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# Assessment on the 2014 Jure Landslide in Nepal – a disaster of extreme tragedy

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# Assessment on the 2014 Jure Landslide in Nepal – a disaster of extreme tragedy

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**Abstract**. The landslides kill many people every year in Nepal and in the Himalayan region, which devastates society in the local area. A famous living memory of an example of landslide induced devastation was the landslide at Tinau river that took place in early September 1981 damming the river completely, which breached after few days causing huge flood downstream. The flood swept away concrete tower of the Tinau Hydropower Project, two suspension bridges, one concrete bridge at Butwal, part of Butwal city was completely damaged and many hundred people lost their life. Similarly, on the night of 2nd August 2014 (02:30 AM), a huge landslide, famously known as "Jure Slide", took place along Sunkoshi River valley on Araniko Highway that connects Kathmandu with Tibet. The landslide killed 156 people who were on sleep in their houses, savaged 120 houses, partially damaged 37 more, dammed Sunkoshi river creating an artificial dam of approximately 50 m high and an approximately 3 km long reservoir was formed. A huge flood occurred after partial breach of the dam damaging barrage structures of the Sunkoshi Hydropower Project located about one kilometre downstream from the slide area. It took over two months to drain artificially created reservoir. The main aim of this manuscript is to describe and evaluate Jure landslide. Critical aspects on the causes of landslide will be highlighted giving emphasis on topography, geology, rock mass, monsoon, and earthquake.

## 1. Introduction

Subduction of Indian Plate beneath the Eurasian Plate has evolved high Himalayan mountain chain covering about 2500 km stretch from Karakorum in the west to Myanmar in the East. While, the width of the Himalayan range extends barely about 200 km within which the altitude varies from approximately 65 masl to ~8849 masl "The Mount Everest". Substantial increase in height within relatively short distances has resulted mountain topography very rough and steep with narrow river valleys where people reside. The region is known to be very dynamic due to active monsoon and frequently occurring earthquakes of different magnitudes. Numerous North-South flowing rivers cross cuts mountainous topography leading to extreme erosion along the valley slope during every monsoon. Both monsoon rain, large variation in temperature over the year and frequent earthquakes make Himalayan rock mass weather relatively fast. As a result, frequent landslides occur during monsoon period and large-scale earthquake events. In general, earthquakes functions as catalyst for largescale landslides since long persisting discontinuities are formed during periodic earthquake episodes [1].

The stability of rock slopes will mainly depend upon the shear strength that is available along the failure plane, which is dependent on the frictional properties governed by roughness, degree of weathering and fracturing, filling condition, presence of groundwater, geometry of the slope and acceleration caused by earthquakes or man-made vibration such as blasting [2 & 3]. Therefore, it is important that the critical rock slopes along steep river valley sides that have potential for the collapse over both short-term and long-term and pose considerable risk and potential to damage properties and human life must be well documented and monitored. Lack of such strategy in any mountainous society may cause sudden and instantaneous collapses along the valley side slopes of the river valleys as had occurred on the night of 2nd August 2014 (02.30 AM) along the Araniko Highway of Sunkoshi river, famously known by "Jure Slide" in Nepal. This manuscript describes about the critical aspects of "Jure Slide".

## 2. Recent landslides and their impact in Nepal

Nepal is vulnerable to landslide hazard due to geomorphology, seismic sensitivity, intensity of monsoon rainfall and unorganized and haphazard construction activities. Nepal is characterized a country having a topography with high steepness and sudden relief, complex geo-tectonic setting, and variable climatic conditions [4]. It is well known fact that all slopes are under stress due to the presence of in-situ stresses caused by both gravity and tectonic movement [5]. If the driving forces along an exposed discontinuity surface of either natural or cut slope exceeds the shear resistance of that discontinuity, it is natural that the slope fails [2]. The shear resistance of any discontinuity surface is dependent on the persistence, roughness, alteration, infilling conditions [6], ground water condition and magnitude and frequency of seismic activities. More importantly, the topographic surface of steep valley side slopes in the Himalayan region is being modified due to development activities such as construction of roads, agricultural excavation, construction of hydropower projects etc., which enables large scale discontinuities to expose (daylight) increasing risk of landslides.

Over 70 percent of the territory of Nepal belongs to hilly and mountainous area which is considerably affected by monsoon rain (June - September). Accelerated global warming has increased complexity in weather pattern, which has increased risk and vulnerability of more frequent landslides and glacier lake outburst floods (GLOFs) causing extensive damage to physical infrastructures, loss of property and human life [7]. Nepal faces varieties of natural hazards associated to topographic, geologic, and climatological origins and is exposed to one or multiple forms of natural hazards [8]. Compared to the territorial area and population, the intensity of natural hazards that Nepalese people are exposed too are much higher in comparison to other countries in the world. Among the most pronounced hazard is off course landslides, which occur during monsoon and major earthquake events. Figure 1 below shows statistical intensity of major landslides with human casualties (loss of life) between 1980 and 2015.

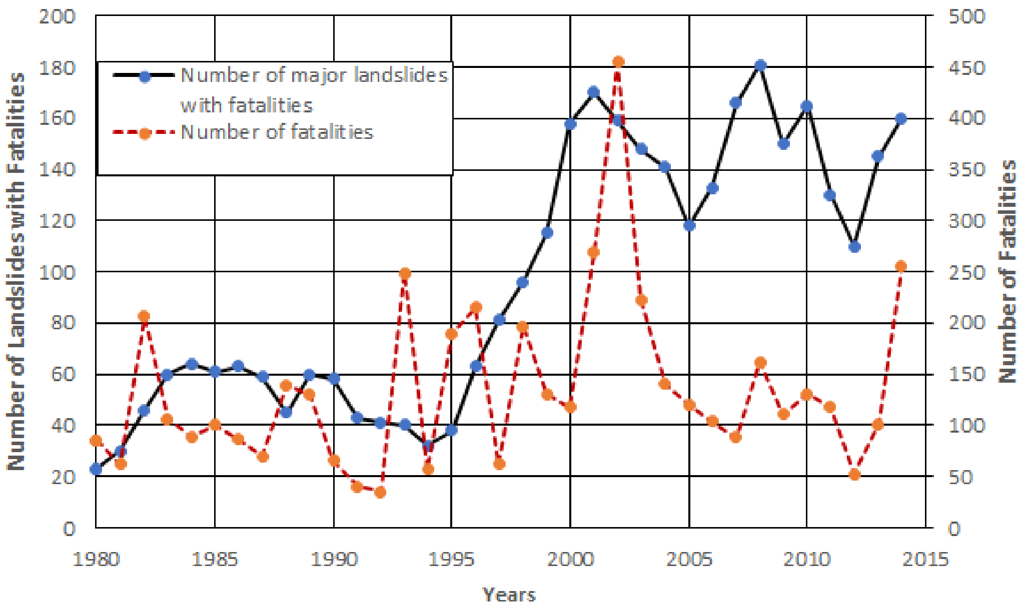


**Figure 1.** Landslides and loss of human life in Nepal between 1980 and 2015.

As one can see in figure 1, landslide is among the major geohazard risk in Nepal. Almost 4200 landslides with fatalities have been registered since 1980 (>100 landslides/year) and about 6100 people lost their life during the same period, which shows an annual average over 150 fatalities.

## 3. Rainfall pattern in Nepal

The seasonal cycle of observed precipitation indicates that the highest proportion of precipitation (over 80 percent) occurs during monsoon season (June-September), followed by about 11 percent during pre-monsoon season (March-May), about 5 percent during post-monsoon (October), and about 4 percent during winter seasons (December-February), respectively [8]. A typical annual monsoon pattern of central Nepal is presented in figure 2. As one can see, the precipitation increases considerably during monsoon period reaching its maximum value in July and then it gradually resides.

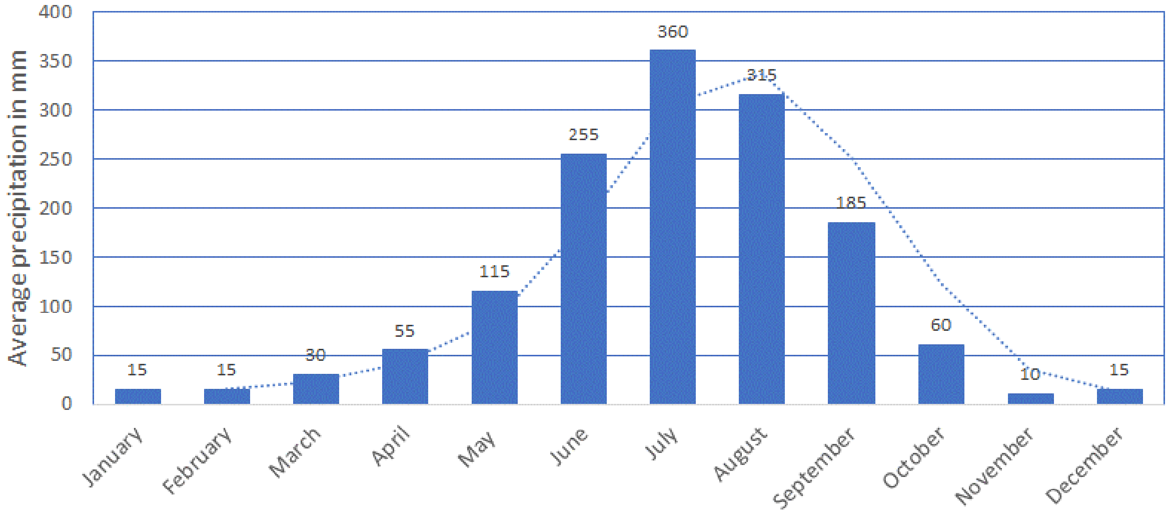


**Figure 2.** Typical annual rainfall pattern in the central Nepal.

Therefore, the rainfall pattern in Nepal is predominantly governed by monsoon season (MS), which varies spatially from place to place over the whole country and ranges from 250 mm to maximum up to 5,200 mm per annum. During monsoon, the wet air mass of Indian Ocean enters from the east and moves westward giving highest precipitation in the central Nepal. On the other hand, the westerly wind system is more pronounced during winter season in the west of the country, which causes some minor precipitation (figure 2). Hence, the months June, July, August, and September are most critical regarding landslides hazards in Nepal.

## 4. Geo-tectonic setting and earthquakes

The Himalayan region is tectonically very dynamic. A collision that took place between Indian and Euro-Asian continental plates about 70-100 Ma resulted to the formation and evolvement of Himalayan mountains. Since collision, the Indian plate from south is continuously under-thrusting beneath upper crust of the Euro-Asian plate, which is resulting persistent compression and convergence with about 5 cm/year [2 & 9]. According to Panthi [2], considerable amount of energy is being accumulated through this compressional process and this energy is being released through ruptures that happen along the tectonic faults and fractures. This process consistently causes occurrence of small, medium, and large-scale earthquakes and the history of earthquakes shows that whole Himalayan region including Nepal is seismically very active. Hence, magnitude of tectonic stress varies over the time due to sudden release of accumulated strain energy through earthquakes causing stress an-isotropy and formation of new faults and fractures in the rock mass. Figure 3 shows the spatial distribution of earthquakes in the Himalayan region.

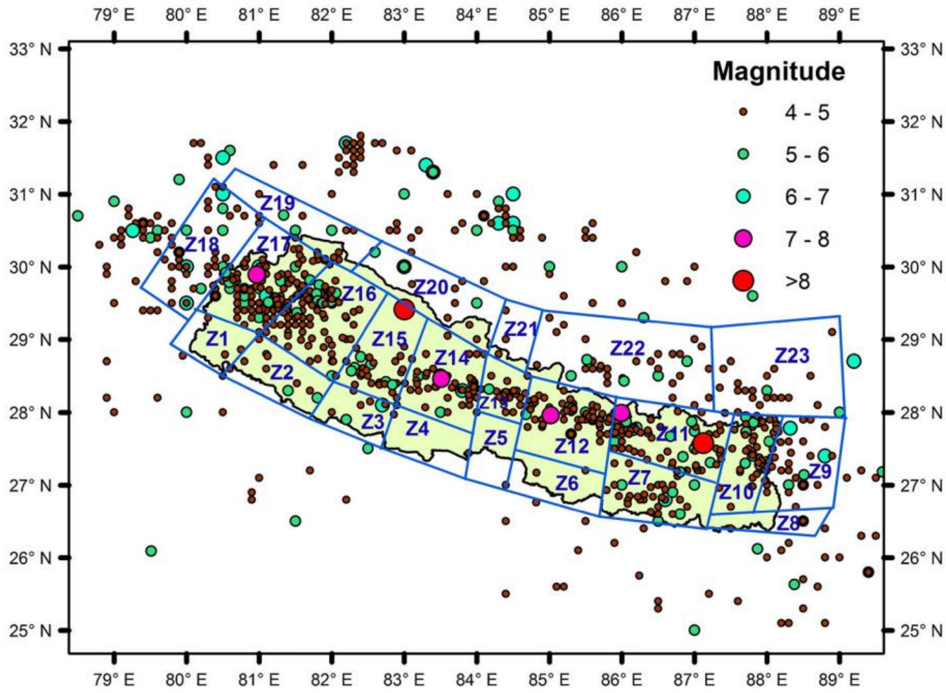


**Figure 3.** Seismic source zones and spatial distribution of earthquakes in and around Nepal [10].

In general, earthquakes in the Himalaya occur along major thrust systems such as Main Frontal Thrust (MFT), Main Boundary Thrust (MBT) and Main Central Thrust (MCT). However, as can be seen in figure 3, majority of earthquakes have been concentrated at and near the MCT area. The recorded prehistoric major and great scale (large-scale) earthquakes (M>7) of past 500 years in the Himalayan region collected from various sources are summarized in the table 1.

**Table 1.** Large-scale earthquakes (M>7) recorded in the Himalayan region in past 500 years

| Date | Magnitude (M) | Date | Magnitude (M) |
|---|---|---|---|
| June 6, 1505 | 8.16 | August 15, 1950 | 8.44 |
| June 12, 1897 | 8.03 | November 18, 1951 | 7.9 |
| April 4, 1905 | 7.79 | April 25, 2015 | 7.8 |
| January 15, 1934 | 8.11 | May 12, 2015 | 7.3 |

Medium to strong (5>M>7) earthquakes are very common in the Himalaya and large-scale (M>7) earthquakes occur quite frequently as well. The peak ground acceleration produced by these earthquakes are catalyst for the formation of new discontinuities, extension of existing discontinuities and complete failure of the rock mass causing small to large-scale landslides.

## 5. The Jure Slide

On the night of 2nd August 2014 (02:30 AM), an estimated 5 to 7 million cubic meter solid volume landslide struck in a densely populated village called "Jure" in Sindhupalchok District located at about 80 km northeast from Kathmandu, the capital of Nepal, on the bank of Sunkoshi River. Even though landslides are common in Nepal during monsoon and during large scale earthquake episodes, this slide was among the deadliest in Nepalese history. The slide caused death to 156 people sleeping at their home, displaced 436 people, 120 houses were destroyed or buried, 37 houses were partially damaged, part of the Araniko highway (approximately 2 km length) was completely damaged. Figure 4 below shows the slide and upstream part of Sunkoshi hydropower project, the formation of dam and lake due to landslide mass and damaged houses and vehicles.


**Figure 4.** Jure landslide, damming of Sunkoshi River and damages caused by landslide.

An approximately 50 m high of dam was created by the slide damming Sunkoshi River about one km upstream from the Sunkoshi barrage of Sunkoshi hydropower project (upper two photos of Figure 4), which resulted to the formation of approximately 3 km long lake upstream (Figure 5, left). The partial dam-burst that occurred after overtopping caused significant damage to the headwork structures of the Sunkoshi HPP (figure 5, right) and on the Araniko highway.

**Figure 5.** Lake formed by the landslide (left) and damage to road and headwroks of Sunkoshi HPP.

It took almost 45 days for the authorities and Nepal army to drain the lake. The continuous drainage work helped to avoid complete failure of the landslide made temporary dam and potential catastrophic damage downstream valley due to sudden flooding. The slide obstructed main transportation network between Nepal and Tibet-China and the Araniko Highway was reopened only after about 4 months by the end of November 2014.

### *5.1. Geology of the Jure area*

Geologically, Jure area belongs to Kuncha formation, which is the oldest rock formation in the Lesser Himalaya. The most common characteristics of the Kuncha formation are well-developed lineations with an orientation towards northeast–southwest [11]. The main rock types in the Kuncha formation consist of phyllite, limestone, slate, dolomite, quartzite, amphibolite, and gneiss of the Precambrian age (figure 6). The rocks are strongly folded, foliated, jointed and an-isotropic in nature due to intense deformation caused by thrusting and faulting [4].

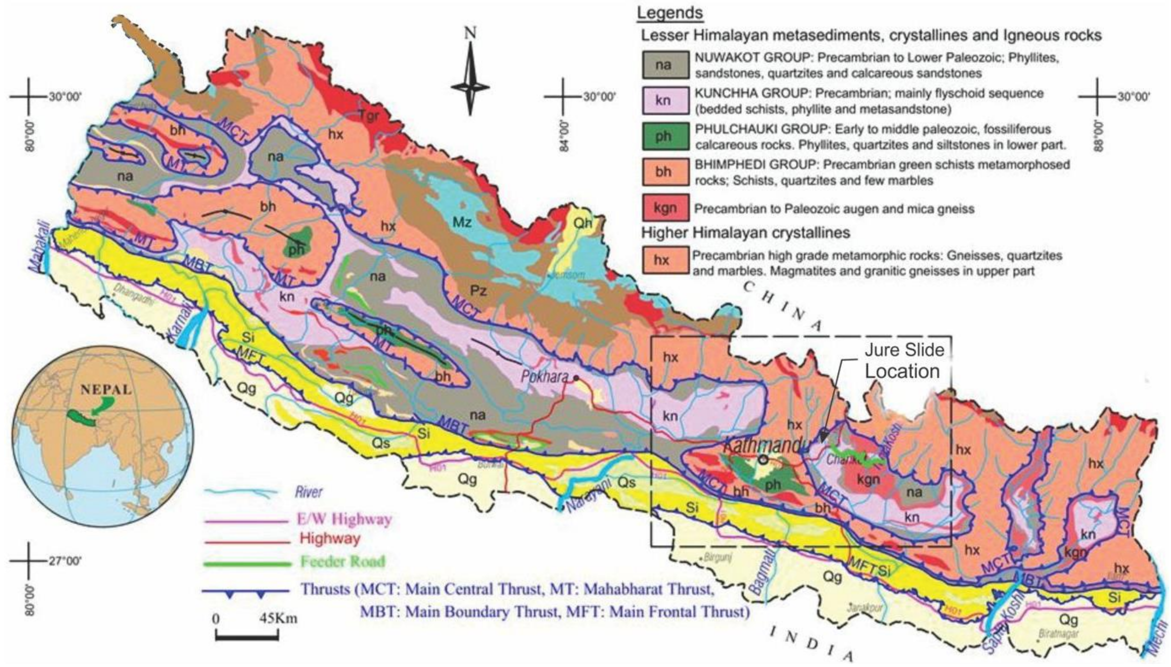


**Figure 6.** Geology of Nepal showing location of Jure slide area, modified from [5].

The Main Central Thrust (MCT) crosses Sunkoshi Valley near Nepal-Tibet (China) border at Tatopani to the north and follows south-west bringing it near proximity of the Jure area (about 5 km). In addition, a local branch of thrust fault between MCT and Sunkoshi River passes through the Jure area. This local branch of thrust fault was catalyst for the formation of tension crack for many years before Jure landslide took place. The rock formation in the slide area is of Kuncha group consisting flyschoid sequence of rock types dominated by phyllite, metasandstone and quartzite schist of sedimentary origin (figure 7). The rock mass at the landslide area is highly schistose, sheared, undulated and relatively weak in strength. The foliation is the dominating discontinuities that oriented north-east south-west direction and dipping towards south-east with an average dip/dip direction of 29/136 degrees. The slope angle is steeper with an average dip/dip direction of 42/135 degrees. Due to high degree of schistocity the frictional angle of the foliation joints is below 25 degrees which is less than the slope angle. Hence, both orientation of foliation joints, slope angle and frictional angle have been very conducive for the dip seated plane failure to occur.

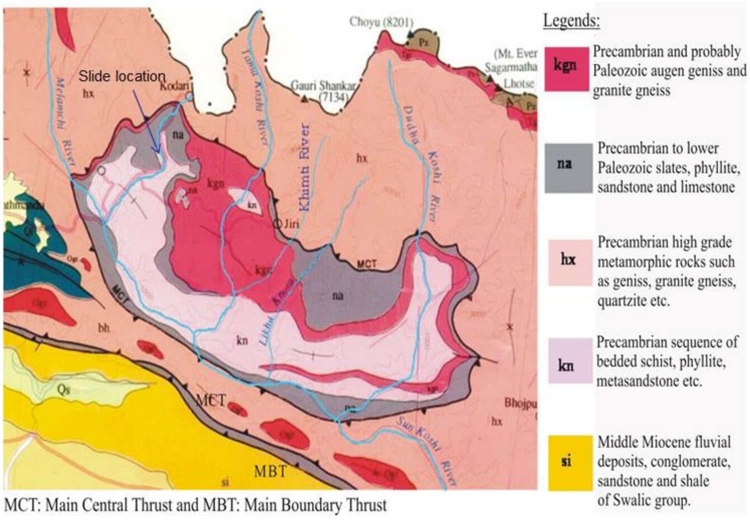


**Figure 7.** Geology and geo-tectonic environment at the Jure area.

### *5.2. History of earthquakes at Jure Area*

As highlighted earlier, large, medium, and small magnitude earthquakes are very common in Nepal, which cause persistence shearing and deformation in the existing faults and shear zones as well as extension and formation of new fractures and fault planes. As presented in table 4, the Himalayan belt was rocked by at least 8 major earthquakes (M>7) during last 500 years. The epicenters of most of these major earthquakes are along the major thrust systems in the Himalaya, i.e. MFT, MBT and MCT [12]. Moreover, medium to small magnitude earthquakes occur along the major splays of these major thrust where strain energy is being accumulated during the event of major earthquakes. Since, the Jure landslide area is located within very short distance from Main Central Thrust (MCT), it is obvious that the earthquakes occurred in the past have direct influence on the stability condition of this slope. Figure 8 shows earthquakes that occur at and surrounding Jure area which could have directly influenced on the stability of the slope at Jure.

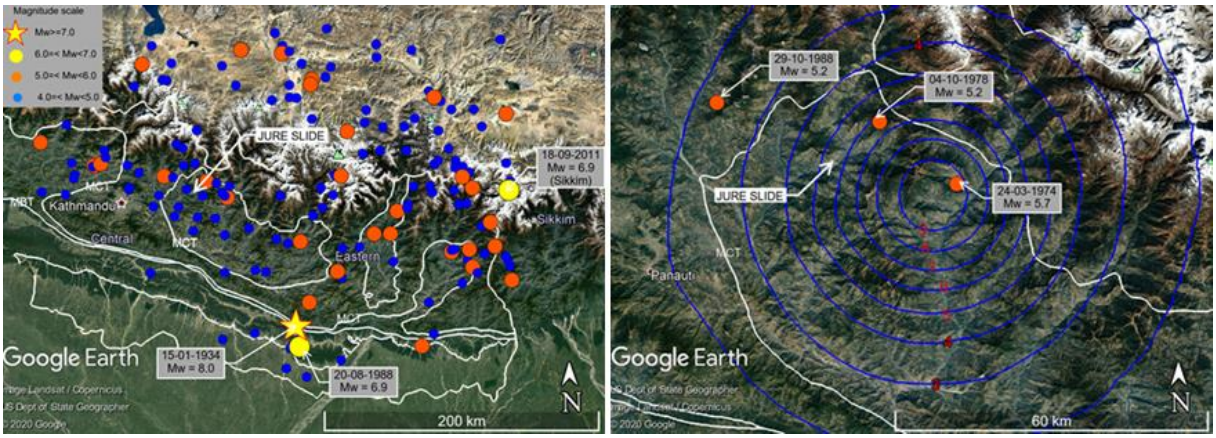


**Figure 8.** Earthquakes of different magnitudes surrounding Jure area (left) and typical ground acceleration scenario for M 5.7 earthquake of 1974.

### *5.3. Rainfall scenario at Jure area before slide*

The Sunkoshi River valley is among the heaviest rainfall area in Nepal. The annual average precipitation in this valley is around 3000 mm of which almost 85 percent rainfall occurs during peak monsoon period (from June to September), see figure 9 (left). As one can see in figure 9, July and August are the heaviest rainfall months in the area, which covers almost 50 percent of the annual average precipitation.

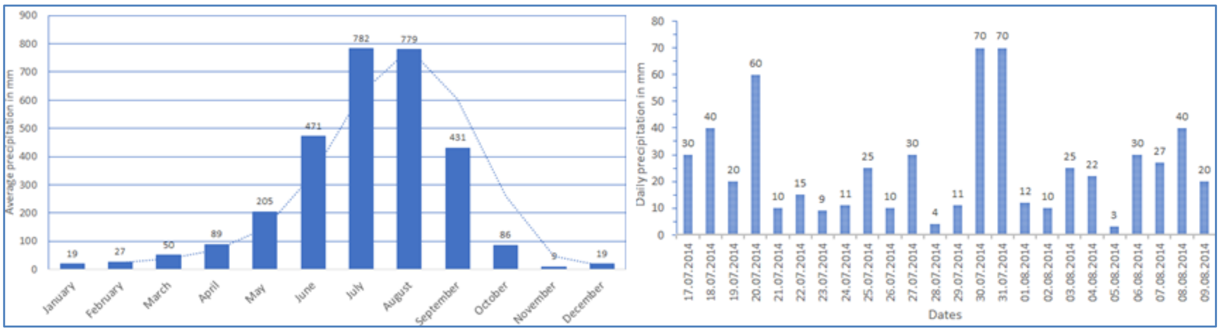


**Figure 9.** Precipitation scenario of monsoon period in 2014.

The precipitation has direct impact on the condition of Araniko Highway, especially upstream from Dolalghat to all the way to Khasa in Tibet. Extreme monsoon rain causes many medium to large scale landslides along the steep topography of this river valley. As one can see in figure 9 (right), there had been continuous rainfall since the middle of July to the night when the Jure landslide occurred. Over 140 mm rainfall was registered during two days (30$^{th}$ and 31$^{st}$ July) at this river valley just one day before the Jure landslide event.

## 6. Discussions and conclusions

The estimated Jure landslide volume is between 5 to 7 million solid cubic meter rock mass. Among the main causes for the Jure landslide to occur may be summarized to following two main catalysts.

a. Repeated occurrence of prehistoric earthquakes of different scales as presented in figures 3 and 8 cause persistent ground acceleration, which have instigated to the extension of pre-existing discontinuities, formation of tension cracks at the top of the landslide, formation of many other joints and cracks in the rock mass and loosening that occurred on the upper layer rock mass material of steeply dipping topographic slope of Jure area.
b. The continuous rainfall during June and July of 2014 caused full saturation in the rock mass. The heaviest rainfall (140 mm) on 30$^{th}$ and 31$^{st}$ July overloaded already saturated rock mass. The combination of overloading and maximum groundwater pressure along the slip surface, which dramatically reduced the shear strength may have been the main source for the disaster of this scale.

A detailed back analysis will be carried out to evaluate this landslide. Finally, it is noted here that the landslide disasters of high magnitude are occurring more frequently in the Himalayan region in recent years. The change in climatic condition caused by global warming has direct impact and increased intensity of precipitation in the Himalayan region. It is important that well planned research and proper monitoring and hazard assessment plans are becoming essential in the Himalayan region so that a disaster of this scale could be minimized and life of human loss due to landslides could be reduced.

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