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Landslide Affected Areas and Challenges Imposed in North Eastern Region of India: An Appraisal

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ABSTRACT

The Earth Observation (EO) data of various Spatio-temporal resolutions are used to study potential sources of landslide hazards in the North Eastern Region (NER) of India. The studies are made in all the eight states of NER, namely Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura on different project modes during the past decade. All types of landslides of various magnitudes and dimensions are triggered by rainfall, earthquakes, or by combined effects in this tectonically active region. Anthropogenic factors also play a role in places, particularly in urban areas. The NER is one of the most seismically active regions in the world, and it falls in highest seismic risk zone, (Zone V), in seismic zoning map of India. The region also receives much rainfall because of its geographic and climatic conditions. We report how the physiography, as well as the local geology, plays the main role in the failure of the rock formation and over burden causing the landslide hazards, which create severe communication disruption and sometimes casualties. Fragile, soft, and weathered rock formations along the steep slope make the terrain much more susceptible to landslides. Deep seated landslides disrupt transportation networks for a longer duration while shallow slides; mostly affect the urban life for a short duration. The reported causalities associated with landslide hazards are much high in the NER compared to other parts of India.

Keywords: Landslides, Hazards, Earthquakes, Rainfall, Geology, NER India, and EO data.

1. INTRODUCTION:

A landslide is the movement of a mass of rock or debris or earth down a slope, under the influence of gravity (Cruden and Varnes, 1996), and it is one of the major geo-hazards in the hilly terrains of North Eastern Region (NER) of India. The NER, which is buttressed between the Himalayan arc collision zone to the north and Indo-Burma arc subduction zone to the east, experiences large/great earthquakes and high rain fall. Thus, landslides and other slope failures occur in these mountainous terrains due to combined effect of several geological factors aided/triggered by rainfall, earthquakes as well as by anthropogenic activities. It causes loss of lives and properties almost every year apart from disruption of communication links.

The NER consists of eight states, namely, Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura. Almost entire region is susceptible to landslides of various degrees due to terrain condition. The plain areas of the Brahmaputra and Barak Valleys of Assam and valley portions of Manipur and Tripura are also susceptible for landslides at places. The region has an area of 262,179sq km (NEC, 2015), from valley to difficult mountainous terrain with elevation as high as 6000m above mean sea level (MSL) in Arunachal Pradesh. The Patkai-Naga-Lusai range of Nagaland and Manipur extends down to Arakan-Yoma belt of Myanmar. The Assam state has lower hill cover area about 24 per cent of the landmass is hilly (GoI, 2013). Mizoram and Tripura states comprise alternate ridge and valley topography, and Meghalaya, on the other hand, is a plateau region of an average elevation 1000m. The whole region has distinctive rocks of different geological ages form Archaean to Quaternary (Bagchi *et al*., 2020).

An attempt is made through this study, to examine and assess the landslide scenario of NER and to understand the challenges it poses to the society and on developmental activities. NER is affected by all types of landslides in varying size and magnitude, and is at the top with respect to Developmental Disability Index (DDI) derived by Government of India (GoI, 2013). More than 50% of the national highways in the region are affected by frequent landslides, especially during monsoon season. We studied different aspects of landslides in NER and highlight the results here.

2. METHOLODOGY:

Various organizations and academic institutions carry out landslide investigation and susceptibility-hazard-risk mapping by conventional and or by innovative techniques for awareness to minimize its affect to the society. The Earth Observation (EO) data of various spatial, spectral and temporal resolutions for different aspects of landslides are studied by many researchers worldwide (Guzzetti *et al.,* 2009; Gorum *et al.,* 2011 and many more). High resolution imagery (QuickBird, IKONOS, CARTOSAT-1 & 2) is one of the best options now for landslide mapping, and various operational sensors are also developed (Westen *et al.,* 2007). The importance and limitations of optical (both mono/ stereoscopic and PAN/multispectral), SAR, LiDAR remote sensing data with varied spatio-temporal resolutions for landslide mapping are elaborately explained by Guzzetti *et al.* (2012). In India use of geo-informatics is evaluated by many experts (Lakhera, 1982; Champati ray, 1996, 2004; Sarkar *et. al.,* 1995, 2004; Martha *et al.,* 2010). In this study, we mostly analyzed the EO data coupled with some field checks either on operational mode or on user demand. The EO data with varying spatio-temporal resolutions, e.g. Cartosat, LISS IV MX, LISS III MX, IKONOS, QuickBird and Google Earth images, are used. The EO data have an advantage due to its synoptic coverage which provides regional appreciation and mapping, monitoring of dynamic changes of the terrain, survey and its evaluation especially in an inaccessible terrain. The mountainous terrain of the NER being inaccessible, it is difficult to survey by conventional method alone; remote sensing data, the only means of survey, are critically analyzed in this study.

2. 1 Geo-environmental set up of NER

2.1.1 Physiography

A major part of the NER belongs to Extra-Peninsula of the mighty Himalayan ranges and its extensions with folded and faulted mountain chains (**Fig. 1**). Broadly the region can be divided into following four groups:

2.1.1.1 Mountainous areas

Arunachal and Sikkim are part of Himalayan ranges with an average elevation of 6400 m in the greater Himalayas. The ranges follow an E-W trend in the western part and gradually swings to NNE-SSW in the northeast till the syntaxial bend, where Arunachal trends NW-SE (**Fig. 1**).

2.2 Valley areas

The Brahmaputra (Assam) valley is narrow and elongated along the gigantic Bramhapura River, about 660 km long and 90 km wide zone (**Fig. 1**). In the western part, the valley is dotted with numerous inselbergs. As the river Brahmaputra is braided in nature, associated geomorphic features are present all along the valley.

The Barak valley in Assam is basically triangular shaped along the meandering river Barak which has originated from Manipur. The valley is transected by north-south trending low- altitude linear hillocks as well as with residual hills at places. The Imphal valley in Manipur is lacustrine in nature, while the plain areas in Tripura show both erosional and depositional features.

2.3 Plateau areas

Almost the entire state of Meghalaya is a plateau with an average elevation of 1000 m, except the foothills of Garo and Jaintia Hills. The highest point (1961 m) of the plateau is called Shillong peak. The Mikir hills in Assam is a fragmented part of Meghalaya (also called Shillong plateau). The Shillong-Mikir plateau is a fragmented part of Indian shield (Evans, 1964; Nandy, 2001).

2.4 Indo-Burma Ranges

The Indo-Burma Ranges (IBR), which extends from Eastern Himalayan Syntaxis (EHS) southwards along the eastern side of the Bay of Bengal to the Andaman Sea, embrace the states of Nagaland, Manipur, Mizoram, Tripura and southern Assam within the Indian territory (**Fig. 1**). In the southern part of NER, the range is N-S trending while gradually swings to NNE-SSW in the northern part in Nagaland. The average height of hill ranges in the southern part is about 900 m above MSL, whereas the general elevation increases towards east with the highest peak Saramati (3841m), located at the eastern margin of Nagaland.

2.5 Geology

The NER represents complete stratigraphic sequences ranging from pre-Cambrian to Recent showing conformity or unconformity relationships between the formations. The oldest geological formation in the region is pre-Cambrian gneissic complex of the Shillong-Mikir plateau. On the other hand, the Himalayas, consist of formations ranging from Proterozoic to early Paleozoic, and vary from low-grade metamorphics in the southern sections to high-grade schists to the crest. The Himalayan foothills zone contains Tertiary rocks of Mio-Pliocene deposits of post-orogenic phase. The rest of the NER is formed by Tertiary rocks with different marine facies, ranging from Eocene to Pliocene deposited either on shelf or geosynclinal basin-system.

2.6 Seismotectonics

Seismically the NER is one of the most active regions in the world due to collision tectonics in the Himalayas to the north and seductions tectonics in the Indo-Burma zone to the east. The Indian plate gently dips below the Himalayas, and atypically subducts below the Indo-Burma Ranges that causes high seismicity forming several seismotectonic domains, namely the Eastern Himalaya collision zone, Eastern Himalayan Syntaxis (EHS) and the Indo-Burma zones at the plate boundaries, and the Meghalaya, Assam valley and Bengal basin in the intra-plate region (**Fig. 1**). The EHS is a much complex zone where the Himalayan arc and the Indo-Burma arc meet (**Fig. 1**). The entire NER is marked as the highest risk zone (Zone V) in the seismic zoning map of India (BIS, 2002). In the collision zone, the Eastern Himalayas produced the 1934 great Bihar-Nepal earthquake (revised Mw 8.2) and several large and strong earth-quakes including the recent 2009 Bhutan (Mw 6.3) and the 2011 Sikkim (Mw 6.9) earthquakes (**Fig. 1**). The 1934 great earthquake, however, falls farther west, out-side of our study region. The EHS produced the 1950 Assam-Tibet great earthquake (Ms 8.7) that caused some 15,200 casualties and huge damages to properties (Poddar, 1950). Magnitude of this earthquake is, however, revised to Mw 8.4 (Ambraseys and Douglas, 2004).

The Indo-Burma subduction zone is seismically most active and marked with several large earthquakes (M 7.0-7.6) **(Fig. 1)**, (Kayal, 2008). In the intra-plate zone, the Meghalaya (Shillong) plateau produced the 1897 great earthquake Ms 8.6 with estimated ground acceleration of 1g and some 1500 casualties and huge property destruction (Oldham, 1899). Bilham and England, (2001) revised its magnitude to Mw 8.1 and proposed a pop-up tectonics model of the Shillong plateau between the Oldham fault and Dauki fault for this great earthquake. The Oldham fault is proposed based on GPS data, that separates the Brahmaputra valley and Shillong plateau, and the gigantic E-W trending Dauki fault separates the Shillong plateau and the Bengal basin (Bangladesh) (**Fig. 1**). The intra-plate Assam valley, on the other hand, produced two large earthquakes, the 1869 (revised Mw 7.4) and the 1943 (revised Mw 7.3), by transverse tectonics along the Kopili fault (Kayal, 2008).

The revised magnitudes of the earthquakes mentioned here are reported by Ambraseys and Douglas, (2004). In addition to these, there are frequent felt earthquakes (Mw 5.0-6.0) with severe shaking in the region (Kayal *et al.,* 2012; Hazarika and Kayal, 2021). These earthquakes play a major role for landslides in the NER.

2.7 Climate

The NER displays the character of tropical climate, especially in the valley areas. The region experiences a prolonged monsoon with heavy to very heavy rains, from June to September with light to heavy premonsoon shower in April and May. The southwest monsoon is the main source of rain; about 90 % of the total rain is received during this period and June is the rainiest month (Dikshit and Dikshit, 2014).There is a climatic contrast between the valley and the mountainous areas. The mean temperature in January in Assam valley is around 16°C, the Arunachal and Nagaland mountainous areas fluctuates between 14°C and a sub-zero temperature. During summer, in April-May temperaturesin the plains vary between 30°and 33°C, while in hills it is of around 20°C with a mean minimum of 15 °C. The NER is the rainiest part of the country and receives much higher rain than the average of 1,000 mm for the whole country (Dikshit and Dikshit, 2014). The average rainfall of Brahmaputra valley is around 2,000 mm with local variations in the rain shadow zones, while Cherrapunji in Meghalaya receives a mean annual rainfall of 11,465 mm.On an average, the hilly areas of the region receive 2,000–3,000 mm of rain yearly.The regional climate in NER is grouped into 3 Koeppen classes, i.e. 'A', 'C' and 'D'.

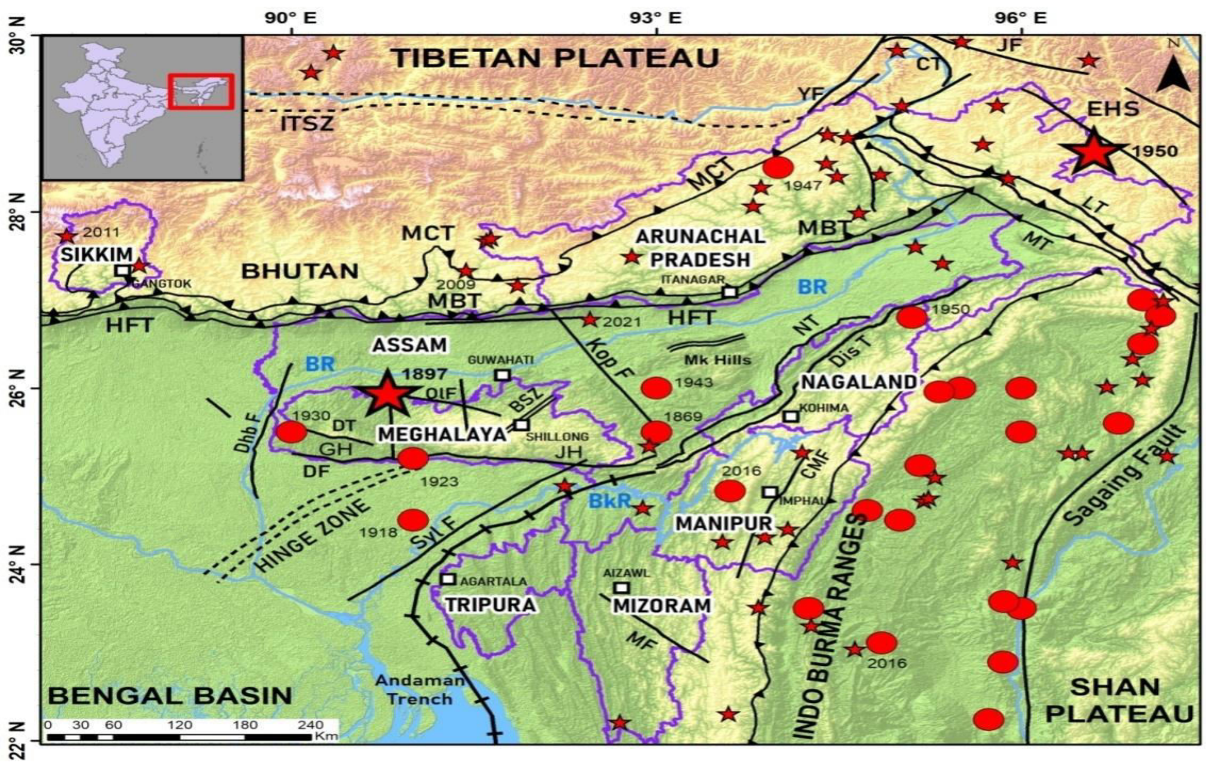

Fig. 1: Geo-environmental set up of the NER, India.

The SRTM elevation data 3 Arc Second (90 m spatial resolution). Base layers taken from NESDR, NESAC database. Major Rivers of the World taken from https://datacatalog.worldbank.org/search/dataset/0042032. Epicentres of the great, large and strong earthquakes (ISC Catalog) are shown in the map. Two great earthquakes (Mw > 8.0) are shown by largest red stars, large earthquakes (Mw > 7.0) by red circles and strong earthquakes (Mw 6.0 - < 7.0) by smaller red stars. Major faults and tectonic features are drawn from EO data taking reference from the published Seismo-tectonic Atlas (GSI. 2000). These are: MCT: Main Central Thrust, MBT: Main Boundary Thrust, HFT: Himalayan Frontal Thrust, ITSZ: Indus Tsangpo Suture Zone, MT: Mishmi Trust, LT: Lohit Thrust, EHS: Eastern Himalaya Syntaxis, JF: Jiali Fault NT, YF: Yemla Fault, CT: Canyon Thrust, NT: Naga Thrust, Dis T: Disang Thrust, CMF : Churachandpur Mao Fault, MF : Mat Fault, Syl F : Sylhet Fault, Kop F: Kopili Fault, OlF: Oldham Fault, BSZ : Barapani Shear Zone, DT : Dapsi Thrust, DF: Dauki Fault, Dhb FDhubri Fault etc. Inset: Key map, rectangle indicates the study region; prominent reference features are: BR: Brahmaputra River, BkR: Barak River, JH: Jaintia Hills, GH: Garo Hills etc.

2.8 Landslides in NER

As described above, based on the geo-environment of different areas in NER, the landslide problems are analyzed area wise to assess the risk zones. These assessment, based on the EO, field surveys and available published data, are presented below.

2.8.1 Mountainous areas

Landslides are major problems for two Himalayan states, Arunachal Pradesh and Sikkim. The 2,500 km long Himalayan collision zone is not uniform in seismicity pattern or in tectonic fabrics (Kayal, 2001 and 2010), so with the geology and slope conditions (Valdiya, 1987). A good correlation of landslide distribution with slope is observed in Arunachal. Majority of landslides occur below the altitude of 2000 m; maximum landslides occur at altitudes between 500 and 1000 m. This concentration of landslides in lower altitude belt may be attributed to geologically younger and geomorphologically unstable state of the frontal Arunachal Himalayas. Additionally, frequency of landslides peaks at slope value of 40° and above. This may be due to the presence of hard rocks at slope <40°areas which remain stable if undisturbed by catastrophic events like earthquakes, rain etc. In analysis of pre- and post- monsoon data of LISS IV MX, image of 5.8 m resolution, it is observed that about 3542 landslides occurred in Arunachal in the year 2014 after monsoon. While a single monsoonal episode in 2014 indicated 1750.8mm rainfall with -1% DEP (Srivastava and Guhathakurta, 2004). Most of these landslides were triggered by heavy rainfall in Arunachal. The state has a population of more than one million with a decadal growth of about 26% (Census, 2011). The 1950 great earthquake (Mw 8.4) recorded the first seismic induced landslides in Arunachal Himalaya. A detailed macroseismic survey was done by Poddar (1950); he reported several landslides and subsequent failures of engineering constructions in Subansiri district area due to severe ground shaking by this great earthquake. Arunachal Pradesh being much rugged and inaccessible, we examined the temporal satellite imagery of Landsat TM and ETM (1987, 1990, 1995, 1996 and 2000), IRS P5 (Cartosat 1stereo data: 2007 to 2011) and IRS P6 (Resource: LISS IV MX of 2008, 2009 and 2012) along with Survey of India (SOI) topographical maps (1960-62 and 1963-64) to assess the landslide risk conditions. A 3D visualization by draping multispectral image over DEM provides a realistic portrayal of the terrain **(Fig. 2)**. It helps us to recognize prominent locations with concave slope pattern and shapes indicating an old landslide of larger dimension in the entire northeast Himalayas **(Fig. 2)**.

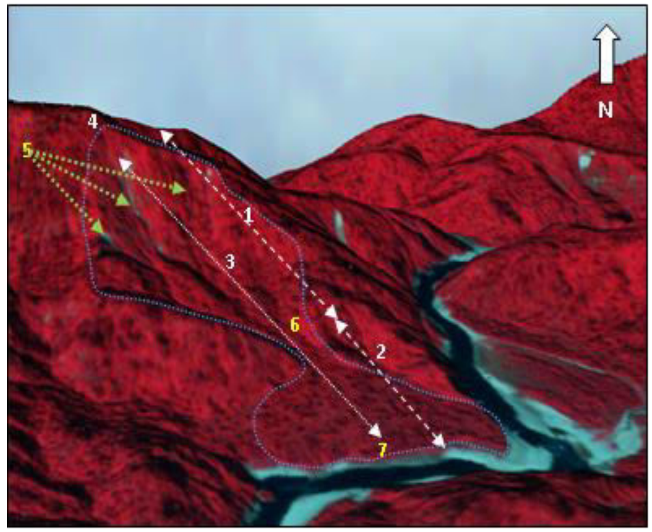

Fig. 2: 3D visualization of an old landslide, different features of landslide is demarcated.

1: Zone of Depletion; 2: Zone of Accumulation; 3: Displaced material; 4: Crown; 5: Radial Cracks; 6: Toe of surface of rupture; 7: Toe. Image: Resourcesat LISS IV MX image of 5.8m spatial resolution; Backgournd: SRTM DEM of 30 m spatial resolution. Source: NESAC-SR-96-2013.

The area mainly falls in Siwalik Group, Gondwana Super Group and quartzite of Miri Fr. Presently, the landslide affected area of the 1950 great earthquake is covered with vegetation with a few smaller landslides along the radial cracks and with almost no human influence. These slides are also responsible for sedimentation in River Brahmaputra and its north bank tributaries. Contrasting bright tones indicating exposed surfaces and shapes help in interpretation of active landslides from EO data **(Fig. 3)**, either though visual interpretation or through semi automated object based classification technique. However, now-a-days, AI based classification techniques are also used for delineation of land-slides from the EO data.

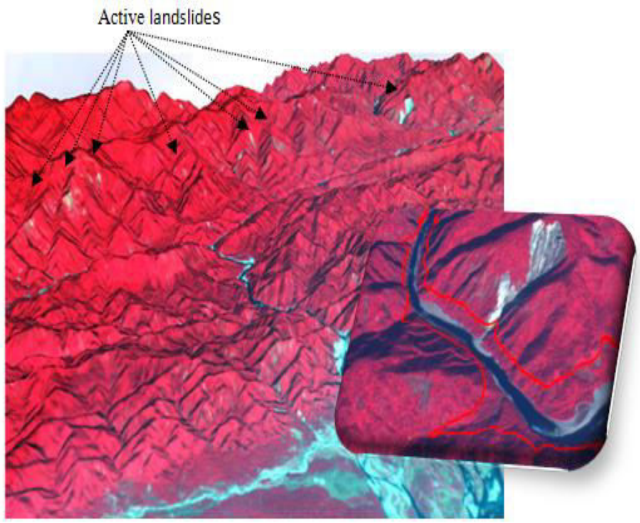

Fig. 3: 3D view of a rock slide (due to wedge failure) in quartzite terrain. Source: NESAC-SR-96-2013. Image: Resourcesat LISS IV MX image of 5.8m spatial resolution; Backgournd: SRTM DEM of 30 m spatial resolution. Source: NESAC-SR-96-2013.

In the year 2020, some 12 casualties were reported from various parts of Arunachal Pradesh, landslides along the road corridors forced commuters to be stranded for few hours. Further, formation of landslide induced natural lakes in the Arunachal – EHS zone is found, which is a well studied phenomenon due to severe earthquakes and geologic conditions. A detailed investigation was done for a natural dam created in July 2020 by landslide(s) blocking the Yigong river, which is found to be a persistent problem in this part. The lake-reservoir and landslides are more or less permanent feature near the clustered earthquake swarm at the intersection of two major strike slip faults, the right lateral Jiali Fault (JF) and left lateral Yigonge Lulang Fault (YLF) (**Fig. 1 & 4**).

Different episodes of moderate to strong magnitude earthquakes (Mw 5.0-6.0) trigger landslides in this zone leading to formation of natural dam & impoundment of water, while intricate fabrics of various fault and thrust systems as well as high altitude mountainous range make this area relatively fragile and susceptible to landslides. Sudden breaches of landslide dams are also responsible for massive floods along downstream of the Siang River in Arunachal Pradesh. At places, river Yiong Tsangpo exhibits braded pattern indicating higher rate of sedimentation resulted from landslide debris.

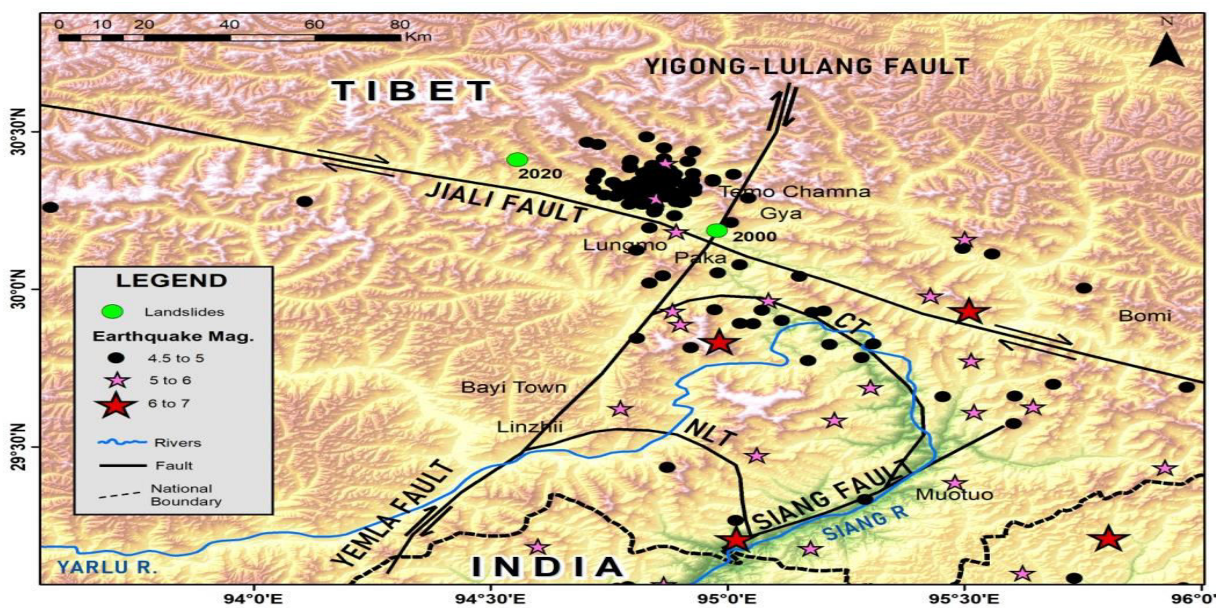

Fig. 4: Location of landslides and natural dam in EHS the WNW-ESE right lateral Jiali Fault. Location of clustered earthquake epicenters and geological structures are after B. Mukhopadhyay, and S. Dasgupta, 2015. YLF: YigongeLulang strike slip fault; YF: Yemla Fault; CT: CanyonThrust.

In Sikkim, adverse geology exhibited by Daling Group of rocks, along with steep slopes mainly make the terrain most susceptible to landslide. Moreover, the Sikkim Himalaya is seismically much active, but earthquakes are much deeper (40-50 km) in comparison to the western Himalayan shallower (depth 10-25 km) seismicity (Kayal, 2001, 2010). Study of temporal EO data shows that many landslides are active since decades (**Fig. 5**). It is observed that reported landslide density in Sikkim is 0.6 slide/km^2 and the state has population of 610,577 (2011, census). Earliest available documentation of landslides in Darjeeling-Sikkim Himalayas was in October 1968 (Rao, 2019). In addition to rainfall triggered landslides, earthquake triggered landslides are also common in Sikkim. Total 1,196 landslides are mapped within an area of 4,105 km^2 using EO data; these were triggered by the September 18, 2011 earthquake Mw 6.9 (Martha *et al.,* 2014). Like Arunachal Pradesh, formation of landslide induced dam and impoundment of water as well as threat related to breaching of the dam is also common in Sikkim (**Fig. 6**).

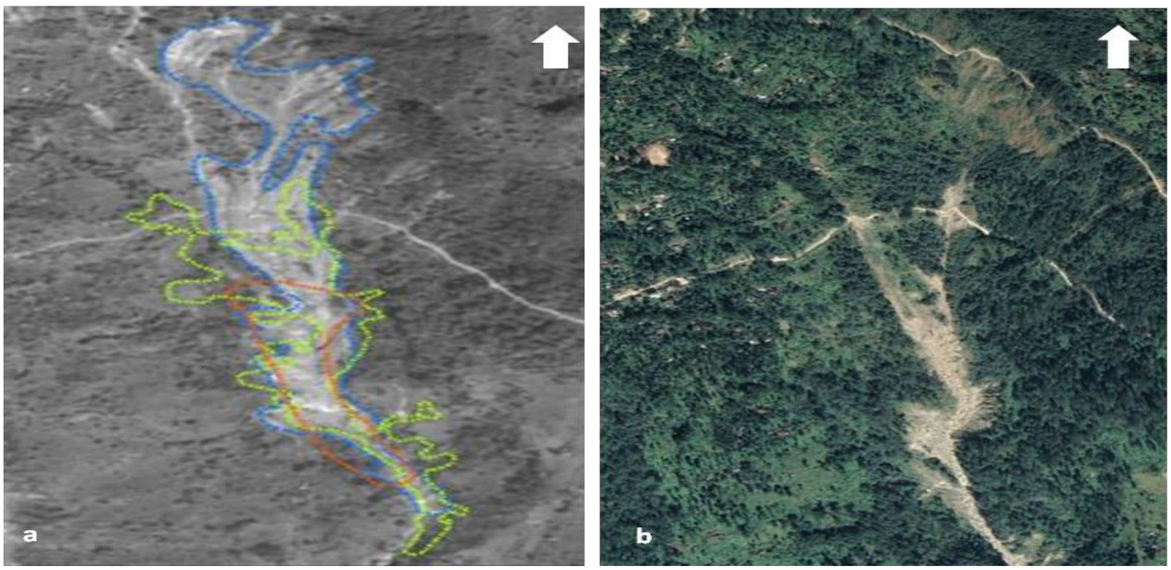

Fig. 5: An active landslide from Sikkim. a). Cartosat-1 image of 2011, and b). Airbus image of 03 Nov 2019.

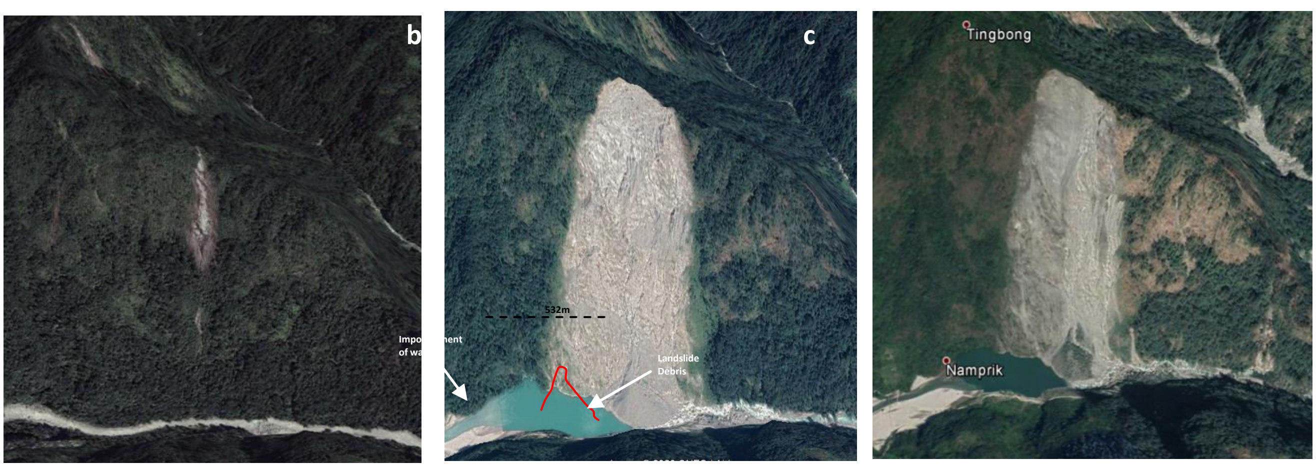

Fig. 6: View of rock avalanche near Mantam village, Sikkim.

Huge landslide debris is seen to block course of Kanka River creating impoundment of water, due to which settlement in Mantam were in vulnerable situation. However, from the vegetation growth on the landslide debris, it appears that the slide has attained some level of stability within a period of 3 years, although lake water near Namprik still exists. It was reported that the landslide washed away 300 km of road downstream and affected numbers of villages which were completely cut off for few days.

2.8.2 Valley areas

Due to topographic conditions, valley areas are mostly devoid of landslides, but some incidences are reported from inselbergs located in and around Guwahati city, capital city of Assam, and from western districts of Assam and residual hills of Barak valley in Assam, and also in some parts of Tripura. Landslides around urban agglomeration of Guwahati city are dominantly anthropogenic; intense or prolonged rainfall is the immediate cause for landslides. Construction of faulty retaining wall, with or without wiping holes adds to overburden weight to the slope. Collapse of such retaining walls on hutments located at lower level causes additional risk. We found that the thickness of weathered zone/soil is fairly high on the denudation hills of Guwahati city. Further, laboratory analysis indicates low strength of the soils which results into its easy erodibility under the action of flowing water and hence generation of debris (Kuntala and Goswami, 2013). However, it is also seen in the field that locals are taking dangerous initiative to reside at the edge of vulnerable slope by spreading plastic sheet etc (**Fig. 7**). Plastic sheets are spread to arrest infiltration of rain water to the weathered material.

Fig.7: Field photographs from Guwahati city, Assam. Plastic sheet is spread to arrest rainfall percolating the slope. Source: NESAC/ATLAS/01/2013.

2.8.3 Plateau areas

The Shillong plateau is basically a hard rock terrain dominated by low to moderately dissected gneissic rock followed by quartzite and intrusive granites. While southern fringes of the Meghalaya state bordering Bangladesh and parts of Assam as well as Garo Hills in the plateau area are highly dissected with somesedimentary terrain. Landslides are mostly observed along road sections of both national/state highways and other minor roads, settlement areas, quarry areas etc. In field surveys, it is noticed that in hard rock terrain landslides are mostly caused due to changed slopes for construction and for excavation. Factors like weathered rock and overburden thickness usually contribute to failure while major triggering factor is rainfall and or earthquakes. The Mikir hills of Karbi-Anlong district, Assam is basically a fragmented part of the Shillong plateau. Extensive slope cuts and weathered layers give rise to both natural and induced landslides triggered mostly by rainfall. An example of earthquake triggered landslide from the southern fringe of Meghalaya is from Sonapur area in Jaintia hills. This slide is reported to be triggered by the 1984 Cachar earthquake Mw 5.8 (Porwal and Dey, 2010), which remained active for years during monsoon seasons. We noted that the dominant causes of these landslides are weak lithology, mapped as Barail Group of sedimentary rocks that are adversely affected by joints, fracture, faults, steep slope etc. The Barail Group, represented by Laisong, Jenam and Renji formations, consist of high to moderately weathered sandstone and carbonaceous shale formations. The boundary between sandstone and shale acts as the slide plane when gets saturated with water. High resolution EO data helped us to demarcate slide boundary and associated features much clearly, which was not possible by field survey due to the exposure conditions (**Fig. 8**). Road connectivity due to small landslides is a chronic problem for its adverse locations in this region. Landslides along the Mawsynram-Balat road, the only connectivity to Balat town located at the southernmost part of the plateau where it forms deep gorges and ravines towards south, is an example of such perpetual problem. The area and its river system is structurally controlled as interpreted from the image interpretation. From a change detection study we observed an increase in slide area from 3320 sq km to 4541sq km within a span of 8 years from 2006 to 2014.

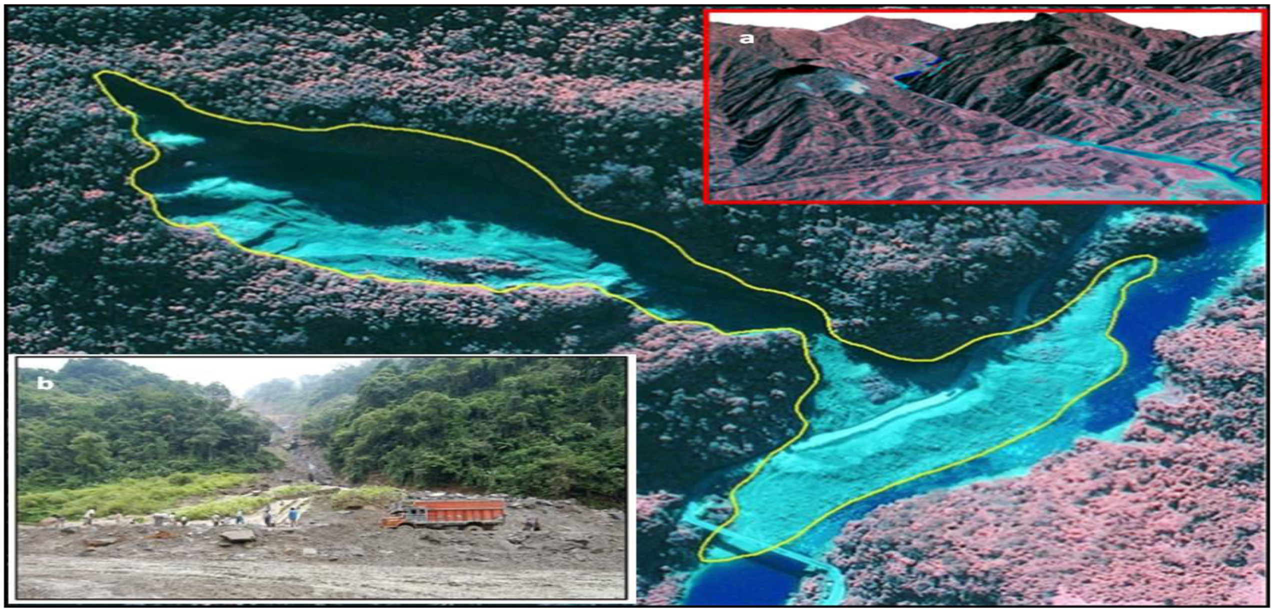

Fig. 8: View of an ill fame landslide area, Sonapur in Jaintia hills of Meghalaya.

Accumulation of landslide debris have blocked the normal flow of River Lubha (Image; IKONOS MX of 2005). a). 3D view of the terrain, interlayer sedimentary strata of of Barail Groups of rock and affect of differential weathering on high and low competent rocks is prominent b). Field view. NESAC/-ATLAS/01/ 2013. Source: NESAC-SR-52-2007.

2.8.4 Indo-Burma Ranges (IBR)

Major portions of the Mizoram, Manipur and Nagaland states and the Dima Hasao district of Assam fall in the IBR. These areas witness many large and small landslides which are frequent and a perpetual problem. Jointed/fractured weathered sedimentary rocks of Bhuban, Disang, Barail, Tipam Groups of rocks comprising sandstone, shale, siltstone and mudstone etc and steep slopes lead to rock and debris slides of different dimensions. This problem of hill slope stability in and around the capital cities, like Kohima city in Nagaland and Aizwal city in Mizoram, is alarming. Numerous small to medium slides take place within the city areas affecting many houses and roads especially during monsoon season. Anthropogenic activities like slope modification for construction, dumping loose overburden deposits and lack of proper drainage system make the slopes much susceptible for failures. It is observed that sometimes the dimension of landslides is small, but fatality and loss of property is comparatively more in urban areas. Some167 and 186 villages in Aizawl district were affected by landslides in the year 2010-2011 and 2008-2009, respectively (HRVA report, 2013). Manipur state is equally vulnerable for landslides. Some 20 people were killed and 12 houses were washed away in Joumol village, Chandel Districtdue to landslides that took place on August 1, 2015. The 210-km long Lumding-Silchar broad-gauge railway track which passes by Dima Hasao area, Assam gets damaged every year due to landslides. This severely disrupts the rail connectivity among the states of Manipur, Mizoram, Tripura and Assam and with rest of India affecting supply of essential commodities every year. Severe disruptions of railway services for one or even two months are reported during 2010, 2012, 2016, 2018 and 2019 especially during the monsoon months of June-July. An average of 200mm rainfall per day continuously for four-five days in the month of April, 2016 trigged many landslides that damaged large stretches of the railway tracks, bridges, tunnels etc in Dima Hasao district, Assam This resulted suspension of railway services for more than one and a half month.

3. DISCUSSION:

The global landslide catalog/map of south-east Asia as produced by the NASA shows concentration of reported landslide events is much higher along the collision as well as subduction zones of plate boundaries. Our study region, the NER of India, is confined within collision zone and subduction zone plate boundaries. The E-W trending Himalayan belt to the north is formed due to collision between the Indian and Eurasian plates, and the N-S trending IBR due to atypical subduction of the Indian plate below the Burmese plate (**Fig. 1**). In addition, various past and present deformational episodes resulted into fragile terrain condition in the intra-plate zone of the NER. In 2020, some 52 casualties are reported from various parts of NER out of which highest number of casualties (25) are reported from Assam intra-plate zone, where only 24% of the total landmass is hilly. Further, the landslide damages increasing drastically as urbanization intensify on the geologically sensitive slopes. Decadal population growth in a range from 12.36% to 27.82% is reported in NER from 2001 to 2011 (Census, 2011), and it is ever increasing. Landslides in the NER are widespread and more frequent than any other natural hazard. Though several earthquake triggered landslides are reported in the region (Oldham, 1899; Poddar, 1950), but rainfall is largely responsible for triggering majority of the landslides in NER (GSI, 2020b). The earliest reported field based landslide study from the NER dates back 1941 from Nagaland, approx. 66 km from Dimapur on the national highway, NH39 (Sondhi, 1941). In this study, we made an attempt to elucidate landslide scenario of the NER, the challenges it poses to the society as well as on developmental activities. Only few examples are cited here to illustrate the fact that every state of the NER is affected by all types of landslides of varying magnitudes and dimen-sions. These are mostly triggered by either rainfall or earthquakes or by combined effect. Seismically the region falls in the highest risk zone in the seismic zoning map of India. It has experienced more than 24 large (Mw > 7.0) earthquakes, two great (Mw >8.0) earthquakes and many severely felt moderate or strong earthquakes (Mw 5.0-6.9) during the past century (Kayal, 2008). Apart from highest rain fall and highest seismicity in the region, anthropogenic factors have a role in accelerating the issue.

4. CONCLUSION AND RECOMMENDATIONS:

A preliminary assessment of landslide susceptible zones in the NER is presented in **Fig. 9** with spatial distribution of the reported major landslides with respect to SW Monsoonal Rainfall (June to September from 1971 to 2020). It shows that landslide hazard is widespread and recurrent phenomenon in the hilly/ mountainous terrains under the influence of SW Monsoon, although local geology, terrain condition as well as land use practice control the dimension and severity of the hazard. The examples of landslides cited in this article are mostly studied using EO data coupled with limited field checks. Utility of the EO data for landslide studies is well demonstrated, and it is observed that data of various spatio-temporal resolutions are the only source of information for the inaccessible terrain. 3D visualisation coupled with detail geomorphological information of the terrain provided by the EO images was helpful to identify location of past landslides. It is observed that landslides that are once triggered by earthquake(s) remain active over years especially during Monsoon season. Deep-seated landslides disrupt transportation network for longer duration while shallow slides are common in urban areas affecting settlements. Frequent disruption of connectivity along the road corridors and railway tracks for long spells, however, causes shortages in supply of essential commodities in the states apart from causing inconvenience to travelers. Geomorphological changes like siltation of river due to accumulation of landslide debris as well as damming of rivers resulting impounddment of water and subsequent dam burst also pose indirect threat to the society. Breaching of a landslide dam is time independent phenomenon; either occurs immediately or takes years depending upon the dam material, dam geometry and characteristics of the upstream catchment area. Efforts are being made by various organizations and academic institutes to prepare large-scale susceptibility maps, followed by vulnerability assessment and risk assessment, and assessment of rainfall threshold for early warning apart from site specific studies to help concerned disaster management authorities. However, considering the gamut of landslide induced problem, a systematic and more comprehensive study is need of the hour. The region, apart from being seismically much active, experiences fairly extensive Monsoon and people in the hilly areas do not have any other alternatives rather than to live on dangerous hill slopes. It's a vicious problem in the NER, and with the increasing population implementation of landslide risk map for dwelling houses is also another challenge to the disaster management authorities.

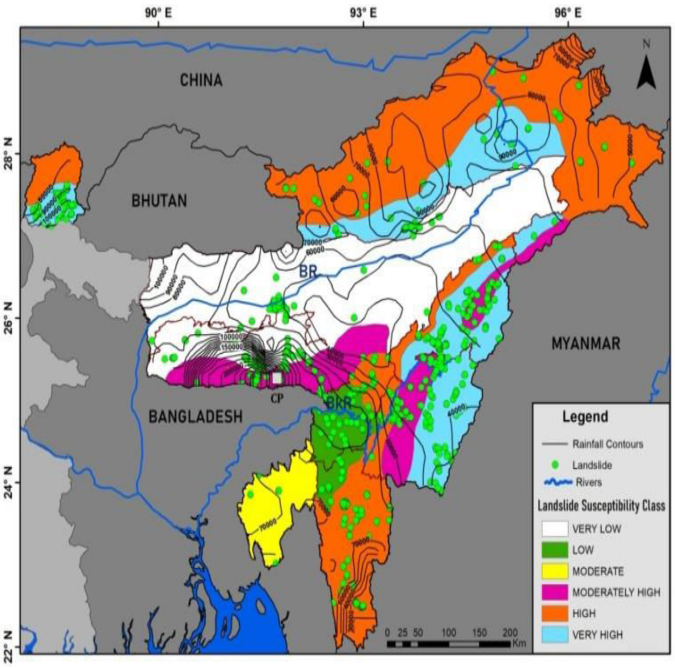

Fig. 9: Spatial distributions of some of the reported major landslides with respect to SW Monsoonal Rainfall distribution pattern (June to September from 1971 to 2020) over pan NER. Background generalized Landslide Susceptibility Map of NER.

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6. CONFLICTS OF INTEREST:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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