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Is the Tupul (Makhuam) Landslide of 29-30 June 2022 in Manipur, India Recognized as One of the Rainfall Induced Massive Landslide?

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Abstract

The present study deals with Tupul landslide in Manipur which triggered on the intervening night of 29th -30th June 2022 in Noney district of Manipur. The death toll was 61 persons in total from Territorial Army, NF Railway's employees, Villagers and labours from various contractors in the construction of railway line from Jiribam to Imphal. We have conducted a drone survey on the landslide site for preparation of large-scale terrain map and compared 2009 CARTOSAT image to pick up the slip surfaces. The detailed fieldwork of the study area deciphers highly jointed, fractured, faulted rock formations and display neo-tectonic movements. The slope failure analysis was conducted using the Phase-2 software and the failure was compared with the Drone made DEM, which is used to estimate the volume of debris falling on the railway formations. The excessive precipitation (375.6mm) during the May 2022 was recorded near the landslide site which was 60% more than the normal precipitation. In order to maintain the safety of the man and materials for the future, a number of suggestions were proposed for future monitoring of slope along coming up railway lines of Northeast Frontier Railways.

Keywords: Rainfall triggered landslides, Terrain, Phase^2, NF Railway.

1. Introduction:

Landslides are one of the most devastating and recurring natural hazards and have affected several mountainous regions across the world. The Himalayan terrain and its extension in NE India is no exception to landslide incidences affecting key economic sectors such as transportation and agriculture and often leading to loss of lives. The high exposure to landslide risk has made these terrains receive increased attention by the planners, researchers and finally stakeholders of the affected areas. The present studies, a recent massive landslide triggered at Tupul area of the Noney District, Manipur on the intervening noight of 29th -30th June 2022. Sixty-one persons in total from Territorial Army (TA), Railway staff, Villagers and labours of contractors lost their lives. Geologically, the western Manipur consists of Tertiary strata (rock formations) which are most vulnerable to the landslide hazards due to the seismically active tectonic terrain. The rock formations are highly jointed, fractured, faulted and display the neo-tectonic movements. The interbedded shales, mudstone, siltstone and sandstone are the main lithological types found in the study area.

The climate is of sub-humid with high rainfall (1600 mm) in the state, which is one of the triggering factors for most of the frequent landslide hazards with existing geological formations and typically rugged topography. The interbedded shale, mudstone, siltstone and sandstone exhibit weak lithology and existing discontinuities in the forms of joints, cracks, faults etc. along the moderate to steep slopes are the main triggering factors for the landslides. The National Highways in the state across these Tertiary Terrains face the increased the triggering of frequent landslides, as most of the alignments traverse along these typical adverse geological and geomorphological situations.

2. Methodology

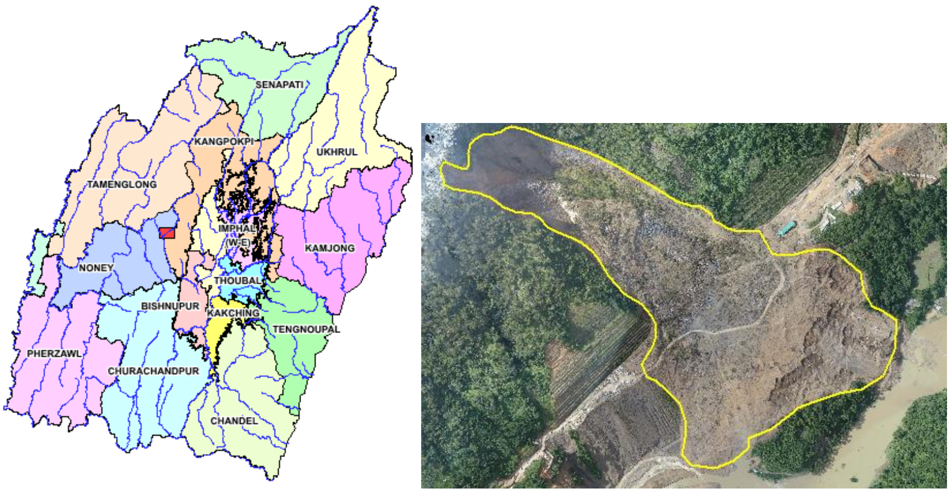
We have used Drone (Phantom 4 Pro) DEM for large scale mapping and CARTOSAT satellite data (2009) for slip surfaces. The field work was conducted to map the geology and geomorphology of the study area. The Phase^2 software was used to understand the causes of slope failure of the Tupul landslide.

3. Observations:

Description of Massive Landslide at Tupul (Makhuam Landslide)

It was triggered on the intervening night of 29th - 30th June 2022. Excessive rainfall was experienced during May' 2022 (375.60mm) and June' 2022 (329.9 mm) at Noney District, which was approximately 60% higher than the normal earlier recorded rainfall. The data was recorded at the nearest station from the landslide site.

In order to assess the dimension of the massive landslide, a drone survey was conducted on 5th July 2022 and data analysis was done to generate a DEM of the site. A large old landslide slump at 1063m msl high hill with steep slope (~42°) which was quite vulnerable for the landslide hazard. The slump became oversaturated due to the excessive incessant rainfall during May-June 2022 and the landslide was triggered (Fig.1).



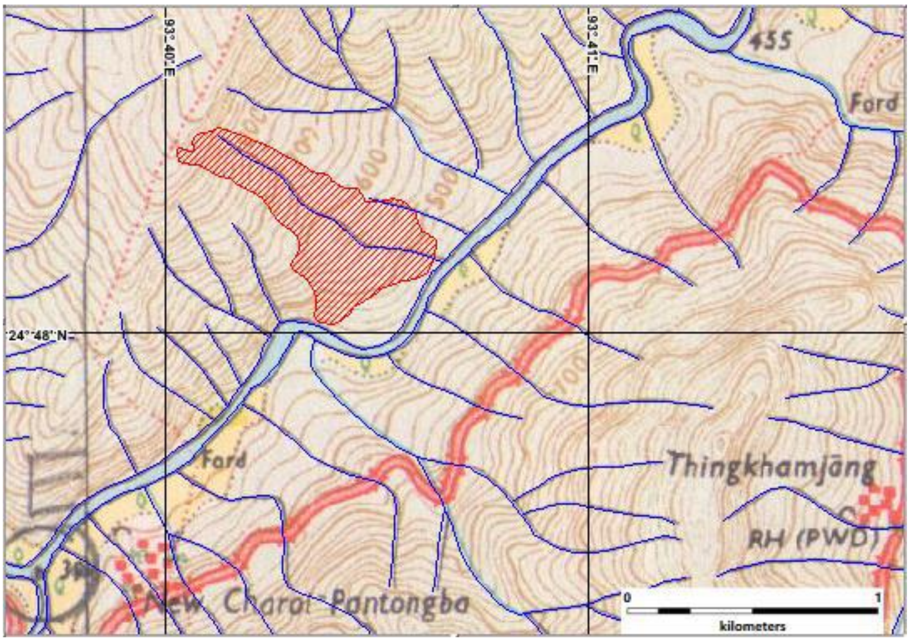


Fig. 1: Location map of the Tupul Landslide

The estimated volume of the sliding materials is calculated using the CARTOSAT DEM (9th April 2009) and compared with the Drone generated DEM (after the landslide i.e on 05th July 2022) (Fig. 2 & 3). The approximate volume of the landslide slump (debris) was about 4.3 lakhs Cubic meters, which slide due to the landslide. The presently piled up debris may be in terms of about 6.02 lakhs cubic meters deposited on the slope of the hill from Railway formation till the river bed. It was also estimated that the volume of the debris resting over the Railways formation estimated to about $2.5x10^5$ m^3 (approximate area spread piled up 465 m in length and 30 m in width and thickness from the existing railway formation 40 m). The large volume of the debris is due to unconsolidated piling of the debris during the landslide of the compact mass before the landslide.

The profile along the slope displays the actual thickness of the piled-up slurry of landslide as well as few slip surfaces have also been developed after the recent event for future sliding whenever excessive rains are experienced (Fig. 4).

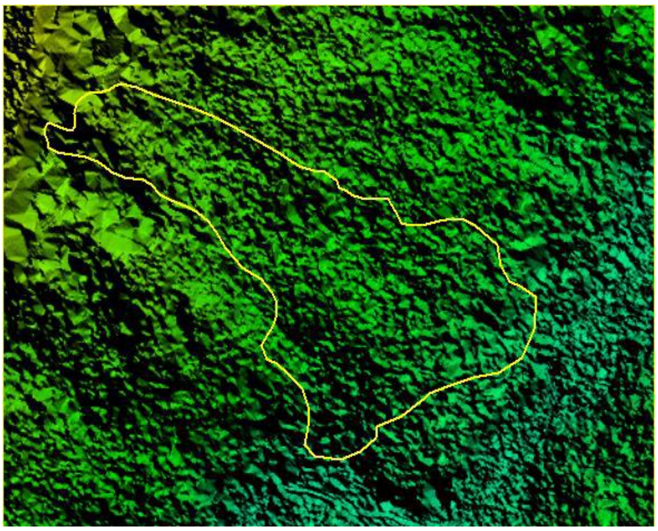


Fig. 2 - CARTOSAT generated DEM before landslide (13th April 2009)

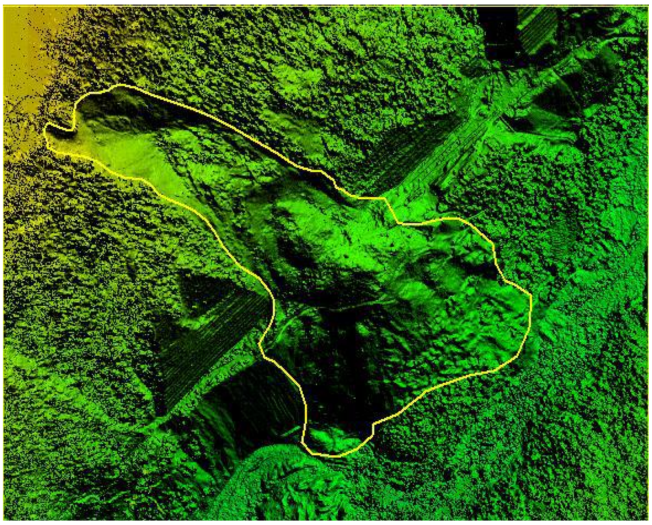


Fig. 3- Drone generated DEM after landslide (July 2022)

It is observed that finite element-based modelling is a quite powerful tool to simulate the model of a landslide, if the modelling parameters are actual based on the field and laboratory investigations. Phase^2 (RocScience Inc.) software was used for 2D finite element modelling of the slide area. CARTOSAT Generated DEM before landslide (13th April 2009) was used to generate the slope profile AB (Fig. 2 and 4). In this preliminary study general rock/soil properties were used using RocLab utility as the parameters are not available during the period of the investigation. The results of 2D FEM of the slide area are presented. The analysis results validate and confirm the already initiated failure zones and expected progressive failure zones as observed in the Drone image, Drone generated DEM and field. It can be seen that, the predicted slope failure and actual landslide incidence have matched.

Modelling has manifold utility for landslide disaster mitigation in terms of identifying stress accumulation zones and also the extent of displacement expected to occur for locating and planning strengthening measures at such zones within a specific landslide. It can also help in accurately locating the sites for placement of sensors for instrumentation and monitoring of actual ground movements in a landslide.

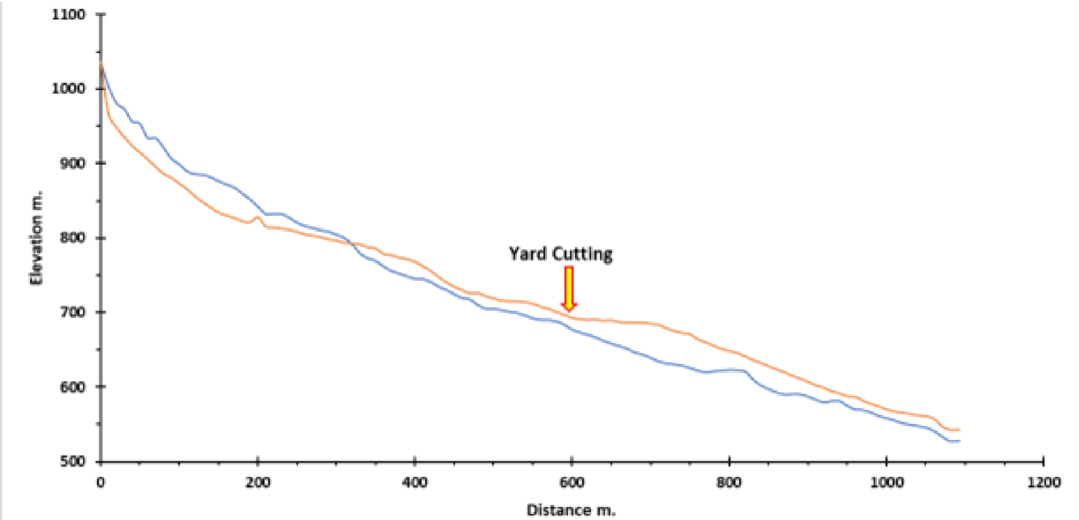


Fig. 4: Longitudinal Section along AB
(Blue Line: April-2009 and Red Brown Line: July-2022)

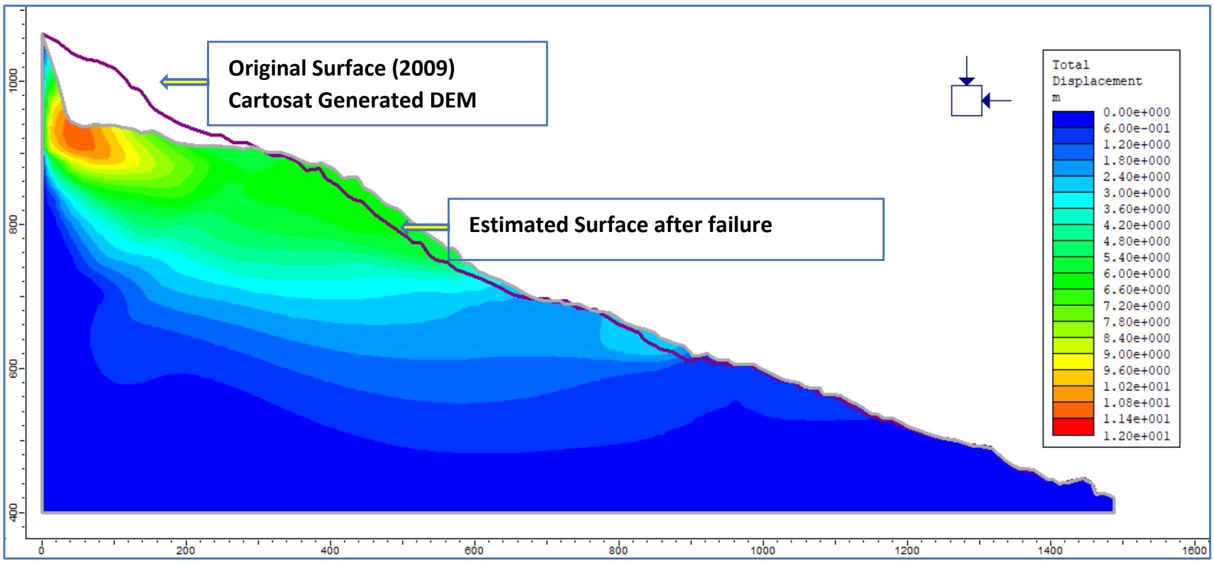


Fig. 5: FEM Analysis for predicting the slope instability.

On the basis of finite element analysis with shear strength reduction method, it can be concluded that the existing yard cutting area is not stable as upper slope of the area may undergo sliding in a rainfall event. And The landslide area was earlier investigated and identified as high to very high hazard under the unpublished doctoral thesis submitted and awarded by Manipur University in the Department of Earth Sciences in 2007 (Thingujam Dolendro, 2007).

4. Causes of the Massive Landslide:

We have assumed the probable cause of the landslide:

Geologically, non-resistant lithologies (shale inter-bedded with mudstone, siltstone and sandstone) of Barail Group exposed in the study area after the modification of the slope geometry that impedes the mountain's ability to resist the existing gravitational force may become one of the causes of landslide. Tectonic activity contributes to slope instability in three ways. First, it creates zones of weak rock along the fault. All types of faulting break down the rock mass along the fault trace (Brideau et al., 2005, 2009), and folding can produce extension cracks along the hinge zone of anticlines. Second, tectonic activity, operating over long periods, produces relief. Strike–slip faults, however, can also generate relief in transgressional zones at kinks in the fault trace. Third, tectonic activity can translate inherited structures within the rock mass into positions that are more favorable to failure, for example by producing inclined bedded planes. The study area seems to be tectonically active, therefore the entire mass wasting slump modified the original slope just below the crest of the hill. It seems that the recent precipitation during May-June 2022 became a threshold for rainfall induced landslide in the study area. In additional to rainfall, the Ijai fault which is 11 km long NE-SW trending fault which gets abruptly terminated against the Tupul fault, located north of Tupul village at the confluence of Ijai and Tupul rivers (after GSI Misc. Publication 1992, Acc. No. 2028).

Secondly, the fine grained lithologies (clay and silt) being less permeable becomes more plastic and reduces the stability of the slope and initiate the sliding, where the resistant lithologies (sandstone and mudstone) still hold water in their pore spaces. These two contrasting combinations of litho units in the western Manipur as well as in the study area seems to be one of the causes for slope instability.

Thirdly, Manipur state is included in the High Seismic Hazard (Zone V, Seismic Zonation Map of India) and hence, the micro seismicity is active besides a large earthquake of 2016 (M6.7) which is near to the recent landslide area. Based on the fault plane solutions (Global CMT Project) of earthquake data, the principal P-axis is towards north, indicating the compression direction, resulting in the extension along east-west. The resulting creeping of micro deformation towards the western slopes of the terrain including the recent landslide area is aligned with the principal T-axis (Kumar et al 2011). It is also seeming to be one of the triggering factors for the hazard as few minor cracks are observed in the cut slopes of the railway yard. However, it is still not clear that after four years of the triggering of 6.7 M earthquake in 2016, how the failure along the natural slope activated only in 2022. It may be another triggering factor.

Rainfall is the main triggering factor of landslides, and rainfall thresholds are the most used parameter to forecast the possible occurrence of a landslide in a given study area; they are defined as the rainfall conditions that when reached or exceeded, are likely to trigger landslides (Guzzetti et al. 2008). In general, White *et al.* (1996) defined a threshold as a condition—expressed in quantitative terms by a mathematical law—whose overcoming results in a change of state of a system. For what concerns landslides, a threshold represents the lower bound of known hydrological conditions (e.g., rainfall, infiltration, soil moisture) that resulted in landslides (Reichenbach et al. 1998). In a Cartesian plane, thresholds are expressed in terms of curves that delimit a portion of the plane containing the hydrological conditions related to known slope failures. An upgrading to this approach is obtained by including in the analysis (and in the Cartesian plane) also the known hydrological conditions not related to landslide occurrences. In these cases, thresholds are defined as the best separators among triggering and non-triggering known conditions (Crozier 1999). A further improvement consists in dividing the Cartesian plane in three parts, by means of two thresholds: a lower threshold, below which no landslides occur, and an upper threshold, above which landslides always occur (Wilson *et al.* 1993). Between the two thresholds, different probabilities of occurrence are defined, with uncertainties related to the incompleteness of knowledge on the physical process (Crozier 1997) and on the landslide database.

The first author introducing the concept of a minimum amount of rainfall necessary to trigger a landslide was Endo (1969). Five years later, Onodera et al. (1974) proposed the first quantitative rainfall threshold for landslide triggering. Afterwards, Campbell (1975) and Caine (1980) published the two most famous pioneering works about rainfall thresholds. In particular, analyzing the rain- fall conditions responsible for the initiation of soil slips in California, Campbell (1975) pointed out that the cause of the failures were the combination of antecedent cumulated rainfall and event rainfall intensity. Further, Caine (1980) proposed the first global threshold, expressed by a power-law equation and representing the minimum boundary of 73 rainfall intensity (I) vs. rainfall duration (D) conditions that have triggered landslides in several parts of the World.

Since those pioneering works—and despite criticisms—rainfall thresholds were widely used to characterize the relationship between rainfall and the triggering of landslides (De Vita et al. 1998; Reichenbach et al. 1998; Corominas 2000; Crosta and Frattini 2001; Aleotti 2004; Wieczorek and Glade 2005). Guzzetti et al. (2007, 2008) published two works proposing an extensive review of the international literature. They highlighted that, since then, rainfall thresholds were broadly used considering: different scale of analysis (global, regional, local), a wide variety of rainfall parameters, various physiographic settings, and different landslide types. Guzzetti et al. (2007) also stated that for defining rainfall thresholds, physically based (process-based, conceptual thresholds) or empirical (historical, statistical thresholds) approaches can be used. Among the latter, three kinds of rainfall measurements were more frequently used: rainfall measurements obtained for specific rainfall events; antecedent rainfall conditions; other thresholds, including hydrological thresholds. Finally, they proposed a global threshold based on a global database of 2626 rainfall events resulted in shallow landslides and debris flows.

In the decade following the works by Guzzetti et al. (2007, 2008), the topic was further investigated, producing abundance of case studies at different scales of analysis, and significant technical and scientific advances. Therefore, we felt necessary to further review the recent international literature, collecting information about the definition, the employment, and the validation of landslide rainfall thresholds worldwide, in order to highlight the best practices, the main drawbacks still affecting recent case studies, the most common critical problems, and the most effective solutions adopted.

5. Discussions

We observed that the lithological trend of the Marangching is along NW-SE which is one of the factors for ongoing deformation processes and initiating slope instability as a continuous phenomenon. We have observed during the site visit and compared with existing terrain maps as well as DEM data that the slope (42º) of the Makhuam hill along with the first order stream drainage lines. The seasonal first order streams along the slope of the hill are the main source of water percolating on these slopes, which become more prone to mass wasting because gravity has an easier time pulling materials down a steep slope as compared to a gentle slope. Heavy incessant rainfall and too much water also weakened its ability to resist gravity. However, a little bit of water actually made it easier for soil particles to bond together and keep the mountain intact. Generally, soil particles lose this bond and break apart after excessive rain. The primary effect of water within the slope was to reduce shear stress (reduced cohesion) acting along the potential slip surface, thereby reducing the shear strength along the surface. The driving force (or moment) is due primarily to the component of the slump block weight acting parallel to the potential slip surface. Movement could be triggered if the ratio of driving to resisting forces (or moments) is altered by adding water by rainfall (60% above the normal rainfall in the last two months) to the slope. This seems to be the main causative factor for the recent massive landslides.

We have consulted Meteoblue Climate Diagrams, which are based on 30 years of hourly weather model simulations (Fig. 6). They give good indications of typical climate patterns and expected conditions (temperature, precipitation, sunshine and wind) on a spatial resolution of approximately 30 km. It is observed from the Metablue data that the pre monsoon precipitation also contribute a considerable amount of rainfall which triggers the landslide incidences in the month of June whenever precipitation exceeds 700 mm (Table 1) such as 2017.

Manipur’s Imphal received the highest rainfall since 1956, recording 2,439.4mm in 2017 till December 13 or 68.71% above the state’s annual precipitation of 1446.3mm, (ICAR Imphal). The rainfall above 2,000mm was recorded only in 1991 (2,110.6mm) and 1993 (2,171.6mm). We have reviewed the precipitation data from Indian Meteorological Department New Delhi and compared with historical landslides and it inferred that 700 mm precipitation is the threshold limit for triggering the landslide incidences.

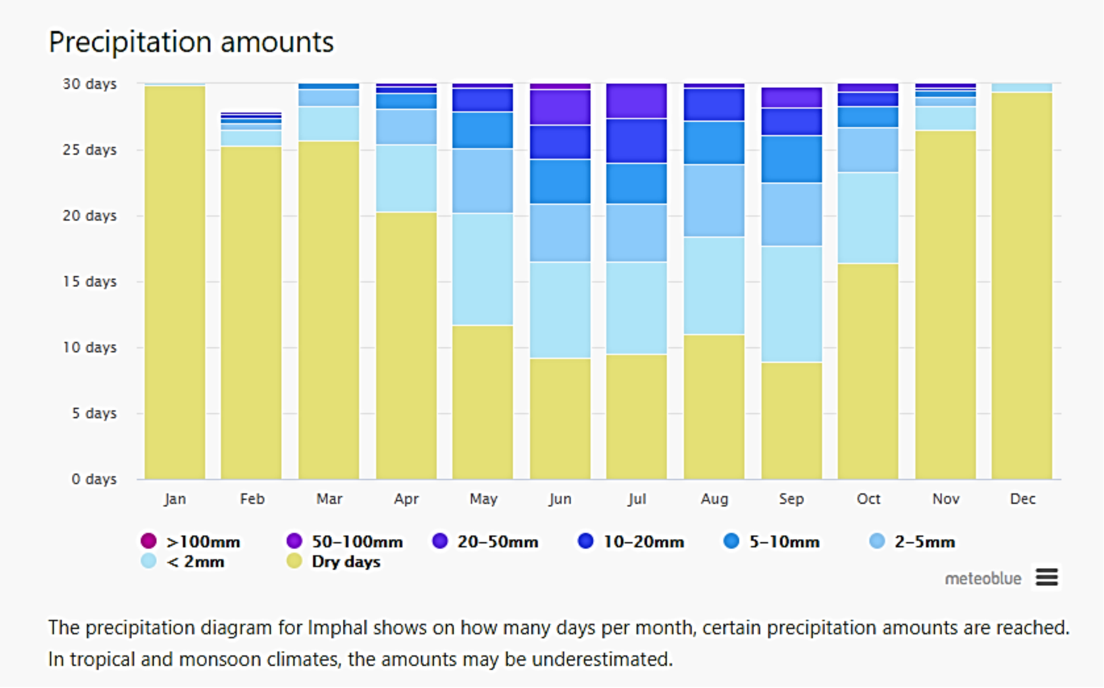


Fig. 6: Meteoblue Climate Diagrams (precipitation) of Imphal

Fig. 7: Tupul Landslide (30th June 2022)

Fig. 8: Tupul landslide (30th June 2022) Damaged Railway Station and platform

Table 1: Database of precipitation and landslide incidences

SN	Year and month	Landslide locality	Precipitation (mm)
1.	10 July 2004	Gopibung Mudflow	1500
2.	July 2004	Phikomei Landslide	1500
3.	2007 August	Zuba Landslide	1199
4.	2010 July	Moreh Landslide	822
5.	2010 July	Tupul Landslide	822
6.	2012 July	Zuba Landslide	1670
7.	October 2013	Tusem Ukhrul	1065
8.	July 2013	Mao	1065
9.	August 2015	Kasom Khullen	962
10.	May 2017	Phisema	1089
11.	April 2017	Sirarakhong	1089
12.	October 2017	Joumuoul (Chandel)	1089
13.	2017	Kali khola Landslide	1089
14	July 2020	Longmai Slide	717
13.	June 2022	Tupul	1766

Fig. 9: Phikomei Landslide of July 2004

It is indicated from the rainfall database of Manipur (Indian Meteorological Department) that, the landslide usually triggered whenever the precipitation is more than 700 mm during April/May as well as July/August. The Pre-monsoon precipitation (>700 mm) is occasionally observed, therefore triggering of landslides takes place during July-August. The landslide of Tupul was triggered when it exceeded >1700 mm and resulted in a massive slide that devastated the entire hill slope including the existing village, railway properties, temporary camps of Territorial Army etc on 22 June 2022. The mudflow incidence was the main cause from the hillslope. We have observed few mudflows in Manipur during the past heavy spells of precipitation (>1500 mm). The Phikomei Landslide (Fig. 9) in Senapati District and Gopibung Mud Flow (Fig. 10) in Kangpokpi District are those of our observed landslide and mudflow which triggered during 10 July 2004 (same day).

Fig. 10: Gopibung Mudflow of July 2004

6. Conclusions:

The Tupul (Makhuam) landslide triggered on the intervening night of 29-30 June 2022 which seems to be triggered by excess precipitation during the month of June 2022 (1766 mm). The topographic factors such as single drainage along the hill with steep slope near the crown, located in a active seismological terrain (3 January 2016 M7.6 Noneh Earthquake) and highly weathered rocks have influenced the triggering of massive landslides during June 2022. We suggest a reassessment of Slope stability (Factor of safety) Analysis for open cuts and yards of the Jiribam Tupul Railway Line. Installation of automatic weather stations for monitoring of weather data at major Railway Station sites from Jiribam to Tupul (precipitation and soil moisture) will be most appropriate tool for developing the early warning system in the future.

7. Acknowledgement:

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