Rainfall variability in Kathmandu Valley, Nepal

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Abstract: This study examines rainfall variability in the Kathmandu Valley from 1971 to 2023, utilizing daily rainfall data from 19 weather stations. The annual, monthly, and seasonal means were determined. The results indicate that July is the wettest month, while November is the driest. Monsoon is the primary source of rainfall, accounting for 78.79%, followed by pre-monsoon (13.53%), post-monsoon (4.62%), and winter (3.06%). Overall average annual rainfall has fallen, including during the monsoon, post-monsoon, and winter seasons, with just a tiny increase during the pre-monsoon season. The spatial investigation found that the northern valley receives more rainfall, particularly in Sundarijal (Mulkharka), except during the post-monsoon season, when Godavari and Changu Narayan receive more. Middle elevations receive more rainfall than lower elevations. Kathmandu's rainfall has decreased in recent decades. The study reveals that the Kathmandu Valley experiences high rainfall variability, with large monsoon rains triggering flooding and extended dry spells leading to water scarcity. The trend study shows that yearly, and seasonal rainfall are decreasing. This emphasizes the importance of good water management measures for dealing with monsoon flooding and year-round water scarcity.

Keywords: Kathmandu Valley; Rainfall variability; Spatial; Temporal; Trends.

Introduction

Rainfall, a key climatic factor, has a considerable impact on water resources around the globe. Understanding rainfall patterns and trends is critical for water resources management, preparing for climate-related hazards, etc. Climate change and unpredictability complicate these patterns, emphasizing the importance of precisely identifying and quantifying changes in rainfall distribution[1].

Climatic phenomena, the El Niño-Southern Oscillation (ENSO) impact rainfall distribution globally. ENSO factors create significant inter-annual variability in rainfall, impacting regions differently and resulting in droughts and floods[2]. For example, the Indian summer monsoon, a vital water source for South Asia, shows significant seasonal variability and has been connected to ENSO episodes[3]. Recent studies have shown a drop in monsoon rainfall in South Asia, raising concerns about the region's future water security[4]. Additionally, Bangladesh has seen a decline in monsoon rainfall trends in recent decades[5], reflecting a broader decrease in monsoon rainfall across South Asia[4].

Nepal receives about 80% of its yearly rainfall between June and September, leaving the remaining eight months with limited rainfall[6]. While there have been studies on Nepalese rainfall variability[7, 8, 9,10,11,12], research on the Kathmandu Valley is limited[13, 14]. Devkota L.P.[14] examined data from 14 sites, including monthly rainfall from Kakani, and discovered a decline in monsoon rainfall in the Kathmandu Valley. Moreover, rainfall is the only source of both surface and groundwater in the valley, making rainfall analysis crucial for understanding water resource availability. This is sufficiency or scarcity is a major local concern, necessitating a comprehensive understanding of rainfall especially relevant in Kathamndu

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Received : 7 Jan, 2025; Received in revised form: 21 Mar, 2025; Accepted: 1 Apr, 2025.
Doi: https://doi.org/10.3126/sw.v18i18.78437

Valley, which has a population of over 3.3 million people[15] and where water sufficiency or scarcity is a major local concern, necessitating a comprehensive understanding of rainfall variation. This study aims to explore the mean monthly rainfall variability, seasonal rainfall totals, and rainfall percentage distribution across different valley locations. By analyzing some historical data, this study seeks to provide insights into the evolving rainfall patterns and their implications for future water resource management by determining relatively drier, wetter, and average locations within the valley. Notably, this is the first study to use such an extensive dataset to quantify rainfall variation over Kathmandu Valley.

Study area

The Kathmandu Valley spans an area of about 932 km² and has been selected for this study (Figure 1). The valley is a circular intermontane basin and geographically bordered by hills.

The study area has elevations ranging from about 415 to 2792 meters above sea level. The spatial distributions of the meteorological stations are shown in Figure 1 and details are tabulated in Table 1. The climate is influenced by the southwest monsoon bringing heavy rain during monsoon. Precipitation varies within the valley, with the northwestern regions receiving the most rain and the southern regions receiving the least[16].

Materials and Methods

Table 1: List of meteorological stations used in this study.

Station Name	Index No.	District	Latitude (° N)	Longitude (° E)	Elevation (M.a.s.l)	Years
Thankot	1015	Kathmandu	27.70	85.20	1552	48
Godavari	1022	Lalitpur	27.59	85.37	1527	53
Khumaltar	1029	Lalitpur	27.65	85.32	1334	53
Kathmandu airport	1030	Kathmandu	27.70	85.36	1339.5	53
Sankhu	1035	Kathmandu	27.74	85.47	1436	53
Panipokhari	1039	Kathmandu	27.72	85.32	1329	53
Nagarkot	1043	Bhaktapur	27.69	85.52	2142	53
Bhaktapur	1052	Bhaktapur	27.67	85.42	1315	53
ChanguNarayan	1059	Bhaktapur	27.71	85.42	1502	50
Chapagaun	1060	Lalitpur	27.60	85.32	1478	48
Khokana	1073	Lalitpur	27.64	85.29	1309	33
Sundarijal (Mulkharka)	1074	Kathmandu	27.77	85.42	1658	30
Lele	1075	Lalitpur	27.57	85.35	1590	30
Naikap	1076	Kathmandu	27.70	85.25	1477	27
Sundarijal (Alapot)	1077	Kathmandu	27.75	85.43	1384	26
Nagarjun	1079	Kathmandu	27.75	85.27	1393	26
Tikathali	1080	Lalitpur	27.65	85.36	1305	24
Jetpurphedhi	1081	Kathmandu	27.78	85.29	1409	24
Nangkhel	1082	Bhaktapur	27.64	85.46	1413	24

Data used and Methodology

The study used daily rainfall data from 19 weather stations in Nepal, covering the period from 1971 to 2023. Each station had at least 24 years of data. Monthly rainfall totals were calculated by adding daily data, and the average annual, seasonal, and monthly rainfall was computed using

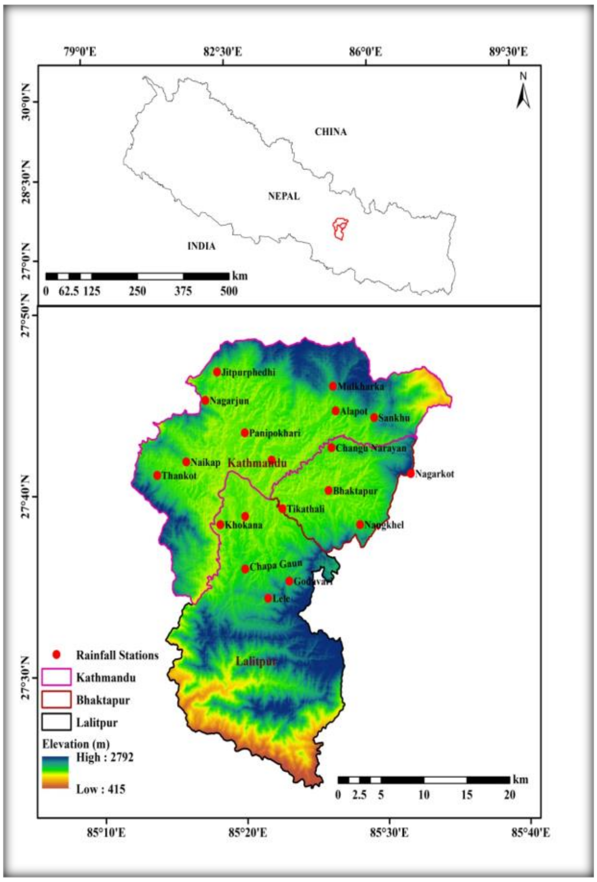

Figure 1: Study area location map with elevation-based rainfall stations.

the arithmetic mean method. The total annual rainfall was found by summing monthly totals from January to December. The months were grouped into four seasons: pre-monsoon (March to May), post-monsoon (October and November), monsoon (June to September), and winter (December to February). Data analysis was done after filling in any missing information, and stations were selected based on having fewer than 5% of missing records.

To estimate missing rainfall data, we used the Normal Ratio (NR) method, which relies on three nearby weather stations. This method was chosen because previous studies showed it worked better than other methods for filling in daily rainfall gaps[17, 16]. We also used the Inverse Distance Weighted (IDW) technique to interpolate and visualize seasonal and annual rainfall. This approach helps us understand how rainfall varies across the basin using Geographic Information System (GIS) tools[18, 19].

The rainfall data series' significance was examined using the Student's t-test.

Using the nonparametric rank-based Mann-Kendall (MK) test, the time series dataset's trends were examined [16, 20].

Results

Rainfall metrics

Figure 2 depicts the monthly average rainfall variation in the Kathmandu Valley. The data show that rainfall increased from January 15.47 mm to July 439.34 mm. Following this peak, rainfall gradually drops, reaching a low of 6.05 mm in November. December has the second-lowest rainfall; with an average of 12.47 mm. Figure 2 also shows that five months of the year receive less than an average of 35 mm of rainfall. Furthermore, the analysis showed that the Kathmandu Valley receives similar amounts of rain in April and October.

According to this study, the Kathmandu Valley receives an average of 78.79% (1333.25 mm) of its annual rainfall during the monsoon season and 3.06% (51.84 mm) during the winter season, which are the largest and lowest seasonal rainfall periods, respectively (Figure 2 and Table 2).

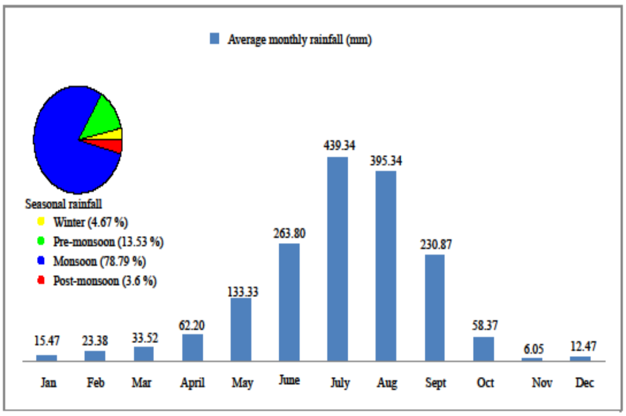

Figure 2: Average Monthly Rainfall and Seasonal Rainfall of Kathmandu Valley from 1971 to 2023.

Annual average rainfall and its variation

The monsoon season is the main source of the Kathmandu Valley's total annual rainfall. The mean annual rainfall varies significantly over different locations. The highest rainfall is recorded at the rainfall is recorded at the Sundarijal (Mulkharka) station, with 2182.13 mm, followed by Sundarijal (Alapot) with 1924.36 mm.

The northeastern portion receives more rainfall than the lower part of the valley. The lowest rainfall is recorded at Khumaltar, with 1232.78 mm, followed by Tikathali station

Table 2: Average Season-wise rainfall in Kathmandu Valley from 1971-2023.

Season	Winter	Pre-monsoon	Monsoon	Post-monsoon
Average rainfall (mm)	51.84	229.00	1333.25	78.11

with 1296.30 mm, and then Khokana and Naikap (Figure 3a).

The MK trend test was used to analyze the annual rainfall data to learn more about long-term rainfall changes. The results for Kathmandu Valley showed that more than half (13 out of 19) of the stations had a decreasing trend in rainfall, while the others showed an increasing trend (Figure 3b). However, the three stations i.e., Thankot, Lele, and Godawari, which are located in the western (former) and southern parts (later two stations) of Kathmandu Valley, exhibited a significant decreasing trend (Figure 3b). According to this analysis, the average annual rainfall from 1971 to 2023 decreased by 0.94 mm annually. The trend magnitude in the Kathmandu Valley varied between –21.57 mm/year and 5.99 mm/year (Figure 3b). In this study, except for the upper northern part, every other part shows a negative slope.

Seasonal trend

The results of the seasonal Mann-Kendall test (Figures 4a, b, c, and d) showed a decreasing trend in most of the stations except in the pre-monsoon season. During the winter season, most of the stations (13 stations out of 19) showed a decreasing trend, however, none of the stations showed a decreasing trend, however, none of the stations showed a significant trend (Figure 4a). During the winter, the lower southern part of Kathmandu Valley exhibited a mild negative slope whereas the northern part exhibited a positive value. Overall, the slopes varied from the lowest of -0.51 mm/year to the highest of 0.81 mm/year.

During premonsoon season, most of the stations (14 stations out of 19) showed an increasing trend. However, two stations (Khumaltar and Nangkhel) showed a significant increasing trend (Figure 4b). Likewise, during the pre-monsoon season Kathmandu Valley, located in the central, western, and peripheral parts exhibited a mild positive slope. The slopes varied between the values of -1.93 mm/year to 3.66 mm/year.

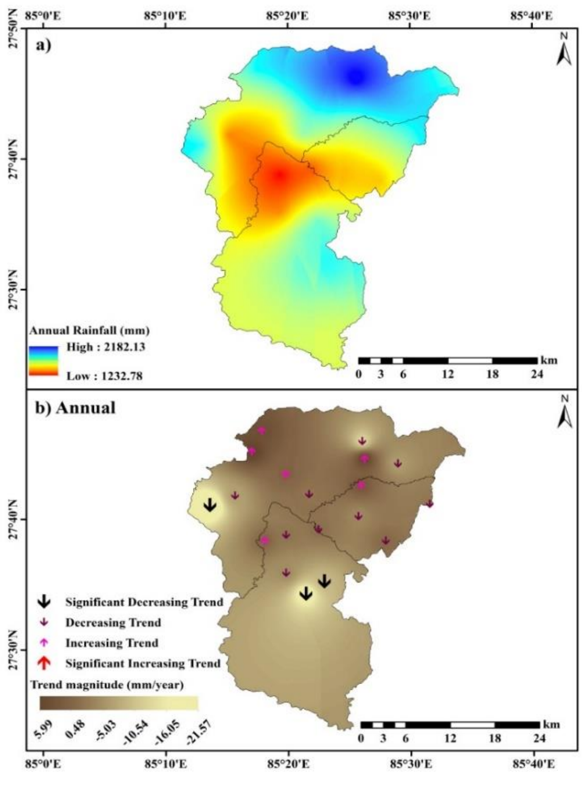

Figure 3: The spatial distribution of annual rainfall (a), the stations with significant trends from the Mann-Kendall analysis, and the trend magnitude (mm/year) from Sen's technique are displayed (b), for the Kathmandu Valley from 1971 to 2023.

Similarly, during the monsoon season, most of the stations (13 stations out of 19) showed a decreasing trend whereas five stations (Thankot, Godawari, Sankhu, Bhaktapur, and

Lele) showed a significant decreasing trend (Figure 4c). It is noted that in the monsoon season, the negative slope lies in most of the Kathmandu Valley while a few northern regions showed positive slopes which are varied -19.09 mm/year and 7.10 mm/year.

Furthermore, during the post-monsoon season, most of the stations (14 stations out of 19) showed a decreasing trend whereas five stations (Thankot, Godawari, Sankhu, and Panipokhari) showed a significant decreasing trend (Figure 4d). The spatial distribution of trend magnitude during postmonsoon showed that almost every part of the Kathmandu Valley has negative slopes, whereas in the few upper parts slopes are positive, which varied from -1.42 mm/year and 2.12 mm/year.

Spatial variation of mean annual and seasonal rainfall

Spatial rainfall analysis involves the study of rainfall distribution and variability across a specific area using statistical methods, and geostatistics, techniques. This analysis aims to model and understand the spatial and temporal patterns of rainfall, flood forecasting, water resource management, and agricultural planning. By deciphering these patterns, areas prone to flooding or drought can be identified, allowing for targeted interventions to mitigate risks. Spatial analysis also facilitates estimating rainfall in locations without monitoring stations, aiding in the study of hydrological and cryosphere systems. Interpolated GIS images depicting annual and seasonal rainfall distributions are illustrated in Figures 3a and 5 a, b, c, d.

While each season exhibits unique spatial rainfall distribution, annual and monsoon seasons generally display similar patterns, likely due to the monsoon contributing approximately 79% of the total annual rainfall. The average annual rainfall in Kathmandu Valley is 1652 mm, with Sundarijal (Mulkharka) recording the highest annual rainfall at 2182.13 mm, followed by Sundarijal (Alapot) at 1946.09 mm, and Sankhu with 1924.36 mm. Areas such as Thankot, Godavari, Kathmandu Airport, Nagarkot, Changu Narayan, Lele, Nagarjun, and Jitpurphedi also receive above-average rainfall. High rainfall pockets are observed in the middle to high elevations of the northern region, while lower rainfall, below 1300 mm, is noted in Khumaltar and Tikathali. The northern part of Kathmandu Valley generally receives more rainfall compared to other regions. Figure 5a illustrates the spatial distribution of average rainfall across Kathmandu Valley from 1971 to 2023, highlighting stations at higher elevations that consistently receive above-average rainfall.

Spatial variation of rainfall in winter season

During the winter season, the spatial distribution of winter rainfall across the valley is visually represented in the isohyetal map (Figure 5a), illustrating varying rainfall level across different locations. Among the studied areas, Thankot received the highest amount of rainfall at 63.74 mm, while Panipokhari recorded the lowest at 38.45 mm, highlighting significant spatial variability in winter rainfall within the Valley.

Among the monitored stations, Sundarijal, located in the northern part of the valley, received the highest pre-monsoon rainfall at 304.42 mm, while Chapagaon, situated in the central southern part, received the lowest at 176.36 mm. This spatial variability of pre-monsoon rainfall is visually represented in Figure 5b, which illustrates the distribution and intensity of rainfall across different locations within the Kathmandu Valley.

In the Kathmandu Valley, the spatial distribution of rainfall during the monsoon season exhibits notable variations. Sundarijal (Mulkharka) station, located in the northern part of the valley, recorded the highest rainfall amounting to 1803.85 mm, whereas Khumaltar, situated in the central part, received the lowest amount at 929.04 mm. This gradient in rainfall distribution is visually represented in Figure 5c illustrates that areas surrounding Kathmandu receive higher monsoon precipitation compared to the central regions of the valley. Moreover, within the Kathmandu Valley, Kathmandu district receives more rainfall during the monsoon season compared to Bhaktapur and Lalitpur districts.

This seasonal analysis reveals a significant spatial variability in post-monsoon rainfall throughout the region Many locations exhibit average rainfall within the range of 40-60 mm, as illustrated in Figure 5d. Notably, Panipokhari recorded the highest post-monsoon rainfall, receiving 89.95 mm, while Naikap experienced the lowest rainfall, with just 48.06 mm. This spatial variation in post-monsoon rainfall is depicted in Figure 5d, which highlights the differences in rainfall distribution across the valley. The map demonstrates how topography and local climatic conditions influence rainfall patterns, with certain areas receiving significantly more or less rainfall than others during the post-monsoon season.

Temporal variability of annual and seasonal rainfall of Kathmandu Valley

Figure 6 depicts the average annual temporal variation of rainfall in the Kathmandu Valley which was calculated using data from 19 stations during a period spanning from a maximum of 53 years to a minimum of 24 years. The analysis shows an average annual rainfall of 1677.92 mm. The maximum average annual rainfall was recorded in 1985 (2252.51 mm), while the lowest was in 2009 (1180.21 mm). Notably, rainfall above 2000 mm happened five times: 1973, 1978, 1985, 1994, and 2022. The study shows an increase in the number of years with more than 2000 mm of rainfall, with a huge 28-year gap between 1994 and 2022. Furthermore, the average annual rainfall for many of the investigated years ranged from 1450 mm to 1900 mm.

Positive values indicate rainy or surplus years, whereas negative values indicate dry or deficit years of varying intensity. Figure 6 depicts the annual anomaly for the Kathmandu Valley. In this 53-year time (1971-2023), 27 years are positive and 26 are negative anomalies. It demonstrates that 1985 was the most positive anomaly

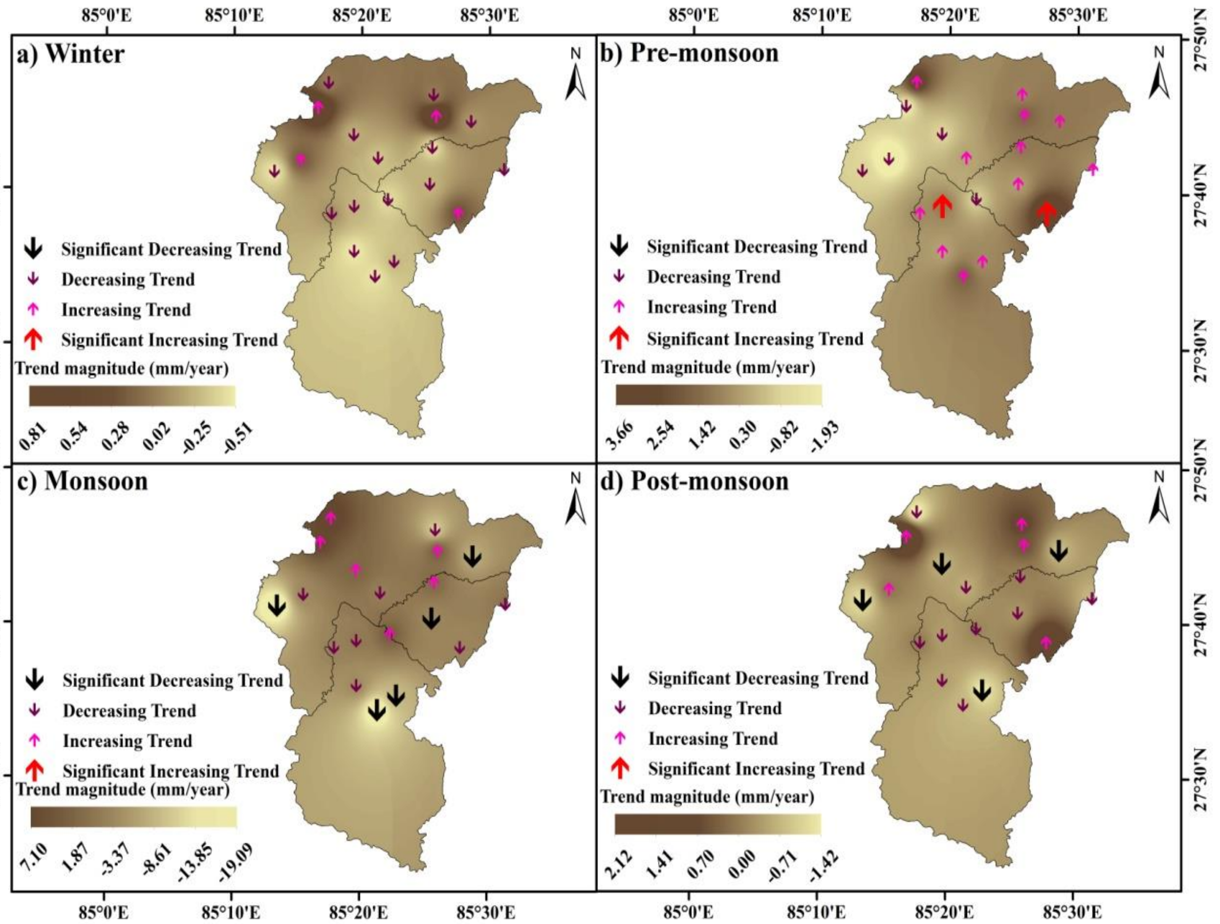

Figure 4: The spatial distribution of stations with significant trends from the Mann-Kendall analysis is displayed together with the trend magnitude (mm/year) from Sen's analysis, for seasonal time series data from 1971 to 2023.

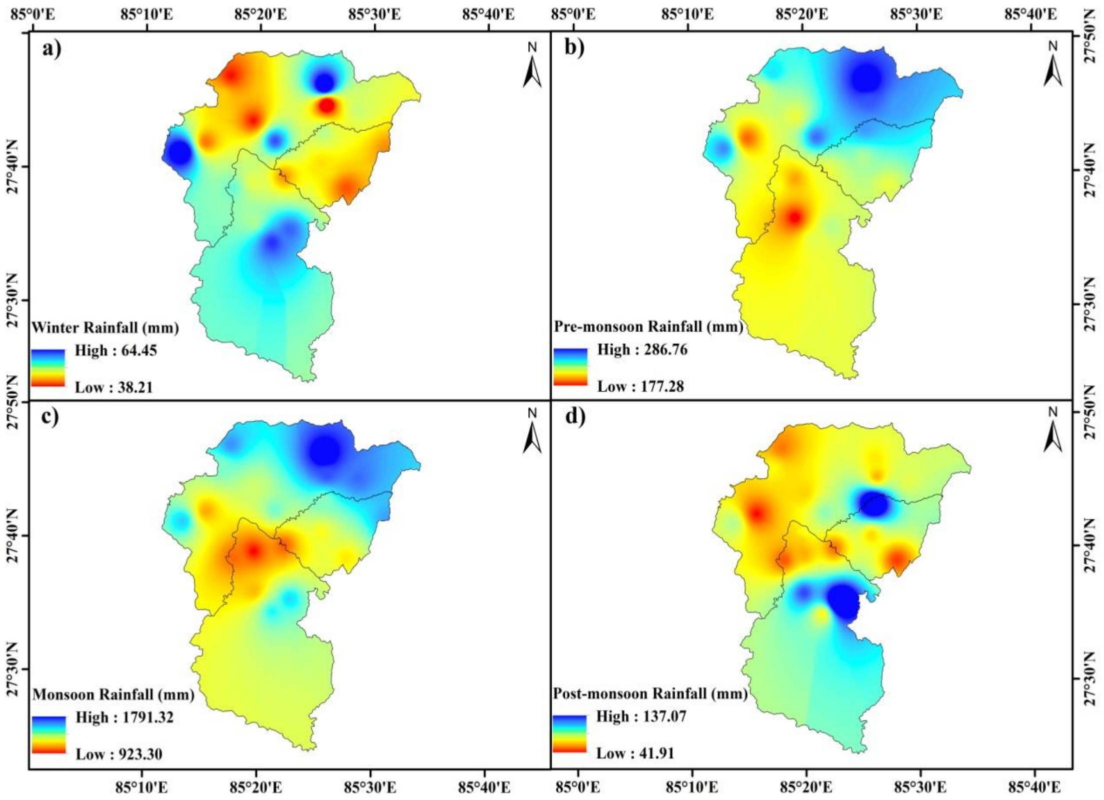

Figure 5: Spatial variation of seasonal rainfall in Kathmandu Valley (1971-2023).

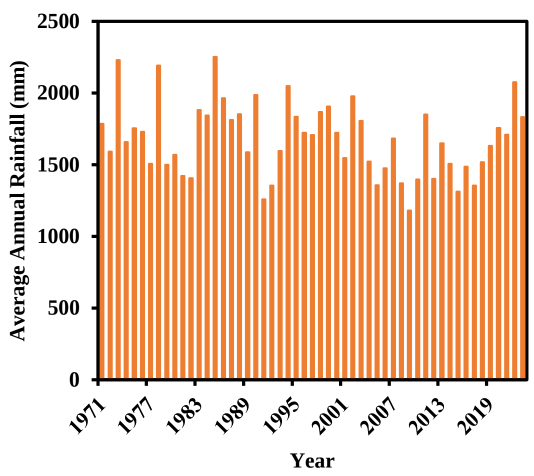

Figure 6: Average annual rainfall variation of the stations.

year, while 2009 was the most negative. Four positive anomaly years were detected, and the positive values represented rainy or surplus years, while the negative values represented dry or deficit years of varying intensity. Two negative anomaly years exceeded the number of 400. Before 2003, two periods had more than 5 years of consecutive positive anomaly, from 1983 to 1988 and 1994 to 2000, respectively, however since 2003, two periods of negative anomaly extended for 5 years, from 2004 to 2010 and 2012 to 2019. It indicates that average rainy years dropped between 2003 and 2019. However, the recent four years demonstrate a positive anomaly.

Seasonal temporal variability of rainfall and its anomaly

Figure 8a illustrates that the year 1998 had the maximum winter rainfall of 139.60 mm, while the winter of 2005 had less than 1 mm of rainfall. Only 10 of the 52 winters investigated received more than 80 mm of rainfall, whereas the other 42 winters did not exceed this threshold. A closer look at the last eight winters (2015-2022) reveals significant variability, with some years receiving more than 90 mm of rainfall while others receiving less than 20 mm. The mean winter rainfall in Kathmandu Valley averages approximately 51.84 mm.

This study found that the average pre-monsoon rainfall was 229.00 mm, with the maximum reported rainfall of 376.59 mm in 2002 and the lowest of 104.25 mm in 2006. Figure 8b illustrates that only six years of the 53 years had less than 150 mm of rainfall, while nine years had more than 300 mm. Furthermore, the most recent six-year pattern has seen average pre-monsoon rainfall ranging from 200 mm to 300 mm.

The summer monsoon, commonly referred to as the monsoon season, is characterized by high seasonal rainfall as Kathmandu Valley receives nearly 79% of its annual rainfall during this period. Figure 8c illustrates that the average monsoon rainfall over the 53 years is 1333.25 mm The driest monsoon within this timeframe occurred in 2009 with 915.85 mm of rainfall, while 1991 also experienced a notably dry monsoon with 955.11 mm. Conversely, the wettest monsoon was recorded in 1973 with 1791.79 mm, followed closely by 1994 with 1778.17 mm. For the majority of the years, average monsoon rainfall ranged between 1000 and 1500 mm. There were five years with more than 1600 mm of average rainfall, but these occurrences are increasing over time. As shown in Figure 5.11, the most recent year with more than 1600 mm of rainfall was 2022, the first such instance since 1994.

The analysis of post-monsoon rainfall in the Kathmandu Valley over the period from 1971 to 2023 revealed an average rainfall of 78.11 mm. Notably, there was considerable variability in the post-monsoon rainfall during this period. The lowest recorded post-monsoon rainfall occurred in 2018, with a mere 11.49 mm, highlighting a year of significant rainfall deficit. In contrast, the highest occurred in 2018, with a mere 11.49 mm, highlighting a year of significant rainfall deficit. In contrast, the highest recorded post-monsoon rainfall was in 1985, with an exceptional 236.15 mm. Throughout the study period, post-monsoon rainfall exceeded 150 mm in six different years, indicating sporadic instances of unusually high rainfall. The most recent occurrence of post-monsoon rainfall surpassing 150 mm was in 2022, marking a notable event after a 23-year gap (Figure 8d). This trend underscores the significant year-to-year fluctuations in post-monsoon rainfall within the Kathmandu Valley.

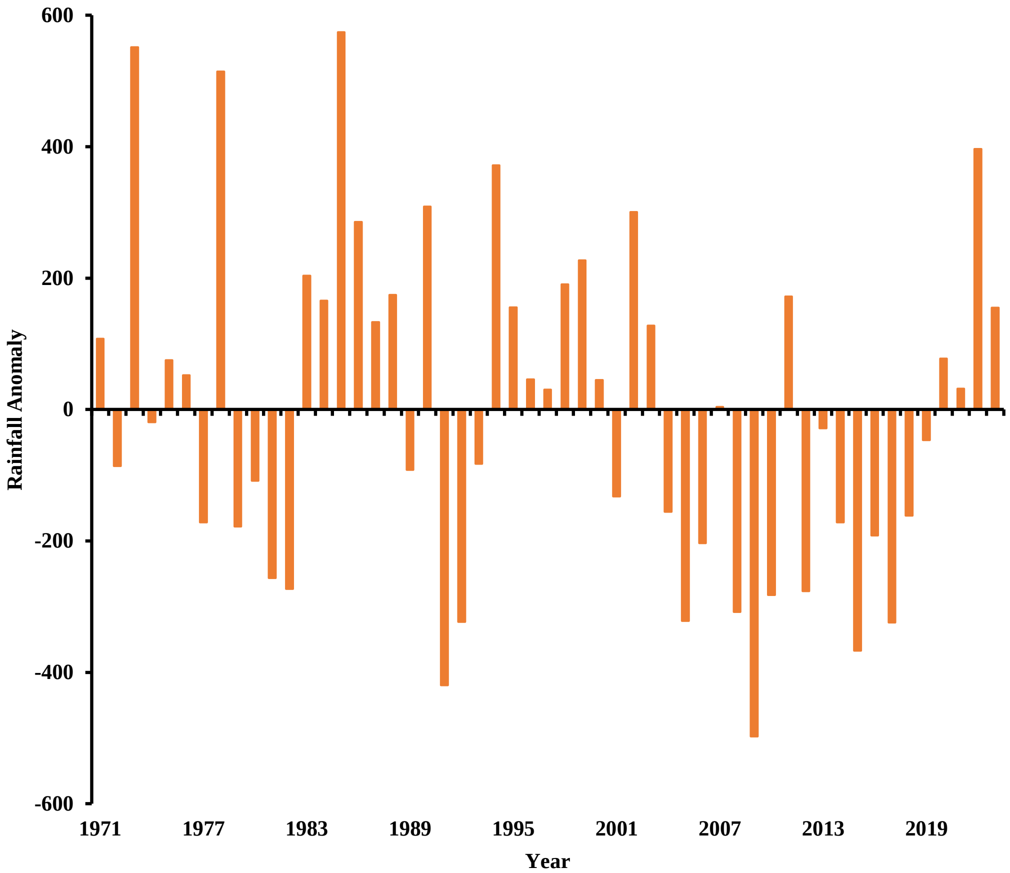

Figure 7: Average annual rainfall anomaly of Kathmandu Valley.

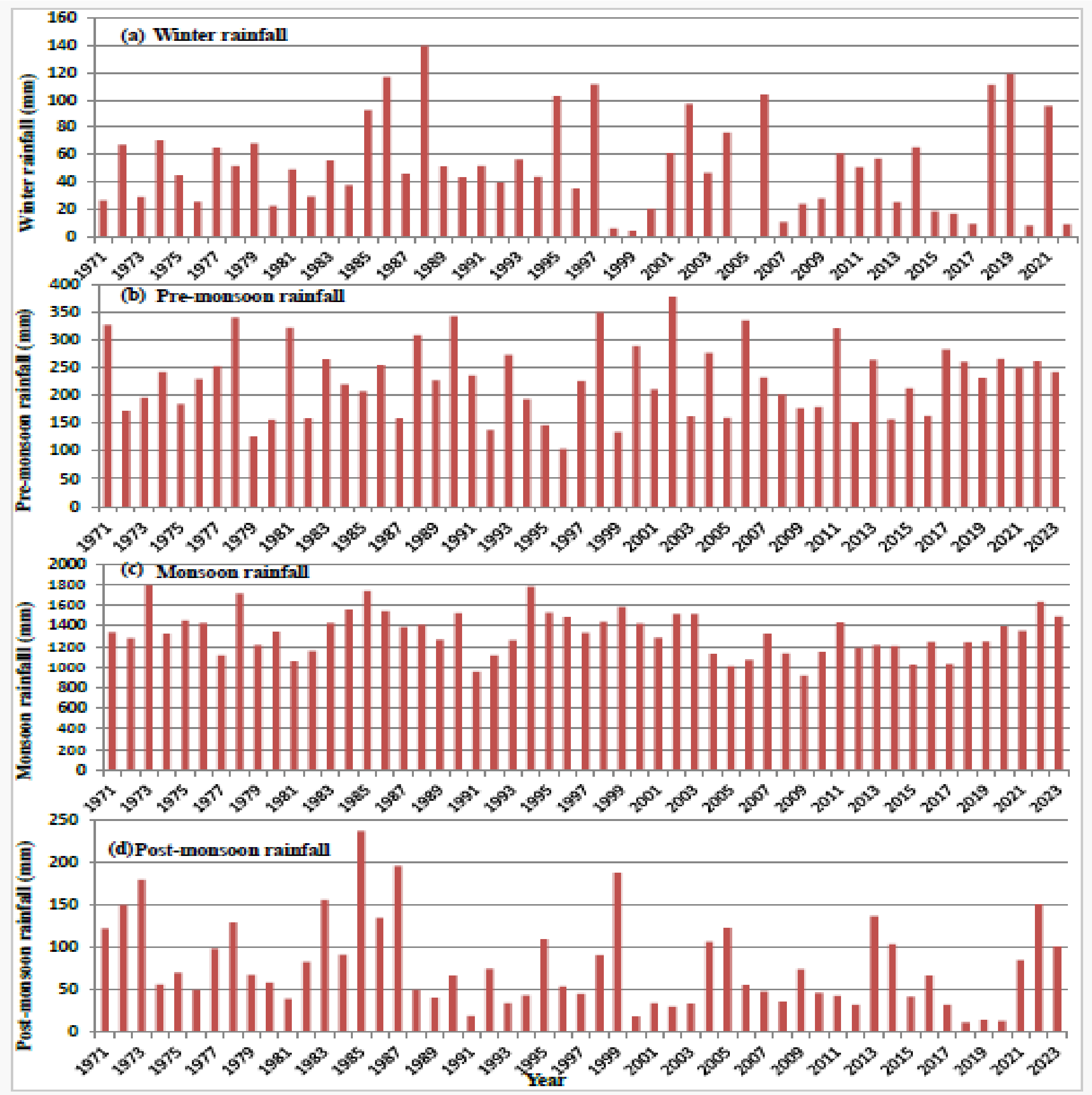

Figure 8: Average seasonal variability of rainfall of Kathmandu Valley.

As depicted in Figure 9a, the average winter anomaly indicates that 22 years had a positive anomaly, while 30 years exhibited a negative anomaly. In the last 16 winters, only six years had positive anomalies, whereas the remaining ten years showed negative anomalies with high deviation. This pattern indicates that winters have become drier over the past one and a half-decades.

Figure 9b displays the anomaly of the average pre-monsoon rainfall over 53 years. Out of these years, 27 exhibit a positive anomaly while 26 show a negative anomaly. From 1996 to 2023, there is a noticeable gradual decrease in the peak anomaly values, whether positive or negative. Specifically, the positive anomaly values were 147.59 in 2002, 105.63 in 2006, 91.78 in 2011, 53.71 in 2017, 35.97 in 2020, and 13.24 in 2023. Although the anomalies over the last five years remain positive, they are very close to the normal value.

Figure 9c displays the anomaly of the average monsoon rainfall over 53 years. Out of these years, 32 exhibit a positive anomaly while 21 show a negative anomaly. From 1971 to 2003, there was not a noticeable change in the peak anomaly values; however, most of them were positive. Specifically, since 2004, negative anomalies highly dominate but after 2019, the anomalies remain positive, which is very close to the normal value.

As depicted in Figure 9d, the average winter anomaly indicates that 21 years had a positive anomaly, while 32 years exhibited a negative anomaly. In the recent decade, most of the years had negative anomalies with high deviation. This pattern indicates that post-monsoon has become drier over the past decades.

However, from last three years showed a positive anomaly.

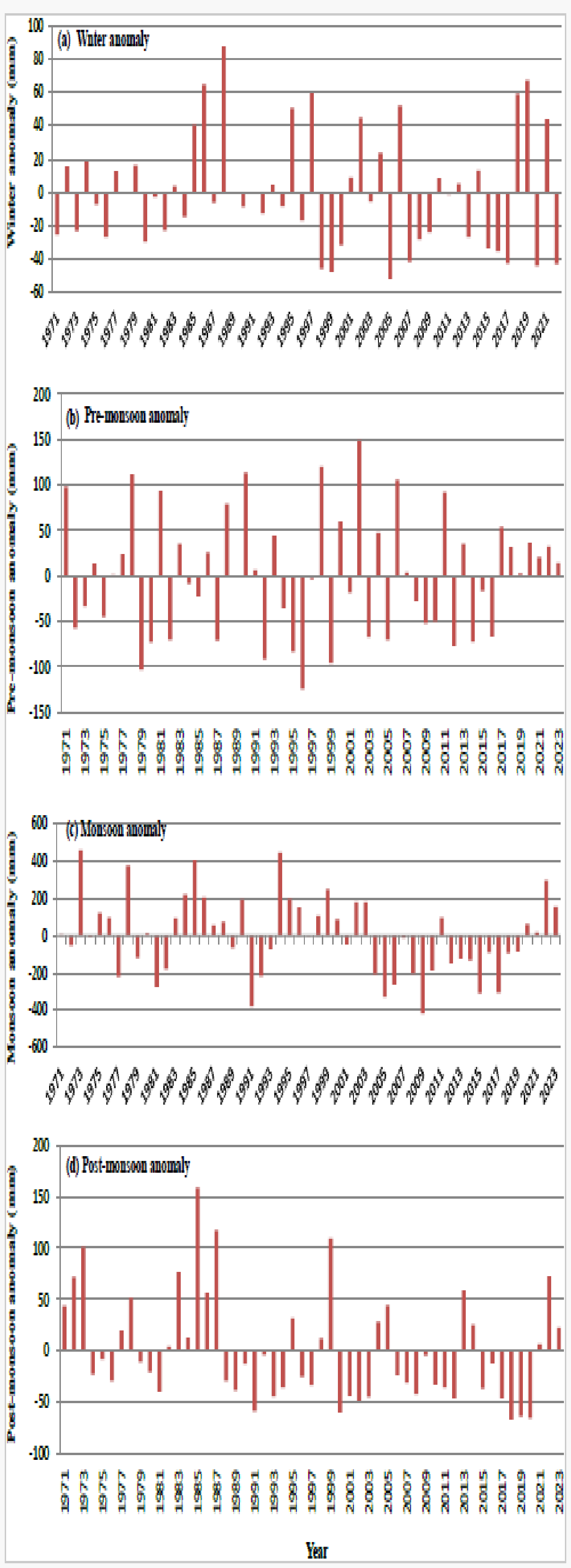

Figure 9: Average seasonal rainfall anomaly of Kathmandu Valley.

4. Discussion

The monthly rainfall data from various stations in the Kathmandu Valley, as well as the valley's average monthly and seasonal rainfall, are consistent with the findings of [14,16]. This consistency verifies our findings and highlights the region's continuous rainfall patterns.

The trend analysis conducted in this study revealed a decreasing trend in the valley's annual rainfall, which is consistent with broader regional trends. For instance, a study indicated that Bangladesh experienced a decrease in average monsoon rainfall from 1961 to 2010 by [5]. Similarly, the trend analysis revealed that yearly rainfall in Kathmandu Valley has declined across the studied period. A comparable finding revealed that seasonal and annual rainfall in Nepal has been declining for several decades. Comparably[16] found that monsoon rainfall in Kathmandu Valley declined (0.96 mm/year) between 1977 and 2013. The region responsible for the decreased rainfall was the weakening of monsoon rainfall in summer and westerly winds in winter. Moreover, our study identified a decreasing trend in annual rainfall over the Kathmandu Valley from 1971 to 2023, with most regions showing significant declines (Figure 3b).

The study data show that the monsoon months account for around 78.79% of annual rainfall in the Kathmandu Valley, followed by the pre-monsoon period (13.53%), the post-monsoon period (4.62%), and the winter season (3.06%). This seasonal pattern emphasizes the valley's reliance on monsoon rains, which cause flooding during these months, and water scarcity or drought during the other eight months. This trend is comparable with prior research by[6, 16]

Our study's temporal examination of rainfall trends is consistent with the findings of[21], those who investigated long-term geographical and temporal rainfall trends in Kathmandu, Nepal. The investigation revealed that both annual and monsoon rainfall decreased between 2003 and 2018. In our analysis, we saw a significant decrease in rainfall after 1990 (Figure 4). This drop could be due to the southwest Indian monsoon circulations, which have shown diminishing tendencies in recent decades[22].

Our research of monthly precipitation data from 1971 to 2023 found a significant rise in precipitation beginning in May, peaking in July due to the summer monsoon, and falling to its lowest point in November. The monsoon is responsible for Kathmandu's annual rainfall. These findings are corroborated by previous research, notably by[16, 23, 24,] which found comparable seasonal rainfall patterns. Furthermore, the monsoon is the main source of annual rainfall in Nepal supported with previous studies [25, 26, 27].

In conclusion, the findings of this study support earlier studies on rainfall trends and seasonal distributions in the Kathmandu Valley and the larger South Asian region. The observed decreasing trends in annual and monsoon rainfall, together with the valley's high seasonal precipitation concentration, show its vulnerability to flooding and water scarcity. These findings highlight the significance of creating adaptable water management techniques to handle the problems faced by shifting rainfall patterns in the Kathmandu Valley.

Conclusion

The study investigated daily rainfall data from 19 meteorological stations in the Kathmandu Valley from 1971 to 2023. The Kathmandu Valley has an average annual rainfall of 1677.92 mm. The seasonal means were (51.84, 229.00, 1333.25, and 78.11) mm respectively for winter, pre-monsoon, monsoon, and post-monsoon. The MK test was used to identify the significance of increasing or declining trends.

The findings showed that July is the wettest month while November is the driest. The monsoon season contributes to 78.79% of the annual rainfall. Despite an increase in monsoon rainfall percentages in recent decades, the overall average annual rainfall has declined, especially during the monsoon, post-monsoon, and winter months. Only the pre-monsoon season saw a small increase in rainfall.

Spatially, the northern half of the valley receives more rainfall, with Sundarijal (Mulkharka) receiving the most during all seasons except the post-monsoon, when Godavari and Changu Narayan receive more. The Kathmandu Valley's middle elevation sections receive more rainfall than the lower elevations. The analysis shows a decline in yearly, post-monsoon, and winter rainfall. Although the percentage of monsoon rainfall has increased, the drop in post-monsoon rainfall indicates significant issues for groundwater recharging, resulting in a drier Kathmandu Valley.

There is significant spatial variability, with the top parts of the valley receiving more seasonal and annual rainfall than the lower sections. The trend analysis revealed a large rise in yearly rainfall at one station, whereas five stations showed significant decreases. Overall, the study suggests that Kathmandu Valley experiences a contradiction of excessive monsoon rainfall, which causes flooding, and lengthy dry periods, which result in water scarcity. This highlights the importance of good water management methods to meet both excess water during the monsoon season and shortages throughout the year.

Author Contributions

Santosh Bhattarai and Damodar Bagale designed the study. Santosh Bhattarai performed data analysis, wrote an original draft, and prepared a paper with significant input from Damodar Bagale and Suraj Shrestha.

Acknowledgment

Nepal Government's Department of Hydrology and Meteorology is acknowledged for providing observed rain gauge data.

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