Discover Water

Case Study

Cloudburst analysis in the Nainital district, Himalayan Region, 2021

Kishan Singh Rawat[1] · Smruti Ranjan Sahu[1] · Sudhir Kumar Singh[2] · Anil Kumar Mishra[3]

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Abstract
Some areas of Uttarakhand faced heavy rainfall during October 17-19th, 2021. In October, rainfall hit its all-time high. A sudden heavy rainfall occurred due to this, which has affected the daily life of humans. More than 50 casualties were recorded during this study period. The main focus of this study was to monitor the Uttarakhand flood event using satellite observations. The Nainital and Almora districts of the state were mainly affected by this sudden heavy rainfall. On October 18th, Nainital received the maximum rainfall of about 21.51 mm at 11:00 am (UTC). The Nainital district has recorded a cumulative rainfall of more than 300 mm on October 18th, 2021. From the observation, we find out that this heavy rainfall occurred due to a sudden cloud burst at Ramgarh in Nainital district. This sudden extreme rainfall further caused a flash flood in the study area. The rainfall pattern has moved towards Assam after it caused a flash flood in the Nainital district of Uttarakhand, India.

Keywords Rainfall · Flash flood · Cloud burst · Nainital

1 Introduction

In several recent studies, the increased risk of flash floods due to changing rainfall patterns over India has been reported [1–5]. Ray et al. [6] have given a brief statement on the recent flood events in India. A cloudburst is one of the major natural disasters in the Uttarakhand state of India; they cause flash floods, landslides, and massive destruction of property.

Kumar et al. [7] suggest that natural climate variability has played a much more significant role in driving these extreme events in the Himalayan region. The major roles of climate change, teleconnections, large atmospheric circulations, and land use/land cover change are major driving forces for these extreme events. Kumar et al. [8] have assessed the cause of landslide hazards and concluded that the extreme rainfall event had influenced landslides in the Jammu and Kashmir Himalaya, northwest India.

The state Uttarakhand experienced a devastating flood and landslide in 2013 as a result of a mid-day cloudburst, multiple rainfall spells, and a Glacial Lake Outburst Flood (GLOF); this was India's worst natural disaster since the 2004 tsunami. It caused a flash flood and a landslide because of the major overflows in the river. Bhambri et al. [9] investigated the massive devastation in the Kedarnath (Mandakini) Valley, Garhwal Himalaya, during 16–17th of June 2013 using satellite remote sensing and in-situ based assessment.

These flood events were some major events that occurred in the Uttarakhand state, India. The above mentioned flood events were recorded in the high altitude area due to heavy rainfall, cloudburst and GLOF. When extreme rainfall

✉ Kishan Singh Rawat, ksr.kishan@gmail.com; Smruti Ranjan Sahu, hellopupu02@gmail.com; Sudhir Kumar Singh, sudhirijnu@gmail.com; Anil Kumar Mishra, anilkumar@gmail.com | [1]Civil Engineering Department, Graphic Era (Deemed to Be University), Dehradun, UK, India. [2]K. Banerjee Centre of Atmospheric & Ocean Studies, IIDS, Nehru Science Centre, University of Allahabad, Prayagraj, Uttar Pradesh, India. [3]WTC, IARI, Puasa Campus, New Delhi, India.

occurs in a short time period, it is called a cloudburst. A cloud burst is the main reason behind the flash flood. The focus of the present work was to assess the flash flood event in Nainital district, Uttarakhand, India during the 17th and 18th of October, 2021 with the aid of satellite observations.

2 Study area

The Nainital district of Uttarakhand, which is located in the Himalayan region of India, was selected as the study area (Appendix I). The study area can be broadly classified into three divisions, namely, the Lesser Himalayas, the Sub Himalayas, and the Piedmont alluvial plains. These divisions are characterised by distinct rock types of varied geological age, structural trends, tectonic setting, and geomorphic features. The major geomorphic features are mountain peaks, hill slopes, topographic depressions, and debris cones.

3 Data and methodology

The Integrated Multi-satellitE Retrievals for GPM (IMERG) is a U.S. multi-satellite precipitation estimation algorithm which combines information from the GPM satellite constellation. It is used to estimate precipitation over the majority of the Earth's surface and provide precipitation records where in-situ precipitation measurements are limited. The IMERG algorithm combines three existing algorithms, such as TMPA, CMORPH and PERSIANN. The IMERG data sets were re-projected and the daily rainfall was computed from half-hourly products. In this research, we have estimated half-hourly (or 30 min) rainfall at a 10 km (or 0.1°) spatial resolution of GPM (https://giovanni.gsfc.nasa.gov/giovanni). During the flood period, half-hourly precipitation data in a netCDF format collected for the study area. We have collected total cloud data for measuring rainfall over the study area and cloud cover data was obtained from NOAA (https://psl.noaa.gov/cgi-bin/db_search/DBListFiles.pl?did=198&tid=95797&vid=4285). Mishra [10] has developed a rain index-based (RI) technique to estimate rainfall. The expression of RI and rain intensity is given in eqns. (1 and 2). For detailed methodology, the readers can consult the work of Mishra and Srinivasan [11].

$$\mathrm{RI} = \mathrm{IR}_{\mathrm{index}} \mathrm{x}\ \mathrm{WV}_{\mathrm{index}} \tag{1}$$

where, IR = infrared; WV = water vapour

$$\text{Rain rate (mm/h)} = \alpha + (\beta \text{ x } \mathrm{RI}^{\gamma}) \tag{2}$$

where α, β, and γ are coefficient.

4 IMERG overview

The IMERG is the Global Precipitation Measurement (GPM, [12]) quasi-global (between 60° N and 60° S) multi-satellite precipitation product. The IMERG is the Level 3 precipitation algorithm of GPM, which has three runs, i.e., an early run (latency of 6 h and can be used for warning of a probable flood event or landslides), a late run (latency of 18 h and suitable for drought monitoring and agricultural forecasting), and a final run (latency of three months and used for observation like precipitation observation).

Now, in the latest Version 06 release of IMERG, the algorithm fuses the early precipitation estimates collected during the operation of the TRMM satellite (2000–2015) with more recent precipitation estimates collected during the operation of the GPM satellite (2014-present).

Satellite rainfall products compared to reference measurement data sets have daily and monthly time scales derived from IMERG level 3 data with the same period as the reference gauges. The data was downloaded from the NASA Earth Data Homepage. The accessible website is https://disc.gsfc.nasa.gov/datasets?page=1&keywords=imerg.

The Integrated Multi-satellite Retrievals for GPM (IMERG) algorithm from the United States provides multi-satellite rainfall products to the GPM team [12]. Precipitation is estimated from various satellites in the GPM constellation carrying associated passive satellite microwave sensors (PMW) computed using the 2017 version of the Goddard Profiling Algorithm, then gridded, inter-calibrated to the GPM Combined Instrument product, and combined into 30 min and

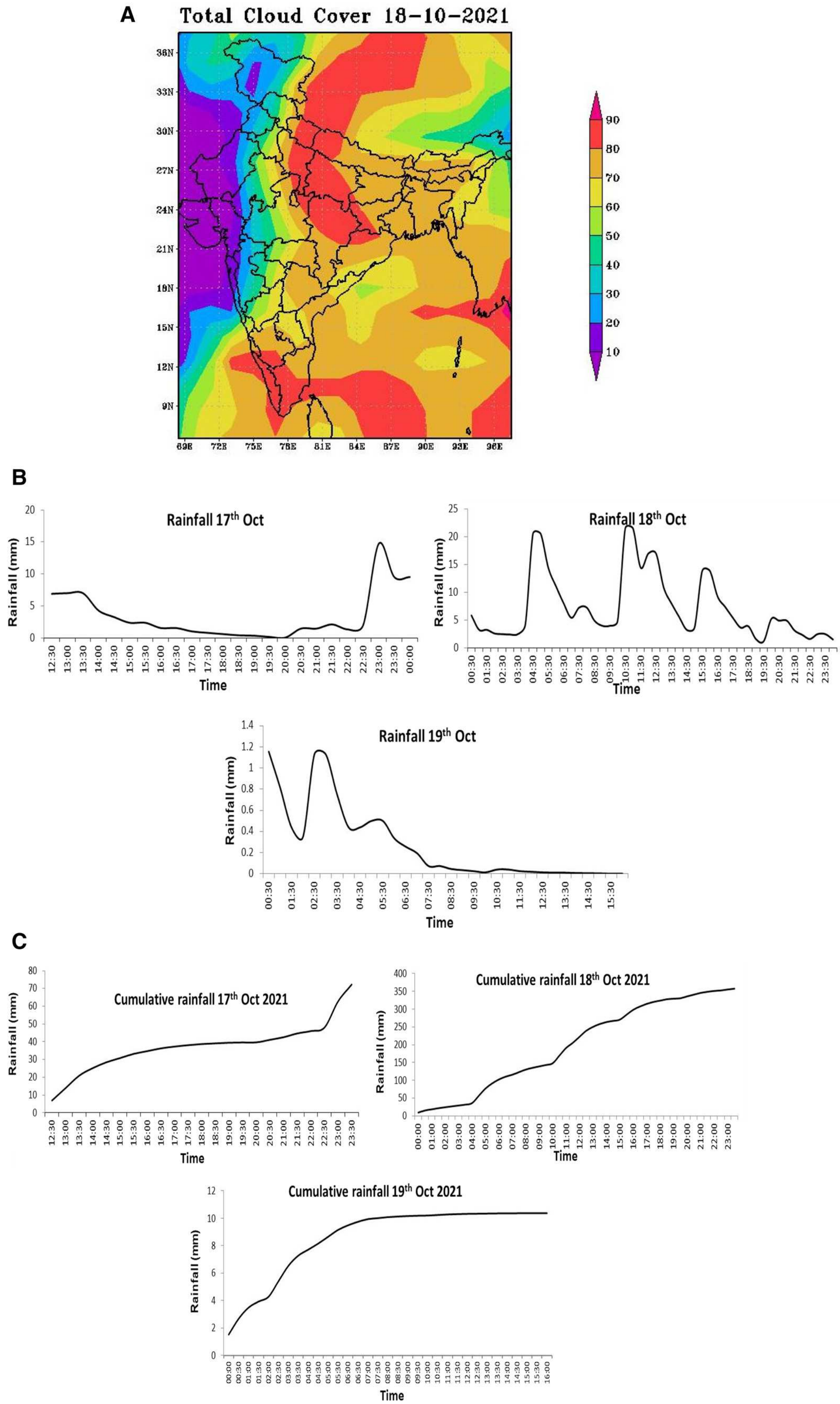
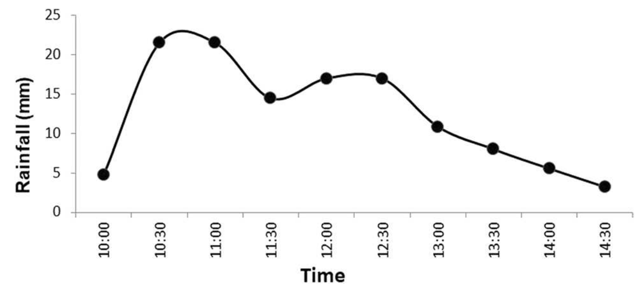


Fig. 1 **A** describe the total cloud cover (18th October), **B** half-hourly rainfall and **C** half-hourly cumulative rainfall of the study area during 17 to 19th Oct 2021

Fig. 2 10:00 am to 14:30 pm half-hourly rainfall of the study area during 18th October 2021



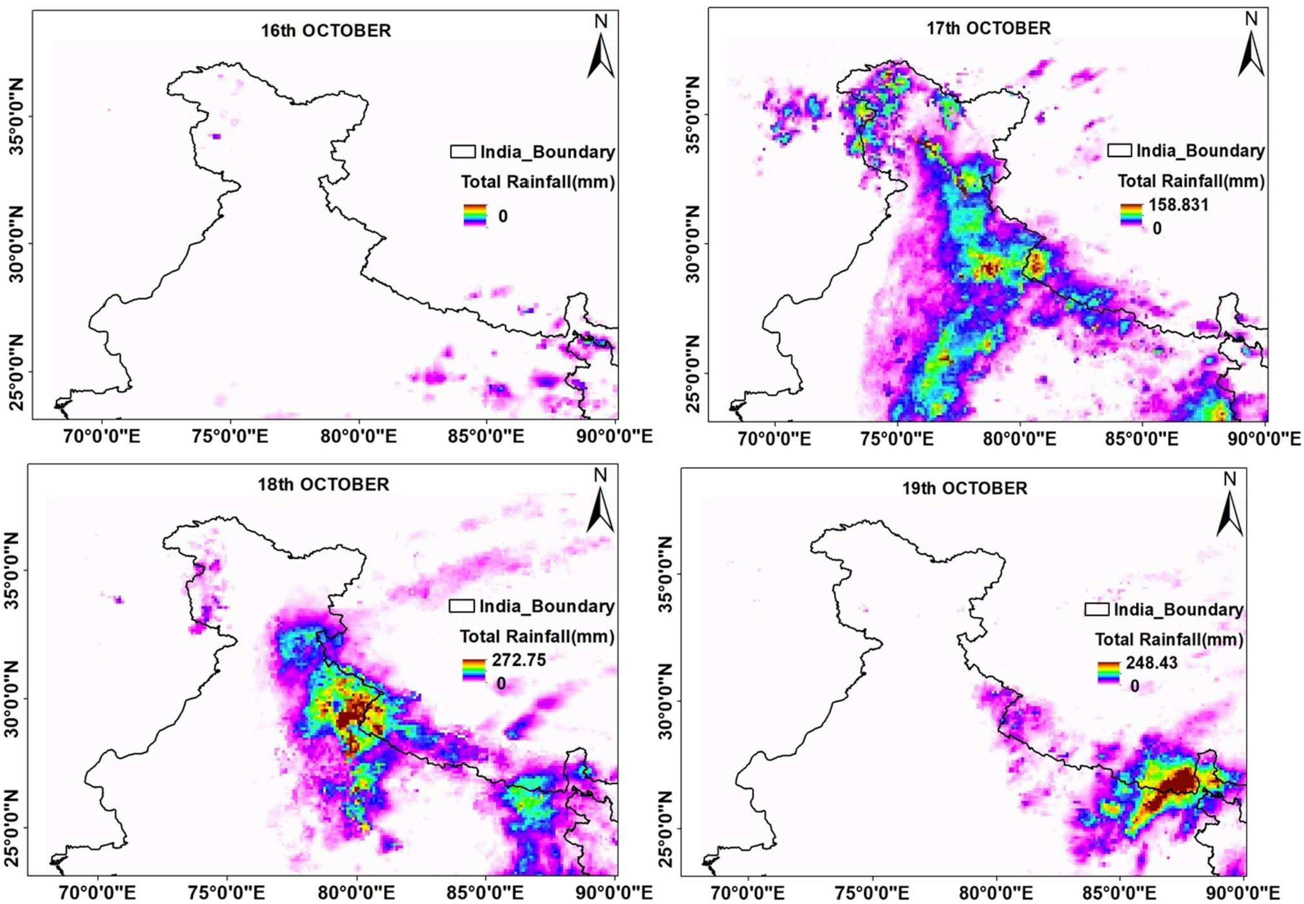


Fig. 3 Daily accumulated rainfall of northern part of India during 16th–19th October

0.1° × 0.1° grid space. The system is run several times for each observation time to produce a quick precipitation estimation (IMERG "early run") with data availability of about 4 h and successively provide better estimates as more data arrives (IMERG "late run") with data latency of about 14 h. The final step uses monthly gauge data to create research-level product (IMERG "final run"). This post-real-time satellite gauge product will be available approximately 3.5 months after observation and gauge analysis.

5 Results and discussions

From the study, we have observed that the cloud cover of the study area increased on October 17th, 2021. In the morning, a cloud burst occurred in the study area, which caused heavy rainfall. This heavy rainfall has mainly affected the Nainital district and some adjoining parts near to Nainital. During the 2 day study period, we found that on October 17th, 2021, the temperature of the study area was slightly increased, which resulted in a low pressure belt in the study area. Further, it has resulted in the formation of a large cloud cover over the area. On October 18th, 2021, it resulted in a cloud burst.

Nainital had received its all-time highest rainfall, resulting in a flash flood. On the 17th, October, the total cumulative rainfall of the area was 72.25 mm, which was changed to 357.76 mm on the 18th of October. On the morning of October 18th, at 4:00 am (UTC), the rainfall was recorded as 4.11 mm hr^{-1} and which increased to 20.54 mm hr^{-1} at 4:30 am (UTC).

Figure 1 (A) depicts the total cloud cover (18th October), (B) half-hourly rainfall, and (C) half-hourly cumulative rainfall of the study area from October 17-19th 2021. We can see that on October 18th, the south part of Uttarakhand has more cloud cover than the rest of the state. The most affected area was Nainital, located in the southern part of the state.

Figure 2 describes the rainfall of the study area from 10:00 am (UTC) to 14:30 pm (UTC), October 18th, 2021. The rainfall was observed to be high at 10.30 am and 11.00 am due to deep convection and again after 11.30 am, there was rainfall reported. The rain recedes after 14.30 pm.

From Fig. 3, we observed the daily accumulated rainfall of the northern part of India during October 16–19th, 2021. On October 16th there was no rainfall, whereas on October 17th the total rainfall was 158.83 mm and it reached a maximum of 272.75 mm and moved slightly north-east and on 19th October the total rainfall reduced to 248.43 and moved slightly south-east.

The impacts of cloudbursts are confined by a large number of geo-environmental factors, namely land use and lithology, high relief, and steep slopes. According to Mishra and Srinivasn [11], higher cumulative rainfall in June 2013 had a significant impact on landslides and the bursting of the lake upstream of the Kedarnath temple on June 16–17, 2013. Kumar et al. [13] studied how hydroclimate influences the particle size distribution of suspended sediments evacuated from debris-covered Chorabari Glacier, the upper Mandakini catchment, and the central Himalaya. Shugar et al. [14] discover that the 2021 disaster was caused by a rock and ice avalanche in Chamoli, Indian Himalayas. The GLOF, forest fires, cloudbursts, and convective storms are all common in the western Himalaya region [15].

Recently, on February 7th, 2021, a sudden flood occurred due to detachment of a sizeable rock mass and overlying hanging glacier in the Chamoli district, Uttarakhand, India [16]. There were 15 casualties and 150 missing during this sudden flood event. Again in May 2021, a series of cloudbursts were recorded in Uttarakhand, which further triggered a severe flash flood. One cloudburst occurred in the Chinyalisaur block of Uttarkashi and multiple cloud bursts were recorded in the Augustmuni in Rudraprayag.

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Author contributions KSR led the development and design of the manuscript, SKS and SRS analyzed the parameters. And writing under the supervision of Prof. AKM. All authors read and approved the final manuscript.

Data availability All data generated or analysed during this study are included in this article.

Declarations

Competing interests The authors declare that there is no confict of interest in this study.

Appendix I

See Fig. 4

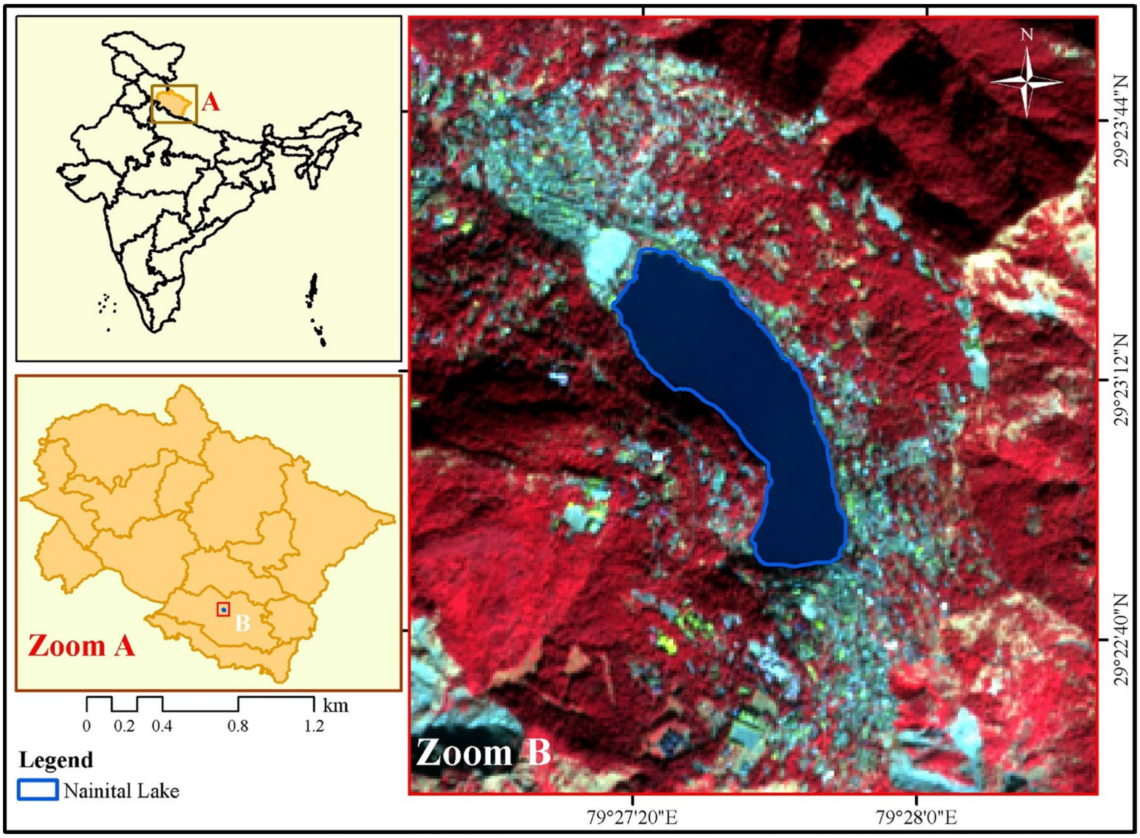

Fig. 4 Study area location map

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