ASSESSMENT OF RAINFALL INDUCED LANDSLIDES OVER NEPAL

A PROJECT WORK SUBMITTED TO THE

DEPARTMENT OF PHYSICS

TRI-CHANDRA MULTIPLE CAMPUS

INSTITUTE OF SCIENCE AND TECHNOLOGY

TRIBHUVAN UNIVERSITY

NEPAL

FOR THE AWARD OF

BACHELOR OF SCIENCE (B.Sc.) IN PHYSICS

BY

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SYMBOL NO: 500370354

TU REGISTRATION NUMBER: 5-2-37-1929-2018

OCTOBER, 2023

RECOMMENDATION

This is to certify that **SANJEEP KHANAL, (**Symbol No. 500370354, T.U. Registration No. 5-237-1929-2018) has carried out project work entitled **" ASSESSMENT OF RAINFALL INDUCED LANDSLIDES OVER NEPAL"** for the requirement to the project work in Bachelor of Science (B.Sc.) degree in Physics under my supervision in the Department of Physics (Tri-Chandra Multiple Campus), Institute of Science and Technology (IOST), Tribhuvan University (T.U.), Nepal.

To my/this knowledge this work has not been submitted to any other degree. He has fulfilled the requirements laid down by the Institute of Science and Technology (IOST), Tribhuvan University (T.U.), Nepal for the submission of the project work for the partial fulfillment of Bachelor of Science (B.Sc.) degree.

……………………………………

Dr. Manoj Kumar Thakur

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Tribhuvan University

9 OCTOBER 2023

DECLARATION

This project work entitled' '**ASSESSMENT OF RAINFALL INDUCED LANDSLIDES OVER NEPAL'** is being submitted to the Department of Physics, Tri-Chandra Multiple Campus, Institute of Science and technology (IOST), Tribhuvan University (T.U.), Nepal for the partial fulfillment of the requirement to the project work in Bachelor of Science (B.Sc.) degrees in Physics. This project work is carried by me under the supervision of Assistant Prof. Dr. Manoj Kumar Thakur in the Department of Physics, TriChandra Multiple Campus, Institute of Science and Technology (IOST), Tribhuvan University (T.U.), Nepal.

The work is original and has not been submitted earlier in part or full in this or any other form to any university or institute, here or elsewhere, for the award of any degree.

…………………………..

Signature

SANJEEP KHANAL

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9 OCTOBER 2023

LETTER OF FORWARD

Date: 9/October/2023

On the recommendation of Assistant Prof. **Dr.Manoj Kumar Thakur,** this project work is submitted by **SANJEEP KHANAL,**Symbol No. 500370354, T.U. Registration No. 5-2-37-1929-2018, entitled "**ASSESSMENT OF RAINFALL INDUCED LANDSLIDES OVER NEPAL**"is forwarded by the Department of Physics, TriChandra Multiple Campus, for the approval to the Evaluation Committee, Institute of Science and Technology (IOST), Tribhuvan University (T.U.), Nepal.

He has fulfilled all the requirements laid down by the Institute of Science and Technology (IOST), Tribhuvan University (T.U.) for the project work.

…………………….

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BOARD OF EXAMINATION AND

CERTIFICATE OF APPROVAL

This project work (PRO-406) entitled “**ASSESSMENT OF RAINFALL INDUCED LANDSLIDES OVER NEPAL** " by Sanjeep Khanal, Symbol No. 500370354 and T.U. Registration No. 5-2-37-1929-2018, under the supervision of Assistant Dr. Manoj Kumar Thakur in the Department of Physics, Tri-Chandra Multiple Campus, Institute of Science and Technology (IOST), Tribhuvan University (T.U.) is hereby submitted for the partial fulfillment of the Bachelor of Science (B.Sc.) degree in Physics. This report has been accepted and forwarded to the Controller of Examination, Institute of Science and Technology, Tribhuvan University, Nepal for legal procedure.

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I would like to express my gratitude to Tribhuvan University and Department of Physics, Tri-Chandra Multiple Campus for giving me the opportunity to conduct the research under the title **“ASSESSMENT OF RAINFALL INDUCED LANDSLIDES OVER NEPAL”**. Also, the report couldn’t be initiated without the assistance of some gracious people whom I must thank. I am extremely grateful to the University Grants Commission for Sponsoring our Project and Head of Department of Physics Iswar Prasad Koirala sir for giving and making sound environment for conducting research project under the supervision of supervisor Dr. Manoj Kumar Thakur sir who gave me fruitful suggestions and guidance to frame out this report and Tribhuvan University for their generous encouragement and undertaking the supervision my entire research work.

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ABSTRACT

This project focuses on the critical issue of rain-induced landslides in Nepal, which is at high risk for such disasters due to the country's remote terrain and monsoon season. This study aims to assess factors contributing to landslide susceptibility, predict landslide-prone areas and develop mitigation strategies. We use advanced geospatial techniques, remote sensing data, and historical rainfall data to analyze landslide patterns and trends. By understanding the relationship between rainfall and landslides, this research seeks to provide valuable insights for disaster preparedness and risk reduction in Nepal, ultimately contributing to the safety and resilience of local communities.

Keywords **:** In-Situ ,IMERG,Landslides ,Nepal,Satellite

शोधसार

यस परियोजनाले नेपालमा वर्षा-प्रेरित पहिरोको महत्वपूर्ण मुद्दामा केन्द्रित छ, जुन देशको दुर्गम भू-भाग र मनसुन मौसमका कारण यस्ता प्रकोपहरूको लागि उच्च जोखिममा छ। यस अध्ययनले पहिरोको संवेदनशीलतामा योगदान गर्ने कारकहरूको मूल्याङ्कन गर्ने, पहिरोको जोखिममा रहेका क्षेत्रहरूको भविष्यवाणी गर्ने र न्यूनीकरण रणनीतिहरू विकास गर्ने लक्ष्य राखेको छ। हामी उन्नत भूस्थानिक प्रविधिहरू, रिमोट सेन्सिङ डेटा, र ऐतिहासिक वर्षा डेटाको ढाँचा र पहिरोको प्रवृत्ति विश्लेषण गर्न प्रयोग गर्छौं। वर्षा र पहिरो बीचको सम्बन्ध बुझेर, यस अनुसन्धानले नेपालमा विपद् पूर्वतयारी र जोखिम न्यूनीकरणका लागि बहुमूल्य अन्तर्दृष्टि प्रदान गर्न खोज्छ, अन्ततः स्थानीय समुदायहरूको सुरक्षा र लचिलोपनमा योगदान पुऱ्याउँछ।

LIST OF ACRONYMS AND ABBREVIATIONS

AMSR2: Advanced Microwave Scanning Radiometer 2

CCI: Climate Change Initiative

DPR: Dual-frequency Precipitation Radar

DoHM: Department of Hydrology and Meteorology

ESA: European Space Agency's

GDP: Gross Domestic Product

GPM: Global Precipitation Measurement

IMERG: Integrated Multi-satellitE Retrievals for GPM

UNDRR : United Nations Office for Disaster Risk Reduction

UNESCO: United Nations Educational, Scientific and Cultural Organization

TRMM: Tropical Rainfall Measuring Mission

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CHAPTER 1

1.INTRODUCTION

1.1.1General Introduction

Nepal is a country with latitudes and longitudes 26° 22'N to 30°27'N and elongated with 80°4' E to 88°12'E east-west longitude..It is also known as independent and sovereign country having a varying of bio diversity on Geography and Topography.It is a landlocked country and having border sharing with China in the North part and India by East,West and South part..It is also known as the country of Mountain having a world`s larget mountain which is Mt.Sagarmatha . Nepal cover total area of approximately 147,181 square kilometers (56,827 square miles). Ten World Heritage Sites are lies in Nepal according to UNESCO World Heritage Sites which are Kathmandu Durbar Square,Bhaktapur Durbar Square,Patan Durbar Square,Changu Narayan Temple,Swoyambhunath Stupa,Boudhanath Stupa,Lumbini,Chitwan National Park and Sagarmatha National Park.(karki et al. 2016)

Nepal has diverse topography due to Himalayas and varying elevations across the country.It has a elevation of 70 meters to 8848 meters.It`s topography are divided into three part :Mountain Region,Hilly Region and Terai Region.Terai is the southernmost part of Nepal border with India. It has a elevation of about 70 meters to 300 meters above sea level.This region has fertile soil and also famous for Agricultural area ,producing wheat,rice,sugarcane and crops.Hilly regions are lies in the Northern part of Terai and characterized by rolling valleys and hills.It has elevation from (300-3000) meters above the sea level .Due to slope land Terrace faming is Suitable here.Mountain Region lies in Northern part of Nepal.It has a maxium of 8848meteres of elevations.This part is barely Populated and primarily used for trekking.(Rai et al. 2022)

Disaster is an incident which occurs unknowingly.It can be categories into two part Natural disaster and Human-Made Disaster. A Catastrophic events that occurs naturally and causes significant destruction, loss of life and property is known as Natural Disaster. It has a capacity to damage a thousands of lives at the single time.This unpredicted events result negatively affects both life and property which causes suffering both Human and Infrastructure. Some types of Natural disaster are :Flood,Landslides,Drought ,Earthquake,Tornado ,Tsunami ,Tropical Cyclone ,Heat-Wave,Cold-Wave, avalenches,and many more.Human-made disaster are known as disaster occurs due to carelessness of human which leads to damage environment and human settlement.Some types of Human-made disaster are:Wildfires,pollution, environmental degradation,etc.

1.1.2 Specific Introduction

Among all disaster, Landslides is most noticeable and frequently occurs which causes climate changing problem inside Nepal. Climate change is the major problem in barrier in the GDP growth of the country.Lanslides is one of them which disturb in the policymaking process for policymaker in different parts such as agriculture,disaster management,Industry and socioeconomic development study of landslides inside country like our is important(Thakur et al.2023) mainly landslides induced here due to precipitation during the monsoon season it start with June and ends at September of month. Precipitation refers to any form of water that falls from the atmosphere and reaches the Earth's surface. This can include rain, snow, sleet, hail, and other forms of frozen or liquid water. Precipitation is an essential part of the Earth's water cycle, as it replenishes freshwater sources and supports plant and animal life. It is caused by a variety of factors, including changes in temperature, humidity, and atmospheric pressure. When air cools, it can hold less moisture, which can lead to condensation and the formation of clouds. As these clouds grow and become heavier, they can release their moisture in the form of precipitation. Precipitation patterns can also change over time due to climate change, which can have far-reaching implications for ecosystems and human communities.

Precipitation-induced landslides, also known as rainfall-triggered landslides, are a type of mass wasting that occurs when rainfall or other forms of precipitation increase the pore water pressurewithin a slope or hill, causing it to become unstable and slide downhill.Landslides causes millions of loss in GDP worldwide.According to a report by the United Nations Office for Disaster Risk Reduction (UNDRR), the direct economic losses from landslides globally between 2000 and 2019 were estimated to be around $ 56 billion USD. However, this figure does not include the indirect economic impacts, such as those related to trade and transportation disruptions.(sim et al. 2022)

Landslides are a common natural hazard that can occur globally in a variety of settings. They can be triggered by factors such as heavy rainfall, earthquakes, volcanic activity, and human activities such as mining or construction. Some regions that are particularly prone to landslides include mountain ous areas, coastal cliffs, and areas with steep slopes and loose soil or rock.

Landslides occur when soil, rock, or other material on a slope becomes unstable and moves down-hill. The factors that can trigger landslides vary depending on the location and local conditions. For example, heavy rainfall can saturate the soil and increase its weight, making it more likely to slide down a slope. Earthquakes can also trigger landslides by shaking the ground and causing the soil or rock to become dislodged. Volcanic activity can cause landslides due to the sudden release of hot, wet ash that can become saturated and unstable. The impact of landslides can be significant, causing property damage, loss of life, and disruption to transportation and infrastructure. The frequency and severity of landslides can vary depending on local conditions, and effective measures to prevent and mitigate landslides require a detailed understanding of the local geology and topography, as well as careful planning and management of human activities. Techniques such as slope stabilization, surface drainage, and vegetation management can be used to reduce the risk of landslides. Early warning systems can also be implemented to alert people to the potential for landslides and allow for evacuation or other safety measures.(Cremen et al.2023)

Figure 1: Landslides that block the road.
Source: Khabarhub,1 August 2022

In the context of Nepal, it is one of the major problems, particularly in the mountainous and hilly regions. Although Nepal is reckoned on Agriculture and Natural resources: Landslides have seriousconsequences on it including loss of life, damage to infrastructure and property, and disruption of essential services. They can also have economic and social impacts, as they can disrupt transportation and access to markets and services which is the major cause of loss in the GrossDomesticProduct(GDP) of the county.

The following are some of the types of landslides that occur in Nepal:

• Complex Landslides: Complex landslides are a combination of two or more types of landslides.In Nepal, complex landslides are common in areas with diverse geology and topography.

• Debris Flows: Debris flows are fast-moving mixtures of rock, soil, and water that flow downsteep slopes. In Nepal, debris flows occur frequently during the monsoon season due to heavy rainfall.

• Earthflows: Earthflows are slow-moving landslides that occur in saturated soil or weak rock.

In Nepal, earth flows are common in areas with steep slopes and heavy rainfall.
• Landslide Avalanches: A landslide avalanche occurs when a large volume of rock or soil slides down a slope and gains momentum, becoming an avalanche-like flow. This type of landslideis common in Nepal, especially in the high Himalayan region.
• Rockfalls: Rockfalls occur when rocks detach from steep slopes and fall to the ground. In Nepal, rockfalls are common in mountainous regions due to the presence of unstable rock formations.
• Shallow Landslides: Shallow landslides occur in the upper layer of soil and are typically trig-gered by heavy rainfall or human activities such as excavation. This type of landslide is prevalent in Nepal's hilly regions. (Robert et al.2021)

1.2 Rationale

Landslides brought on by rainfall pose a serious geological risk, particularly during the monsoon season. These natural disasters have the potential to have catastrophic effects on infrastructure, communities, and the environment. For these landslides to have less of an impact, it is essential to recognize the causes and create mitigation techniques that work. The necessity of performing a project on the evaluation of rainfall-induced landslides during the monsoon season is explained in this justification.

Regions susceptible to landslides are more vulnerable during monsoon seasons because of the heavy and protracted rainfall they experience. Climate change, Infrasture construction, and urbanization are all contributing factors that are increasing the frequency and severity of rainfall-induced landslides. In order to lessen the effects of these landslides and increase resilience, assessment is crucial. Landslides brought on by rain pose a serious hazard to lives and property. These landslides can cause fatalities, evictions, and severe economic losses in highly populated areas. Landslides can also result in environmental deterioration, which can have an impact on ecosystems, water quality, and natural habitats. For disaster management and sustainable development, it is crucial to determine how much of an impact certain factors have.

It is essential for forecasting and mitigating rainfall-induced landslides to comprehend the fundamental mechanics and causes of these events. By analyzing elements that affect landslide occurrence, such as soil composition, topographical features, and rainfall patterns, this initiative will add to the body of scientific knowledge. These revelations can aid in the creation of better land-use planning and early warning systems.

In conclusion, the evaluation of monsoon-season rainfall-induced landslides is an essential undertaking that tackles a critical geological hazard with far-reaching effects. The results of this study can help reduce the risk of disasters, advance scientific understanding, and improve government, eventually protecting people's lives, their property, and the environment in disaster-prone areas.

1.3 Objectives

1.3.1. General Objective

The general objectives of my project work on the topic of “Assessment of Rainfall Induced Landslides Over Nepal ” are :

- Identifying and defining high-risk locations for rainfall-induced landslides while taking geological, topographical, and hydrological elements into consideration.
- To systematically record and describe the prevalence, regularity, and spatial distribution of rainfall-induced landslides in the target area throughout the monsoon season.
- To suggest and rank various ideas and tactics for preventing landslides, such as slope stabilization, reforestation, land-use planning, and emergency preparedness plans.
- To provide a baseline for tracking historical trends in rainfall-induced landslides, enabling for the evaluation of the efficiency of adaptation and mitigation measures.

1.3.2. Specific Objective

The specific objectives we are carrying out in this research work:

- To investigate the rainfall-induced landslides patterns over Nepal.

- Investigate the Landslides Triggering Mechanisms.
- To analyze how far are we from the use of satellite and In-Situ precipitation products.

CHAPTER 2

2. LITERATURE REVIEW

Several studies have been done on the topic landslides because of their ubiquitous occurrence and potentially disastrous effects, complete understanding of rainfall-induced landslides is critical. Rainfall, a key cause of landslides, is impacted by a number of factors, including preceding rainfall, rainfall intensity, and duration. Guzzetti et al. (2008) and Crozier (2010) research has emphasised the importance of these parameters in landslip initiation. The creation of effective landslide susceptibility and hazard maps has been critical in identifying landslide-prone locations. Integrating topographical, geological, and land cover data with rainfall information, as advocated by Aleotti and Chowdhury (1999) and Van Westen et al. (2003), has played a crucial role in land-use planning and risk mitigation. Kirschbaum et al. (2015) investigated how advanced rainfall forecasting and early warning systems have significantly improved our capacity to monitor and anticipate rainfall events that may cause landslides, allowing for prompt evacuation and mitigation activities. Climate change's influence on precipitation patterns has added to the complexity of the landslip risk environment. Huggel et al. (2015) address the ramifications of climate change and how it may increase the likelihood of landslides. Case studies have been essential in gaining a better knowledge of regional variability in rainfall-induced landslides. For example, severe monsoon rains in tropical places such as Southeast Asia frequently cause catastrophic landslides (Petley et al., 2005), but countries with Mediterranean climates, such as California, have elevated hazards owing to dryness followed by excessive rainfall (Staley et al., 2015). A thorough grasp of regional variability is required for designing mitigation actions. Terlien et al. (2017) research also emphasises the significance of comprehensive risk management, including land-use planning, structural measures, and community-based methods, to improve resilience in the face of landslip risks. Despite considerable advances in landslide research, continued studies are critical, particularly in the context of climate change, to mitigating the growing danger of landslides across the world.

CHAPTER 3

3. DATA AND METHODS

There are various types of research methods and materials depending on their nature. We have follow theoretical as well as data-based methods to study the facts about precipitation-induced Landslides.We have present different facts describing Landslides with the help of the Journal of Research, and different types of reports from different countries. We will try to apply this type of methodology which can aware people of upcoming hazards by Landslides and also be able to study prone areas in our country Nepal. We have gather information from different sites.

3.1 Data

3.1.1 In-situ Data

The data were collected from [https://www.dhm.gov.np] Department of Hydrology and Metrology which is government agency inside our country responsible for monitoring, studying, and providing information related to weather and water resources. DoHM plays a crucial role in managing water resources and providing early warning systems for natural disasters like floods, landslides, and droughts.We have deal with their data to evaluate its real-time performance with the IMERG dataset.There are more than Hundreds of Hydrology and MeteorologyStations in Nepal.

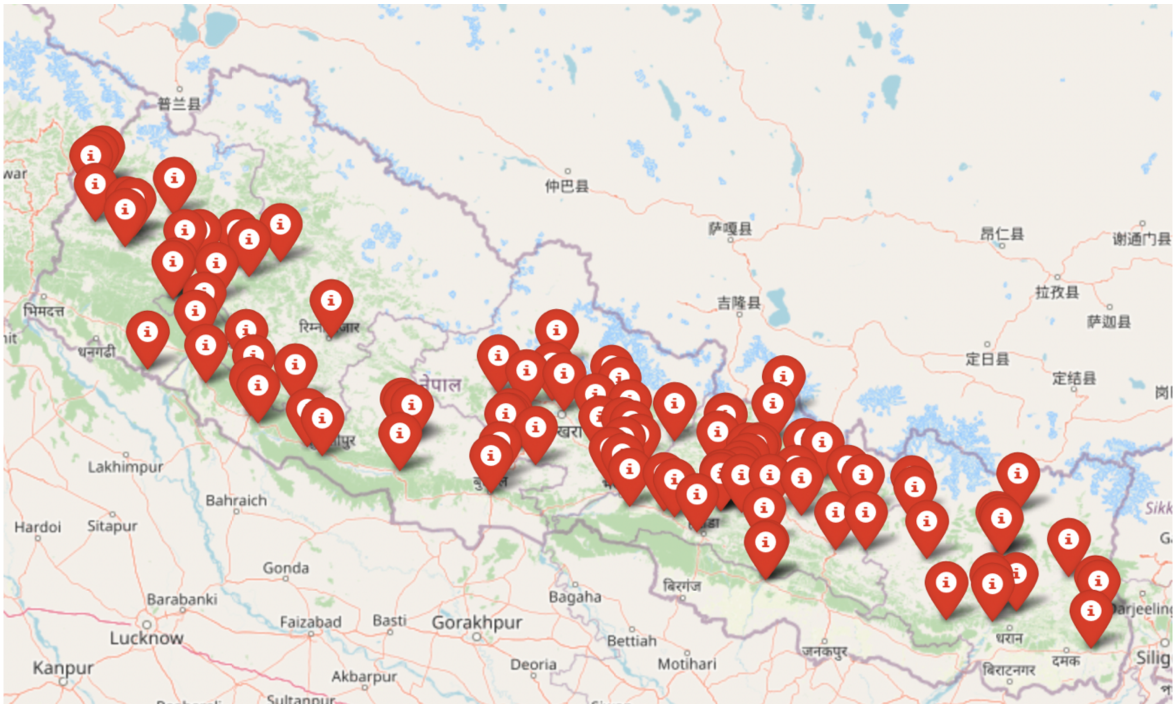

Figure 2: Major Hydrology and Meteorology Stations of Nepal

3.1.2 EARTH DATA

Earth data refers to the collection, analysis, and use of data related to the Earth and its various systems, including the atmosphere, oceans, land surface, and ice. Earth data is collected from a variety of sources, including satellites, ground-based sensors, and models, and is used for a wide range of applications, including weather forecasting, climate monitoring, natural resource management, and disaster response.

One of the primary sources of Earth data is Earth observation satellites, which provide a global perspective on the planet's systems and enable the monitoring of changes over time. These satellites collect data on a variety of variables, including temperature, humidity, precipitation, wind, ocean currents, and vegetation cover (werner et al.2020).

Earth data is also collected from ground-based sensors and networks, such as weather stations, buoys, and river gauges. These data sources provide detailed information on local conditions and can help fill in gaps in satellite data coverage.

The use of Earth data has revolutionized our understanding of the planet and its systems, and has enabled more accurate predictions of weather and climate patterns. Earth data is also used to inform decision-making related to natural resource management, such as water allocation and land use planning, and to support disaster response efforts by providing real-time information on natural hazards such as hurricanes, Landslides,floods, and wildfires.

The availability and accessibility of Earth data have also led to the development of new technologies and applications, such as precision agriculture, renewable energy planning, and urban planning. As the volume and complexity of Earth data continue to grow, new approaches to data management, analysis, and visualization are needed to fully realize its potential for addressing global challenges and informing sustainable development.

3.1.3. IMERG DATA

IMERG stands for Integrated Multi-Satellite Retrievals for Global Precipitation Measurement, and it is a product of NASA's Global Precipitation Measurement (GPM) mission. IMERG is a dataset that provides global precipitation estimates at a high spatial and temporal resolution.

IMERG combines precipitation data from multiple satellites, including microwave and infrared sensors, to provide accurate and reliable precipitation estimates around the world. The data is available at 0.1 degree spatial resolution, which is approximately 10 km at the equator, and 30-minute temporal resolution.

IMERG provides a range of precipitation estimates, including hourly, daily, and monthly precipitation accumulation values. The dataset also includes information on the uncertainty associated with each precipitation estimate, which is important for us to understand the level of confidence in the data.

IMERG data has a variety of applications, including weather forecasting, climate monitoring, and hydrological modeling.It has an important dataset for understanding precipitation patterns around the world and has a variety of applications in different fields and we have focus on Landslides as a specific topic.(Huffman et al.2020)

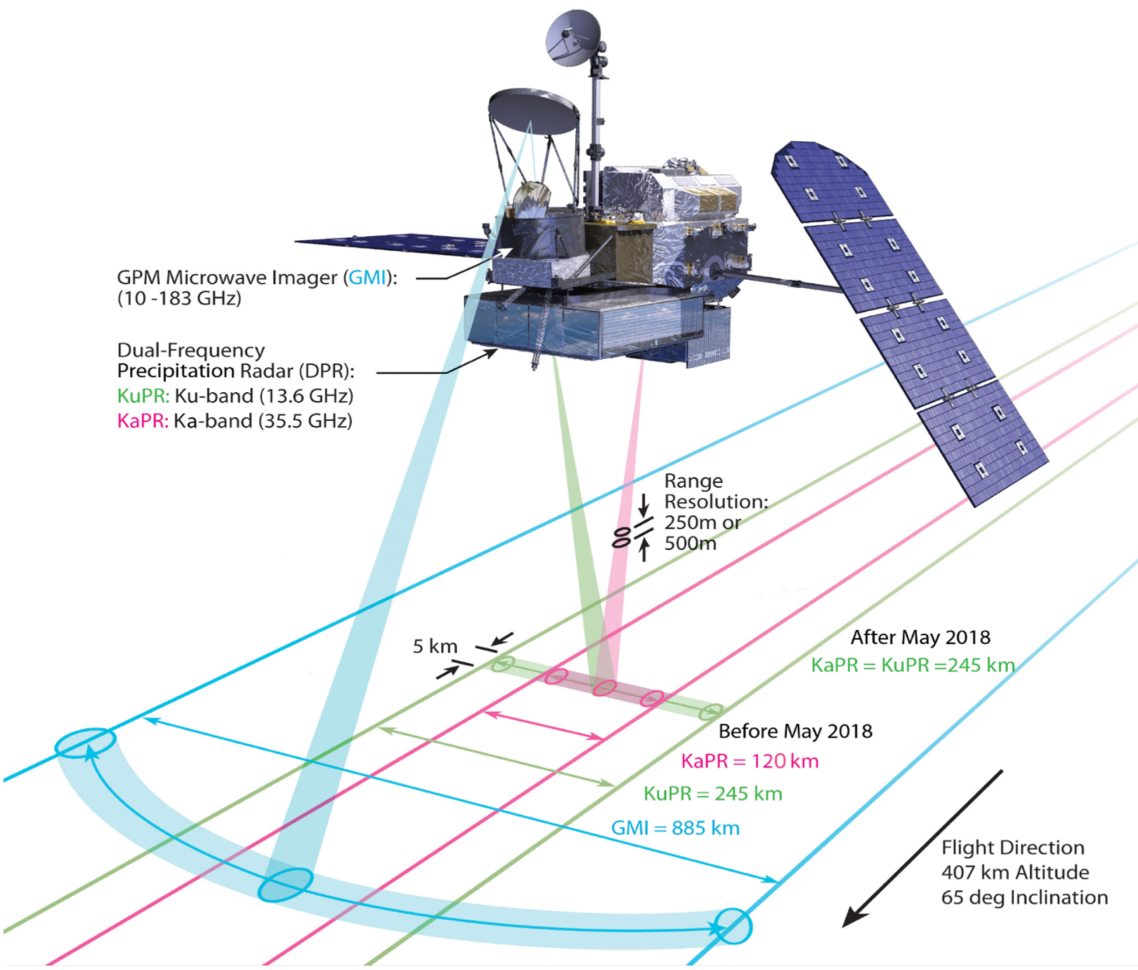

Figure 3 : The GPM Core Observatory's Dual-frequency Precipitation Radar (DPR) and GPM Microwave Imager (GMI) instruments.(As of May 2018 the KaPR swath width is also 245km.)

3.1.4 Global Precipitation Measurement

The GPM mission, is a collaborative effort between NASA and the Japan Aerospace Exploration Agency (JAXA) to measure precipitation around the world using advanced satellite technology. Launched in 2014, the GPM mission is the successor to NASA's Tropical Rainfall Measuring Mission (TRMM), which was in operation from 1997 to 2015.

The GPM mission involves a constellation of satellites that work together to provide global coverage of precipitation. The primary satellite in the GPM constellation is the GPM Core Observatory, which carries two instruments: the Dual-frequency Precipitation Radar (DPR) and the GPM Microwave Imager (GMI). The DPR uses radar technology to provide three-dimensional measurements of precipitation, while the GMI uses microwave technology to provide measurements of the amount and intensity of the precipitation.

In addition to the Core Observatory, the GPM constellation includes a network of partner satellites from various international space agencies, including JAXA's Advanced Microwave Scanning Radiometer 2 (AMSR2) and the European Space Agency's (ESA) Climate Change Initiative (CCI) Rainfall product (Jackson et al.202).

The data collected by the GPM mission is used by scientists and researchers to improve our understanding of Earth's water cycle and climate system. It is also used by meteorologists and weather forecasters to improve their ability to predict and monitor precipitation events, which can have significant impacts on agriculture, water resources, and public safety.The GPM mission represents a major advancement in our ability to measure precipitation on a global scale, and it has the potential to improve our understanding of the complex interplay between precipitation, weather, and climate.

3.1.5 Global Landslides Catalog

We can get the data about the landslides from the site (data.gov) which comes under the file Landslides Catalog .It is a collection of facts and figures about landslides from all over the world. It offers thorough information on landslides, including their traits, causes, and effects.

Researchers, decision-makers, and experts working on catastrophe risk reduction and mitigation can all benefit from the catalog. A comprehensive database that offers data and documentation regarding landslides around the world is called the Global Landslide Catalog (GLC). It is a project that the NASA Goddard Space Flight Center created in association with other businesses and academic institutions. The catalog's goal is to gather and examine data on landslides in order to increase our knowledge of these geological risks and our capacity to lessen their effects (Dandrige et al. 2023).

The GLC has details on numerous landslide types, including rockfalls, debris flows, and landslides brought on by earthquakes or torrential rain. It includes information on each landslide event's location, date, size, features, and other pertinent geological and environmental details.

The Global Landslide Catalog is available online, and users can use the interactive tables, graphs, and maps to examine the data. Researchers, scientists, and policymakers can investigate landslide patterns, trends, and possible danger areas using the catalog's statistical analysis and visualization capabilities.

The Global Landslide Catalog enhances our knowledge of landslide occurrence, distribution, and triggers by gathering and evaluating a variety of landslide data. This knowledge is essential for disaster risk reduction initiatives, infrastructure development, and land-use planning to reduce the impact of landslides on people's lives, property, and the environment.

3.2.Methods

3.2.1Study Area

Nepal is a Himalayan nation in Southern Asia with a landmass of 147,516 km^2.It is a landlocked country with mountains ranging in height from 8848.86 meters on Mount Everest to 70 meters above sea level in the Terai. Nepal's natural diversity is comprised of the Terai, the interior hills, and the mountains, which are three key biological zones. Due to the simple terrain, productive crops, and excellent facilities, Terai regions have large people, yet the environment's temperature is relatively high (Sharma et al. 2021).

We are going to study about the Landslides over Nepal during the Monsoon season from 2007 A.D to 2016 A.D but maxium number of Landslides occurred during (2012 A.D – 2015 A.D) .Therefore we have picked Ten Majors Landslides Events in our project.

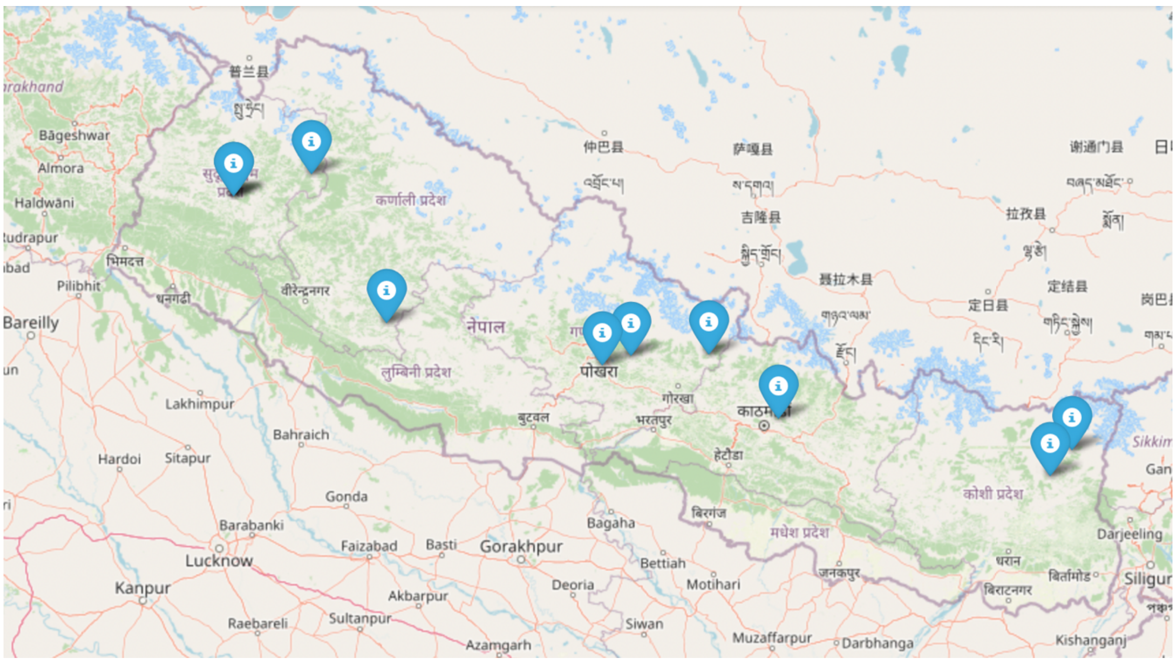

Figure 4: Main Landslides Event over Nepal during(2007- 2016)A.D

CHAPTER 4

4. RESULT AND DISCUSSION

4.1 Overview of Landslides Caused by Rainfall in Nepal

The analysis of rain-induced landslides that occurred in Nepal during the monsoon season has provided important new information about the occurrence, distribution, and contributing elements of landslides in this physically sensitive area. The goal of this study was to present a thorough understanding of the landslide danger brought on by monsoonal rainfall in Nepal.

4.1.1 Patterns of Rainfall and Causing Factors

The study investigated the relationship between rainfall patterns and the occurrence of landslides. It was clear that prolonged, severe rainstorms had a direct impact on landslide triggers. Particularly, locations with significant rainfall intensities, particularly for brief periods, showed a higher susceptibility for landslides. An additional major component determining landslide vulnerability was revealed as antecedent rainfall, as well as soil moisture content.

4.2 Landslides Pattern Analysis

We have taken different stations to analyze the rainfall pattern over the period of time from year 2012 A.D to 2015 A.D. Several Landslides were triggered every year and we have specified our timelines of In-Situ precipitation data Over Satellite data.

We have Tabulated Landslides events with its details of Event number, Date of event,lanslides occurred district with it`s Latitude and Longitude .To clarify this we have Province number as well as the Landslides size and triggered by types of precipitation.

Table 1: Landslides Events details

Event no	Landslide Event Date	District	Province no.	Latitude in Degree and Minute (North-direction)	Longitude in Degree and Minute (East - direction)	Elevation(m)	Landslide size	Landslide trigger
Event 1	05 May 2012	Kaski	4	28.15	84.01	975	large	downpour
Event 2	18 June2013	Salyan	6	28.45	82.28	1338	large	rain
Event 3	02 August 2014	Kathmandu	3	27.77	85.43	1658	large	continuous_rain
Event 4	08 August 2014	Gorkha	4	28.23	84.87	550	medium	continuous_rain
Event 5	10 June 2015	TAPLEJUNG	1	27.55	87.79	1807	large	downpour
Event 6	11 June 2015	TAPLEJUNG	1	27.36	87.62	700	large	downpour
Event 7	29 June 2015	Bajura	7	29.50	81.67	1411	medium	continuous_rain
Event 8	05 July 2015	Lamjung	4	28.22	84.24	1430	medium	continuous_rain
Event 9	10 August 2015	Doti	7	29.34	81.05	2249	medium	continuous_rain
Event 10	11 August 2015	Doti	7	29.34	81.05	2249	medium	continuous_rain

4.2.1 Landslides occurred nearby Nirmal station (Event -1)

In year 2015 A. D ,landslides event was occurred within the latitude and longitude of 28° 15'N and 84° 01' E which nearby station is Nirmal Pokhari station located in Pokhara , Kaski district .It has an elevation of 975 meters(m) above the sea-level.

Table 2: Antecedent rainfall amount from In-Situ and Satellite (Event -1)

Date	In-Situ Precipitation Data(mm per day)	Satellite Precipitation Data(mm per day)
1 May 2012	0	0
2 May 2012	0	0
3 May 2012	0	9.1
4 May 2012	39	21.7
5 May 2012	39	22.1

Landslides event date was on 05 May 2012 A.D. Its size was large landslides which caused 72 fatality during that time.

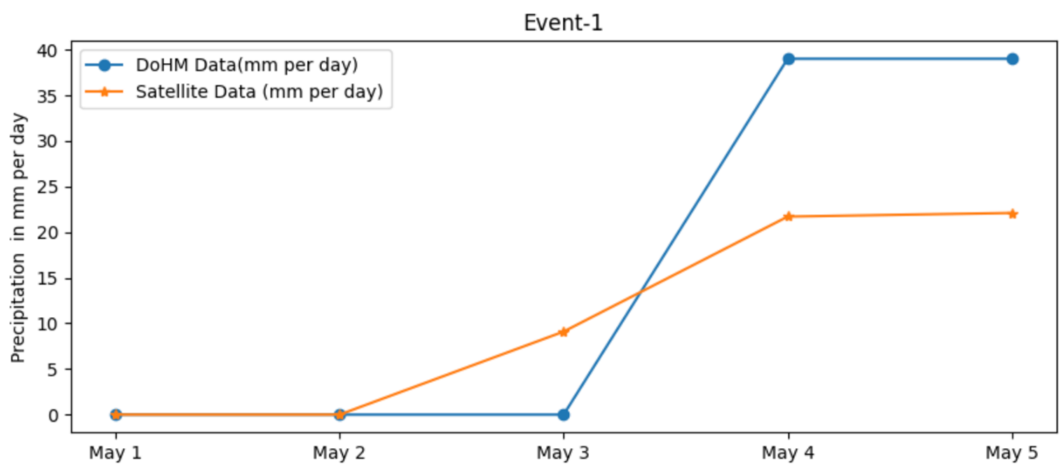

Figure 5: Five days accumulated rainfall pattern (Event -1)

In the month of May 2012 A.D landsides was triggered .To study about the landslides behavior we have taken date of 1 May to 5 May .During the first two days both In-Situ and Satellite recorded the same amount of precipitation data. In 3 May , Satellite precipitation amount data was above by 9.1 mm than In-Situ data. In 4 May ,In-Situ precipitation amount crosses the Satellite recorded precipitation by 17.3 mm more .In 5 May,that day when landslides was triggrered both precipitation amount recorded by In-Situ and Satellite was 39 mm and 13 mm respectively.

Figure 6: Landslides caused flood in Seti River

Source : Flash flood in Nepal kills at least 15, with up to 36 more missing

This image source showed that Landslides was occurred in Pokhara near seti river which caused losses of Human as well as animals life.

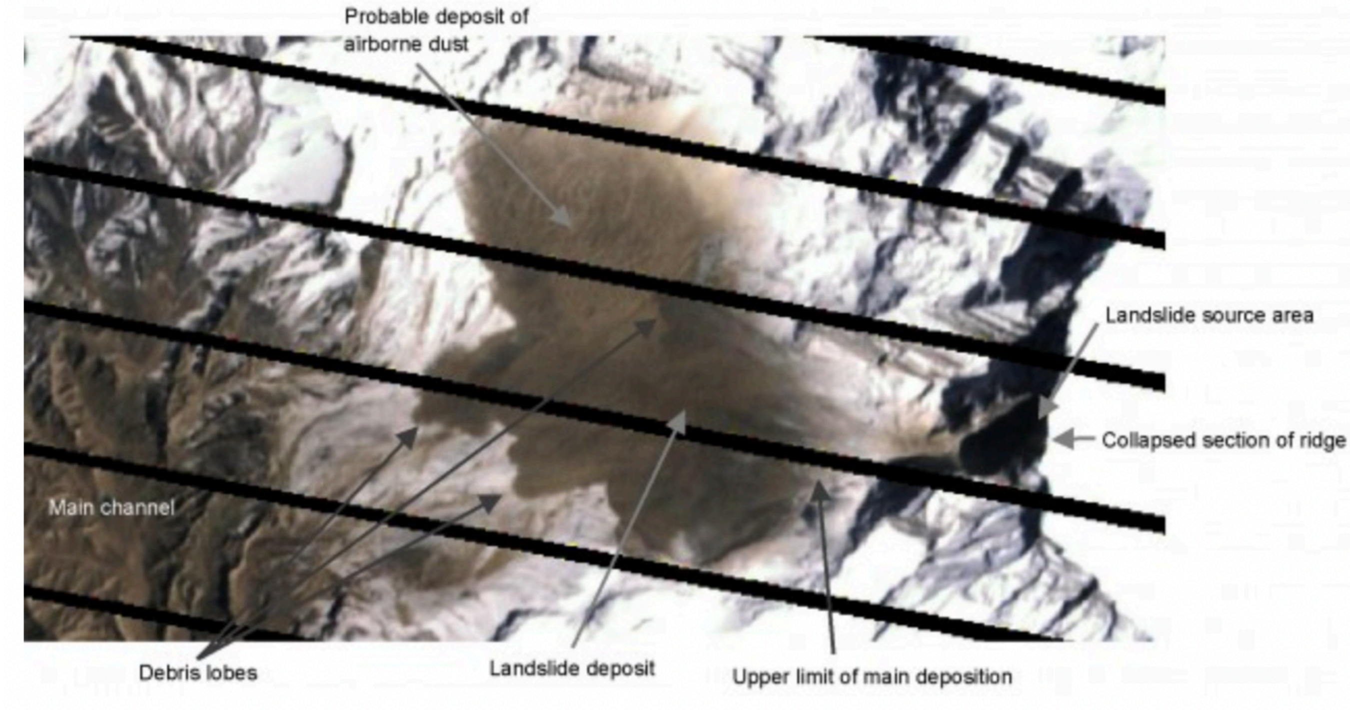

Figure 7: Landslides Event Occurred in 5 May 2012 A.D in Pokhara

Source: The Seti River landslide disaster in Nepal: two years on

From this source we can see that Landslides actual prone area .

4.2.2 Landslides occurred nearby Tharmare Station (Event -2)

In year 2013 A.D, Large size landslides was occurred in Salyan district which nearby station is Tharmare station located province number six of Nepal at latitude and longitude of 28° 45' N and 82° 28' E respectively. It has an elevation of 1338 m high above the sea-level.

Table 3: Antecedent rainfall amount from In-Situ and Satellite (Event -2)

Date	In-Situ Precipitation Data(mm per day)	Satellite Precipitation Data(mm per day)
14 June 2013	10.9	13.1
15 June 2013	39.3	13.4
16 June 2013	39.3	67.3
17 June 2013	76.5	154.3
18 June 2013	76.5	184.5

Landslides event was occurred in 18 June 2013 A.D.It was triggered by rain and caused injured two people on that spot and 28 familes has been displaced.

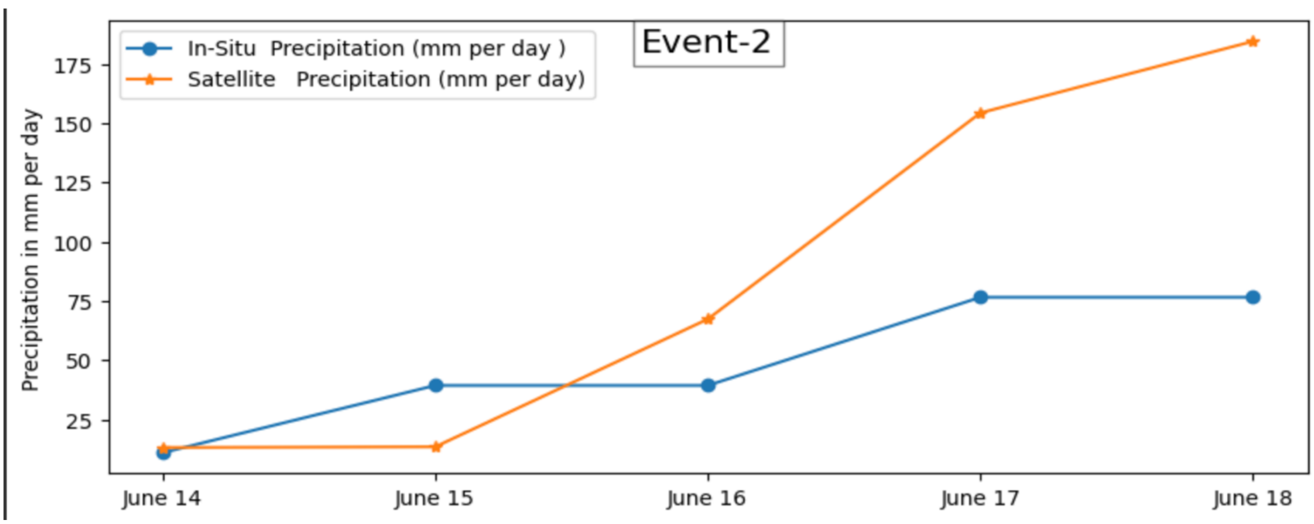

Figure 8: Five days accumulated rainfall pattern (Event -2)

In June 14, In-Situ and Satellite precipitation reading was close to each other. In next day the accumulated data of In-Situ data was 25.9 mm higher than the other. In June 16 to June

17 Satellite precipitation reading was in increased order of 28 mm,77.8 mm respectively to that of In-Situ. We can see during the Landslide Event precipitation reading difference was of 108 mm.

4.2.3 Landslides occurred nearby Sundarijal (Mulkharka) Station (Event -3)

In 2014 A.D, Continuous rainfall triggered landslides nearby Kathmandu Valley and Sundarijal Station within the latitude and longitude of 27° 77' N and 85° 43' E respectively. Landslides events was took placed at 1658 m high above the sea -level. Its size was large landslides above the river which caused death of 174 people and 52 was injured.

Table 4: Antecedent rainfall amount from In-Situ and Satellite (Event -3)

Date	In-Situ Precipitation Data(mm per day)	Satellite Precipitation Data(mm per day)
29 July 2014	18.7	17.4
30 July 2014	74.6	38.7
31 July 2014	95.3	45.1
1 August 2014	96	51.5
2 August 2014	96	58.9

Landslides event was occurred in 2 August 2014 in that day antecedent precipitation measurements from In-Situ and Satellite was 96 mm and 58.9 mm respectively.

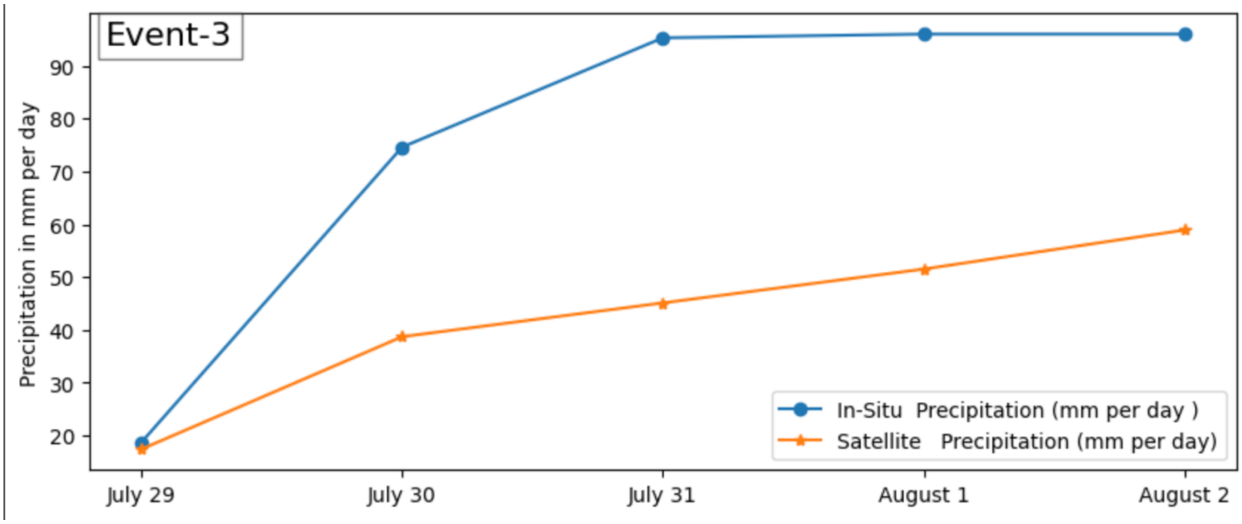

Figure 9: Five days accumulated rainfall pattern (Event -3)

In June 29, Satellite and In-Situ precipitation measurement have 1.3 mm of difference then on the next day that In -Situ data was observed 74.6 mm which have difference as near to twice of Satellite reading data. From July 29 to August 2 Satellite precipitation reading was below from the In-Situ reading. In the last two days In-Situ data was constant with 96 mm that means on the landslides triggered day there was no precipitation data from ground sides whereas satellite captured the difference of 7.4 mm of precipitation from the previous day.

4.2.4 Landslides occurred nearby Machhi Khola Station (Event -4)

In 8 August 2014 A.D, medium size landslides was triggered by continuous rain within the latitude and longitude of 28° 33' N and 84° 87' E with the elevation of 550 m above the sea-level.

Table 5: Antecedent rainfall amount from In-Situ and Satellite (Event -4)

Date	In-Situ Precipitation Data(mm per day)	Satellite Precipitation Data(mm per day)
4 August 2014	11.5	2.6
5 August 2014	54.4	10.6
6 August 2014	60.9	21.9
7 August 2014	71.9	40
8 August 2014	81.5	52.9

While comparing of In-situ precipitation and Satellite precipitation Data in the antecendt pattern of rainfall In-Situ data have highest amount of rainfall in each increasing days.

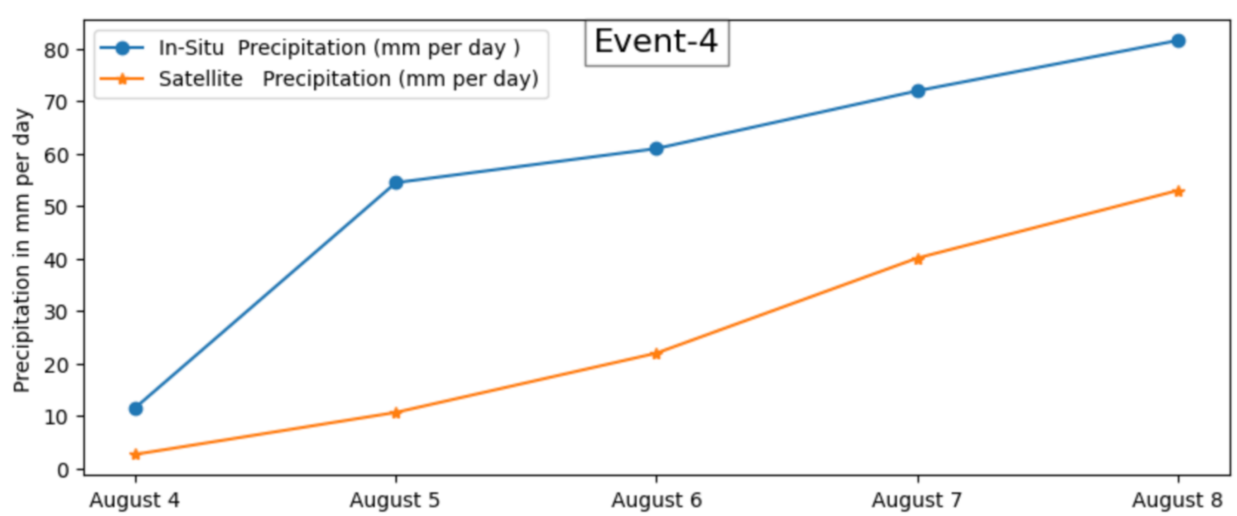

Figure 10: Five days accumulated rainfall pattern (Event -4)

In 4 August In-Situ and Satellite precipitation measured data was slightly difference of 8.9 mm .While moving towards 5 August it have the difference of 43.8 mm amount of rainfall from that day to 8 August we can see it was seems to be move like a parallel line having a difference in each days between them which are 39 mm,31.9 mm and 28.6 mm amount of precipitation per day.During the landslides incident day accumulated rainfall reading in satellite and In-Situ data are 52.9 mm and 81.5 mm .

4.2.5 Landslides occurred nearby Lungthung Station (Event -5)

In 10 June 2015 A. D, large size landslides was triggered by downpour in Taplejung district within the latitude and longitude of 27° 55' N and 87° 79' E in province number 1 of Nepal. It has an elevation of 1807 m above the sea–level.

Table 6: Antecedent rainfall amount from In-Situ and Satellite (Event -5)

Date	In-Situ Precipitation Data(mm per day)	Satellite Precipitation Data(mm per day)
6 June 2015	0.9	10.3
7 June 2015	18.3	10.8
8 June 2015	24.8	11
9 June 2015	40.7	15.8
10 June 2015	40.7	67.5

During Landslides event day 15 people was dead and no one was injured.

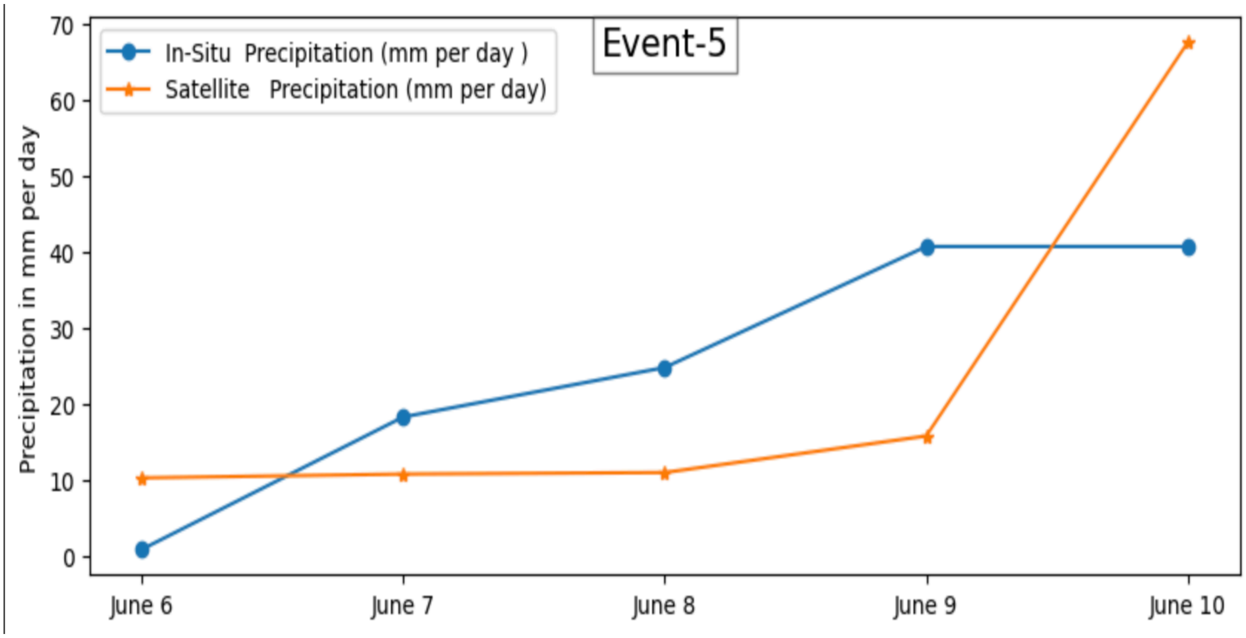

Figure 11 : Five days accumulated rainfall pattern (Event -5)

In above figure we can see that there was 9.4 mm precipitation difference between In-Situ and Satellite precipitation data reading. From the next day satellite recorded data was slowly increased whereas In-Situ data was above the satellite from 7 June to 9 June .When the landslides event was triggered there was a 26.8 mm amount of precipitation difference between the two source.

4.2.6 Landslides occurred nearby Lungthung Station (Event -6)

In 11 June 2015, large size landslides was triggered by downpour which land setting was natural slope lies in Taplejung district within the latitude and longitude of 27° 36' N and 87° 62' E.It has an elevation of 700 m above the sea – level.

Table 7: Antecedent rainfall amount from In-Situ and Satellite (Event -6)

Date	In-Situ Precipitation Data(mm per day)	Satellite Precipitation Data(mm per day)
7 June 2015	9.8	8.6
8 June 2015	20.8	11.1
9 June 2015	26.7	11.2
10 June 2015	36.4	47.8
11 June 2015	47.2	98.7

During the landslides event 88 people are dead and 8 more people are injured.

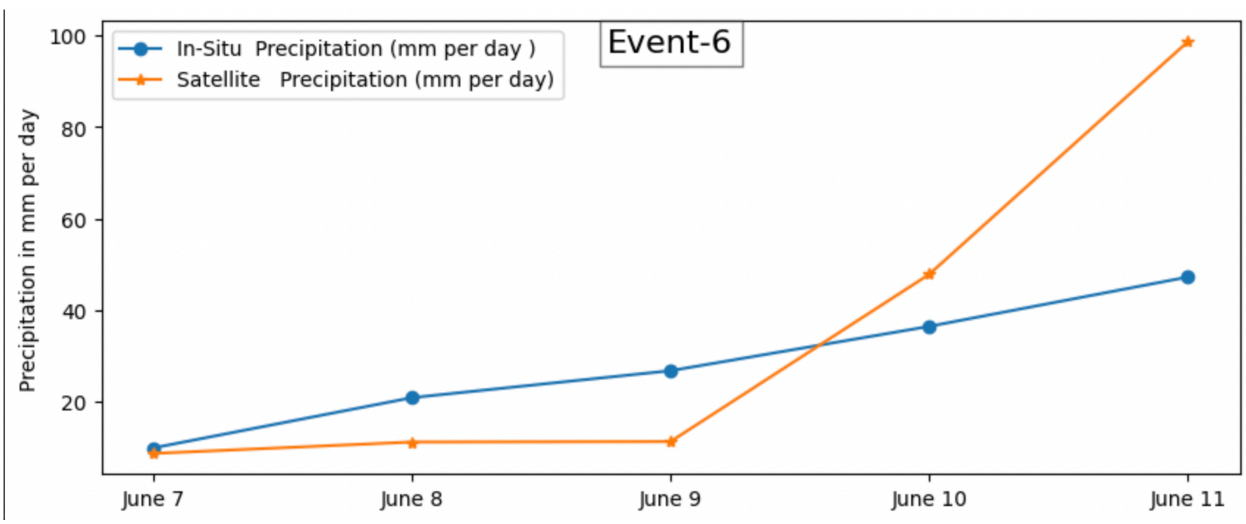

Figure 12: Five days accumulated rainfall pattern (Event -6)

In 7 June 2015, both In-Situ and satellite precipitation amount have a difference of 1.2 mm.Later that day,In-Situ precipitation reading are high till June 9 compare to satellite .After that in 10 June both reading have a difference of 11.4 mm amount of precipitation .Final date was the landslides event date at that time Satellite reading was double that of In-Situ.

4.2.7 Landslides occurred nearby Kolti Airport Station (Event -7)

In 29 June 2015, medium size landslides was triggered by continuous rain in Bajura district within the latitude and longitude of 29° 50’ N and 81° 67' E nearby Kolti Airport .It has an elevation of 1411 m above the sea-level.

Table 8: Antecedent rainfall amount from In-Situ and Satellite (Event -7)

Date	In-Situ Precipitation Data(mm per day)	Satellite Precipitation Data(mm per day)
25 June 2015	4.2	82.1
26 June 2015	37.7	84
27 June 2015	80.7	96.2
28 June 2015	120.9	123.2
29 June 2015	128.3	124

During the landslides in 29 June, it harmed the public property as well as government hospital.

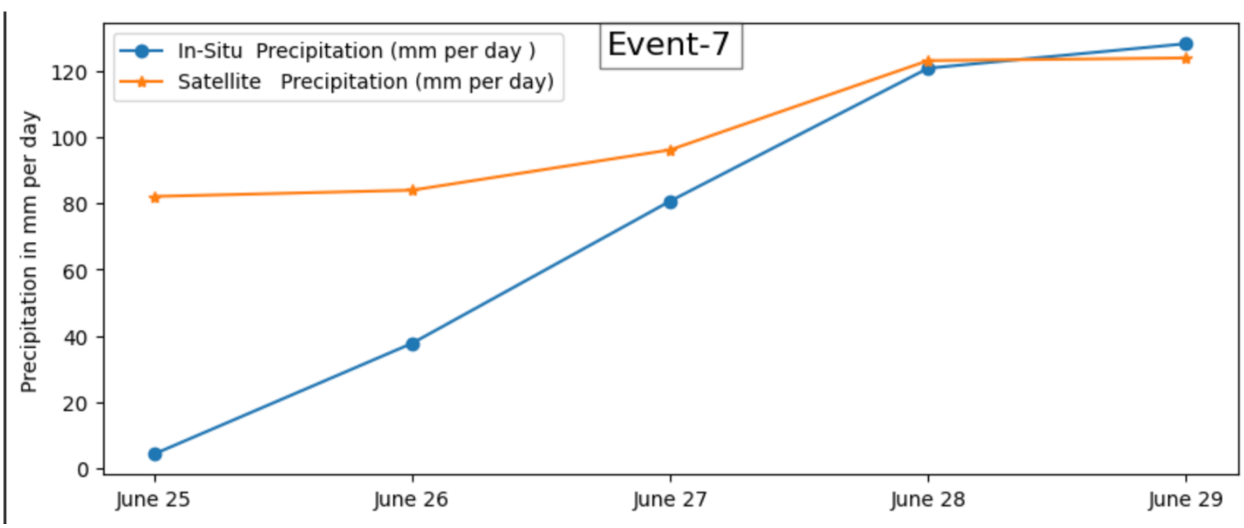

Figure 13: Five days accumulated rainfall pattern (Event -7)

In 25 June 2015, In-Situ and Satellite data have a very high difference of 77.9 mm amount of precipitation. Accumulated In-Situ precipitation data was increased towards the Satellite data.In 28 June they have a slightly difference of 2.3 mm of rainfall while in landslides event day it has a difference of 4.3 mm of precipitation.

4.2.8 Landslides occurred nearby Gilung Station (Event -8)

In 05 July 2015, medium size Landslides was triggered by continuous rain in Lamjung district within the latitude and longitude of 28° 22’ N and 84° 24' E with the elevation of 1430 m above the sea-level.

Table 9: Antecedent rainfall amount from In-Situ and Satellite (Event -8)

Date	In-Situ Precipitation Data(mm per day)	Satellite Precipitation Data(mm per day)
1 July 2015	33	3.1
2 July 2015	39.2	10.3
3 July 2015	79.2	24.4
4 July 2015	119.2	47.1
5 July 2015	132.2	52.3

During the landslides events 200 people from 21 families have been displaced .

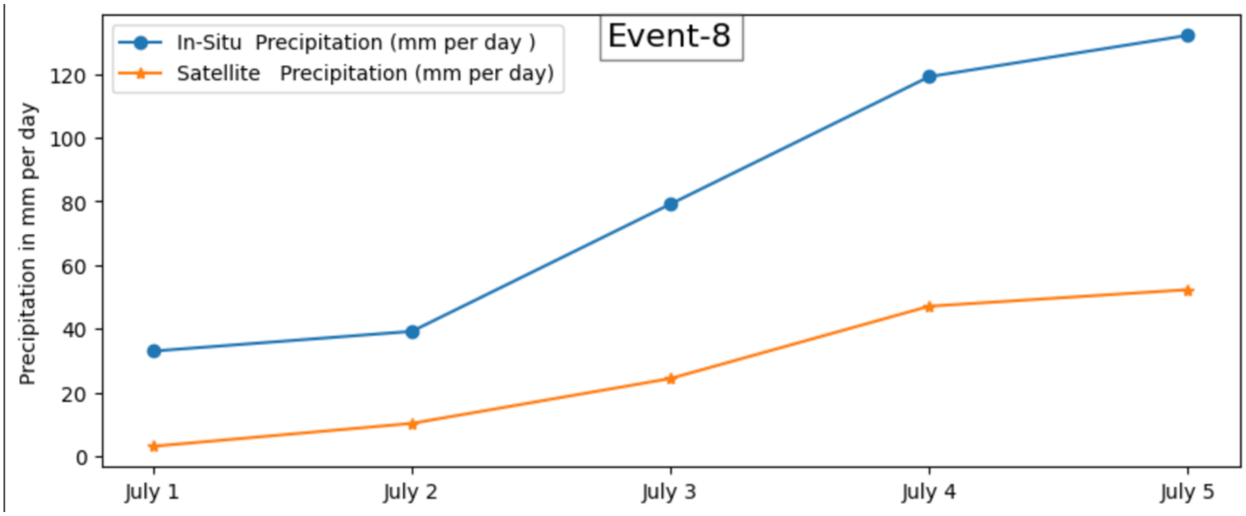

Figure 14 : Five days accumulated rainfall pattern (Event -8)

In 1 July 2015, satellite and In-Situ precipitation have the difference of 29.9 mm of rainfall reading. From start to end accumulated rainfall In-Situ precipitation are above the satellite precipitation. Next day 28.9 mm of precipitation difference was observed between two data sets.At the landslides event day In-Situ measured 132.2 mm and 52.3 mm amount of precipitation .

4.2.9 Landslides occurred nearby Jhingrana Station (Event -9 and Event -10)

In 10 and 11 August 2015, medium size landslide was triggered by a continuous rain in Doti district within the latitude and longitude of 28° 22’ N and 84° 24' E with the elevation of 1430 m above the sea-level.

Table 10: Antecedent rainfall amount from In-Situ and Satellite (Event -9)

Date	In-Situ Precipitation Data(mm per day)	Satellite Precipitation Data(mm per day)
6 Aug 2015	3.1	0.6
7 Aug 2015	28.3	26.1
8 Aug 2015	43.3	30.5
9 Aug 2015	83.5	66
10 Aug 2015	128.7	119.9

During the landslides event in 10 Aug 2015, five people were killed and one was injured.

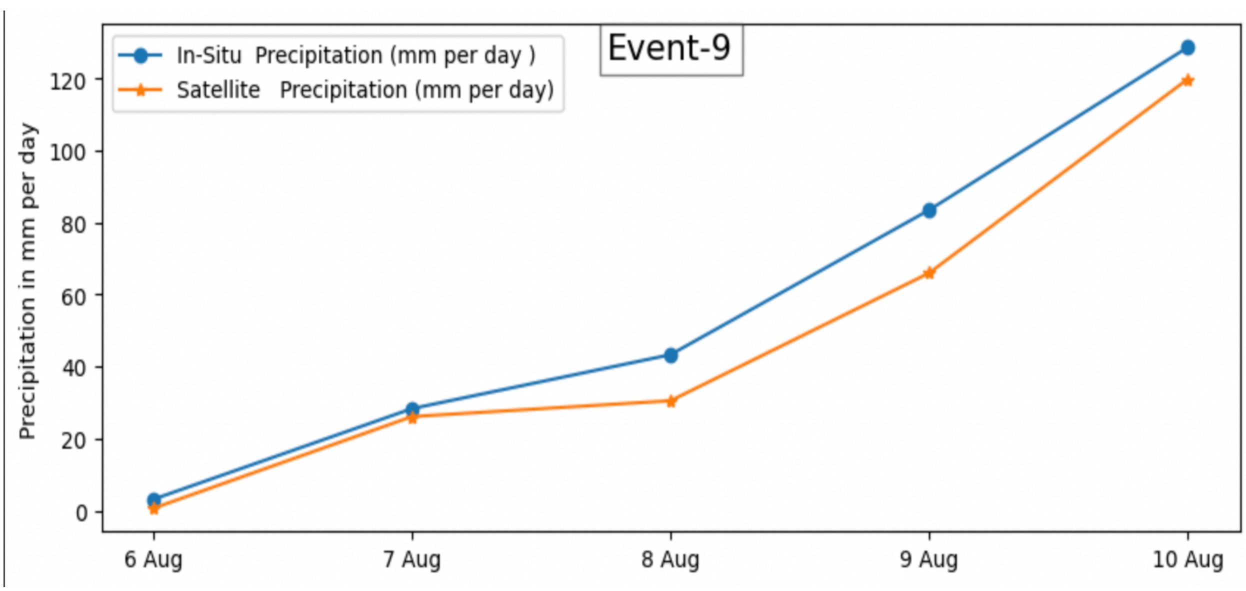

Figure 15: Five days accumulated rainfall pattern (Event -9)

Since the data was taken as a accumulated rainfall In-Situ precipitation measured or move above the satellite precipitation data. In 6 Aug and 7 Aug 2015 both In-Situ and satellite precipitation was moved in similar pattern. In 8 Aug they have a difference of 12.8 mm of precipitation. In next day they have a difference of 17.5 mm and during the landslide triggered event date it have a difference of 8.8 mm amount of precipitation.

Table 11: Antecedent rainfall amount from In-Situ and Satellite (Event -10)

Date	In-Situ Precipitation Data(mm per day)	Satellite Precipitation Data(mm per day)
7 Aug 2015	25.2	25.5
8 Aug 2015	40.2	29.9
9 Aug 2015	80.4	65.4
10 Aug 2015	125.6	119.3
11 Aug 2015	173.8	146.1

During the Landslide event in 11 Aug 2015 one people was killed by a landslide.

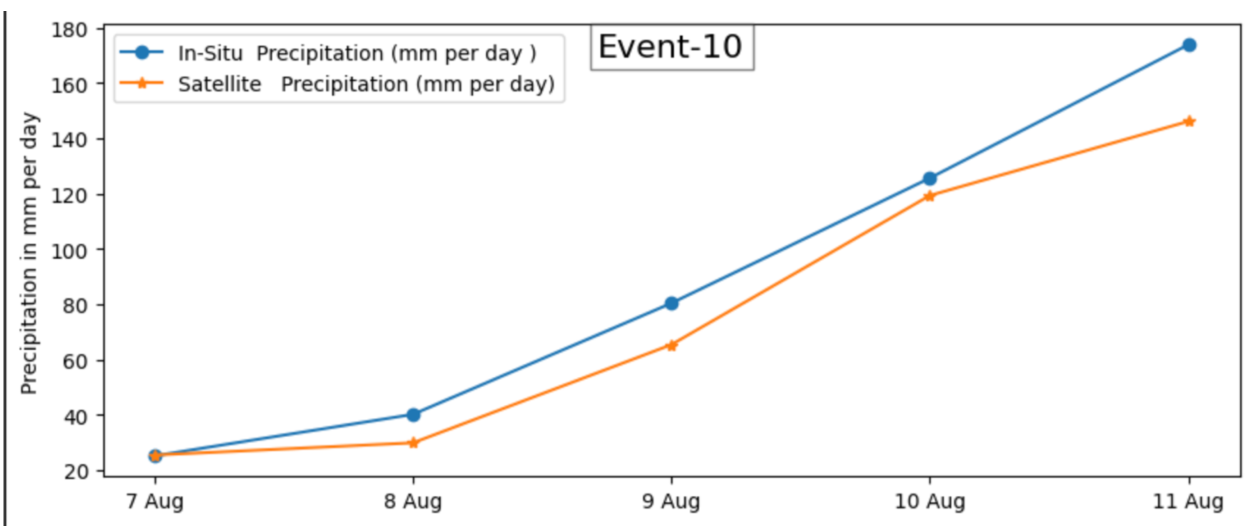

Figure 16: Five days accumulated rainfall pattern (Event -10)

In 7 Aug 2015 both In-Situ and Satellite precipitation data was near to each other. In 8 and 9 Aug they have a difference of 12.8 mm and 17.5 mm of precipitation amount. Next day they have a difference of 6.3 mm of precipitation amount. During the Landslides event day they have a precipitation measurements of 173.8 mm and 146.1 mm amount of precipitation.

CHAPTER 5

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusions

Through our course of study, we found that the continuous rain can cause landslides, especially in areas with steep terrain and specific geological features. Rain that falls for a lengthy period of time saturates the soil, diminishing its cohesiveness and stability. The weight of the soil rises when it becomes wet, putting additional strain on slopes and hillsides. Water also works as a lubricant, decreasing friction between soil and rock particles and allowing the material to flow down slopes more easily. Furthermore, constant rain can induce erosion at the base of slopes, weakening soil and rock stability and eventually leading to landslides.

As a result, monitoring rainfall and soil moisture in landslide-prone areas is critical for anticipating and reducing possible landslide hazards, as landslides can have serious effects, including property damage, loss of life, and interruptions to transportation and infrastructure.

5.2. Novelty and National Prosperity aspect of project work

Assessing the impact of rainfall-induced landslides on an area may provide both novelty and contribute to national development. This project can stand out in terms of uniqueness by utilising cutting-edge technology and new techniques. Using modern remote sensing techniques like LiDAR and satellite images, for example, can give a more thorough and precise evaluation of landslide-prone locations. By combining these data sources with machine learning algorithms for landslide prediction and early warning systems, a unique way to reducing the disastrous impacts of landslides can be developed. Incorporating climate change forecasts into the research, which investigates how altering rainfall patterns may worsen landslip hazards, adds a forward-thinking and novel component to the project.

This initiative can make a major contribution to national prosperity by addressing a fundamental facet of catastrophe resilience. The economic effect of rainfall-induced landslides may be significant, including infrastructure damage, transportation network interruptions, and agricultural losses. By estimating these economic losses, the study can help policymakers and urban planners prioritise mitigation actions. Proposing infrastructure resilience methods, such as enhanced building standards and land use planning, can also protect critical national assets. This initiative can eventually boost national economy by encouraging stability, preserving investments, and strengthening the resilience of communities confronting landslip threats. With its originality and ability to contribute to national prosperity, a project focusing on the evaluation of rainfall-induced landslides can play a critical role in protecting both lives and economic well-being.

5.3. Limitations of the work

While analysing rainfall-induced landslides is obviously important, it is also critical to recognise the limits of such initiatives. The intricacy of landslip mechanisms is one key restriction. Numerous factors impact rainfall-induced landslides, including soil type, slope angle, plant cover, and antecedent rainfall conditions. It might be difficult to adequately capture all of these characteristics in models or evaluations. Furthermore, the particular triggers and thresholds for landslides might differ from location to region, making a one-size-fits-all solution challenging to build. As a result, any initiative in this subject may encounter constraints in the generalizability of its results and suggestions.

Second, data availability and quality might be significant constraints. Rainfall-induced landslides frequently occur in remote or inaccessible places, making data collecting and monitoring difficult logistically. Furthermore, previous landslip data may be insufficient or incorrect, making it difficult to create accurate forecast models. Obtaining real-time rainfall data with great geographical and temporal precision may also be expensive and need specialised infrastructure. These data constraints may have an impact on the project's capacity to develop exact forecasts and generate dependable early warning systems, thus lowering its efficacy in landslip risk reduction. Addressing these constraints through improved data collecting and modelling methodologies is critical to the success of any project involving rainfall-induced landslides.

5.4. Recommendation for further work

To begin, it is critical to concentrate on regional and site-specific analyses. While the study may initially give a broad overview of landslip susceptibility and dangers, delving further into specific places that are particularly vulnerable would be advantageous. In-depth case studies in areas with a history of frequent rainfall-induced landslides might provide useful information. To understand the specific causes leading to landslides in each place, these case studies should involve extensive geological, hydrological, and climatic investigations. The project can have a greater impact on lowering landslip risks and their consequences by customising mitigation measures and early warning systems to the unique characteristics of these locations.

Second, the initiative should go deeper into multidisciplinary cooperation and community participation. Collaborating with professionals in social sciences, disaster management, and local communities can help to create holistic ways to reducing landslip risk. Local communities participating in data collecting, risk awareness, and preparedness measures can improve the effectiveness of early warning systems and resilience-building efforts. Involving stakeholders from diverse sectors, such as government agencies, non-governmental organisations, and private businesses, may also develop a more comprehensive and long-term strategy to tackling landslip concerns. The initiative may contribute more significantly to national prosperity and community resilience in landslide-prone regions by broadening its scope and incorporating a larger variety of stakeholders.

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APPENDIX