Observed Precipitation Patterns of Flash Floods in Hindu Kush Himalaya and Swiss Alps

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ABSTRACT

Flash floods occurred in the Hindu Kush Himalaya and in the Swiss Alps. It damaged the infrastructure, human habitats and landscapes. This research observed that flash floods often followed by the high precipitation of several days before the day of the flash flood occurred in the mountain regions. The objective of this research is an attempt to detect satellite based daily precipitation signals in the cryosphere zone and human habitat zone of the mountainous regions. The Integrated Multi-satellitE Retrievals for Global Precipitation Measurement (IMERG), is a unified satellite precipitation product produced by National Aeronautics and Space Administration (NASA) to estimate surface precipitation over most of the globe. The daily observed precipitation data is downloaded and calculate the daily mean and daily maximum precipitation of each watershed or sub watershed or district over the Hindu Kush Himalaya and Switzerland. The number of days that received above the threshold daily mean and maximum precipitations were categorized in the attribute tables of each watershed or sub watershed or district, as the preliminary flash flood risk maps. Furthermore, the time series observed daily precipitation signals or graphs were plotted for selected watershed or sub watershed or district which have received high mean precipitation and maximum precipitation. The time series signals, and preliminary risk maps jointly indicated that flash floods do not occur suddenly. It requires certain days to set the stage for flood events in future. Therefore, it could provide enough time to inform the forewarning to the people and infrastructure operators such as hydroelectric dams to endure the flash floods with minimal damage, to save lives and infrastructures. Python programming language and ArcGIS Pro software are applied in this research. This research attempts to contribute to saving lives and infrastructures from the flash floods using remotely sensed estimated daily precipitation data from the IMERG satellites.

Keywords: floods, flash floods, precipitations, observations

1. Introduction

Flash floods are characterized by an intense, high velocity torrent of water. They are triggered by torrential rain falling within a short amount of time within the vicinity or on nearby elevated terrain. Flash floods can also be caused by a sudden release of water from an upstream levee or a dam. They can be very dangerous and destructive, not only because of the force of the water, but also the hurtling debris that is often swept up in the flow. Annual floodings of alluvial landforms has created several problems. When flood water overflows onto floodplains, deposited sediment often obscured property and field boundaries and poor, sandy soils on top of previously productive fields of silt-loam.

In the first week of June 2024, the Lake Constance, the Rhine and the Reuss caused local floodings on the Maschewander Allemend in the cantons of Zug and Zurich, **Switzerland**. Due to the heavy rainfall on 9 and 10 June 2024, in addition to Lake Constance, there was flooding on Lake Zurich and lake Lucerne and their outflows. On 21 June2024, persistent heavy rainfall in the Alpine region and in the Jura Mountains – reaching 125 mm of rain fell within 24 hours in the Grisons Mountain valley of Valle Mesolcina. Rhine river continued to cause the water level of Lake Constance to rise again. Zermatt town, Val d'Anniviers and highway between Sierre and Sion in valley canton suffered from the floods and discharges due to the persistent heavy rainfall. On 25 and 26 June of 2024, the heavy rainfall moved to southwestern part of Switzerland, flood occurred in Liestel town in Basel-Landschaft canton and Morges town in Vaud canton. Geneva airspace was temporarily closed.

The Hindu Kush Himalaya suffered flashfloods during the Monsoon season from June to October annually while Switzerland was passing her summer months. On July 6 of 2024, Kathmandu, **Nepal** suffered flash flood after the torrential rains which led to the flood of Bagmati River. On August 10 of 2024, flash flood occurred at Dechencholing, Thimphu, capital city of **Bhutan**. Heavy rainfall during 2024 monsoon season resulted in severe flooding and landslides across several regions of **India**. In June 2024, Karimganj, Darrang and Tamulpur districts in India being worst hit by the floods. Severe flooding also occurred in Sikkim and Meghalaya. People in villages in Utter Pradesh state in India impacted by the flash flood on 11-12 July 2024. From 27 June to 16 August 2024, landslides and flooding occurred in Himachal Pradesh. In July 2024, the landslides were caused by heavy rains in Wayanad district, Kerala districts in India. Floos in Tripura on 19 August 2024 damaged households and injured the people. Several parts of Gujarat were flooded during - 25 August to 2 September 2024 due to the heavy rains. On July 29, 2024, heavy rainfall triggered floods in Bago city in Bago township, Taikkyi township and Kungyangon townships in **Myanmar**. Myitkyina, Waingmaw, Bhamo, Mogaung, Hpakhant and Hkamati townships of Myanmar were flooded by the prolonged heavy rainfall since the last week of June 2024 until 2 July 2024. In August

2024, flash floods impacted the townships of Namsang, Kholam, Kunshing, Mongnai, Langkho (Linkhay), and Mong Pan in southern Shan state, and Tachileik township in eastern Shan state of Myanmar. Due to the heavy rain which triggered the flooding between 20 and 25 June 2024 in the North-East regions of Bangladesh, Sylhet and Sunamganj districts of **Bangladesh**. Sylhet, Sunamganj, Moulvibazar, Habiganj, Kishoreganj, and Netrokona districts suffered severely. Around June 19th, 2024, Lalmonirhat, Kurigram, Gaibandha, Bogura, Sirajganj, Jamalpur, Tangail, and Munshiganj districts suffered flooding severely due to continuous rainfall and upstream water flow. Pakistan experienced continued floods due to heavy rainfall from April 12-28, primarily affecting Khyber Pakhtunkhwa (KP) and Balochistan provinces of **Pakistan**. Peshawa, Pakistan was flooded on 15 April 2024. Pakistan and Afghanistan received rainfalls in March and April, earlier than other Himalayan country. On 16 April 2024, houses submerged after heavy rains flood Nowshera district, Khyber Pakhtunkhwa province in **Afghanistan**. On 17 and 18 May 2024, heavy rains in the Northern and Western Regions of Afghanistan caused further flooding incidents, affecting Faryab Provinces in the Northern Region, and Ghor, Herat, Badghis, and Farah Provinces of Western Region. In April 2024, heavy rains caused floods in Guangdong Province in **China**. Jiangxi province in China was flooded on July 5, 2024, after following the days of heavy rainfall. According to the report of Give2Asia, Statistics show that the current rainfall in **southern China** is characterized by its high intensity, concentration, sustained duration, and widespread impact, affecting 12 provinces including Guangxi, Guangdong, Guizhou, Jiangxi, Hunan, Fujian, Sichuan, Chongqing, Hubei, Henan, Shandong, and Zhejiang.

1.1 Motivation and Assumptions

It is evident that floods occurred frequently in the Hindu Kush Himalaya (HKH) countries in the monsoon season in India, Nepal, China, Bhutan, Myanmar, Bangladesh and pre-monsoon season in Pakistan and Afghanistan. Although the HKH is fragile due to the topography and geology, the acute weather changes that activate the (acute) rainfall is one of the factors that trigger the flash floods and landslides. While studying the HKH, the Switzerland (the Swiss Alps and the Swiss Jura) is undergoing through the flash floods in the Swiss summer following the days of heavy rainfall. Similar high precipitation pattern is assumed to be the major factor that initiate the flash floods and landslides in Swiss Alps, Swiss Jura and Himalaya. It is also assumed that high rainfall for several days continuously or frequently activates flash floods or landslides - several days before the actual events occur.

It is motivated to observe and process the daily rainfall pattern (mean and maximum) from IMERG NASA Satellites over hydrographic regions of Switzerland and the districts of India, China, Bangladesh, Afghanistan, Nepal, Pakistan, Gewogs of Bhutan and townships of Myanmar to detect the possible signals or patterns of precipitation before flash or landslides occurred.

It is also motivated to explore the applicability of satellite based observed data instead of meteorological station data to study the flash floods and landslides as data access is an issue in the HKH region.

2. Data sources

The daily mean precipitations and maximum precipitations were derived using constellation of NASA IMERG satellites - daily late run liquid data. The detail information and algorithm of the IMERG datasets could be found at https://gpm.nasa.gov/data/imerg. Districts of Switzerland data is downloaded from https://www.swisstopo.admin.ch/en/landscape-model-swissboundaries3d. Country boundaries of HKH countries was downloaded from the Regional Database System of ICIMOD at https://rds.icimod.org/. The districts of India, Pakistan, China, Afghanistan and Bangladesh are downloaded from the Humanitarian Data eXchange (HDX) at https://data.humdata.org/dataset/. The townships boundary of Myanmar was downloaded from the Myanmar Information management Unit (MIMU) at https://www.themimu.info/. The Gewogs boundary of Bhutan was downloaded from the Regional Database System of ICIMOD at https://rds.icimod.org/. These national and sub-national boundaries are only for the cartographic presentation purpose and to populate the precipitation data within these polygon boundaries to derive summary statistics.

The IMERG precipitation data are available for 30-minute, 3-hour, 1-day, 3-day and 7-day files, and 1-month files from https://gpm.nasa.gov/data/imerg as the Tiff and NetCDF file formats. The research downloaded the daily late run tiff files for each month of selected year from https://jsimpsonhttps.pps.eosdis.nasa.gov/imerg/gis/. Precipitation values are scaled by the IMERG team - a factor of x10 (0.1mm) for 30-minute, 3-hour, 1-day, 3-day and 7-day files, and are scaled by a factor of x1 (1mm) for 1-month files. **It is important to note that the pixel values are not rescaled to preserve the original values of the IMERG 1-day data in this research study.** When reading the profile charts, the readers should divide the y-axis precipitation values in **mm of IMERG** by 10 to get the estimated precipitation in mm of meteorological station.

3. Rainfall Classification

This paper adapted the rainfall classification: Intensity of Rainfall in 24 hours of Weather and Climate Services Division of Royal Government of Bhutan and relate it to the IMERG precipitation values of pixels.

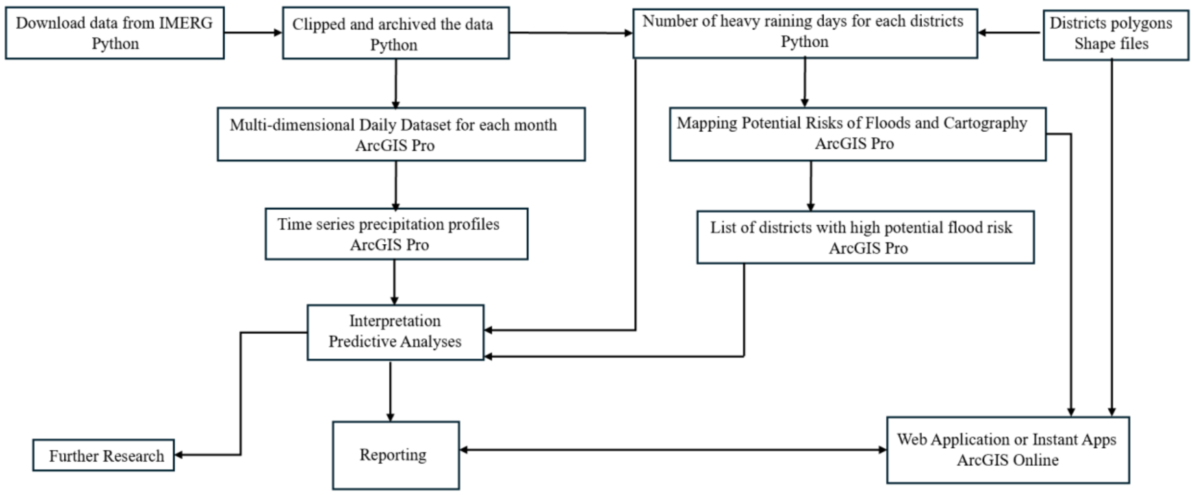
Term	Definitions	IMERG mm value
No rain	Rainfall amount realized in a day is 0.00 mm	0 mm
Very light rain	Rainfall amount realized in a day is between 0.1 to 0.9 mm	1 – 9 mm (>0 - <=9)
Light rain	Rainfall amount realized in a day is between 1.0 to 0 10 mm	10 – 100 mm (>10 - <=100)
Moderate rain	Rainfall amount realized in a day is between 11 to 30 mm	110 – 300 mm (>100 - <= 300)
Heavy rain	Rainfall amount realized in a day is between 31 to 70 mm	310 – 700 mm (>300 - <= 700)
Very heavy rain	Rainfall amount realized in a day is between 71 to 150 mm	710 – 1500 mm (> 500 - <= 1500)
Extremely heavy rain	Rainfall amount realized in a day is equal or more than 151 mm	>1510 mm

https://www.nchm.gov.bt/attachment/ckfinder/userfiles/files/Rainfall%20intensity%20classification.pdf

4. Tools and Methodology

Python programing language, ArcGIS Pro and ArcGIS online are the tools for data downloading, data preparation, data visualizing, creating multidimensional monthly datasets, charting precipitation profiles of selected months for the selected districts, predictive data analyses, data processing, data presentation and sharing information as web application or instant Apps in this study.

Figure-1 outlines the methodology workflow.



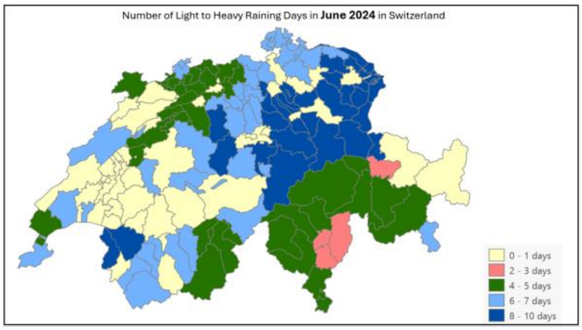
The daily precipitation data are downloaded and clipped over Switzerland and the HKH by the Python codes. The total number of days that exceed the mean daily rainfall of more than 100 **IMERG mm** (light rain) and total number of days that exceeded maximum daily rainfall of more than 300 **IMERG mm (**moderate and heavier rains**)** are derived by the python codes for each district. The higher the number of days in the near past indicates the higher the potential risks of flash flood or landslide at the present and future soon. The list of total number of heavy rainfall days for each district based on mean daily rainfall and maximum daily rainfall is reported by using the Python code. The potential flood risk to each district is presented as the choropleth map by joining the list from the Python with the districts shape files of Switzerland and Hindu Kush Himalayan countries in ArcGIS Pro to visualize the potential flood risks across the HKH or Switzerland.

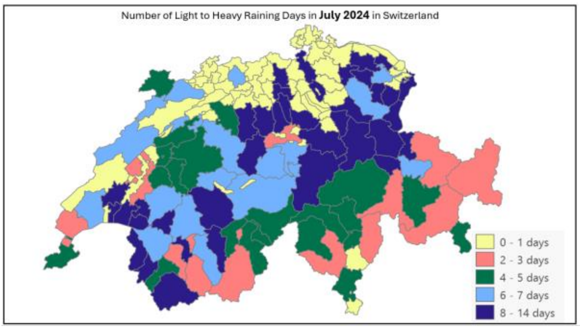
The multidimensional data set of daily rainfall is created for - weekly or biweekly or monthly to each month in ArcGIS Pro. Then, plot the temporal profile of daily rainfall (mean and maximum) patterns to observe the signals for near future events of flashfloods and landslides within an area, or region or point of interest.

Both potential risk maps and pattern graphs reveal the potential risks of flash floods or landslides in the future-soon based on the recent past patterns. The local governance, operators of hydroelectric dams, insurance of infrastructure and most importantly people who are living in these districts, townships or gewogs could be alert and prepare for the worse case.

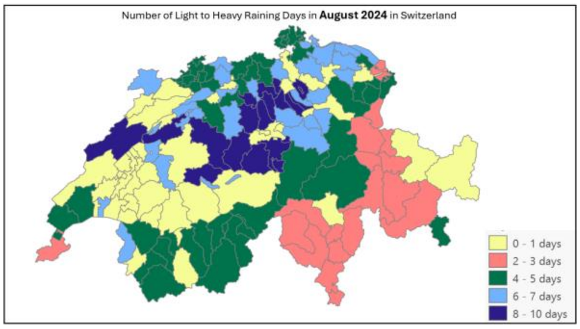
5. Results and Discussions

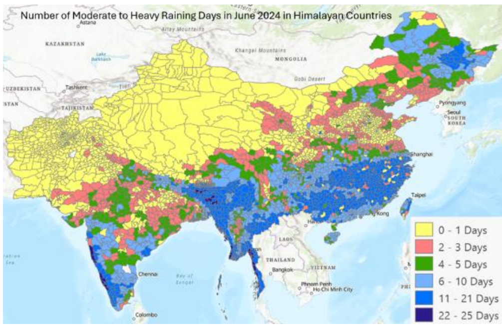
Potential flash flood risks of the districts of Switzerland and Hindu Kush Himalayan (HKH) countries in June, July and August 2024 based on the total number of light to moderate to heavier raining days are derived. The higher the total number of days, the higher the risks of flash floods in each district. Light blue and dark blue colored districts receive more number of days of light to heavy rain each month so that these have higher risks of floods.



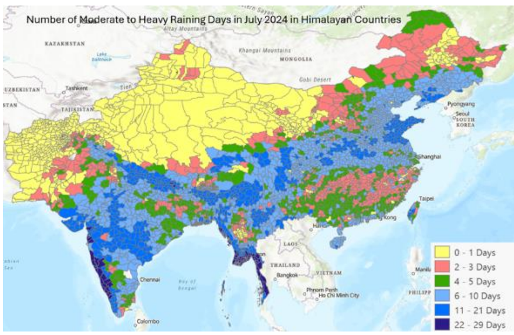


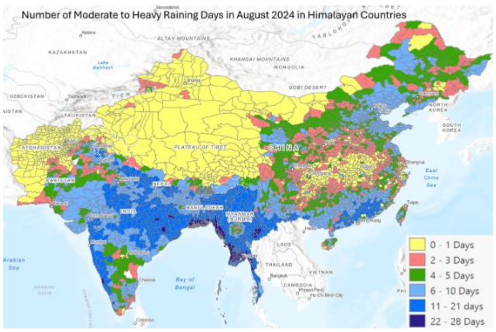
Raining days in in June and July 2024 in Switzerland





Raining days in August 2024 in Switzerland and June 2024 in HKH

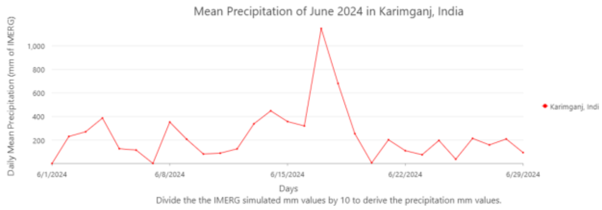


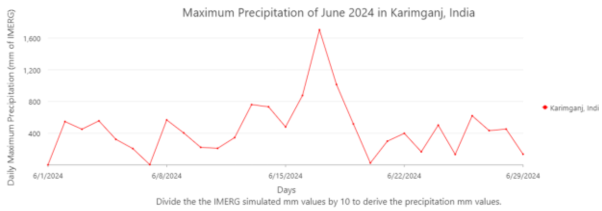


Raining days in July and August 2024 in HKH

The temporal precipitation profiles of high-risk districts (light blue and dark blue) should be generated and monitored on a day-by-day basis by the analyst or by a smart algorithm. Actual flash floods events were validated with the potential risk map. The temporal precipitation profiles of some districts where flash flood occurred in June, July and August are presented below as an example profiles. **These profiles are based solely on satellite data observations instead of meteorological station data**.

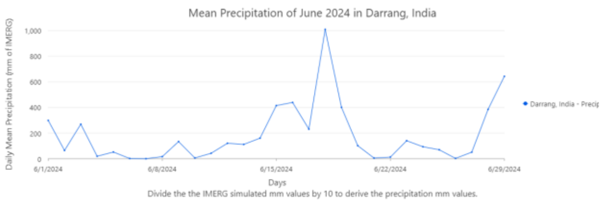
5.1 Karimganj district in India in June 2024

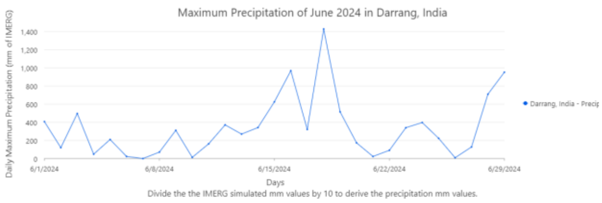




Karimganj district in India - received moderate and high rainfall from 40 mm to more than 100 mm daily mean rainfall for several days prior to the actual flash flood events. The temporal profile could be (should be) generated during the monsoon season for day-today basis and monitored by the concerned agencies.

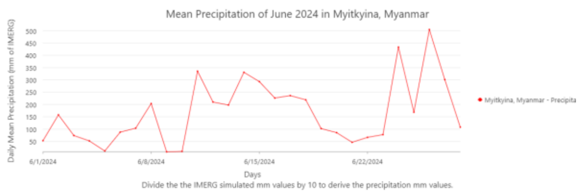
5.2 Danage district of India in June 2024

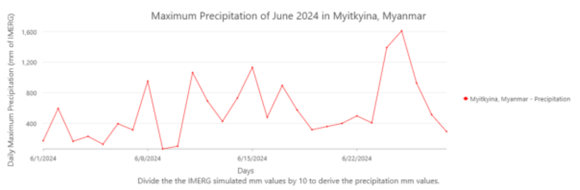




Danage district of India have received 30 mm to 140 mm rainfall for several days prior to the actual flash floods. The Y-axis values of the temporal precipitation profile are IMERG simulated mm values. It is necessary to divide by 10 to estimate the precipitation measurement similar at the meteorological station.

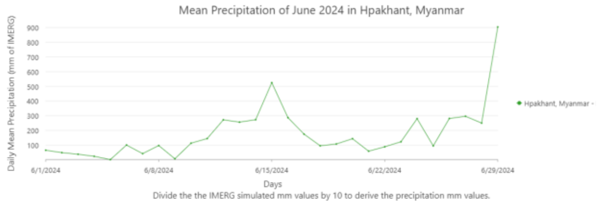
5.3 Myitkyina Township of Myanmar in June 2024

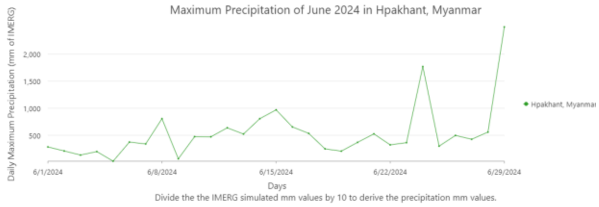




Myitkyina Township of Myanmar where two tributaries meet to create the Irrawaddy River in Myanmar. Myitkyina district received light to moderate to very high rainfalls for several days since the first week of June 2024, before the actual flash occurred. Such flash events should be able to be predicted by monitoring

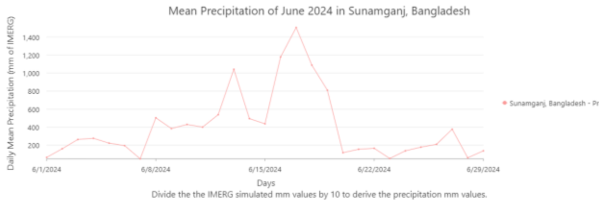
5.4 Hpakhant District in Myanmar in June 2024

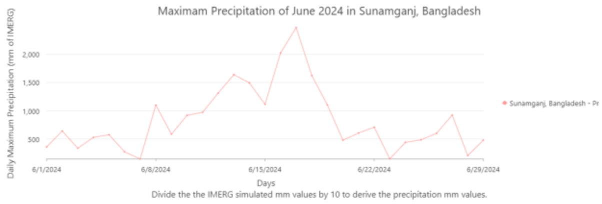




Hpakhant township is the source of jade mining in Myanmar. Since the beginning of the second week of June 2024, 50 mm to 200 mm range of precipitation have been received before the actual flash flood occurred. It is observed that flash flood occurred the day after the day which received very high rainfall.

5.5 Sunamganj District of India in June 2024

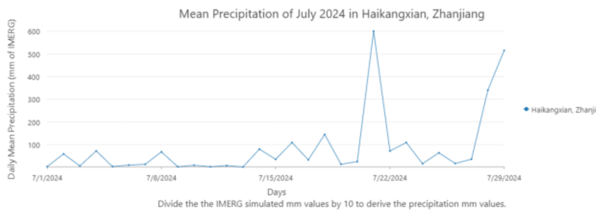


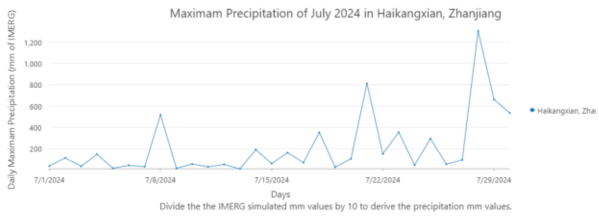


Sunamganj District of India received 50 mm to 200 + mm daily precipitation within two weeks starting from 8 June 2024 before the actual flash flood occurred. Such flash flood should be predictable by creating precipitation profile of past 14 days to 30 days from the present day by the team of analysts or by the smart algorithm.

Rainfall shifts the patterns throughout HKH comparing the June 2024 and July 2024. Although there seems not much rainfall in June in Pakistan, more rainfall appeared in Pakistan in July. Southern China received more rainfall in June 2024 than July 2024.

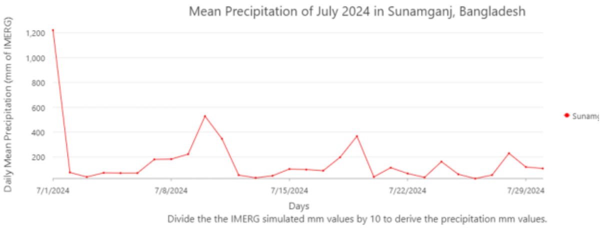
5.6 Haikangxian, Zhanjiang Province in China in July 2024

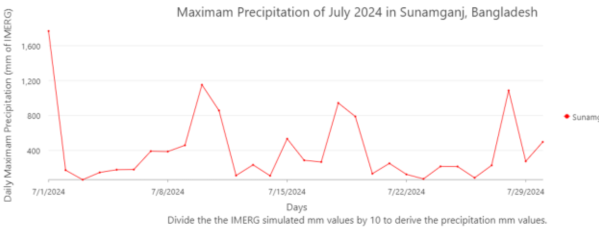




Southern China is more vulnerable to floods due to the continuous rainfall. An unusually sudden shift of rainfall was detected by IMERG. The temporal precipitation profile highlights the sudden shift of rainfall from almost 10 mm precipitation to 90 mm to 120 mm – warning the potential flash flood occurrence.

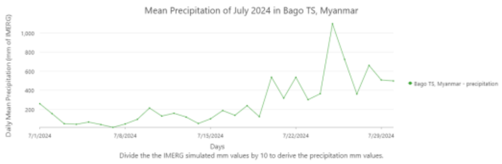
5.7 Sunamganj district in Bangladesh in July 2024

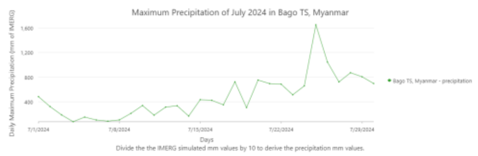




Sunamganj district in Bangladesh received very high rainfall (120 mm to 160 mm) in the beginning of July 2024 and continued to receive moderate to high rainfall. Although Bangladesh was prone to flash floods, it could (should) be predictable and could provide forewarning to the people by simply monitoring the daily precipitation profiles.

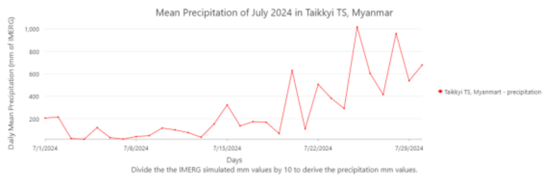
5.8 Bago Township in Myanmar in July 2024

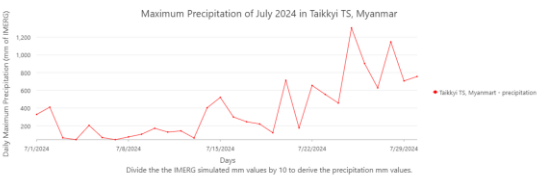




The location of Bago township is at the base of Bago Range which is known as the home of teak. Since the beginning of July 2024, Bago township received 40 mm to 100 mm to 160 mm rainfall for several days until the day when flash flood happened.

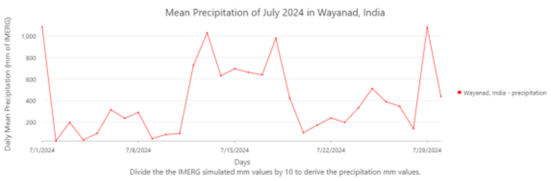
5.9 Taikkyi Township of Myanmar in July 2024

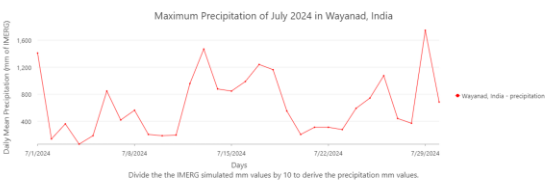




Taikkyi township is the neighborhood township of Bago. It received a similar pattern of temporal precipitation profile as Bago township until the day the flash flood took place.

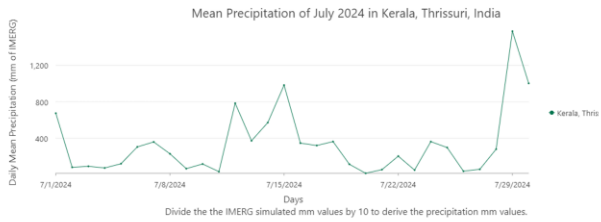
5.10 Wayanad district of India in July 2024

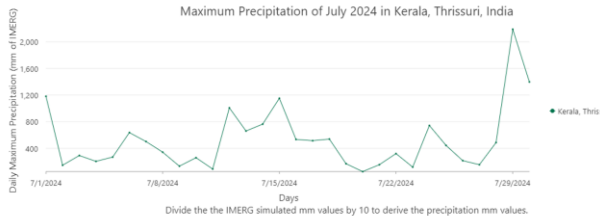




Wayanad district of India received very high precipitation in the beginning week, middle week and the end week of July 2024. Daily precipitation ranges from 20 mm to 100 mm to 160 mm based on the temporal profile of precipitation.

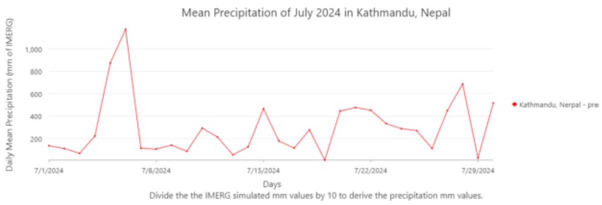
5.11 Kerala in Thrissuri district in India in July 2024

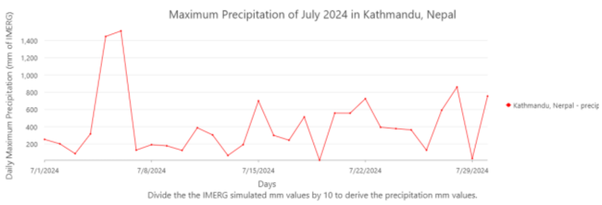




Kerala is the coastal town of Thrissuri district in India. It received a similar temporal profile as the Wayanad district throughout the month of July 2024. Persistent moderate to high daily rainfall – ranges from 40 mm to 200 mm - was significant until the flash flood circumstance.

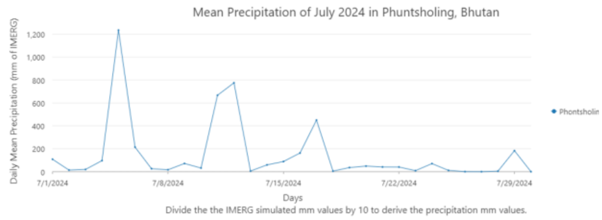
5. 12 Kathmandu district in Nepal in July 2024

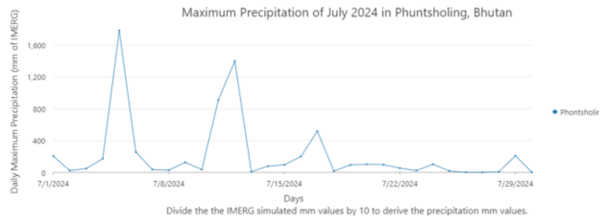




Kathmandu town and district received very high rainfall (100mm to 140 mm) during the first week of July 2024. Kathmandu received 20 mm to 80 mm consistently throughout the month of July 2024 – leading to the flash floods and overflow of the river at the end of July to August 2024.

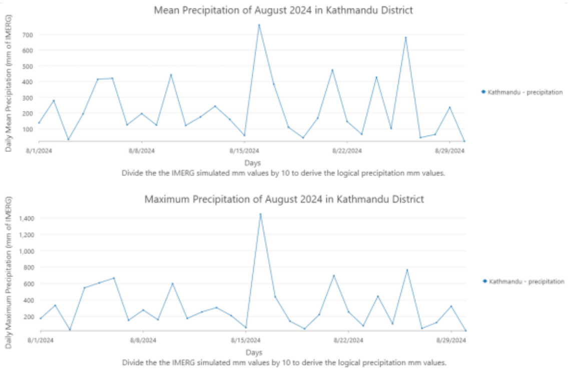
5.13 Phuntsholing Gewog in Bhutan in July 2024





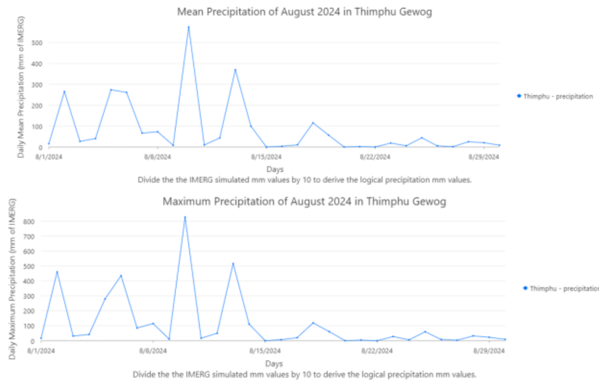
Phuntsholing is famous trading town bordering with India. In July 2024, Phuntsholing Gewog received 40 mm to 160 mm daily rainfall (mean and maximum) during the first three weeks of the month as the major cause of flood. Daily dynamic pattern of precipitation could be observed.

5.14 Kathmandu district in Nepal in August 2024



Kathmandu district received from 20 mm to 70 mm to 140 mm rainfall throughout the month of Jula and August 2024. It was unsurprising that Kathmandu was flooded by observing the daily dynamic precipitation patterns of IMERG data driven charts

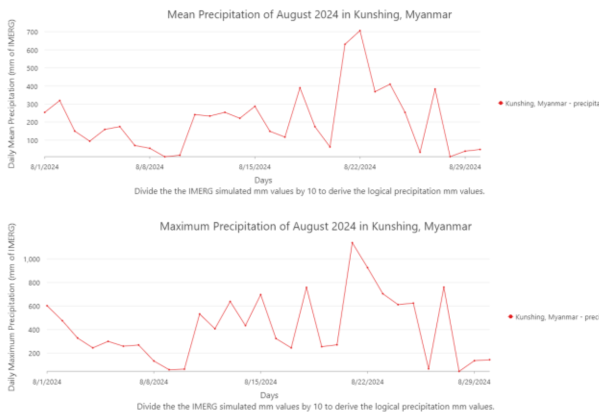
5.15 Dechencholing, Thimphu Gewog, Bhutan in August 2024

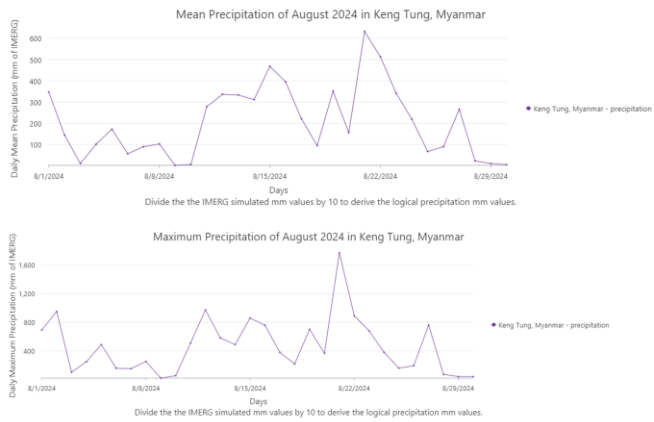


Dechencholing, Thimphu Gewog of Bhutan received light rain 10 mm to heavy rain 80 mm during the first 10 days of August 2024. Due to the persistent moderate to high rainfall, flash flood was occurred.

5. 16 Flash floods in August 2024 in Myanmar

Several townships in Shan state, Myanmar suffered flash floods during August 2024. Daily dynamic precipitation temporal profiles of Kunshing township and Keng Tung township are provided as an example below.

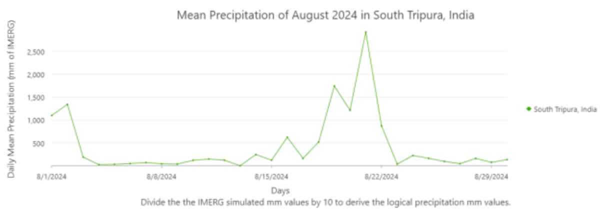


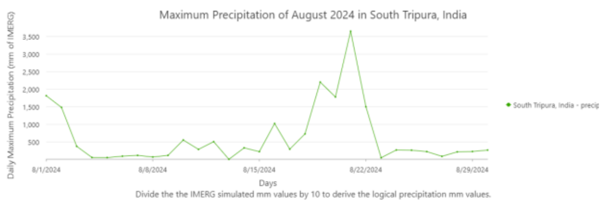


Daily Temporal Profile of Precipitation patterns are evident for happening the flash floods. Rainfall ranges from 30 mm to 160 mm were detected during the month of August 2024 before happening the flash floods.

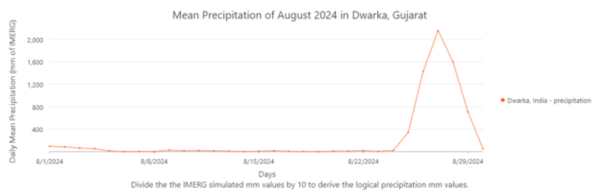
5.17 Flash floods in August 2024 in India and Bangladesh

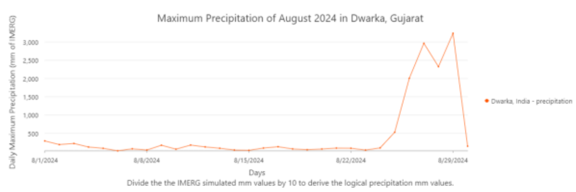
Several districts of India and Bangladesh suffered from the flash floods. Daily dynamic precipitation temporal profiles of South Tripura district, Dwarka district, India and Habiganj district, Bangladesh are provided



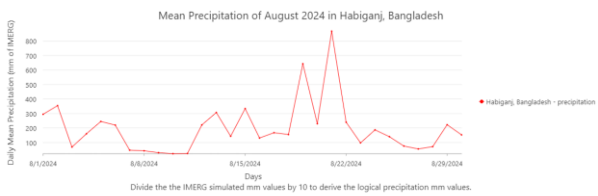


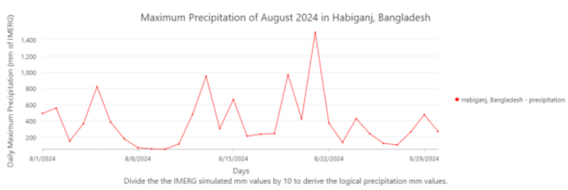
The South Tripura district received from 50 mm to 250 mm daily mean rainfall for 7 days since the beginning of the second week of August 2024. It is one of the reasons why flooding in south Tripura district.





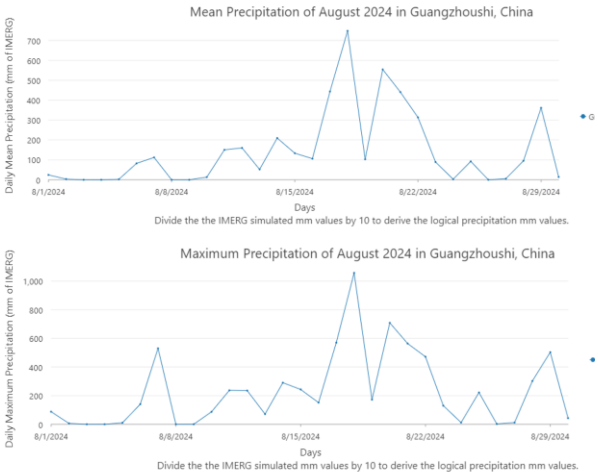
Dwarka district in India received 200 mm mean daily rainfall and 300 mm maximum daily rainfall within 3 days at the end of August 2024. It is one of the major causes for the flood at Dwarka district at the end of August 2024.





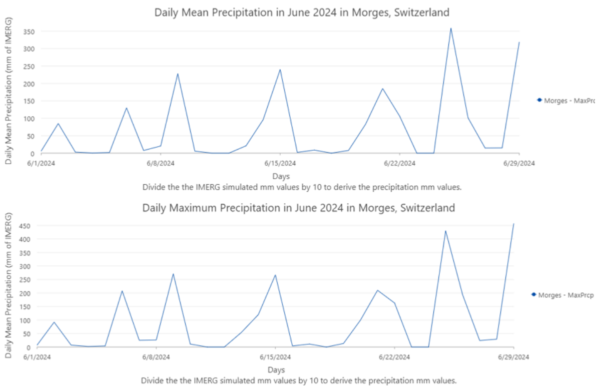
Habiganj district of Bangladesh received 30 mm to 140 mm daily precipitation (mean and maximum) since the beginning of the August 2024. Almost continuous moderate to heavy rainfalls for several days let happen the flash flood in Habiganj district of Bangladesh.

5.18 Potential Flood Risk Example of Guangzhoushi, China



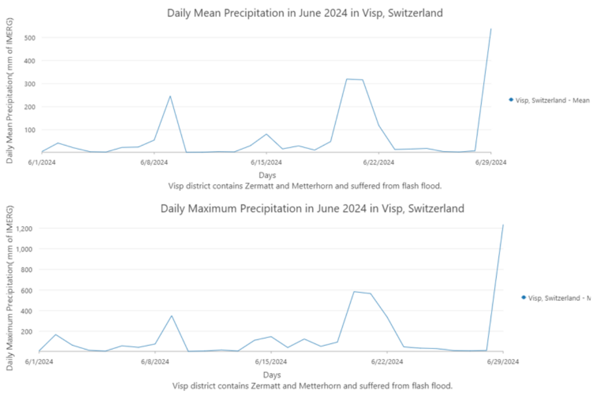
Guangzhoushi province, China received 40 mm to 100 mm precipitation since the beginning of the second week of August 2024. The moderate to heavy rainfall continued until the end of August 2024. It is a good example of daily temporal profile to create and monitor by the analysts or by the smart algorithm to forewarn the potential risk of the flood.

5.19 Morge town and district of Switzerland in June 2024



Morge district of Switzerland received moderate to high rainfall to the maximum of 10 mm to 45 mm for total 7 days within June 2024. Beautiful Morge town was flooded after receiving very high rainfall on 25th June 2024.

5.20 Visp, Vallais Canton of Switzerland in June 2024



Visp district, Vallais canton of Switzerland received 3 days of rainfall more than 100 mm of mean daily rainfall frequently and 4 days of rainfall more than 300 mm maximum daily rainfall since the beginning of June 2024. Visp district and Zermatt tourist region suffered from flash flood although the rainfall pattern of the month signals it since beginning of the month.

6. Conclusion

This research highlights that flash floods due to high precipitation could be predicted and provides forewarning to the people in the administrative areas such as districts, townships or Gewog before the actual flash floods occurred, if the team of analysts and/or smart algorithm monitored it.

According to https://gpm.nasa.gov/missions/two-decades-imerg-resources, the NASA's IMERG – the Integrated Multi-satellitE Retrievals for Global Precipitation Measurement (GPM) -- combines information from a constellation of satellites are operating in Earth orbit, at a given time, to estimate precipitation over the majority of the Earth's surface. This algorithm is particularly valuable over the majority of the Earth's surface that lacks precipitation-measuring instruments on the ground. This research study recognizes that the NASA IMERG daily data is a major contributor to map the potential flood risk of administrative boundary for a nation or a region, whether it is data rich or data poor country. Furthermore, the analysts could recognize the pattern of precipitation temporal profile of past 14 to 30 days for sooner event of flash floods.

This research produced potential flood maps or preliminary flash flood risk maps of Switzerland and Hindu Kush Himalayan countries for the months of June, July and August 2024 based on daily late run precipitation IMERG data to highlight the risky districts. Temporal Profile of daily precipitation charts or time series signals of certain districts where flash floods occurred – are presented to the readers for assessment and validation. This research provided the time series signals for 20 flash floods events in Switzerland and Hindu Kush Himalaya.

This research demonstrated that the time series signals, and preliminary risk maps jointly indicated that flash floods do not occur suddenly. It requires certain days to set the stage for flood events in future. Therefore, it could provide enough time to inform the forewarning to the people and infrastructure operators such as hydroelectric dams to endure the flash floods with minimal damage, to save lives and infrastructures. This research attempts to contribute to saving lives and infrastructures from the flash floods using remotely sensed estimated daily precipitation data from the IMERG satellites.

7. References

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