Spatial Distribution of Extreme Precipitation Events
and Its Trend in Nepal

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Abstract The mountainous country with complex topography and climatic conditions over Nepal, the Tropical Rainfall Measuring Mission (TRMM-3B42), were evaluated for monitoring extreme precipitation events using 142-gauge observation from January 1998 to December 2018. Several extreme precipitation indices based on daily timescale data were selected for evaluation. Detection skills, spatial distribution, and trends in extreme precipitation were also investigated. TRMM product moderately capture (POD>70%) the true precipitation events (Probability of Detection) at most of the station. Although, TRMM product shows higher (FAR>40%) false precipitation events (False Alarm Ratio) however, it accurately captures (ACC>80%) the precipitation and no-precipitation events (Accuracy) over the country. Based on five different extreme precipitation indices; heavy precipitation events (R10mm), extreme precipitation events (R25mm), 7 Consecutive Dry Days (CDD), 7 Consecutive Wet Days (CWD), and one-day maximum precipitation (Rx1day), it was observed that the TRMM product can reproduce the spatial distribution of heavy and extreme precipitation events however, it tends to underestimate (overestimate) the frequency of R25mm and CDD (R10mm and CWD spells). Further, increasing (decreasing) trend of dry (wet) spells are observed in both datasets (observed and TRMM) during the study period. The highest Rx1day (about 500 mm/day) was observed during 2014 and 2017; differently, TRMM product shows during 2008 with the highest Rx1day about 300 mm/day. This study provides accuracy of TRMM product to represent the spatio-temporal distribution of extreme precipitation events and its recent trends in Nepal, which is of great significance to hydro-meteorological application. In general, the TRMM product is a good alternative to monitoring extreme precipitation events in Nepal; however, there is still space for further improvement in rainfall retrieval algorithms, especially in high-elevation areas.

Keywords: precipitation, Nepal, spatial pattern, TRMM, extreme events

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1. Introduction

Climate change has amplified the extreme precipitation events, which has become more intensive in recent times [1]. High intensity related to extreme precipitation events is the crucial factor that leads to flood and flash floods and triggers landslides' risk. Further, these extreme weather events can lead to several social, economic, and environmental problems globally [2]. Thus, continuous global as well as regional precipitation monitoring is essential for predicting severe weather, high intensity related extreme events and drought to minimize losses [3,4,5].

Nepal is a South Asian mountainous country situated in the steep terrain of the central Himalayan range. The physiographic nature and local scale climatic influence, precipitation in the country varies spatially leading to the high probability of floods, landslides, and debris flows, mainly during monsoon season [6,7,8]. A recent study by [9] reported that more than 80% of the total population is at risk of natural disasters. The high mountains located in the north are the major source of rivers that flow towards southern plains. When considerable precipitation occurs in upper stream areas, the large portion of bare southern areas experiences the devastating flood impacting millions of people downstream (southern plain of the country called Terai). High-intensity related precipitation events often induce devastating floods and landslides, causing
substantial loss of life, property, and arable land every year [10]. Such extreme precipitation events have broad societal impacts and appear to be increasing with ongoing climate change. For instance, the cloudburst of 14-17 June 2013 in the northwestern mountainous region near the Nepalese border [11], a massive rainfall event of 14-16 August 2014, 29-30 July 2019, 15-20 July 2020 have caused massive flooding and triggered several landslides, resulting in huge losses of life and property, affecting millions of households across the country. Thus, it is essential to monitor the precipitation extremes to minimize the losses. Moreover, the availability of high-resolution gridded rainfall datasets is a prerequisite for disaster risk reduction and management.

Tropical Rainfall Measurement Mission (TRMM), a space mission jointly launched by NASA and the Japan Aerospace Exploration Agency (JAXA) that provides several products of rain estimates in near real-time to post-real-time from a combination of passive microwave, visible/infrared, and rainfall radar data [12]. Although, TRMM product provide precipitation in high spatio-temporal resolution, however it is indirect measurement and thus it need further validation before its application.

Several previous studies evaluated the spatio-temporal pattern of precipitation in Nepal. For example, Reference [13] concluded that the spatial distribution of high-intensity precipitation extreme is different than annual and monsoonal distribution. Authors also mention that lowlands and mountainous areas are exposed to high-intensity precipitation extremes with a higher probability of floods and landslides. Similarly, the peak annual and 1-day extreme precipitation are concentrated between mid-elevation (2,000 and 3,500 m) and lower elevation in the southern foot-hills, respectively, with its highest intensity in the country’s central region [14]. Some basin level study also reported the decrease in average annual precipitation over the Koshi basin from 1997 to 2016 [15]. Moreover, Reference [16] evaluated the TRMM product and found that TRMM precipitation product is good alternative to gauge observation over Nepal. Further, precipitation and its extremities pattern change over time and continuous analysis is need to monitor such events. Thus, this study aims evaluate the spatial distribution of extreme precipitation and its trend for recent two-decade (1998-2018) using TRMM and 142-gauge observation over monotonous country Nepal. Furthermore, this study will provide new insights into the high-resolution satellite product with its applicability in the country for future studies. Therefore, understanding the spatial and temporal variability and recent precipitation trends over Nepal is essential for decision-makers and climate scientists, including hydrologists, agriculturalists, emergency managers, and industrialists.

2. Material and Methods

2.1. Study Area

Nepal is located in a typical monsoon region (i.e., the South Asian monsoon region), with evident spatio-temporal variability of precipitation and the related mechanisms. Geography, the country is located between 26° 22′ N to 30° 27′ N in latitude to 80° 40′ E to 88° 12′ E in longitude, covering an area of 147,516 km² (Figure 1). The country extended about 885 km length from east to west, and about 193 km width from the north to south. It has irregular topography with elevations varying between 60 and 8848 m a.s.l. (above sea level) and generally increasing from south to north. Nepal can be divided into five physiographic regions: Terai, Siwalik, Middle Mountain, High Mountain, and high Himalaya. The country features a very diverse climate from tropical savanna in low-elevation to polar frost in high-the Himalayas resulting from its uneven topography [17]. The south-east part of Nepal is greatly influenced by monsoon circulation, while the westerly derived circulation system dominates the north-west part of the country during the winter season [18,19,20]. The four distinct seasons are pre-monsoon (March-May), summer monsoon (June-September), post-monsoon (October-November), and winter (December-February). The topography of the country is very complex, and the precipitation is closely related to the topography. As the topography plays a vital role in generating distinct local climate, mid-elevation areas receive higher precipitation than low- and high-elevation areas of the country [21]. Moreover, the mean summer precipitation over the country during 1987-2015 is 1685 mm [20].

![Figure 1. The digital elevation model (DEM) and spatial distribution mean annual precipitation (mm/year) at 142 meteorological stations. The blue line shows the 3000 m contour line and color bar represent the elevation in meter](image-url)
2.2. Data

2.2.1. Rain Gauge Data

The hydro-meteorological gauge stations in Nepal are routinely maintained by Department of Hydrology and Meteorology (DHM), Government of Nepal. Daily precipitation records from 141 meteorological stations for 1998-2018 were collected from DHM (www.dhm.gov.np). All these DHM observed datasets provide optimal spatial coverage over the study region with continuous precipitation records. In addition to DHM observation, data from a high-elevation Automatic Weather Station (AWS) located in the Everest region (27.95°N to 86.20°E, 5050 masl), Pyramid was also used. In total, 142 daily gauge observations are used to evaluate the accuracy of the TRMM product were further subjected to quality control. For strict quality control, an examination of erroneous values and discarded questionable data to ensure the high quality of the rain gauge data. The selected 142 station ranges from ~60 m to 5050 m elevation. However, rain gauge stations in high elevation areas were sparse due to a remote location with rugged topography and challenging to routine maintenance. The geographic location and mean annual precipitation during the study period are presented in Figure 1.

2.2.2. TRMM Product

TRMM is the first global monitoring satellite mission jointly launched by the National Aeronautics and Space Administration (NASA) and Japan Aerospace Exploration Agency (JAXA) on 28 November 1997 [22]. TRMM measurement is the combination between visible infra-red and microwave sensor with high frequency for monitoring and recording data both space and time. The satellite launched as a part of the TRMM mission covers a band between 50°N and 50°S, which operates in orbit with 400 km of altitude, an inclination of 35°, and a period of 92.5 min, allowing it to rotate around the Earth 16 times a day. However, the satellite revisits the same scene of the earth's surface twice a day. The rainfall measuring instruments on the TRMM satellite includes five main type sensor, Precipitation Radar (PR), TRMM microwave Image (TMI), Visible Infra-red Scanner (VIRS), Clouds and the Earth’s Radiant Energy System (CERES), and Lighting Imaging Sensor (LIS) [22]. The TRMM program provides various algorithms, including the TMPA (TRMM Multi-satellite Precipitation Analysis) 3B42 Version that provides rainfall estimation products through the combination of a set of data from TRMM and various satellite sensors that provide similar data as those on board of TRMM. The seventh version of the 3B42 algorithm (3B42 V7), available since 22 May 2012, incorporated several significant changes compared to its predecessor (3B42 V6). In addition to the data used in the previous version, the 3B42 V7 algorithm uses new data sources in order to enhance the rainfall estimations. In this study, we used the daily TRMM 3B42-V7 precipitation product with a spatial resolution of 25 km, between January 1998 and December 2018 for comparison with the DHM observed precipitation dataset. The TRMM-3B43 is a merged precipitation product is based on a combination of microwave, infrared, and radar information from TRMM and other precipitation-relevant satellite sensors, infrared data from geostationary satellites (TRMM multi-satellite), and ground-observed data merged in the Global Precipitation Climatology Centre (GPCC) [23,24,25]. TRMM 3B43-V7 data were downloaded from the NASA Goddard Earth Sciences Data and Information Services Center website (http://mirador.gsfc.nasa.gov/).

2.3. Methodology

TRMM precipitation product provide precipitation in 25x25 km grid box, while observed datasets are at the point scale. Following the previous study [26,27,28,29], a point-to-pixel method was adopted to compare the gridded TRMM product with 142-gauge observation. It is common practice in evaluation studies to compare the point-based observed precipitation data against the gridded satellite precipitation product to avoid errors by gridding the observed precipitation data. For this, the precipitation values from each rain gauge and the grid where the same gauge is located were extracted in pairs for evaluation. Some of the station data do not feature regular data, and quality control is conducted for data consistency; if the observed daily data contain missing values, then the corresponding daily TRMM data were also considered to be a missing value.

Further, daily performance assessment was calculated for the TRMM product based on categorical statistics to detect rain and no rain days at each station (Table 1). For the assessment, three categorical indexes are considered in the study; the probability of detection (POD), which represents the TRMM's ability to detect rainy days correctly, and ranges from 0 to 1 (with 1 is a perfect score); False Alarm Ratio (FAR), provides the TRMM's capabilities to detect no rain events (when there is no rainy days in gauge observed measurement) and ranges from 0 to 1 (with 0 is a perfect score); and Accuracy (ACC), which is the fraction of TRMM's events that were correct. ACC ranges from 0 to 1, with one as a perfect score. These daily categorical statistics are mainly based on two possible cases; a day with or without rain.

Table 1. The contingency table and definitions of derived scores were used in this study

| Estimated rain | Observed rain | Observed no-rain |
|---------------|---------------|------------------|
| Estimated no-rain A (hits) C (misses) D (correct rejects) | B (false alarms) |
| Probability of Detection POD A/(A+C) | |
| False Alarm Ratio FAR B/(A+B) |
| Accuracy ACC (A+D)/(A+B+C+D) |

* Where, A and D denote count of days when rainfall above 1 mm/day recorded by both datasets (gauge observed and TRMM). Meanwhile, B and C denote count of days when gauges and TRMM, respectively, record rainfall below 1 mm/day.

To evaluate the extreme events, we have considered the five indicators on extreme precipitation indices, developed and recommended by the Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI), jointly established by the World Meteorological Organization (WMO) Commission for Climatology and the Research Programme on Climate Variability and Predictability (CLIVAR) (Table 2). Among the five extreme
precipitation indices, four of them related to "wetness" [RX1day, R10mm, R25mm, Consecutive Wet Days (CWD)] while one of them related to "dryness" [Consecutive Dry Days (CDD)], described in Table 2. All of the selected stations were used for calculating the extreme precipitation index. These statistics are computed for the individual station to quantify the capacity of the TRMM product to detect the daily precipitation events (Table 2). All these indices, including the annual maximum of 1-day precipitation, referred to as RX1day and threshold indices comprise of several heavy precipitation days (R10mm) and extreme precipitation days (R25mm). R10mm and R25mm denote the counts of days in a year when precipitation was ≥10 mm <25 mm and ≥25 mm, respectively. The duration indices encompass the consecutive wet and dry days (CWD and CDD), which describe the maximum lengths of seven consecutive wet and dry days, respectively. The above considered extreme precipitation indices are primary indicators of floods and droughts indicators, which in combination with the leading indicators, provide valuable information. For instance, RX1day indicates the magnitude of very intense precipitation events that trigger flash floods and landslides. R10mm and R25mm represent the frequency of heavy and extreme precipitation events. On the other hand, CDD and CWD indirectly indicate droughts, which is essential for agricultural activities [30]. However, we introduce a slight modification to the selected indices.

Table 2. The description of ETCCDMI (Expert Team on Climate Change Detection, Monitoring, and Indices) used in the study

| Indicators         | Definition                                      | Unit       |
|--------------------|-------------------------------------------------|------------|
| RX1day             | Intense precipitation events: maximum 1-day     |            |
|                    | precipitation                                     |            |
| R10mm (Prec ≥10<25mm) | Heavy precipitation days: number of days with precipitation larger than 10 mm day⁻¹ | days       |
| R25mm (Prec ≥25mm) | Extreme precipitation days: number of days with precipitation equal or larger than 25 mm day⁻¹ | days       |
| CDD                | Consecutive 7 Dry Days: maximum number of CDD  |            |
|                    | (Rday <1mm/day)                                  | days       |
| CWD                | Consecutive 7 Wet Days: maximum number of CWD   |            |
|                    | (Rday ≥ 1mm/day)                                | days       |

3. Results

3.1. Detection Capability

Figure 2 illustrates the spatial distributions of the POD, FAR, and ACC values for TRMM products at each station across the country. These values were calculated based on daily precipitation data. TRMM product detected >60% of actual precipitation events (POD) at most of the stations (Figure 2a). The FAR score in TRMM product ranges between 30 and 40% at most stations, indicating that the TRMM product shows more precipitation days when there is no precipitation in gauge observation during the study period (Figure 2b). It is worth noting that POD is lower at most of the selected stations across the country, indicating that TRMM products well detected both the precipitation and precipitation events across the country (Figure 2c). The average POD, FAR, and ACC over the country were 0.69, 0.48, and 0.75, respectively. Overall, the TRMM product shows the best performance in mid-elevation areas and poor performance in high-elevation areas, revealing that the error was lower when the precipitation amount was higher.

3.2 Extreme Precipitation Events

The heavy precipitation events (R10mm) and extreme precipitation events (R25mm) at each station over the country between 1998 and 2018 are presented in Figure 3. As the high-elevation areas of the country are relatively dry, a small number of R10mm and R25mm precipitation events (<100) are observed in these areas (Figure 3a and Figure 3b). It is worthy of mentioning that a higher number (500-700) of R10mm events are concentrated in mid-elevation areas country (above 500 events), while R25mm are concentrated mid-elevation areas of the central and eastern region. The highest number (>900) of heavy and extreme events is observed in the central and eastern region's mid-elevation areas. TRMM product mostly underestimated both of these events (R10mm and R25mm) over the country. However, these events' spatial distribution is almost identical to observed datasets, i.e., the occurrence of a smaller number of events in high-elevation than low- and mid-elevation areas (Figure 3c and 3d). It can be concluded that the total number of R10mm and R25mm events vary with the location, and these indices reveal that mid-elevation areas of the central and eastern region should be taken into greater priority as they have chances to be affected by the landslide and soil erosion and low-elevation areas by floods.

Figure 4 presents the spatial distribution of seven CWD and CDD spell in observed and TRMM products at each station during the study period. Spatial distribution of CWD and CDD reveals a mixed pattern over the country. A higher number of (above 500 spells) of dry spells was found in most stations at low and high-elevation areas of the country (Figure 4a). Meanwhile, a smaller seven CWD spell (below 100) was found at most stations except few stations in mid-elevation areas of the central and eastern regions (Figure 4b). TRMM product underestimated and overestimated the total CDD, and CWD spells, respectively across the country (Figure 4a and Figure 4b). The station located in the mid-elevation area (relatively higher precipitation) has smaller dry spells. In contrast, stations at mid-elevation throughout the country recorded higher wet spells (Figure 4c and Figure 4d). Further, the number of dry spells are higher as compared to the wet spells. Moreover, the TRMM product can represent the spatial distribution of extreme precipitation events over the country; however, it underestimated (overestimated) total frequency of CDD (CWD) spells.

3.3. Interannual Variation of Extreme Events and Its Trend

Figure 5 shows the time series of R10mm, R25mm, and one-day maximum precipitation events (RX1day) in gauge observation and TRMM product during the study period. The temporal time series of heavy event shows the minimum number of events mainly during 2005, 2009,
and 2012, while the years 2003, 2007, 2011, 2016-2018 show maximum number heavy precipitation events. Moreover, the observed datasets show an increasing trend, in contrast to observed, TRMM product shows the decreasing trend of heavy events. Although, TRMM shows very similar temporal distribution with observation (Figure 5a); however, it overestimated the observed heavy precipitation events throughout the study period. The maximum number (above 3000) of R10mm were observed during 2003 and 2007, while minimum number of events (below 2000) were observed during 2005 and 2015 over the country (Figure 5b). Similar to observed datasets, TRMM product also shows the maximum number of R10mm events i.e., about 2800, 3000, 2800, and 2500 in 2003, 2007, 2011, and 2013, respectively (Figure 5b). Differently, TRMM product show the smaller number R25mm events about 1900 in the year of 2006 and 2012. Further, both datasets show the significant decreasing trend of the extreme precipitation events, with the higher decreasing rate in the TRMM product. It is worth noting that TRMM precipitation product underestimated (overestimated) the total frequency of R25mm events (R10mm) throughout the study period (Figure 5a-b).

The temporal distribution of CDD spell in observed and TRMM product during the study period is presented in Figure 5c. The interannual variation of CDD spell in TRMM product is similar to observed datasets. The maximum number of CDD spell are observed about 4000, 4500, and 4000 in 2006, 2009, and 2012. Whereas, the minimum number of CDD (less than 3000) events are observed in the years 2003, 2007, and 2015. Meanwhile, the observed CWD spell was minimum for years 2005, 2009, and 2015. TRMM product also shows the minimum and maximum CWD spell in the same year as observation (Figure 5c and d). However, the overestimation of CDD and underestimation of CWD spell might be related to the overestimation of heavy (R10mm) and underestimating extreme precipitation (R25mm) events in TRMM datasets. Further, the higher numbers of CWD spell in 2007, suggesting that the wettest year, whereas CDD spell in 2009, indicating the driest year among the study period (Figure 5c-d). The results show frequent occurrences of the wet (flood) and dry (drought) spells over the study region during the study period. Moreover, both data shows the increasing and decreasing number of dry and wets spells during the study period. The interannual variation of one day maximum precipitation (RX1day) in observed datasets is not consistent with TRMM product (Figure 5e). The highest Rx1day events (~500 mm/day) was observed during 2014 and 2017, while the TRMM product shows much less Rx1day about 300 mm/day during 2008. Moreover, the observed data set shows no trend, whereas the TRMM data set shows the significant decreasing trend at the rate of -4.69 mm/day.

![Figure 2](image1.png)
**Figure 2.** Spatial distribution of (a) Probability of Detection (POD), (b) False Alarm Ratio (FAR), and (c) Accuracy (ACC) in % at each station during the study period. The black and blue lines denote the national boundary and 3000 m elevation contour, respectively

![Figure 3](image2.png)
**Figure 3.** Spatial distribution of (a, c) heavy precipitation events (R10mm), and (b, d) extreme precipitation events (R25mm) in observed and TRMM product at each station over Nepal during the study period
4. Discussion

TRMM product emerges as a potential alternative of observed rainfall records for various hydro-meteorological studies worldwide. TRMM is one such rainfall measurement mission that provides high-resolution estimates of rainfall and has applied different hydro-meteorological application globally [12,13,22,23,25,31,32]. With the ability to remotely estimate the rainfall events, the approach is particularly advantageous for regions with inaccessible steep terrains and a sparse gauge region, especially mountainous region [33,34]. This study evaluates TRMM product's ability to represent the spatial and temporal distribution of extreme events and its trends in reference to 142-gauge observations from mountainous country, Nepal.

The comparison of daily extreme precipitation events with observation, TRMM product revealed the dual nature of bias during the study period. The overall rainfall magnitude falling for the range of 10mm to <25mm (R10mm) represents positive bias, whereas consistent negative bias was found for rainfall magnitude above
25mm (R25mm). It shows that TRMM is consistently underestimated the extreme rainfall events, whereas overestimated the observed heavy precipitation events over the country. Overall, the TRMM product underestimated the extreme precipitation events and 7 CWD spells, while overestimated the heavy precipitation events and 7 CDD spells over the country; this could be associated with the overestimation of low precipitation values and underestimation the higher precipitation values over the country as similar to the study conducted in China [35,36] and India [37]. In contrast, Chen, et al. [38] found that TRMM product underestimated low-intensity rainfall and overestimated high-intensity rainfall over China. It is evident that passive microwave sensors are inefficient in resolving the orographic precipitation in the liquid phase over highly uneven terrain [39,40]. Since the Himalayan area of the study region is characterized local climatic and unique topographic features, the inferior performance of satellite-based precipitation estimates are greatly influenced by the limited retrieval ability to exist passive microwave sensors and algorithms used to convert microwave signals into precipitation estimates. Apart from low magnitude rainfall, TRMM estimates are also underestimated for those months with a medium rainfall magnitude range over the Himalayan region. The months having light rainfall mainly occurs in the winter season. The inability of TRMM to capture the light rainfall may be related to the snowfall during the winter season. Moreover, high-elevation areas of the country are covered with snow or glacier. The poor performance of TRMM over regions with high snow content and complex terrain is discussed in many past studies [41,42,43]. Additionally, scattering of microwave signals in snow-covered regions, the sensitivity of TRMM Microwave Imager to sub-freezing temperature, multiple scattering of microwave signals in mountainous terrain might be the another reason of uncertainties in TRMM product.

Moreover, TRMM product well captured the precipitation and no-precipitation events correctly; however, the monthly performance is depends on the quality and quantity of assimilated GPCC gauge-based precipitation records. Post real-time TRMM precipitation product is calibrated using monthly gauge based GPCC datasets [44]. However, these datasets are only calibrated for those areas where rain-gauge data are available. Further the influence of altitude on precipitation estimation for the TRMM satellite product still exists. Hence, the performance of TRMM product is also influenced by the quality and temporal range of the adjusted gauge-based GPCC datasets.

5. Conclusion

This study primarily evaluates the precision characteristics of the TRMM precipitation product and assessed their ability to monitoring extreme precipitation over Nepal. The observed precipitation from 142 meteorological stations from DHM were adopted as reference data to evaluate TRMM product. Five different widely used indices was selected to verify the potential utility of TRMM product in extreme precipitation monitoring. The major conclusions are as follows:

(1) The TRMM product well captured the true precipitation events at most of the station over the country. Although, TRMM product detected false precipitation events, however, the accuracy was much higher (above 70%) to detect precipitation and no-precipitation events over the country.

(2) The distribution of high intensity related to extreme precipitation events vary spatial, i.e., R10mm and R25mm, are more pronounced in mid-elevation areas of the country, indicating the higher chances of landslides and floods over the low-elevation areas of the country. Also, a similar spatial variation is CWD, and CDD spells are observed over the country. TRMM precipitation product also show a similar spatial distribution of R10mm and R25mm events over the country. The temporal time-series of extreme events (R10mm, R25mm, CDD, and CWD) show an inter-annual variation during 1998-2018. Overall, the TRMM product underestimated the extreme precipitation events and 7 CWD spells, while overestimated the heavy precipitation events and seven CDD spells over the country. The highest one-day maximum precipitation (about 500 mm/day) was observed during 2014 and 2017, while the TRMM product shows much less high precipitation, about 300 mm/day in 2008.

(3) Trend analysis of last two decade further revealed that dry spells are increasing, while wet spells and heavy precipitation events are decreasing over the country. It is worthy of mentioning that TRMM product shows similar trend with observation for extreme events, dry spell, and wet spells. In contrast, TRMM product shows increasing trend for heavy precipitation events, which is decreasing in observed datasets.

Overall, the terrain of Nepal is very complex, and the meteorological stations are very sparse. The interpolation of rain gauge data leads to the uncertainty of precipitation estimation. Therefore, it is necessary to evaluate the satellite precipitation for future hydro-meteorological research. Despite the uncertainties, the findings are still very valuable. TRMM product provides precipitation estimates in higher temporal and spatial resolution and larger coverage, which is of great significance for those areas with complex terrain and data scarce region to the future research and application of meteorology, hydrology, and natural disasters. Moreover, we recommend to evaluate satellite-based precipitation product on sub-daily time scale in near-real time. Nevertheless, this study on the spatial and temporal variability extreme precipitation and its trend over Nepal will help to select TRMM product for the future hydro-meteorological application in the mountainous county.

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Conflicts of Interest

There is no conflict of interest among the authors.

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