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A Review of Seismotectonics and Seismicity of Lower Subansiri District of Arunachal Pradesh

Nirupam Deb[1] and Dr.Olympa Baro[2[56979284600]]

[1] National Institute of Technology, Silchar- 788010, Assam,India
[2] National Institute of Technology, Silchar- 788010, Assam,India
nirupam_rs@civil.nits.ac.in
olympa@civil.nits.ac.in

Abstract. The Lower Subansiri district falls under seismic Zone–V as per Seismic Zoning Map of the country given in IS 1983 (Part I): 2002.It is bounded on the north by the Upper Subansiri district of Arunachal, on the south by Papum Pare District of Arunachal Pradesh and Assam, on the east by West Siang and some part of Upper Subansiri, and on the west by East Kameng district of Arunachal Pradesh. A total of three hydroelectric project/dams located are located in lower Subansiri district which make it necessary to assess seismic hazard/potential in the district. Physiographic features of Lower Subansiri district predominantly consists of hill side slopes with narrow valley with hillocks on its western side. The historical record of EQ events in Arunachal Pradesh shows that three major EQs ($7.0 \leq M_W \leq 7.9$) occurred from 1900 to 2022. In this study, we have identified and characterized seismic sources contributing to the seismic hazard potential of the lower Subansiri district. A total of 125 linear seismic sources consisting of Thrust fault, Normal fault, Lineaments and strike-slip faults located inside a radial distance of 500 km from the centre of the lower Subansiri district are recognized and studied from the literature and other digital sources. This paper presents a detailed review of the seismicity and seismotectonic in and around lower Subansiri district of Arunachal Pradesh. This study highlights the need for detailed seismic hazard assessment studies in the lower Subansiri district such that ongoing seismicity can be considered for future hazard and risk studies.

Keywords: Lower Subansiri district, seismotectonics, faults

1 Introduction

The northeast Indian region is highly populated and seismically most active. The region falls in zone V in the seismic zoning map of India (IS 1893:2016). This region has experienced several moderate-to-large-sized EQs, including the 12 June, 1897 Shillong EQ (M_w 8.1) and the 15 August, 1950 Assam EQ (M_w 8.7) (Thingbaijam et al. 2008). According to a hazard map by the Global Seismic Hazard Assessment Programme, the northeastern region can expect to have a Peak Ground Acceleration (PGA) of 0.24g to 0.48g.

The active tectonics of this region is controlled by a combination of factors: (a)the North-South(N-S) convergence and under thrusting of the Indian plate beneath the eastern Himalayas and southern Tibet (Mitra et al., 2005); (b) the East-West(E-W) convergence and oblique subduction of the Indian plate beneath the Burma micro plate with an eastward dipping seismic zone extending down to approximately160 km (Copley and McKenzie, 2007); (c) uplift and over thrusting of the Shillong Plateau northward over the Brahmaputra Valley and south-ward over the Bengal Basin (Bilham and England, 2001; Mitra et al., 2005; Clark and Bilham, 2008); and (d) active dextral strike-slip motion in the Kopili fault zone (Vernant et al., 2014; Kayal et al., 2012).The merging point of the Indian, Burmese and Eurasian plates is called as the Eastern Himalaya Syntaxis which is the meeting point of the Himalayan and Indo-Burma Ranges(Angelier and Baruah, 2009). The collision of these three tectonic plates led to the development of several faults in this region. One of those faults is the Po-Chu Fault zone which generated the 1950 Assam EQ(Nandy,2011).

The 1950 Assam earthquake caused extensive devastation throughout the upper Assam, including the Lower Subansiri district located in the foothills of Assam-Arunachal Himalayas (https://earthquake.usgs.gov/earthquakes/eventpage/official19500815140934_30/impact). Politically the Lower Subansiri District lies in the North-east Indian region in the state of Arunachal Pradesh. The Lower Subansiri district lies between 92º40′ E and 94°21′ E Longitude and 26° 21′ N and 28°21′ N Latitudes. The district which covers an area of 3,460 Sq.km., is bounded on the North by Kurung-Kumey and Upper Subansiri Districts of Arunachal; on the South by Papumpare District of Arunachal Pradesh and Assam; on the East by West Siang and some part of Upper Subansiri; and on the West by some part of Kurung-Kumey and Papumpare Districts of Arunachal Pradesh(https://lowersubansiri.nic.in).

In recent years the Lower Subansiri district gained popularity among the common people of the neighboring state Assam, after the commission of the 2000 MW Lower Subansiri hydroelectric project. The Lower Subansiri district has a total of three hydroelectric projects, namely Tago-I, Subansiri middle, and Subansiri Lower. However, the hydroelectric project located on the Subansiri River is of concern among the public as the river water is shared by both the states as well as due to the high seismicity of the region. The local people have showed concern that the high seismicity of the region can lead to the damage of the Lower Subansiri hydroelectric project, which could flood the downstream region. Taking into account the concerns of the common people, an attempt is made in this study to understand the seismic hazard potential of the Lower Subansiri district. A 500 km radius around the Lower Subansiri district is considered in this study. The location and orientation of the faults along with the faulting mechanism within this 500 km radius is identified based on past studies. An in-depth discussion about the tectonics of these faults is given in the following sections. Further, the damages that had occurred in the Lower Subansiri district due to previous EQ is also dealt in details in the next sections.

2 Tectonic setting of Lower Subansiri District

The Lower Subansiri district is bounded by the Himalayan fold and thrust belt, Mishmi tectonic Block to the east, Indo Burma ranges to the south east and by the Shillong plateau to the south west. The Himalayan fold and thrust belt came into existence due to the Indian plate is gently dipping beneath the Eurasian plate (Zhao et al., 1993). This continued subduction of the Indian plate has resulted in the evolution of a series of East – West to North East – South West trending thrust systems in the Himalayas, namely Main Crustal Thrust, Main Boundary Thrust, Main Frontal Thrust (MFT) (Mazumdar & Sawaiyan, 2006).The Himalayas form a well-defined arc to the north of Indo-Gangetic plains and extend over a length of nearly 2500 km from West-northwest to the East-Northeast. On the eastern side, the Himalayan arc takes a sharp turn of nearly ninety degrees near 28°N and 96°E to meet the Burmese arc, which trends in a North North East -South South West to North-South direction. This region is known as Eastern Himalaya Syntaxis (Gupta 2006). As per the studies done by Kayal (2008), the Himalayan Mountain range from west to east can be divided into three segments: namely (i) the North-western and the Western Himalaya which includes Jammu and Kashmir, Himachal Pradesh, Garhwal and Kumaon Himalaya; (ii) the Central and the Eastern Himalaya which includes Nepal, Sikkim and Darjeeling Himalaya; and (iii) the Northeastern Himalaya which includes Bhutan and Arunachal Pradesh Himalaya. Kayal (2008), based on the thrust system of the Himalayas, divided the North-eastern Himalaya into the Trans-Axial Himalaya, Central Himalaya, Lesser Himalaya and Outer Himalaya.

The thrust systems of North-eastern Himalayas consists of MCT, MBT and the Himalayan Frontal Thrust (HFT).As per Jayangondaperumal et al. (2018),MBT demarcates the boundary between sub Himalayas and the lesser Himalayas composed of fossiliferous riphean sediments overridden by several thrust sheet. It is laid across a distance of 1500 km from Arunachal Pradesh in the east to Kashmir in the west (Khwaja and Khwaja, 2005). MBT is a longitudinal thrust fault representing a series of thrusts. MCT lies to the north of MBT which also extends almost the entire length of the Himalayas. From east to west, the MCT separates the Lesser Himalayas from the Central Himalaya (Kayal,2008).

Towards the north of MCT, there lies the Yarlung Zangbo suture zone (YZS) which forms a curved tectonic boundary between the Gangdese continental margin of the Lhasa terrane and the Tethys Himalaya Unit and is marked by dismembered ophiolites and mélange (Xu et al., 2012). The YZS formed from Carboniferous – early Permian, and subducted from early and middle Triassic; the ocean basin closed in Eocene-Miocene (Tang et al., 2010). In the middle section, the YZS decade-year timescale strain rate of approximately 4 mm/yr measured by GPS (Gan et al., 2007) denote present day rate of activity, is comparable with the value of ~3 mm/yr estimated by Chen et al. (2004).Further towards north of YZS there lies few normal fault such as F63N and F64N(Kang Li; 2018).Further north we have the Beng Co fault(BCF) is a major right-lateral strike-slip fault, which strikes East South East(ESE) for a distance of 150+ km across the eastern Central Tibetan plateau. Slightly towards northeast of BCF, there is presence of the Bangong suture zone which is approximately 1200 km long and trends in an east–west orientation and located in central Tibet between the Lhasa (southern block) and Qiangtang (northern block) terranes (Shi et al.; 2008). Moving much downwards (towards MCT) we have the North West – South East trending Mishmi Thrust (MIT) which is an easterly dipping fault where the Pre-Quaternary metamorphic rocks are thrusted over the Brahmaputra Alluvium and are profusely crushed and sheared. The sheared quartzite overrides the fan sediments along the Mishmi Thrust. Among the important faults in the Arunachal Himalayan region, another one is the NS trending right lateral Bame fault (BMF).According to Chaudhury and Srivastava (1976), the Lohit Thrust(LOT) of about 200 km length extended from Chulum pass to near Endoline in the Dibang valley.

The Himalayas and the Indo–Burma Ranges meet at the Eastern Himalaya Syntaxis. In southern Tibet around eastern Himalaya syntaxis a mixture of normal and strike-slip faulting is present (Armijo et. al, 1986; A. Yin et. al, 2000). The strike-slip fault system is represented by the Karakoram-Jiali Fault Zone (KJFZ), consisting of a set of NW-SE aligned, right-lateral faults. The KJFZ is bounded by the Jiali fault (JLF) zone in the east. To the southeast, it splays into two major branches, namely the Puqu (Po Chu) (PCF) and Parlung faults (PLF), which extend toward the eastern margin of the Himalayan Syntaxis (Armijo et. al, 1989). Towards the south, the Canyon thrust (CNT) marks the boundary between the Indian and Eurasian plates. Towards south of Canyon Thrust there lies Namula Thrust (NMT) branching out from Yiemla fault (YMF) eastward.

Towards south-east of the Lower Subansiri district, is the Indo-Burma Ranges According to Kundu and Gahalaut (2013); the Indo-Burmese arc is the plate boundary between India and Burma Plates. After the collision of the India plate with the Eurasian Plate, the Burma plate rotated clockwise to become pre-dominantly north-south trending (Hall, 2002). According to Kundu and Gahalaut(2013), the Churachandpur-Mao Fault(CMF), which accommodates a large part of the India-Sunda(Burma) plate motion, is not associated with any EQ and slips aseismically and joins the contact surface between the Indian Plate and the Indo-Burmese wedge. Churachandpur-Mao Fault is approximately 170 km long right-lateral oblique-slip fault (Wang et al; 2014).

Another major fault in this region is the Sagaing Fault that cuts through the center of Myanmar broadly dividing the country into a western half moving north with the Indian plate, and an eastern half attached to the Eurasian plate. Sagaing Fault (SSF) is a strike-slip 1500 km long fault that links major thrust systems in the north such as the Naga, Lohit and Main Central thrust zones near the eastern Himalayan syntaxis to the Andaman Sea spreading centre in the south (Win Swe 1970; Le Dain et al. 1984). Tectonic fault that passes through the cities of Nay Pyi Taw Bago, Sagaing and Mandalay, and close to Yangon. Towards east of the Churachandpur-Mao Fault there lies the Kabaw fault defines a major geological boundary between Indo-Burma Range in the west and the Chindwin basin to the east (Win Swe, 2012). The western Indo-Burman Ranges and is bounded by the Kaladan fault zone to the west and by the CMF zone to the east. The Kabaw fault (KBF) and Kaladan faults having the complex structure reveal both strike-slip and thrust features. The Kabaw fault (KAF) in the Indo-Burmese range having ~280 km length eastward dipping fault that ruptured during the 1762 Arakan EQ (Wang et al., 2014).The Mat Fault(MF) is located on the central part of the outer wedge of the Indo-Burmese Wedge and geologically in the southern part of Surma Basin (Mizoram). The Mat Fault region is characterized by low seismicity and in the past 50 years no EQ of M >4.5 has occurred on the Mat Fault and no EQ of M>5.5 has occurred within 100 km from the fault (Sailo et al. 2011). The Mat fault is a NW–SE trending strike- slip fault of length ~85 km.

The NE–SW trending Naga Hills constitutes the northern part of Indo-Burma Ranges (IBR) in the northeastern Indian states of Manipur, Nagaland, parts of Arunachal Pradesh and the adjoining areas of western Myanmar (Ghose et. al ,2014). Towards the south-west of Naga hills, the junction between alluvium and the hills is marked by the thrust called the Naga thrust (NAT). The extension of the Naga thrust to the south-west is called the Disang thrust (DST) which in turn extends as Haflong fracture zone (Das et al ; 2007). West of the Naga hills is the Sylhet Plains variously known as the Sylhet Trough, the Surma Basin or as the northern part of the Bengal Basin. Towards west, the Surma Fold Belt is approximately limited by the Sylhet Fault (SF) which is seismically active. A prominent fault of the Bengal and Bangladesh alluvium is the northeast–southwest-trending strike-slip Sylhet fault (Kayal, 2008). The Sylhet fault was the source of the 1918 Srimangal EQ (M_b = 7.6).

To the north of the Sylhet Plains is the Dauki fault (DAF) which is an E–W trending 320-km long north dipping reverse and right strike slip located in the southern margin of the Shillong Plateau fault (Nayak et al., 2008; Srinivasan, 2005). The movement along this fault was confirmed for the first time by a trench investigation at Gabrakhari Village. The trench investigation at Gabrakhari, on the western part of the Dauki fault, revealed that the Dauki fault ruptured in AD 1548 (Morino et al., 2014). As per Oldham (1899); rupture along the Dauki fault led to the occurrence of the 1897 Shillong earthquake. According to studies done by Kayal (1987), Kayal and De(1991) , Kayal (2001) ,western extension of Dauki fault was named Dapsi thrust(DPF) which is 100 Km long with a strike-slip component. To the west of the Shillong Plateau lies the north-south trending Dhubri Fault which bounds the Shillong plateau in the west of lower Assam. Kopili – North Dhansiri Fault which is seismically active is a NorthWest–SouthEast (NW-SE) trending, 300–400 km long and 50 km wide fault located at the north east of the Shillong plateau and it demarcates the Shillong Plateau and Mikkir Hills. Also the Shillong Plateau is characterized by a number of faults/shear/lineaments of which some major are the North-South trending Dudhnoi Fault(DUF) and Kulsi Fault, the NE trending Barapani shear zone(BSZ) and several other Northeast Southwest and North-South lineaments. The Kopili valley has NW-SE trending Kopili fault in the west, Dighalpani Kakijan fault(DPKF) in the east and the East-West trending Kalang Lineament in the north. Towards Northwest of Dudhnoi fault(DUF) we have the Chedrang Fault(CDF) which is a 24 km long NW-SE trending gravity fault that has been reactivated during 1897 Shillong EQ and slipped up to 11 m (SEISAT, 2000).

As per Bilham and England (2001) north of the Shillong plateau, lies a South dipping fault known as the Oldham fault(OLF). This fault lies at the boundary of the Shillong plateau and Brahmaputra valley and was the causative fault for the 1897 great EQ. Oldham fault is an approximately 110 km, long, 57° north dipping reverse fault (Nayak et al., 2008; Bilham and England, 2001).

Towards the west of the Lower Subansiri District and in Assam-Bhutan Himalayan sector south of MBT/ HFT lies the Ultapani Thrust(UTT) which is a 30km long, East-West trending, southerly dipping, seismogenic thrust extending between Leupani river in the east and Penkhua river in the west. This active fault is categorized as Frontal Back Thrust (FBT) dealing with geology, geomorphology and seismic landscape of the area (Dasgupta et al., 2013). The active segments of MFT around Bhalukpong Village in the foothills of the Eastern Himalaya is expressed as Bhalukpong thrust (BHT) in the north and Nameri thrust(NET) in the south with growing Balipara anticline in the middle. Using the age and geometry of uplifted river terraces a minimum Holocene slip rate of 23.4±6.2 mm/yr is established along the decollement of the 10 km wide MFT zone in the far eastern Himalaya. This slip rate is partitioned on three structures: at 8.4 mm/yr on the Bhalukpong thrust in the north, at 10 mm/yr across the growing Balipara anticline in the middle, and at 5 mm/yr on the Nameri thrust in the south (Burgess W. P. et al; 2012). Nakata (1989) recognized a few active faults in the foothills of North Bengal, Eastern Himalayas (south of the Siwalik Hills) towards the west of lower Subansiri District. According to Nakata (1989), the Matiali fault (MAIT) represents the MBT and the Chalsa fault, the HFT. The located few faults in this area are divided into two main families, the E—W trending and the N—S trending ones. Gorubathan(GOT), Matiali, Chalsa(CLT) and Baradighi faults belong to the E-W family where a total shortening of 11.1 ± 1.5 mm/yr is observed.

From the above discussion it is evident that the Lower Subansiri District is surrounded by a network of tectonic faults. All of these faults are located within a radial distance of 500km from the district center of the Lower Subansiri District. Hence, based on the above discussion a tectonic map of 500km radius has been developed around the Lower Subansiri District. Fig. 1 shows the orientation of the faults located within the 500km radius tectonic map of the Lower Subansiri District. Some of the noteworthy faults within this tectonic map are Oldham, Po-Chu and Kopili which have generated great (M_W>8) and major ($7.0 \leq M_W \leq 7.9$) earthquakes in the past.

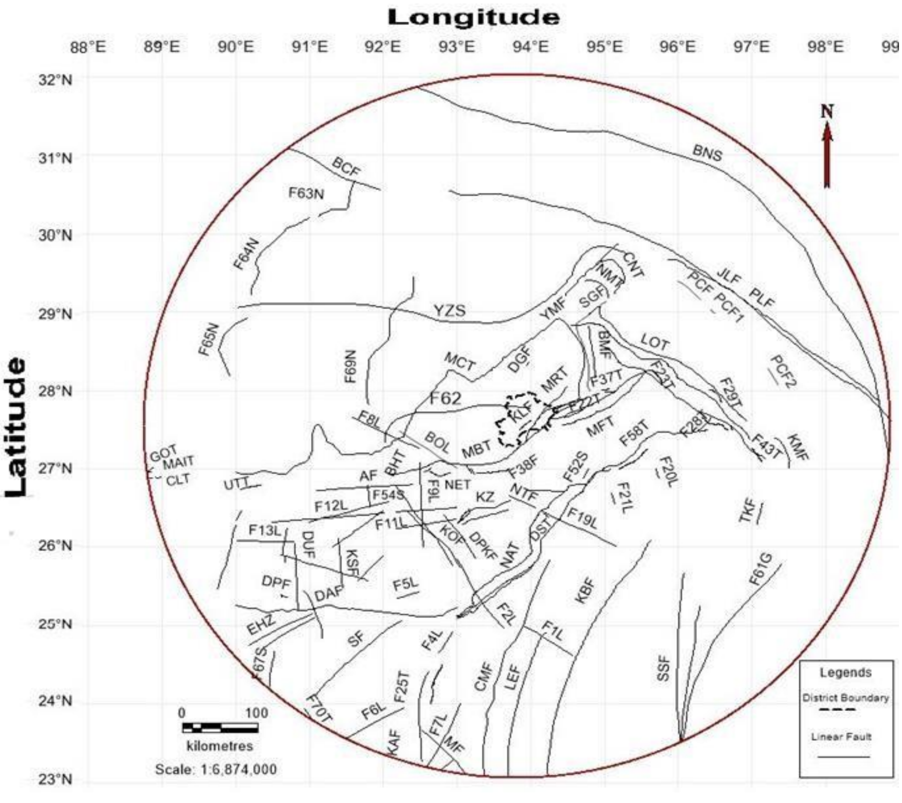

Fig. 1.Tectonic map of Lower Subansiri District showing all linear seismic sources (TKF:Takri Fault, EHZ:Eocene Hinge zone, KAF:Kale fault, AF:Atherkhet Fault, MRT:Miri Thrust, KMF:Kumon Fault, LEF:Lelon Fault, KZ:Kalyani Shear, BNS: Bongong Nujiang Suture zone, NTF: Natukure fault, BOL: Bomdila Lineament

3 Damages in the Lower Subansiri district due to past Earthquakes

The Lower Subansiri district has experienced several minor as well as major earthquakes. As per the past reports, till date a total of 3 major earthquakes have caused the most significant damages in the Lower Subansiri district.

One such earthquake was the 1942 Assam EQ (M_s -7.2), the epicenter was located 13 km southwest of Dergaon, Golaghat, Assam. The ground shaking intensity varied from IV to V (in MMI scale) in the lower Subansiri district. Also, the Peak ground acceleration was observed to be 0.02g-0.05g(https://earthquake.usgs.gov/earthquakes/eventpage/iscgem900054/map)

Another EQ occurred in 1947 eastern Xizang-India Border (M_w 7.3) whose epicenter was at Upper Subansiri, 123 km west of Along, West Siang, Arunachal Pradesh. This EQ was felt over larger region – Assam, Arunachal Pradesh, Bengal (up to Kolkata) & Bihar (upto Purnea). Intensity varied from IV to V (in MMI scale) in the lower Subansiri district (https://earthquake.usgs.gov/earthquakes/eventpage/iscgem897970/map). The Peak ground acceleration was observed to be 0.05g-0.1g. At Jorhat in Assam water overflowed riverbanks. At Dibrugarh, Jorhat & Tezpur cracks in walls & failure of electricity at Guwahati. Fig.2 shows the Ground Shaking Intensity Map of 1947 Indo-Xizang earthquake.

On 15th August 1950, the 6th largest earthquake (M_w = 8.7) of the 20th century hit the Lower Subansiri district. The epicenter of this earthquake was found to lie near Rima in the Arunachal Himalaya. The estimated focal depth was about 50 km and the source fault was found to be the in the Po Chu fault zone located in the northeast extremity of the Mishmi block (Nandy, 2011). As per NIDM (2011) the shaking was felt throughout north-eastern India and in many parts of eastern India. It was also felt throughout Bangladesh, Bhutan and Myanmar. Though it struck a relatively sparsely populated region along the Indo-China border 1500 people were killed and the drainage of the region was greatly affected. The resultant floods were the cause of most of the fatality's aftermath of this EQ. The initial shock was followed by thousands of aftershocks. There was wide-spread liquefaction due to intense ground shaking. Vast areas of land either were elevated or subsided, altering the drainage of the region. Large landslides blocked the Subansiri River. This natural dam broke 8 days later, creating a wave 7 m (23 ft) high which inundated several villages and killed 536 people. This 1950 Assam EQ destroyed the railroad bridge in the North Lakhimpur district, cutting the main connection between Assam and the rest of the subcontinent (see Fig.3). The Lower Subansiri district experience a shaking of intensity V and VI as shown in Fig. 4 (https://earthquake.usgs.gov/earthquakes/eventpage/official19500815140934_30/map)

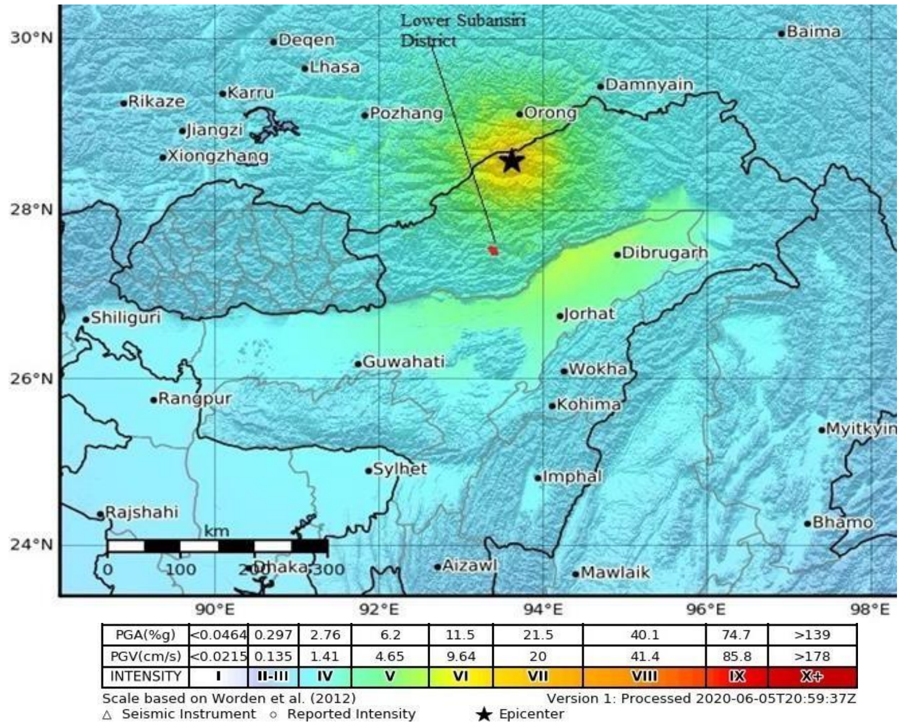

Fig.2. Ground Shaking Intensity Map of 1947 Indo-Xizang earthquake (https://earthquake.usgs.gov/earthquakes/eventpage/iscgem897970/map)

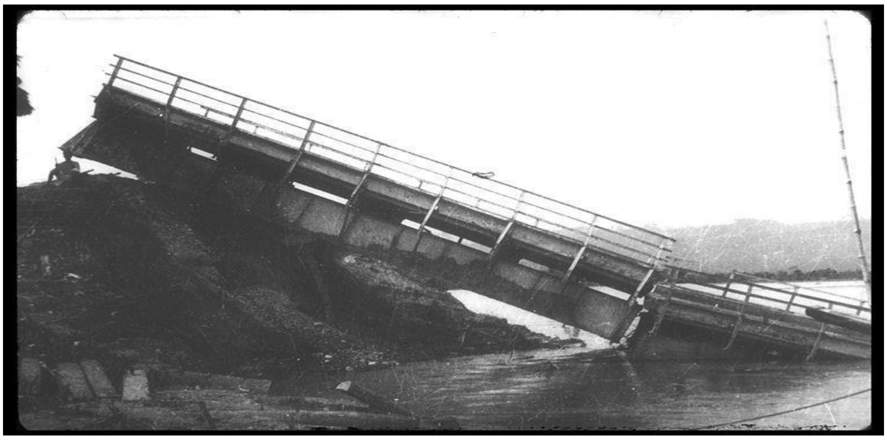

Fig.3 Collapsed railroad bridge in North Lakhimpur district of Assam during the to 1950 Assam EQ

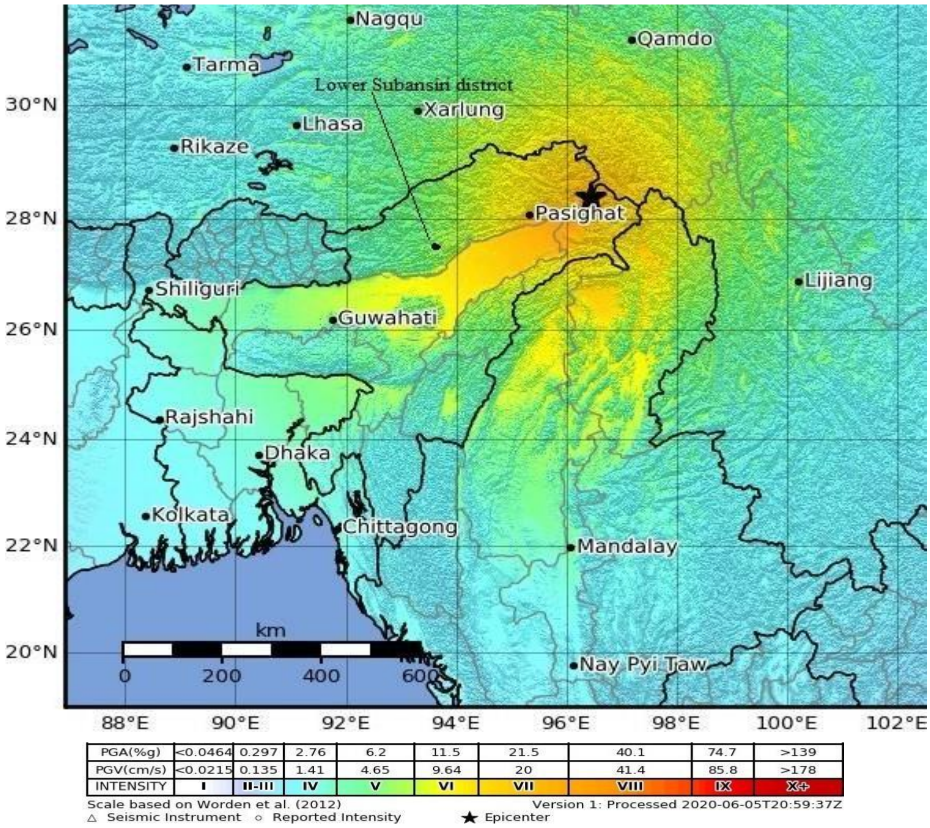

Fig.4. Ground Shaking Intensity Map of 1950 Assam earthquake (https://earthquake.usgs.gov/earthquakes/eventpage/official19500815140934_30/map)

4 Conclusion

The Lower Subansiri district of the Indian state of Arunachal Pradesh is home to 3 hydro power project of India. The most controversial among these is the Lower Subansiri hydroelectric power project or the Subansiri dam. The reason for this controversy is the presence of the intense network of tectonic faults, the geology, the occurrence of major to great earthquakes and the ground shaking experienced in the district in the past. In this study, the above mentioned parameters have been discussed in details. A tectonic map of 500km radius has been developed showing all the faults located in the vicinity and around the Lower Subansiri district. A total of 125 faults have been identified to exist within the 500km radius tectonic map of the Lower Subansiri district Identification of the location, orientation and faulting mechanisms of these faults would pave the path towards understanding of the seismic hazard potential of the Lower Subansiri district.

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