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RESEARCH ARTICLE

Temporal variability of seasonal and annual rainfall in Nepal

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ABSTRACT

This study analyzed 107 weather stations' 42-year rainfall data (1977-2018), using the normal ratio method to estimate missing rainfall from nearby stations. This study identified the mean winter, monsoon, and annual rainfall as 69.7 mm, 1433.2 mm, and 1791.5 mm respectively. The winter, monsoon, and annual rainfall have large temporal variability. Nepal received high rainfall from Jun to September (monsoon) and the rest of the eight months received low rainfall causing water scarcity in Nepal. This study examined the increase of rainfall with heights up to mid-mountain then the rainfall decreases with height in monsoon season. But in winter generally, the rainfall amount increases with height. However, rainfall totals both seasonal and annual have been decreasing since 2000 both nationally and regional-wise.

Keywords: ***Temporal, Variability, dry and wet episodes, Seasonal, Nepal***

INTRODUCTION

In South Asia, the monsoon is the major rainfall period. There is large-scale variability of rainfall such as; intra-seasonal, and inter-annual. According to Wang et al. (2020), interactions between the various Asian monsoon subsystems, mid-latitude processes, and tropical cyclones have a greater impact on the South Asian nation. Specifically, a large portion of the inter-annual variability of the Asian monsoon in the tropics is explained by the El Nino Southern Oscillation (ENSO) (Webster et al., 1998). However, such a relationship is nonstationary (Kumar et al., 1999). In India, monsoon rainfall fluctuation has depended on the ENSO conditions (Varikoiden et al., 2015). Numerous previous researchers (Varikoiden et al., 2015; Kumar et al., 2013; Krishnamurthy, and Gowashmi, 2000; Balme and Jadhav, 1984; Ramanadham et al., 1973) have examined the seasonal rainfall study in India. South Asian region receives relatively less rainfall during ENSO monsoon years (Kumar et al., 2013; Sein et al., 2015; Bagale et al., 2021).

In Nepal, rainfall is the primary water source, influenced by both local and large-scale climatic factors. The monsoon, which brings the majority of rainfall, occurs between June and September due to the southwest Indian monsoon (Bagale et al., 2023a). This monsoon approaches Nepal through southeasterly circulation, drawing moisture from the Bay of Bengal and sometimes the Arabian Sea (Bohlinger et al., 2017). Numerous studies have examined rainfall variability by previous researchers (Bagale et al., 2023a; Shrestha et al., 2019; Karki et al., 2017; Sigdel and Ikeda, 2012; Ichiyanagi et al., 2007; Kanskar et al., 2004).

Bagale et al. (2023a) analyzed data from 107 stations across Nepal from 1977 to 2018, highlighting significant variability in monsoonal rainfall and identifying both deficit and wet episodes. Ichiyanagi et al. (2007) examined seasonal and annual rainfall variability, noting an altitudinal dependency, with enhanced monsoon rainfall up to 2000 m, and a decline at higher altitudes. Karki et al. (2017) found that the eastern region of Nepal experiences more frequent decreases in seasonal and annual rainfall trends compared to the western region. Shrestha et al. (2019) analyzed rainfall data from 43 stations between 1981 and 2015, revealing a declining annual rainfall trend in the Kaligandaki and Koshi river basins. Panthi et al. (2015) observed a reduction in pre-monsoon, post-monsoon, and winter rainfall in most zones, although the Gandaki River basin in central Nepal saw an increase in monsoon rainfall. These findings provide crucial insights into Nepal's shifting rainfall patterns. Most of the previous studies have examined the east-to-west variability; there is still lacking gradient-wise (Terai, mountain, and Himalayas) rainfall studies in recent decades. The main objective of this study is an identify lowland, midland, and highland-wise rainfall variability in Nepal.

Study Area

Nepal is a landlocked, mountainous nation. China's Highland Tibet is located on the side facing north, and India is on the side south. Its latitude ranges from 26° 22' to 30° 27' N and its longitude ranges from 80° 04' to 88° 12'E (Fig. 1).

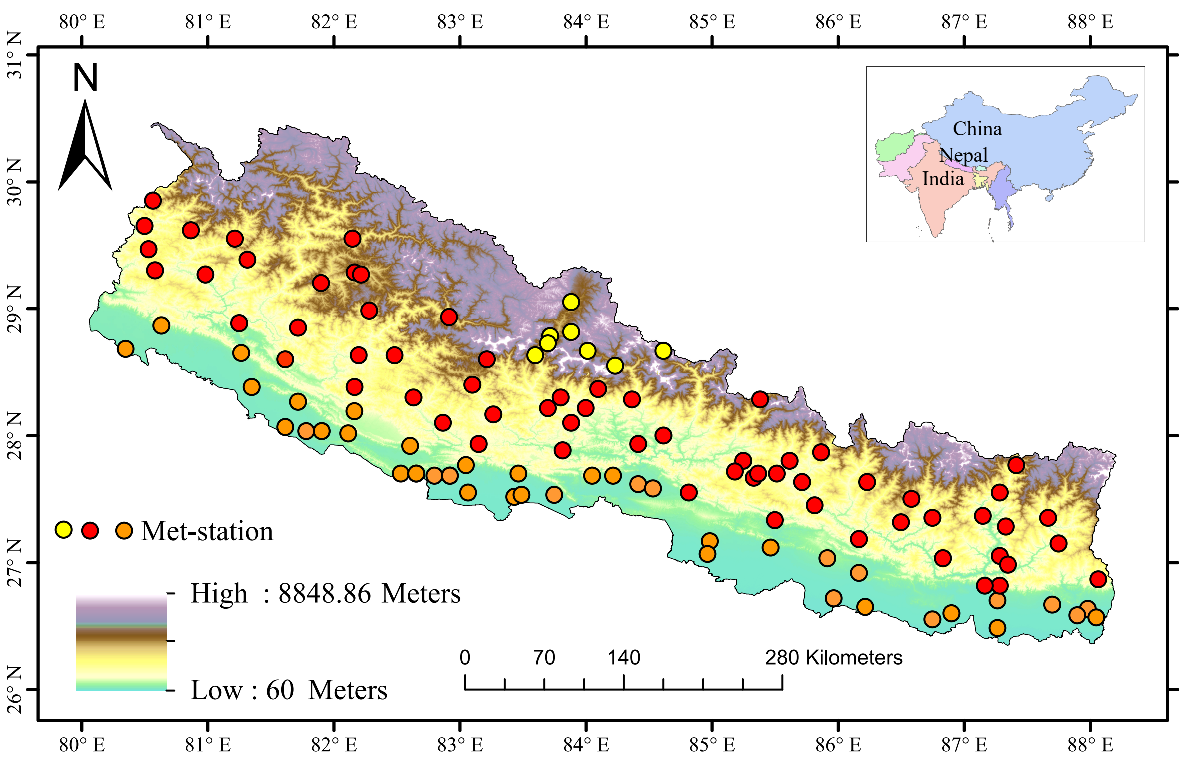

Fig. 1: Spatial distributions of stations over the Himalayas (yellow), midlands (red), and lowlands (orange) in Nepal.

Nepal has a varied terrain that runs from the low Terai area in the south, which is only 60 meters above sea level, to the high Mount Everest region in the north, which is 8848.86 meters above sea level. The nation has an area of 147516 km2 (Fig. 1). We have used 40, 59, and 8 stations for the Terai, Mountain, and Himalayas [lowland (L), midland (M), and highland (H)] of Nepal.

METHODOLOGY

Data (methods of data collection)

The Department of Hydrology and Meteorology, Government of Nepal, provided daily rainfall data from 107 meteorological stations covering 1977–2018. Monthly total rainfall was calculated by summing daily rainfall, and annual totals were obtained by summing monthly data. Seasonal rainfall was also computed for the summer monsoon (June–September) and winter (December–February). The arithmetic mean method was applied to calculate the annual, seasonal, and monthly averages for each station. Furthermore, rainfall data selection and management detail procedures are followed (Bagale et al., 2023a). Missing rainfall values were estimated using the Normal ratio method (Myrondis, D and Nikolaos, T., 2021; Bagale et al., 2023b).

RESULTS

Rainfall statics

Using time series data from 107 stations, the annual profile of monthly and seasonal total rainfall has been computed, located in the Terai, Mountain, and Himalayas [lowland (L), midland (M), and highland (H)] of Nepal (Fig. 2b). We have used 40, 59, and 8 stations for LMH-wise study (Fig. 2a). There is high amplitude variation of intra-annual rainfall. In December, January, and February, highlands and midlands observed higher rainfall than lowlands. In April, May, June, July, September, and October low land received more rainfall than midland and highland in Nepal. In March highlands observed more rainfall than mid and lowlands. In August and November, midlands received more rainfall than highlands and lowlands. The rainfall of Nepal is observed to increase from January up to July maximum and decrease toward November minimum (Fig. 2a).

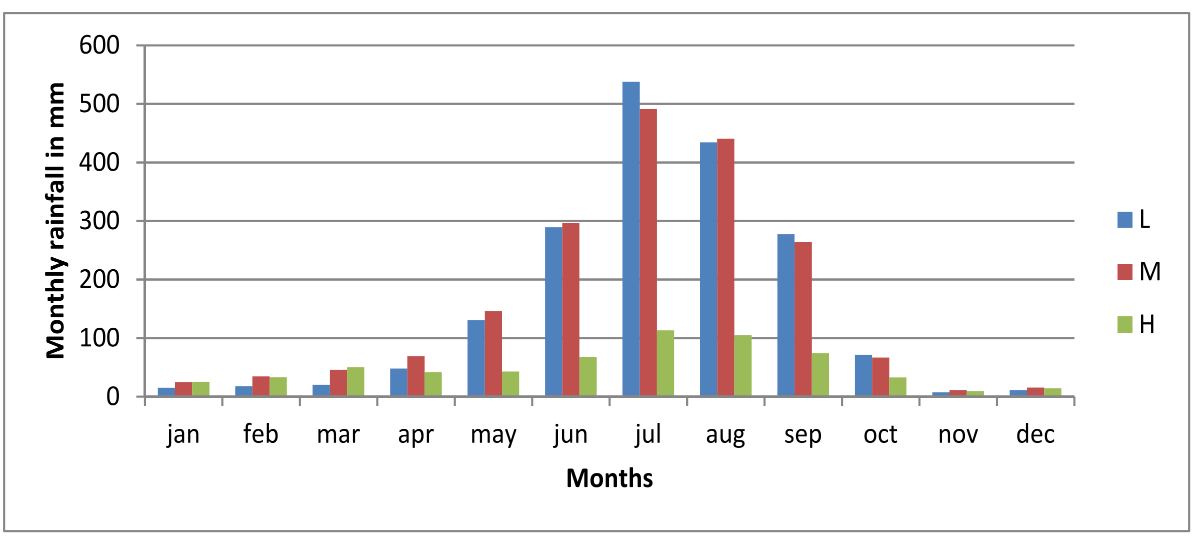

Fig. 2a: The average monthly rainfall figures showed fluctuation from 1977 to 2018.

Midland observed more rainfall than the lowlands and highlands annually (Fig.2b). In pre-monsoon and post-monsoon show similar rainfall patterns only the amount is different. Generally, the midland of Nepal received heavier rainfall than the lowland and highlands. Compared to mountainous and lowland areas, the Himalayan region received little rainfall during the pre-monsoon, monsoon, and post-monsoon seasons but received high rainfall in the winter season..

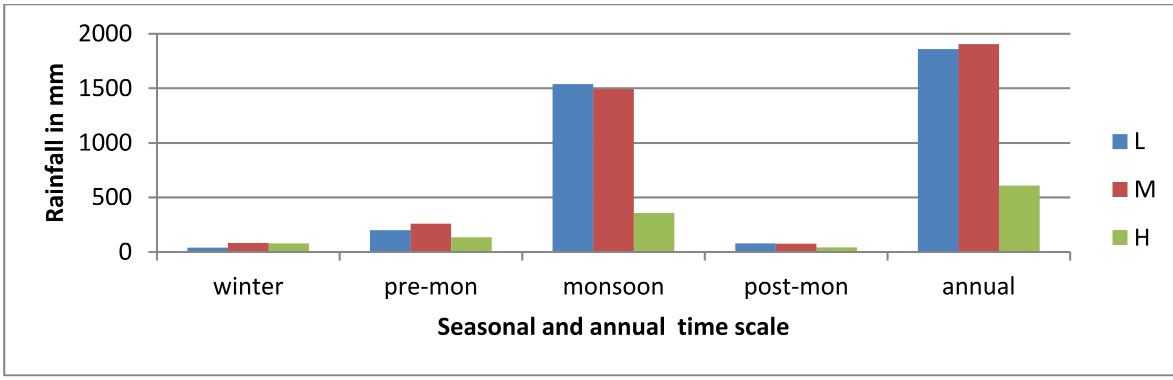

Fig. 2b: The average seasonal and annual rainfall figures from 1977 to 2018 in different regions lowland, midland, and highland (LMH) of Nepal.

Table 1: Regional and national rainfall statistics

Time scales	National	Lowlands	Midlands	Highlands
Winter	70.34	40.83	81.53	79.13
Pre-monsoon	228.36	198.64	260.66	134.69
Monsoon	1425.16	1538.32	1491.74	359.94
Post-monsoon	75.24	78.41	77.59	41.72
Annual	1791.52	1858.89	1904.34	608.49

Table 1 shows that the highlands had less total annual rainfall, it received more rainfall in the winter than other regions. From the lowlands to the midlands, there is an annual rise in rainfall. However, midlands regions in the central region had pockets of heavy rainfall. Pre- and post-monsoon rainfall levels in Nepal rise from the lowlands to the midlands but are negligible in the high-mountain regions.

Spatial distribution of annual rainfall

Annual rainfall in Nepal shows significant spatial variation, with rainfall decreasing from the eastern-central to the western regions (Fig. 3b). However, high mountainous areas of central Nepal receive more rainfall than other regions. Rainfall ranges from less than 200 mm in the lower Himalayan areas to over 4000 mm in central Nepal, highlighting the strong influence of topography on rainfall patterns across the country. Rainfall is somewhat heavy on the windward side of the region and very light on the leeward side. Because orographic forces predominate, the country's highest rainfall was recorded up to the midlands, after which it gradually dropped. The annual cycle of monthly rainfall is lowest in November and highest in July (Fig. 3a).

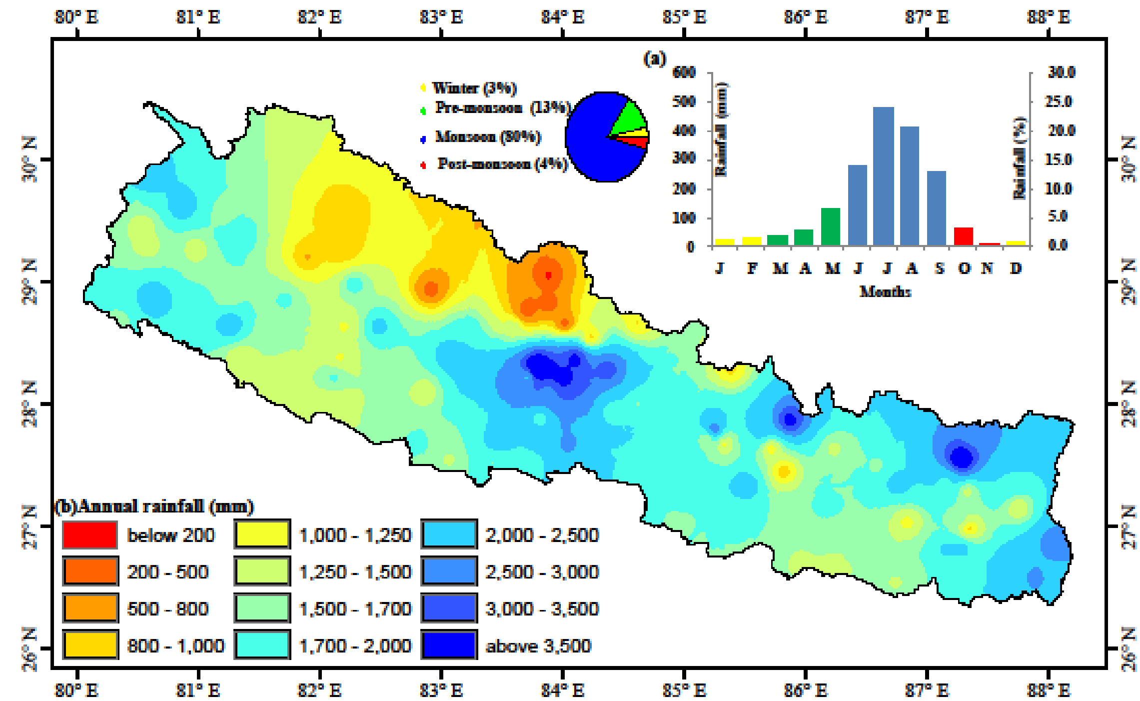

Fig. 3: Spatial variability of the average annual rainfall over Nepal from 1977 to 2018, along with the variability of the average monthly rainfall cycle from 1977 to 2018, and represented as a pie chart with the seasonal quantity of rainfall (%).

The monsoon season, from June to September, brings the majority of rainfall, with around 80% falling during this period of intense rainfall. The rest is distributed as follows: 3% during the pre-monsoon, 13% in the post-monsoon, and 3% in the winter (Fig 3a).

Temporal Rainfall Variability in Nepal

This study used rainfall data from 107 stations to analyze the temporal variation in rainfall. According to long-term climatology, Nepal receives 1791.52 mm of rain on average annually between 1977 and 2018. A significant inter-annual fluctuation occurs across the research periods. The statistical study indicates that during annual intervals, there is a temporal variability between the minimum rainfall in 1992 and the maximum in 1986.

The average rainfall data from 107 sites was used in this study to generate the temporal variability of seasonal rainfall. The long-term climatology from 1977 to 2018 showed that Nepal's average seasonal rainfall was 1433.42 mm for the monsoon season and 69.67 mm for the winter season. Similarly, long-term climatology indicates that Nepal receives 1791.52 mm of rainfall on average annually. The summer and winter seasons differ greatly from one another. According to the statistical analysis, there are 19 seasons with monsoon rainfall below the mean and 23 seasons with above-average rainfall (Fig. 4a). Similarly, Fig. 4b shows the variability of winter rainfall.

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The temporal variability of rainfall throughout the monsoon season ranges from minimums in 1992 to maximums in 1986. Since the monsoon rains predominate in Nepal each year, a similar pattern of rainfall was seen there as well. Comparably, it was shown that the variability of winter rainfall peaked in 1989 and decreased to a minimum in 2006. This study identified a significant rainfall deficit/excess during the monsoon and winter seasons over the last 42 years, as seen in Fig. 4(a, b)

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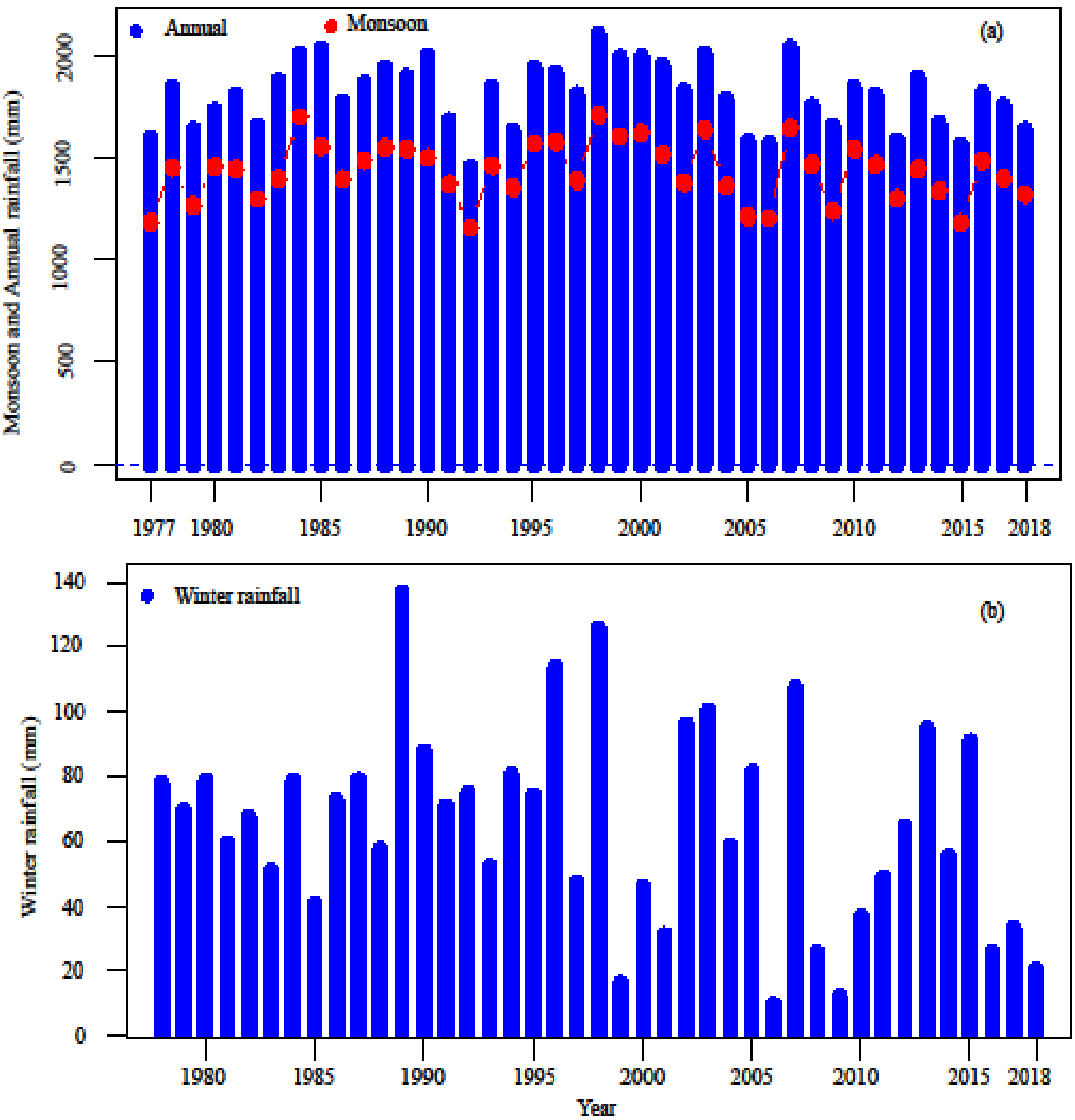

Fig. 4 Temporal variability of seasonal (winter and summer) and annual rainfall over Nepal averaged from 107 stations. The time series of seasonal and annual rainfall averaged over different regions from 1977 to 2018

During the seasonal and annual time scales there was a large variability of rainfall in deficit to excess episodes is clearly shown in Fig. 4a, and b.

LMH-wise temporal variations of winter, summer, and annual rainfall

Time series of seasonal and annual rainfall averaged over Nepal from 1977 to 2018 from monthly precipitation data of 107 stations in different regions. Out of 107 stations; we used 8, 59, and 40 stations for the Himalayas, Mountainous, and Terai regions for seasonal and annual rainfall analysis. The temporal variability of rainfall of different regions; winter, summer, and annual rainfall depicted in [Fig. 5 (a, b, c)]. Similarly, during the study period, the average seasonal and annual rainfall received in different regions are tabulated in Table 2.

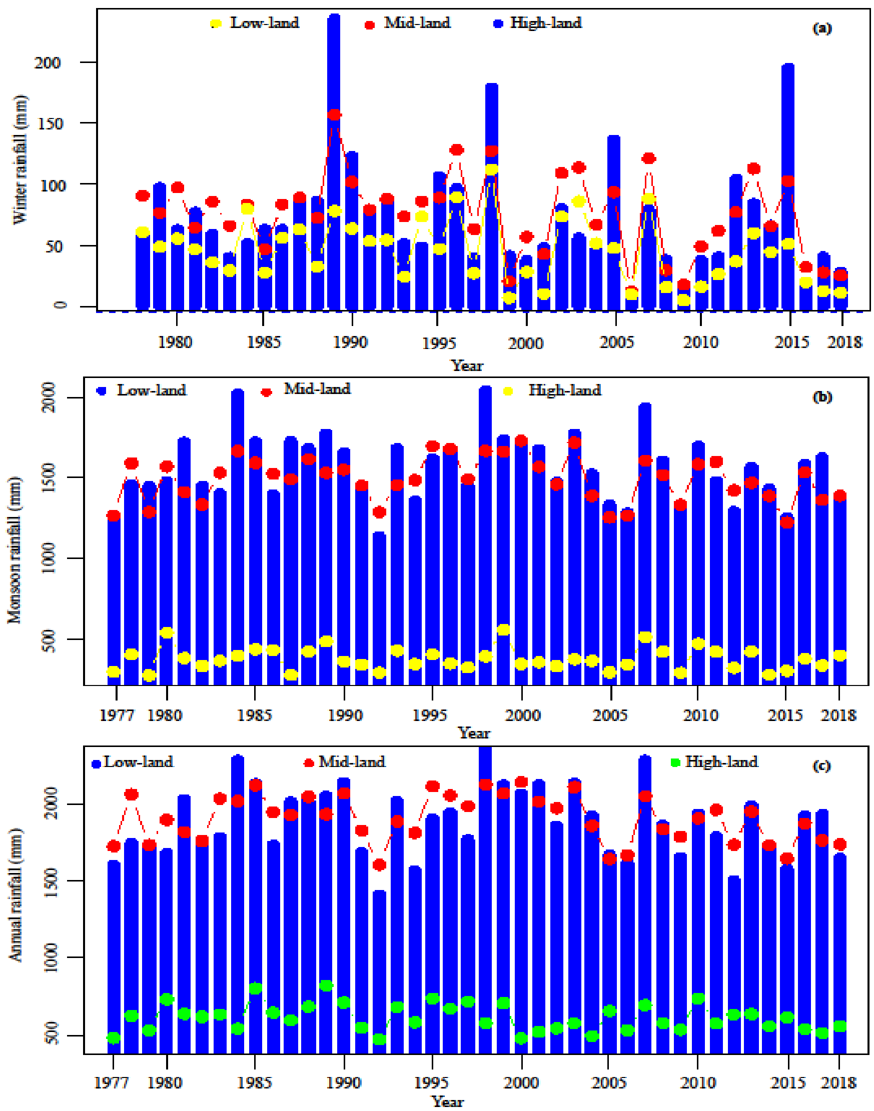

Fig. 5: Temporal variability of seasonal (winter, summer) and annual rainfall over the Himalayas, midlands, and lowlands of Nepal averaged from 8, 59, and 40 stations. The time series of seasonal and annual rainfall averaged over different regions from 1977 to 2018.

Table 3: Average rainfall of 1977-2018 for different regions and different time scales.

Regions	Winter	Summer	Annual
High-lands	79.12	359.94	608.49
Mid-lands	81.53	1491.74	1904.34
Low-lands	40.83	1538.32	1958.90

During the winter, summer, and annual seasons, there was a large variability of rainfall in deficit to excess episodes for the different regions only the magnitude is different in Fig. (5a, b, and c). The average winter, summer, and annual time steps season rainfall observed in highlands, midlands, and lowlands (Table 2). The temporal variability of low-lands, mid-lands, and high-lands rainfall was observed in (Fig. 4) and Table 3.

The highlands received a lower amount of total rainfall than the midlands and lowlands. The lowlands and midlands of Nepal observed neck-to-neck rainfall in comparisons between them. On average between them a little bit more in the lowlands. There is more rainfall fluctuation in the lowlands of Nepal. Lowlands received the maximum rainfall in 1999 and the minimum in 1992. Highlands received maximum precipitation in 1986 and minimum received in 1997. The midland observed more rainfall in 1986 followed by 1996. During the winter and summer seasons there was a large variability of rainfall in deficit episodes to excess episodes for the different regions only the magnitude is different Fig. (5a, b, c). During the winter and summer seasons, there was a large variability of rainfall in deficit episodes to excess episodes for the different regions only the magnitude is different in Fig. (5a, b)
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Discussion

The monsoon is the primary source of rainfall, accounting for approximately 80% of total rainfall during the monsoon season. Pre-monsoon rainfall is 13%, post-monsoon rainfall is 4%, and winter rainfall is 3%, as illustrated in Fig. 2(a). This study's findings are similar to previous research results (Karki et al., 2015; Kansakar et al., 2004) identified monsoons accumulate around 80% of annual rainfall totals.

Ichiyanagi et al. (2007) have noticed that rainfall increased from low land to high land up to 2000 m and normally rainfall totals decrease at higher elevations > 2000 m (especially in lesser Himalayas). The present study's findings resembled with above-mentioned researchers' findings decrease in rainfall in higher altitudes.

Total annual rainfall is very low in the Himalayas (Ichiyanagi et al., 2007; Bagale et al., 2023a). The region is dominated Indian monsoon system only the magnitude is variable. Compared to the Terai and Mountainous regions, the Himalayan region experienced greater rainfall during the winter months but less during other periods.

Rainfall variability in Nepal is highly unpredictable across different time scales, from intra-seasonal to decadal (Karki et al., 2017; Ichiyanagi et al., 2007; Bagale et al., 2023a). This study identified low and high rainfall patterns (Fig. 4a, b, c), with findings aligning with previous research. The results also match studies in India (Vorikoedal et al., 2015) and Bangladesh (Ahasan et al., 2010), supporting similar results.

The rainfall analysis identified that the monsoon rainfall decreased more than the winter rainfall in Nepal after 2000 the decreasing monsoon is more than winter. Similar results were presented by previous researchers in neighboring countries in India (Kumar et al., 2013). Similarly, Choudhary et al. (2003) noticed monsoon rainfall observed decreasing in Bangladesh
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Conclusion

This study analyzed rainfall data from 107 stations in Nepal between 1977 and 2018. It focused on the temporal variability of rainfall, examining variations across different time scales, including intra-seasonal, intra-annual, and inter-annual periods. The study has focused on the past four decades' overall rainfall patterns, dry and wet rainfall, and rainfall characteristics. Nepal has received high rainfall in the June to September months and the rest of the months received low rainfall causing water scarcity in Nepal. The highlands of Nepal have received low rainfall. The monsoon precipitation dominates the annual rainfall due to heavy monsoon rainfall. The monsoon and winter rainfall have large temporal variability during the study periods. However, rainfall totals both seasonal and annual have been decreasing since 2000. Furthermore, the average seasonal and annual rainfall received in Nepal was 63.97 mm/winter, 1422.42 mm/monsoon, and 1791.52 mm/annual respectively during the periods 1977-2018.

Acknowledgments

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