
5	Guwahati, Assam	26º08′35.21″	91º47′23.19″	Tremor felt by many	IV	Times of India-Guwahati
6	Cachar, Dima Hasao, Guwahati Assam	24º50′09.25″	92º45′54.32″	windows rattled, Felt by many	IV	Pratidin Time
7	Kohima, Nagaland	25º40′30.41″	94º06′30.21″	Slightly Felt	V	India Today Northeast
8	Guwahati, Karbi Anglong,	26º08′35.56″	91º47′23.25″	Felt by many	IV	India Today Northeast
9	Golaghat, Nagaon			Felt by many	III	India Today Northeast
10	All districts in Mizoram	–	–	Felt by many	VI	Vanglaini; DD
11	Aizawl	23º43′32.66″	92º43′08.51″	Felt by many; two water pipelines along the road in Aizawl anticline were cracks	VII	Personal experience, Vanglaini, DD, Zonet & LPS News
12	South Khawbung	23º10′20.11″	93º13′11.25″	Strongly felt	VIII	Vanglaini & DD
13	Samthang	23º09′40.10″	93º15′59.26″	Strongly felt	VIII	Vanglaini & DD
14	Vaphai	23º08′54.48″	93º19′32.16″	Strongly felt	VIII	Vanglaini & DD
15	Zawlsei	23º09′25.51″	93º12′29.39″	Strongly felt	VIII	Vanglaini & DD
16	Dungtlang	23º11′38.65″	93º15′02.61″	Strongly felt	VIII	Vanglaini & DD
17	Farkawn	23º04′45.38″	93º17′37.57″	Strongly felt	VIII	Vanglaini & DD
18	Leithum	23º14′29.35″	93º16′09.45″	Strongly felt	VIII	Vanglaini & DD
19	Zokhawthar	23º21′55.86″	93º23′57.82″	Strongly felt	VIII	Vanglaini & DD
20	Khuangthing	23º05′42.08″	93º11′54.00″	Strongly felt	VIII	Vanglaini & DD
21	Khuangleng	23º18′26.21″	93º18′46.16″	Strongly felt	VIII	Vanglaini & DD
22	Champhai	23º28′37.03″	93º19′18.22″	Felt by many	VII	Pasaltha & DD
23	Serchhip	23º18′30.91″	93º51′23.69″	Felt by many	VII	Serchhip Times
24	Khawzawl	23º31′19.85″	93º11′08.61″	Felt by many	VII	Vanglaini News
25	Mamit	23º55′30.52″	93º29′30.49″	Felt by few	VII	Telephonic

Table 3 (continued)

Sl. No	Location	Latitude (N)	Longitude (E)	Report	MMI	Source
26	Saitual	23°41′17.65″	93°57′45.56″	Felt by some	VII	Telephonic
27	Lawngtlai	22°31′54.73″	92°53′37.70″	Felt by few	VII	DD
28	Siaha	22°29′22.55″	92°58′28.43″	Felt by few	VII	Vanglaini News & DD
29	Lunglei	23°53′25.10″	92°44′35.64″	Felt by some	VII	DD & Telephonic
30	East Lungdar	23°12′06.81″	93°05′12.93″	Felt by many	VII	DD
31	Biate	23°14′46.81″	93°07′17.77″	Felt by many	VII	DD
32	N. Vanlaiphai	23°07′57.31″	93°03′40.90″	Felt by many	VII	Telephonic
33	Cherhlun	23°00′00.00″	93°05′29.71″	Felt by many	VII	Telephonic
34	Khawhai	23°22′49.38″	93°07′59.55″	Felt by many	VII	Vanglaini News & DD
35	Thenzawl	23°16′55.01″	92°46′24.92″	Felt by some	VII	Telephonic
36	Mualcheng	23°10′59.23″	93°03′31.82″	Felt by many	VII	Telephonic
37	Khawruhlian	23°51′59.38″	93°52′42.20″	Felt by many	VII	Telephonic
38	Ngopa	23°53′08.08″	93°12′41.20″	Felt by many	VII	Telephonic

Fig. 3 **a** Fracture/Cracks developed along the main road near Aizawl District Collector office (trend of fracture: 150°) due to the 21st June 2020, Mw 5.1 earthquake, Aizawl earthquake; **b** Prominent fractures occurred during the Champhai Earthquake (trend of fracture: 050°)

Fig. 4 Pictures showing damage patterns and cracks developed along the rupture propagation direction of different villages in the Champhai region after 22nd June 2020, 5.5 Mw Champhai Earthquake

to high degree weathering (Bharali et al. 2021), which aids in the active soil formation process. Infiltration of water along the inclined beds and joint surfaces make a slippery base which results in failure of the uppermost rock layers and associated soil horizon. It is also observed that unstable bedding conditions and the presence of a NW–SE lineament contributed to most of the landslides (Rakshit et al. 2020). This deformed linear feature might be associated with other lineaments in the region and is a possible deformation front of the Aizawl anticline. Many rock and wedge failures are also observed in several places.

3.2 Intensity–attenuation relationship

A standard intensity–attenuation relationship for some significant earthquakes in the Indian subcontinent was introduced by Johnston (1996) and Ambraseys and Douglas (2004). They formulated the areal measurements of isoseismals contours and maximum shaking region and then assigned the magnitude and epicentral track of the events. Later Szelliga et al.,

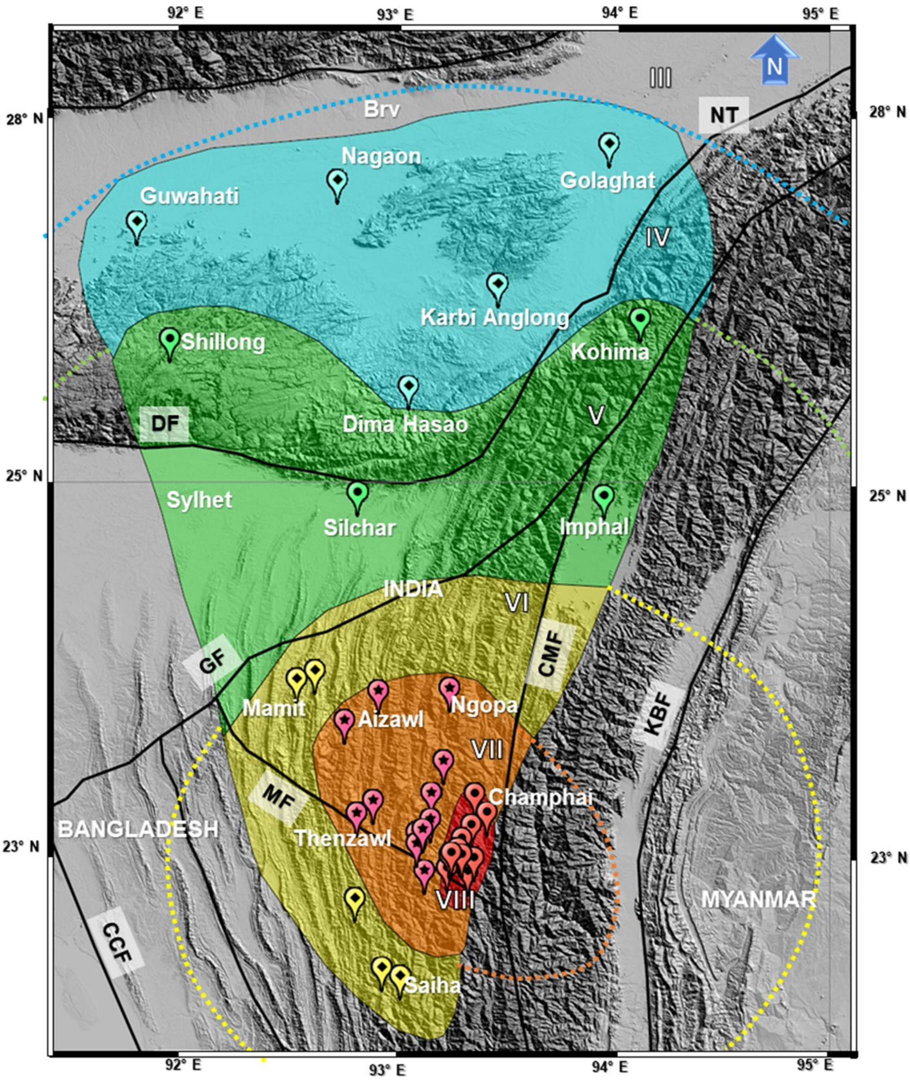


Fig. 5 Isoseismal map of the 22nd June 2020, Mw 5.5 Champhai Earthquake (embedded in the ASTER DEM)

(2010) derived a regression relation, defining intensity (**I**) as a logarithmic function of hypocentral distance (**R**):

$$\mathbf{I} = \mathbf{a} + \mathbf{bR} + \mathbf{clogR}$$

Here **a**, **b** and **c** are constants to be determined. In this equation, Howell and Schultz (1975) suggested that the above relation correlated the intensity which is logarithmically proportional to the energy density of a point source. The convolution terms **bR** and **clogR**, which are quite complex to resolve independently, represent the intrinsic attenuation and geometrical spreading, respectively. Figure 8 shows the relation between the Intensity and hypocentral distances for the mainshock Mw 5.5. The curve follows the Eq. (1) in which **a = 8.6757**, **b = − 0.0078** and **c = − 0.3623** with Root Mean Square (RMS) error 0.5210.

4 Discussion

Seismically, the Mizoram state in NER that lies in the OIBW zone and situated away from the plate boundary zone is relatively less active compared to the IIBW or Core part of the subduction zone. However, towards its north, neighbouring state Manipur experienced a strong earthquake of Mw 6.7 on 4th January 2016 (Fig. 2a), which was felt severly in the whole region. In this region, ground shakings are occasionally felt due to strong or large earthquakes in the deeper part of the Indo-Myanmar subduction zone. According to several geophysical investigations, ground vibration in this region is typically high due to amplification of seismic waves caused by the thick sedimentary column of Surma Basin (Verma and Mukhopadhyay 1977; Nandy et al. 1983; Dasgupta 1984; Saikia et al. 2018).

The early morning of 22nd June 2020, the Mw 5.5 earthquake (mainshock) occurred in the Champhai district of Mizoram at a shallower depth (20 km), and the shaking was severely felt in the whole region. This event did much damage to man-made structures and

Fig. 6 Picture showing different scale of fractures occurred during the Champhai Earthquake: **a** 5-inch crack observed in Samthang village, in the epicentral zone; **b** offset of 13 inches recorded from Chawngtui village

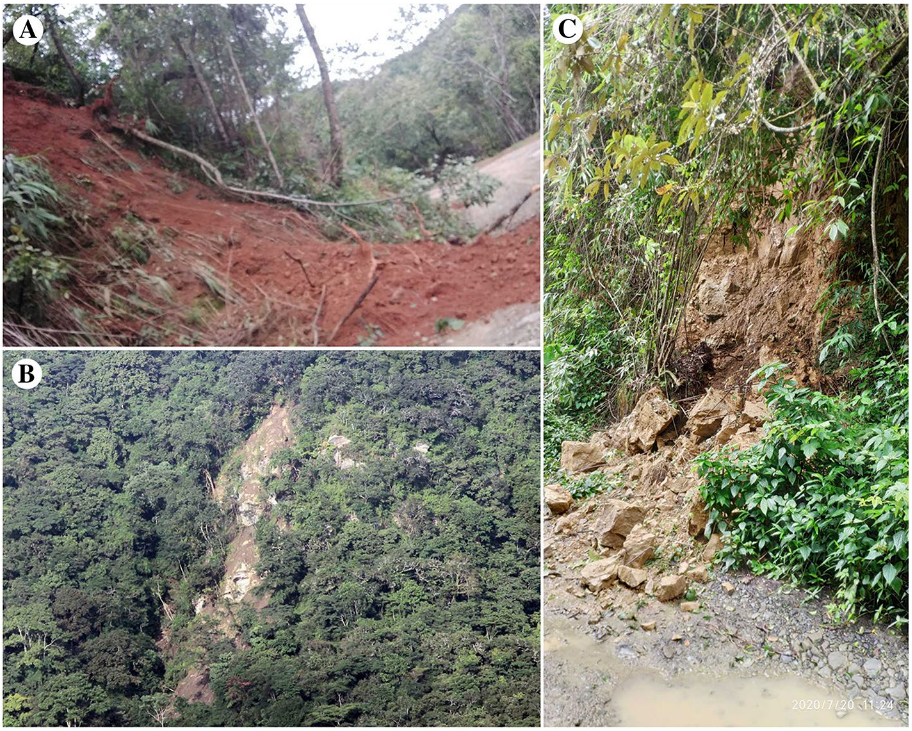


Fig. 7 Picture of earthquake-induced mega-scale landslide including rockfall observed along Aizawl-Champhai Highway

caused landslides at various hill slopes. The mainshock was associated with a swarm type of activity initiated by an earthquake of Mw 5.1 on 21st June 2020 near the capital city Aizawl which, caused minor damages in the epicentre tracks.

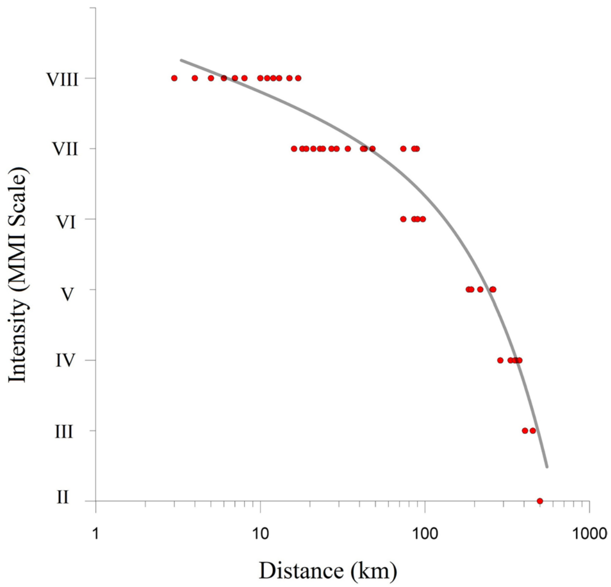
Following the two consecutive earthquakes of Mw 5.1 and Mw 5.5 on June 21 and June 22, respectively, another six earthquakes of Mw 4.0–5.0 and numerous earthquakes of Mw 3.0–3.9 occurred within the epicentral region. All these earthquakes were shallow (depth < 30 km) and occurred in the OIBW bounded by the CMF (Fig. 2b). Another moderate earthquake of Mw 5.3 occurred on 27 August 2020 nearly 50 km North of the Champhai district, followed by an aftershock of M 4.0–5.0 and two of M 3.0 aftershocks. By the month of August, there were 23 earthquakes of magnitude above 3.0 reported by NCS (Table 1), although numerous tremors were felt by the local people. From September 2020, a few felt earthquakes of magnitudes above ($M \geq 3.0$) were observed at the northern margin of the Champhai region near Manipur mostly along the CMF. Two moderate-sized earthquakes, one of Mw 5.3 that occurred in the Tamenglong district of Manipur state at 23:08:00 IST on 10th October 2020 and another of Mw 4.1 occurred on the west of Mizoram in Bangladesh side at 08:51:07 IST on 24th October 2020. These were within the epicentral track of 6.7 Mw, 4th January 2016, Tamenglong, Manipur earthquake. These earthquakes were also felt in the bordering region of Manipur, Mizoram, Tripura and Assam state. From the preliminary location reported by NCS, the 27th August 2020, Mw 5.3 earthquake cannot be correlated with the Champhai earthquake sequence, rather it can be related to the activation of the CMF. This earthquake was located near the CMF and ground motion is oblique-slip type resembling the trend of CMF. The sequence of earthquakes in the region is likely to activate the CMF and its associated structures, triggering further earthquakes in the region. We can infer regional stress from the world stress map (http://www.world-stress-map.org), which may have a significant role in the Champhai region's swarm activity (Fig. S3). In the stress map, the stress components were derived either from fault plane solutions or breakouts. The majority of the regional stress component shows northeast directional forces, suggesting the compressive stress due to Indian Plate motion.

The 22nd June 2020, Mw 5.5 earthquake that occurred in the juncture of MF and CMF, within 15 km periphery of the MF, shows right-lateral strike-slip fault mechanism and the main nodal plane or fault plane of the focal mechanism solution coincide with the NW–SE-trending MF. From the series of well-located earthquakes of magnitude above M 3.0, it can be clearly observed that most of the earthquake epicentres were within the 25 km periphery of MF (Fig. 2a). This series of swarm activity for the two months shows the seismicity is along the MF and is the causative tectonic feature of this swarm activity. As in the latter stage of this swarm activity migrated towards the CMF, it can be inferred that the MF which transects the CMF fault activated the CMF in the complex seismotectonic setting of the Mizo Fold Belt region.

5 Conclusion

The mainshock 22nd June 2020, Mw 5.5 Champhai earthquake and its associated swarm activity continued for 2 months and more than 6 strongly felt earthquakes of magnitude Mw ≥ 4.0 were felt in Mizoram and neighboring areas. The earthquakes occurred at shallow depth, mostly within 20 km and along the NW–SE-trending active Mat River Fault (MF). The migration of seismicity also observed for post-events and occurred near the

Fig. 8 The curvature represents the intensity in the MMI scale with respect to the hypocentral distance for the 22nd June 2020, 5.5 Mw Champhai earthquake



CMF. Based on the field report, a maximum intensity of VIII is assigned to the mainshock of 22nd June 2020. All the possible and adequate ground reports show a NNE–SSW elliptical-shaped isoseismals trend is observed, which indicates the plausible rupture trend. The major axis of the ellipticity extends to 300 km and reaches the Brahmaputra valley on its northern boundary. Maximum damage was observed in the Champhai region within 20 km radius due to local site effects like instability of hills slope or subsurface thick sedimentary strata which amplified the ground motion. The intensity helps us in determining the general distribution of shaking effects. The observed attenuation relation of intensity is $\mathbf{I = a + bR + c\log R}$, where $\mathbf{a = 8.6757}$, $\mathbf{b = -0.0078}$ and $\mathbf{c = -0.3623}$. This attenuation relationship between intensity and hypocentral distance might be very useful in assessing seismic hazard and risk for potential sizeable to big earthquakes, which could be extensively used for earthquake resilient society in this seismically active region.

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Author Contributions SS and BB designed the research. LDP and BB visited the earthquake affected sites and prepared the report, SS has performed the seismotectonic analysis, BB and RR have drafted the geological background of the study area and prepared some figures, SB contributed to the much-sought input about the inference of the study. Overall SS did the science planning, execution and build final manuscript based on inputs from other members.

Data availability All the data are available with this manuscript. Seismic event catalogue was collected from www.seismo.gov.in. Field data are collected by the authors of the manuscript.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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