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ASSESSMENT ON THE IMPACT OF THE TRIPURA EARTHQUAKE (JANUARY 3, 2017, M_W = 5.6) IN NORTHEAST INDIA

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Abstract: The northeastern part of the Indian subcontinent, considered as the most active seismic zone of the Indian subcontinent, was hit by an earthquake of M_w 5.6 on January 3, 2017. The epicenter of this earthquake was Kanchanbari located in the Dhalai district of Tripura. The present study aims to assess the environmental and socio-economic impact of this earthquake in the vicinity of the epicenter. To assess and determine the level of damage, the affected areas were visited during the first week of the 2017 earthquake. Various Government offices were also consulted to acquire data on damages caused by the earthquake. Moreover, Remote Sensing and Geographical Information System (RS & GIS) techniques were applied to address the influence of this earthquake on bank erosion. During the field visit, the striking features of soil liquefaction generated by the earthquake were observed in the flood plain area of the Manu River. Landslide, with three casualties in India and the neighbor Bangladesh, and damages of infrastructure were also reported. Additionally, an assessment of the bank erosion study revealed that the rate of the post-earthquake bank erosion increased to 592%, compared to the pre-earthquake bank erosion within the study length of the Manu River. The findings highlighted that the impact of this earthquake is minimal. However, the seismotectonic features and observation of the liquefaction within the risk zone of the earthquake indicate a possible significant threat for the future.

Keywords: earthquake; impact assessment; liquefaction; awareness; Tripura (Northeast India)

Introduction

Earthquakes are considered the most disastrous natural calamity of the Earth's surface (Tiwari, 2002) which results from a sudden release of energy in the Earth's crust (Gahalaut, 2010). It is usually caused by the movements along the faults, which have evolved through geological and tectonic processes (Tiwari, 2002). This disastrous natural calamity can cause death and injuries to a large extent. Moreover, earthquakes damage human properties and destroy natural resources on massive scale. According to the United Nations Developmental Programme (UNDP) (2003) and Gahalaut (2010), earthquakes often cause extensive casualties, economic damage, and significant hydrologic and hydrogeologic changes. On the other hand, as secondary hazards/disasters, rock falls, landslides, avalanches, tsunami, etc. occur due to earthquakes.

The northeastern part is considered the most active seismic zone of the Indian subcontinent. The region consists of the East Himalaya, which extends approximately E–W and marks a collision

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boundary between the Indian Plate and Eurasian Plate, Indo-Burmese Arc, which extends approximately N–S and joins with the Andaman Arc. The Eastern Himalaya syntaxis lies at the junction of the East Himalaya and Indo-Burmese Arc (Gahalaut & Kundu, 2016). According to the seismic zonation map of India published by the Bureau of Indian Standards (2002), this region has been placed in zone V which is known to have the highest level of seismic hazard potential. In the last hundred years, this region witnessed 18 large earthquakes ($M_w \geq 7$), along with several hundred small and microearthquakes. The Shillong earthquake (1897, M_w 8.7) and the Assam-Tibet border earthquake (1950, M_w 8.7) have been considered as the great earthquakes in this region (Dey, Paul, & Sarkar, 2014). According to Dewey and Bird (1970), the reason behind this high seismicity is collision tectonics between the Indian Plate and the Eurasian Plate in the north and subduction tectonics in the Indo-Burmese Wedge (IBW). Various studies (e.g., Debbarma, Martin, Suresh, Ahsan, & Gahalaut, 2017; Kundu & Gahalaut, 2012) suggest that the Indian Plate's subduction probably occurred in the Indo-Burmese wedge until ca. 50 Ma, when the entire arc was predominantly southeast-northwest trending. Although, there is evidence of the presence of the subducted Indian Slab under the IBW (Steckler, Akhter, & Seeber, 2008) whether the subduction is still active is debated (Satyabala, 2003). The M_w 5.6 earthquake of January 3, 2017 struck at 14:39 IST with its epicenter in Kanchanbari situated in the Dhalai district (24°1'N and 91°57'E) of Tripura about 50 km away from the state capital Agartala (Figure 1, Table 1).

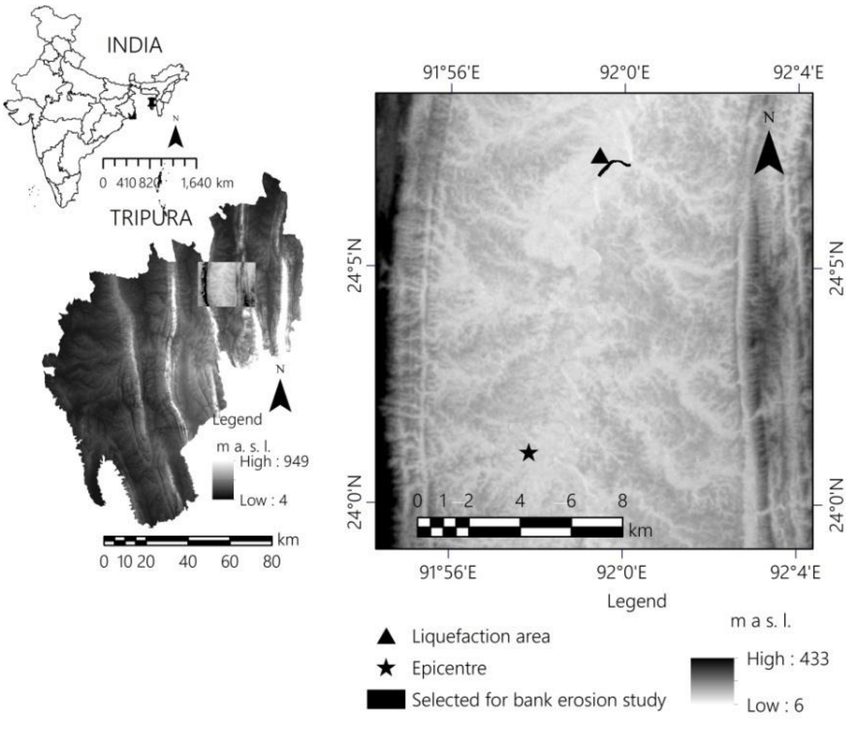

Figure 1. Location map of the study area. Data used for the representation of terrain altitude are obtained from *Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global data* [Data set], by United States Geological Survey, Earth Resources Observation and Science Center, 2014 (https://doi.org/10.5066/F7PR7TFT). In the public domain.

The focal depth was 31 km according to National Center for Seismology, India (Table 1). The state of Tripura is located in the Indo-Burma wedge, and occurrences of crustal deformation and associated seismicity have become a significant concern. According to the previous researches of Le Dain, Tapponnier, and Molnar (1984) and Gahalaut (2010), the main reason for such crustal deformation and associated seismicity occurrence is the interaction of the Indian and Sunda Plate (Figure 2).

Seismotectonic settings and geological history of Tripura

Tripura is situated in the northeastern part of India, adjacent to the Himalayan belt that is seismically very active due to the convergent boundary of the Indian plate with the Eurasian plate (Anbazhagan et al., 2019). Generally, this seismogenic area experiences mild to moderately severe seismic shocks very often. The folding style manifests as a series of longitudinal N–S/NNW–SSE trending anticlines and synclines, whereas the conjugate fracture systems and the deformations of the rock types involved in such folding indicate that the whole region was subjected to E–W compressive stress since Pliocene time (Sitharam & Sil, 2014) (Figure 3). It was continued up to the Pleistocene period (Dey et al., 2014; Sitharam & Sil, 2014). There was a period of tectonic inactivity when the flat-lying Dupitilla formation was deposited in the structural valleys over an erosional surface marking the beginning of the Quaternary period.

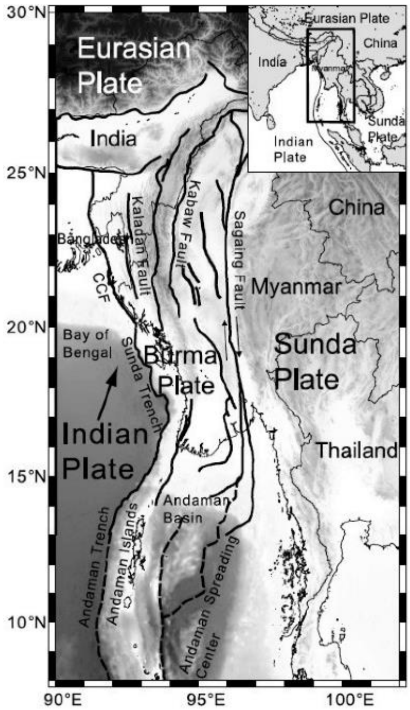

Figure 2. Tectonic setting of the Northeastern region of India. From "Detailed geometry of the subducting Indian Plate beneath the Burma Plate and subcrustal seismicity in the Burma Plate derived from joint hypocenter relocation" by N. Hurukawa, P. P. Tun, and B. Shibazaki, 2012, *Earth Planets Space*, *64*(4), p. 334. Copyright 2012 by The Society of Geomagnetism and Earth, Planetary and Space Sciences (SGEPSS); The Seismological Society of Japan; The Volcanological Society of Japan; The Geodetic Society of Japan; The Japanese Society for Planetary Sciences; TERRAPUB.

Table 1
Seismological data of the 3rd September 2017 earthquake from different sources

Date	NCS	IMD	USGS	EMSC	ISC	GEOFON
January 3, 2017	09:09:02 UTC 24.01°N 91.96°E 31 km depth 5.6 M_w	09:09:03 UTC 24.1°N 91.9°E 28 km depth 5.7 M_w	09:09:02 UTC 24.02°N 92.01°E 36 km depth 5.5 M_w	09:08:02 UTC 24.01°N 92.03°E 35 km depth 5.6 M_w	09:09:02 UTC 24.10°N 91.99°E 34.6 km depth 5.6M_w	09:09:02 UTC 24.01°N 91.96°E 36 km depth 5.6 M_w

Note. NCS = National Center for Seismology; IMD = Indian Meteorological Department; USGS = United States Geological Survey; EMSC = European-Mediterranean Seismological Center; ISC = International Seismological Center; GEOFON = GEO-ForschungsNetz.

It also summarized that the region is still under the influence of E–W stresses, apparently directed from the east. Moreover, isostatic adjustment is an ongoing process in the area, being located to the south of the Shillong plateau with a strong positive Bouguer gravity anomaly (Ravi Kumar et al., 2020).

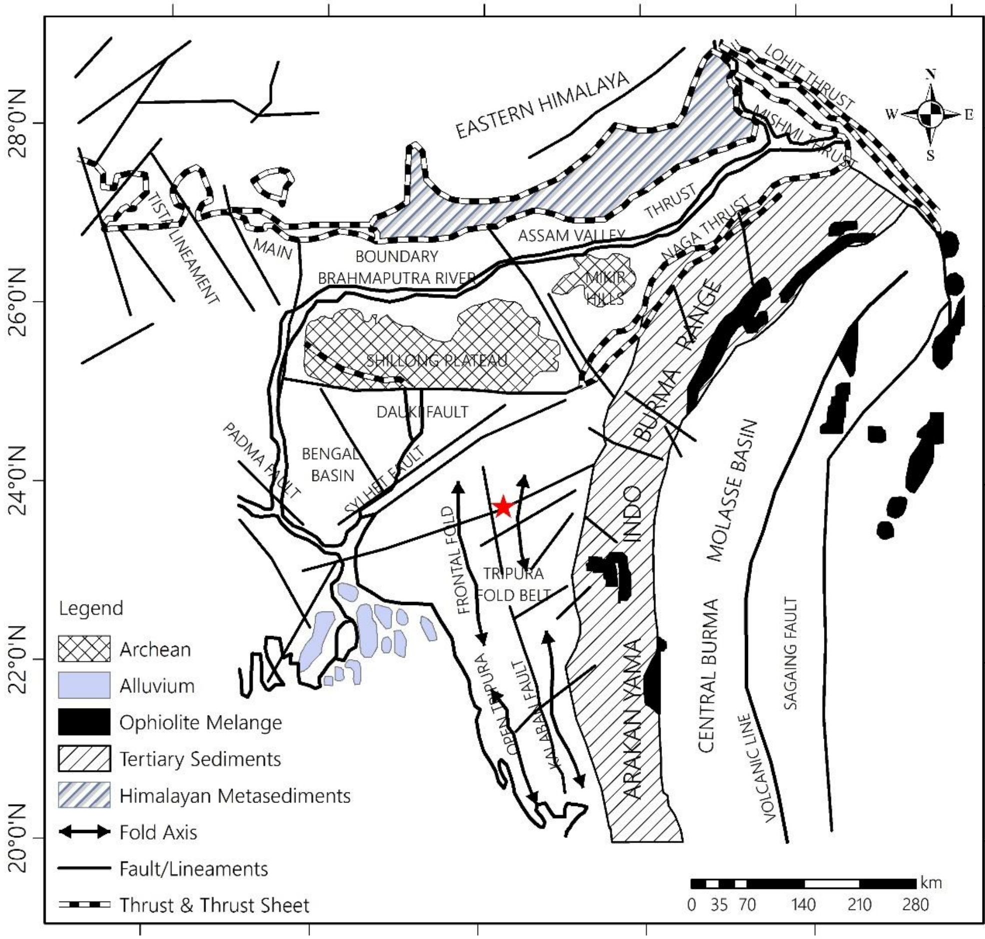

Figure 3. Tectonic map of Northeast India and surroundings. From "A note on earthquake of magnitude 5.5 M_L of January 3, 2017 in Tripura Mizoram border area, India" by Geological Survey of India, 2017. Copyright 2021 by Geological Survey of India. The star within the map shows the location of the epicenter of Tripura earthquake.

According to the recorded seismicity data, it can be stated that Tripura is mostly struck by a moderate earthquake activity. The 2017 Manu earthquake (M_w 5.6) was regarded as one of the strongest earthquakes within the border of Tripura in the last half-century (Anbazhagan et al., 2019). Still, the 1950 Srimangal earthquake (M_w 6.3), Chittagong district of Bangladesh, was also the largest known earthquake in the history of Tripura (Dey et al., 2014) (Table 2).

Table 2
Last 100 years earthquakes in Tripura and the adjoining areas

Year	Place	Geographical Location	M_w	Severity
1920	West of Saitlan, Chin Division (Indo-Myanmar Border region)	22.20°N and 93.20°E	6.0	High
1950	NW of Srimangal, Chittagong, Division (Bangladesh)	24.40°N and 91.70°E	6.3	High
1957	South of Silchar, Cachar District (Assam-Mizoram Border Region)	24.50°N and 93.00°E	6.0	High
1967	NE of Agartala (Indo-Bangladesh Border region), Tripura	24.00°N and 91.50°E	5.1	Moderate
1968	NE of Agartala (Indo-Bangladesh Border region), Tripura	24.10°N and 91.60°E	5.2	Moderate
1971	East of Agartala (Tripura)	23.80°N and 91.80°E	5.4	Moderate
1980	North of Agartala (Tripura)	23.52°N and 91.50°E	5	Moderate
1984	SE of Agartala (Tripura)	23.65°N and 91.50°E	5.3	Moderate
1984	South of Silchar (Assam-Mizoram border region)	24.64°N and 92.89°E	6.0	High
1989	Tripura-Mizoram-Assam border region	24.40°N and 92.43°E	5.1	Moderate
1997	Southern Mizoram	22.21°N and 92.70°E	6.1	High
2013	Tripura-Bangladesh Border region	24.73°N and 91.70°E	3.1	Low
2017	North-east of Agartala (Dhalai District, Tripura)	24.01°N and 91.96°E	5.6	Moderate

Tripura, a state of northeastern region is well-known by its broad geologic and geomorphic diversity. Generally, this part of northeast India, located in the eastern geotectonic province of the Bengal basin remained tectonically very dynamic during the Neogene and Quaternary period of the movement of Indian Plate (Alam, Alam, Curray, Chowdhury, & Gani, 2003). Moreover, the research work of Dey et al. (2014) supported that the geological succession of this part shows that in Miocene epoch the area was dominated by marine coastal environment and landform development in this part onset by sediment deposition (Marine coastal deposition) during the middle Miocene epoch (Table 3).

Table 3
Generalized Geological Succession of the Tripura

Group	Sub-Group	Formation	Lithology
Recent		Recent	Alluvium represented by unconsolidated pale to dirty gray silt, sand, clay, silty clay, sandy clay, etc. Sometimes with decomposed vegetable matters and yellowish brown, coarse river sand, gravels and concretions.
Unconformity (Erosional)			
Dupitilla		Dupi Tilla	Earthy brown to buff sandy clays with grayish brown to reddish brown sand loam, mottled sandy clays, clayey sandstone, coarse to gritty ferruginous sandstone including lenticular bands, and pockets of bluish gray plastic clays, white silica and laterites.
Unconformity			
Tipam	Tipam Sandstone	Champaknagar	Massive medium to coarse friable sub-arkosic sandstone with occasional laminae of sandy shale and abundant lumps of silicified fossil wood.
		Manu Bazar	Fairly bedded fine to medium sub-arkosic sandstone including laminated layers and thick lenticular bands of sandy shale, siltstone and sandy mudstone.

Table 3
Continued

Group	Sub-Group	Formation	Lithology
Contact Transitional			
Surma	Boka Bil		Thinly laminated and thinly bedded repetition of sandstone siltstone/ shale alternations, shales, mudstone and ferruginous sandstone, with irregular partings of fine to coarse sand and inter-stratified thick occasionally lenticular horizon of medium to coarse sandstone to mudstone.
	Bhuban		Indurated hard compact, both massive and well-bedded sandstone dark to olive shale sandy shale and siltstone repeated in space.
Base not seen			

Note. From "Miscellaneous Publication No. 30. Geology and Mineral Resources of the States of India. Part IV-Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland and Tripura" by Geological Survey of India, 1974. Copyright 1974 India, Geological Survey (https://www.gsi.gov.in/webcenter/portal/OCBIS/pagePublications/pageViewGSIPublication). In the public domain.

Methodology

The seismotectonically-affected areas were visited during the first week after the 2017 Manu earthquake main shock to assess and determine the level of damage. In order to get a clearer vision about the impact of this earthquake, we visited the district offices of Dhalai and Unakoti and gathered more information about the damage. This primary and secondary information was supplemented by reports from local newspapers. To get the knowledge of the damaged structure and casualty, we have consulted the Tripura Disaster Management Authority (TDMA) (2017) report.

The epicenter of the 2017 Manu earthquake is located at the bank of the Manu River (Figure 1). As a result, during the field visit, we observed the cracks on the river bank which were possibly the reason to accelerate the rate of bank erosion in that area. Therefore, to understand the effect of the earthquake on bank erosion, the pre- and post-earthquake status of the Manu river channel was assessed. The pre-earthquake period considered the years 2014–2017 and the post-earthquake period comprised the years from 2017 to 2020. To identify such a change within this segment, the area under erosion and the erosion rate was calculated. The bank erosion was assessed with the help of Remote Sensing (RS) and Geographical Information System (GIS) techniques (Debnath, Das (Pan), Ahmed, & Bhowmik, 2017). The riverbank line was identified from the satellite images of 2014, 2017 and 2020 (USGS, 2013-present) (Figure 6). The demarcated bank lines were digitized for both the right and the left banks using the GIS technique. Subsequently, the polygon vector layers were overlaid, and the overall migration of the channel within a one-kilometer stretch was calculated.

Results

Soil Liquefaction

Liquefaction is observed when there is a rapid loss of strength in saturated and cohesionless soils due to dynamic loading, especially during an earthquake. This soil liquefaction was also observed after January 3, 2017 earthquake in the epicenter region of Tripura (Figure 4). This striking feature of earthquake occurred in the flood plain area of the Manu River in Kanchanbari region of Tripura.

Though the extent of the liquefaction was not large, according to the Debbarma et al. (2017) such type of feature had not been found previously in Tripura after earthquakes.

Local people witnessed and observed the sand boil features in the agricultural land. They reported that sand spouting continued up to 15–20 minutes after the earthquake. The extent of the liquefaction occurred within the flood plain of the Manu River. Typically, the River Manu is famous for its dynamic nature (Debnath, Das (Pan), Sharma, & Ahmed, 2019) and the present epicenter area as part of its dynamic nature has been formed by the river deposition. According to Anbazhagan et al. (2019), the presence of the sediment and the existence of a water table near the surface could be a reason for the liquefaction in this area.

Figure 4. Soil liquefaction after the earthquake at Kanchanbari, Tripura.
(Photograph taken on January 4, 2017; Location: 24.11°N; 91.99°E).

Effect on the riverbank

Bank erosion due to liquefaction and mud cracks is common for erosion-prone rivers. Generally, the formation of mud cracks is a preparatory rather than erosive process. It includes wetting and drying of the soil and leads to the weakening of the bank prior to fluvial erosion responsible for the block erosion in a river (Kotoky, Bezbaruah, Baruah, & Sarma, 2005). On the other hand, leaching of the clay minerals also influences bank erosion (Thorne & Osman, 1988). The earthquake occurred in the bank of Manu River which is famous as an erosion-prone river of Tripura. According to the local perception of Kanchanbari (epicenter of the earthquake), this area is already experiencing bank erosion due to the Manu River. Moreover, the meandering nature of the river also indicates that the area is already an erosion-prone zone. Several cracks with the soil liquefaction were observed along the bank of the Manu River in the epicenter area after the 2017 earthquake (Figure 5).

Figure 5. Fractures in the Manu River bank after the earthquake at Kanchanbari, Tripura. (Photograph taken on January 4, 2017; Location: 24.12°N; 91.99°E; Line of sight is towards NE).

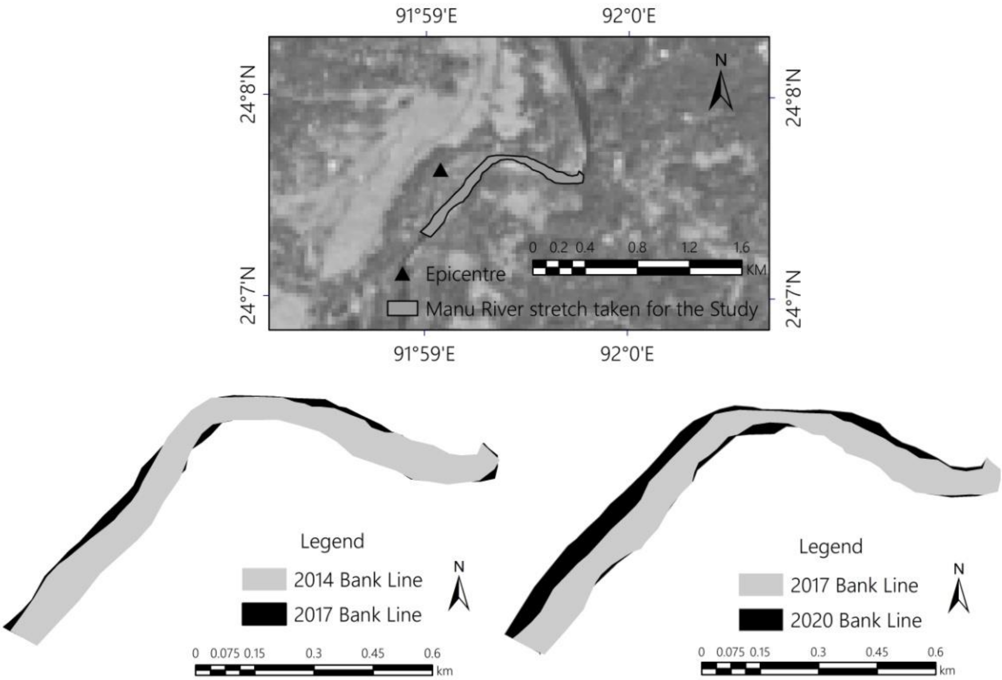

Figure 6. Shifting of the Manu River planform near the epicenter of the 2017 earthquake for the period of 2014–2017 and 2017–2020.

These factors have weakened the soil, reduced the resistance power of the bank, and led to the cogenetic reason for bank erosion. Generally, to realize the impact of the 2017 Tripura earthquake on the bank erosion, the present research examined the channel of the Manu River up to 1 km stretch near the epicenter. This bank erosion was assessed for the period of three years before and after the 2017 earthquake. The pre-earthquake period comprised the period 2014–2017 and post-earthquake period was from 2017 to 2020. The epicenter of this earthquake, i.e., the Manu Riverbank at Dhalai, was visited twice after the earthquake (during 2017 and 2020) and the prominent left bank erosion of the channel was observed. The overlaid channel of the two periods also expressed a similar direction of lateral erosion within the study reach (Figure 6). During the pre-earthquake study period, the area under erosion in the Manu River's left bank was 11,063 m^2 (Figure 7a), with a rate of 1,918 m^2/year (Figure 7b).

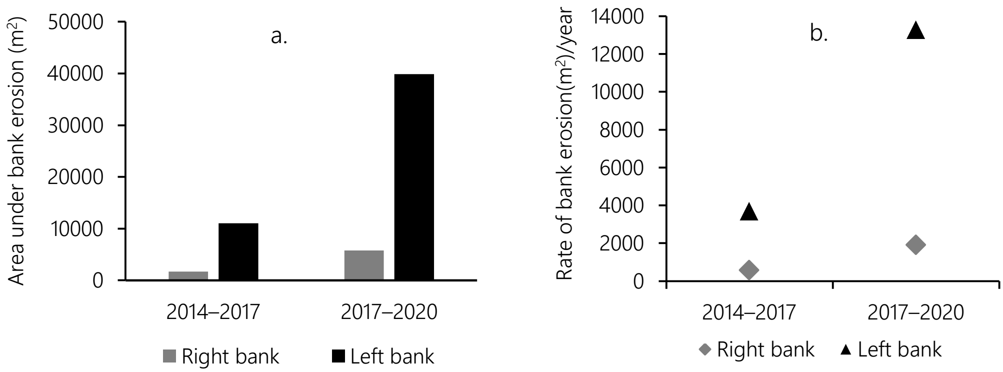

Figure 7. Area under bank erosion (a) and rate of bank erosion (b) for the periods 2014–2017 and 2017–2020.

On the other hand, during the post-earthquake period, the area under erosion covered 39,865 m^2, with a rate of 13,288 m^2/year. Similarly, the right bank also experienced increased erosion but lesser than the left bank. Thus, it was noticed that since the 2017 earthquake, the area under bank erosion and the rate of the bank erosion of the River Manu increased to 260% and 592% respectively near the epicenter.

Landslides

Landslides are regarded as one of the most destructive secondary hazards associated with earthquakes in the mountainous and hilly areas (Tanyaş, van Westen, Persello, & Alvioli, 2019). The epicenter of January 3, 2017 is located between the two hill ranges of Tripura, i.e., Longtarai and Sakhantlang. According to the report of the TDMA (2017), landslides occurred in numerous places along Chhamanu-Gobindabari road of the Dhalai District. There was no report of any casualties, but the road was blocked for a certain period.

Casualties

Reports of earthquake casualties (TDMA, 2017) included one death owing to a heart attack after the earthquake and many injuries due to the collapse of walls and fear due to the shaking. Although the main shock was felt in all the parts of Tripura, the casualties were maximum near the epicenter (Dhalai and Unokoti district of Tripura). According to TDMA (2017) report, one woman died in the Mayachari Gaon panchayet under Kamalpur Subdivision, and many were injured due to this earthquake. In the Unokoti district adjacent to the epicenter, many people were injured due to the earthquake. Moreover, the tremor killed two people and left many people injured in Bangladesh ("Tremor panic kills 2 in Sunamganj," 2017). In the Sunamganj district of Bangladesh, one person died due to heart attack after the earthquake, whereas in the Sylhet district, one schoolgirl died after falling down a flight of stairs when the earthquake hit.

Panic

According to sociologists, panic is a rare phenomenon, but in specific major earthquakes, it may be common and widespread (Alexander, 1995). Sometimes this panic can cause life-threatening effects. According to the daily newspaper report, the tremor created widespread panic throughout the state (Tripura), including other northeastern countries and in the neighboring Bangladesh. According to the news of Tripurainfoways.com, the tension gripped Tripura after the earthquake. People started to run out of their homes and students rushed from their rooms after the earthquake shocks. According to the report, most people and students were injured while they were rushing from home and the schoolroom to the open space.

Infrastructure

The shocks of the earthquake damaged and destroyed many infrastructure objects, especially in the Dhalai, Unakoti, and Sepahijala districts of Tripura. According to TDMA (2017) report, 5,200 houses were partially damaged, 1,450 houses were severely damaged, and about 42 houses were fully damaged. Fractures and cracks were developed in the walls of almost all the houses in the epicenter area. There were reported cases of damage to public property like Kamalpur Sub-division office, hospital building, and a few police stations. Mostly mud houses were damaged severely, and reinforced concrete frames with masonry infill houses and buildings also suffered severe damage. Cracks were developed in the roads and bridges of the Dhalai district.

Discussions about the awareness on earthquake

The state (Tripura), which is in zone V of the seismic risk, has already been affected by a moderate earthquake. Though this moderate earthquake damaged less, it showed a degree of our consciousness and preparedness for facing such hazards. The Parliament of India (2005, December 23) enacted the "Disaster Management Act". According to this Act, the state has the State Disaster Management Authority (SDMA) and the District Disaster Management Authority (DDMA). The authority receives financial assistance as a disaster response fund and disaster mitigation fund. The state has the National Disaster Response Force, which is always giving mock drills and workshops all over the state. Even though the Central and State Government are both trying to sensitize the people, there is still unawareness and unpreparedness.

Since the population is increasing day by day, vulnerability is also increasing (Ara, 2014). Gradually, remote areas are also being inhabited by humans. The rough terrain of Tripura is generally not suitable for transport networks; hence, road connectivity is still not established in the remote parts of the state. So, the question comes how far the state is secure and prepared for such kind of disaster management. The state is still lacking effective warning systems like Earthquake Early Warning System (EEWS). The EEWS is used to describe a real-time earthquake information system that can provide a warning prior to significant ground shaking (Chamoli et al., 2019). EEWSs are already introduced in many countries, and meanwhile, Japan and Taiwan got success stories from these systems (Chamoli et al., 2019). In India, several seismologists at the Indian Institute of Technology (IIT), Roorkee already started a project to implement the EEWS in northern India (Chamoli et al., 2019), but the result is awaiting.

According to the National Disaster Management Authority (2007), the houses should be made as per norms to reduce the casualties and economic losses during an earthquake. India's first national seismic code was developed in 1962 (Bureau of Indian Standards, 1986, 2002), and as per the field observation, it was realized that a growing populated state is experiencing the absence of strict laws. Safety against disasters is the most critical concern in the newly developed Indian hill towns and the existing building regulations (Kumar, 2018). Inferior awareness level in the community is another problem for such kind of disaster management and mitigation. The community should be the prime participant in disaster management. There still exists a gap between the community people and management authority. So, there is a need for the coordination between different management departments and communities to implement the disaster management plan properly.

Conclusion

The January 3, 2017 earthquake (M_w) is recognized as one of the strongest earthquakes within the borders of Tripura, India, which occurred within the Indian Plate underlying the Indo-Burmese wedge. Even though the earthquake's magnitude was quite low, it impacted Tripura (India) and the neighboring Bangladesh, causing casualties, widespread panic, disturbance in electricity supply, damages to human properties, transport networks, etc. Liquefaction was observed with the sand blows within the region of the epicenter. The earthquake resulted in landslides in many places. Severe damages were observed mostly in the mud houses and reinforced concrete frames with masonry infill houses and buildings. Cracks were developed in the roads and bridges. Moreover, it changed the momentum of the bank erosion in the Manu River situated near the epicenter. Since the 2017 earthquake, the area under bank erosion and the rate of the bank erosion of the River Manu has been increased to 260% and 592%, respectively, near the epicenter. Such an event within the risk zone of an earthquake indicates a significant threat to the future. This earthquake was an alarming incident that highlighted the status of the vulnerability of the state. Therefore, for disaster risk reduction, the researchers and management authorities should pay more attention to this region.

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