ZIBELINE INTERNATIONAL™ PUBLISHING
E-ISSN: 2990-9295
CODEN: MAGACU

Malaysian Applied Geography (MAGG)

DOI: http://doi.org/10.26480/magg.02.2024.95.100

CrossMark

RESEARCH ARTICLE

VARIABILITY OF WINTER RAINFALL OVER NEPAL DURING THE DRY YEARS

Damodar Bagale, Madan Sigdel*, Deepak Aryal and Binod Dawadi

Central Department of Hydrology and Meteorology, Tribhuvan University, Kathmandu 44613, Nepal
****Corresponding Author Email: madan.sigdel@cdhm.tu.edu.np***

ARTICLE DETAILS

Article History:

Received 01 December 2024
Revised 03 January 2025
Accepted 05 January 2025
Available online 06 February 2025

ABSTRACT

This study investigated winter rainfall variability from 107 meteorological stations from 1977 to 2018. The average winter rainfall was observed at 63.97 mm. The yearly contribution of winter rainfall variability was 7.04% in 1989 and 0.68% in 2006. There were diverse winter rainfall dynamics over the western, central, and eastern regions. The intrinsic heavy rainfall patterns observed on high complex mountain ranges in the central and eastern regions are in contrast to the minimum rainfall observed in the low land of the eastern regions. The study identified eight winter large dry years based on standardized anomalies. Among those years, 2006 was the worst drier year which quantifies a significant rainfall deficit of about 50 mm from an average rainfall. Major dry winter episodes frequently evolved whole Nepal as well as in different regions in a couple of decades. The western region had observed a large dry winter episode in the year 1999. Similarly, the central and eastern regions had observed deficit winter anomalies in 2006. There were two successive 2008-2009 and three successive drier episodes from 2016 to 2018 observed in recent decades.

KEYWORDS

Rainfall; dry years; variability; winter; Nepal

1. INTRODUCTION

The Asian monsoon circulation system has an annual cycle and fluctuates sporadically on intra-seasonal, annual, and inter-annual timeframes with a high amplitude, and has two separate wet and dry phases (Webster et al., 1998). According to Webster et al. (1998), the "dry phase" is the half of the year when the wind brings cool, dry air from the continents. Particularly in the Karakoram, Hindu Kush, and northern Indian and Nepalese regions, the Western Disturbances increase winter rainfall (Dimri et al., 2015; Dimri, 2006; Lang and Barros, 2004). The development of snow and glaciers in this area was greatly aided by the hilly northwestern regions of India and Pakistan (Dimri et al., 2015). The primary cause of winter precipitation in Nepal is synoptic weather disturbances, which differ dynamically from monsoon season weather patterns (Barlow et al., 2002, 2005). During the winter, extra-tropical storms, often referred to as western disturbances, are directed toward Nepal by the westerly jet stream that forms over the southern Himalayas (Wang et al., 2013). Strong seasonal variations in the frequency of winter storms are associated with the polar/Eurasian teleconnection pattern (Li et al., 2008; Lang and Barros, 2004). This pattern connects Nepal's winter climate to other, more extensive natural climate variability, like the North Atlantic and Arctic Oscillations (Wang et al., 2013). Although winter precipitation is essential for groundwater recharges, drinking water supply and management, irrigation, and agricultural practices, it predominates over the summer precipitation in Nepal. In terms of naturally occurring high rainfall patterns, the intricacy and distinctive pattern of the mountainous areas of central and eastern Nepal are still mainly unknown. In mountainous and Terai regions, dry conditions were brought on by variations in winter precipitation patterns. In Terai and hilly rural communities, dry conditions have impacted livelihoods, agricultural productivity, and drinking water. But up until now, it hasn't been thoroughly documented from both a regional and a national standpoint.

Few previous research has been conducted on Nepal's winter rainfall (Hamal et al., 2020; Karki et al., 2015; Sigdel and Ikeda, 2012; Shrestha et al., 2000). Along with the ocean-atmosphere circulations, examined the inter-annual variation of winter precipitation over Nepal (Hamal et al., 2020). Karki et al. (2015) studied seasonal rainfall trends. According to Sigdel and Ikeda (2012), Nepal's rainfall variability is impacted by the seasonal contrast of ocean-atmospheric circulations. Shrestha et al. (2000) determined the connection between rainfall and large-scale circulations. In Nepal, the Southern Oscillation Index (SOI) and winter rainfall exhibit a slight association (Sigdel and Devkota, 2013; Shrestha et al., 2000). Furthermore, research on winter dry years that is basin-specific and regionally limited is lacking. Nevertheless, there hasn't been winter rainfall research with several stations and long-term observed data sets over Nepal in recent years. The spatial distribution of winter rainfall variability in each of Nepal's main dry years is not documented. The country's major dry spells and the regional variability of winter rainfall is still lacking.

According to the study's research premise, Nepal has seen a steady increase in winter dry rainfall episodes over the past few decades, and climatic changes may be hastening this trend. This paper's primary goal is to calculate how much winter rainfall Nepal has received over the past forty years. In a similar vein, this study examines how winter rainfall varies in the eastern, central, and western regions. The particular goals are to (a) determine which significant dry events occurred throughout the research period and (b) examine how these episodes developed over time and space.

2. MATERIALS AND METHODS

2.1 Study Area

Nepal is a landlocked country with mountains that is situated in the central Himalayan area of South Asia. Its latitude ranges from 26° 22´to 30° 27´ N and its longitude ranges from 80° 04´ to 88° 12´E (Fig.1). With a total size of 147516 square kilometers, the country is 885 kilometers long from east

Quick Response Code	Access this article online	
	Website: www.magg.com.my	**DOI:** 10.26480/magg.02.2024.95.100

Cite The Article: Damodar Bagale, Madan Sigdel, Deepak Aryal and Binod Dawadi (2024). Variability of Winter Rainfall Over Nepal During The Dry Years. *Malaysian Applied Geography, 2(2): 95-100.*

to west and 130 to 260 kilometers long from north to south. The country has been further separated into its eastern, central, and western regions for the sake of this study. To do this, we analyzed the geographical and temporal variability of rainfall in the western, central, and eastern regions using stations 28, 47, and 32, respectively.

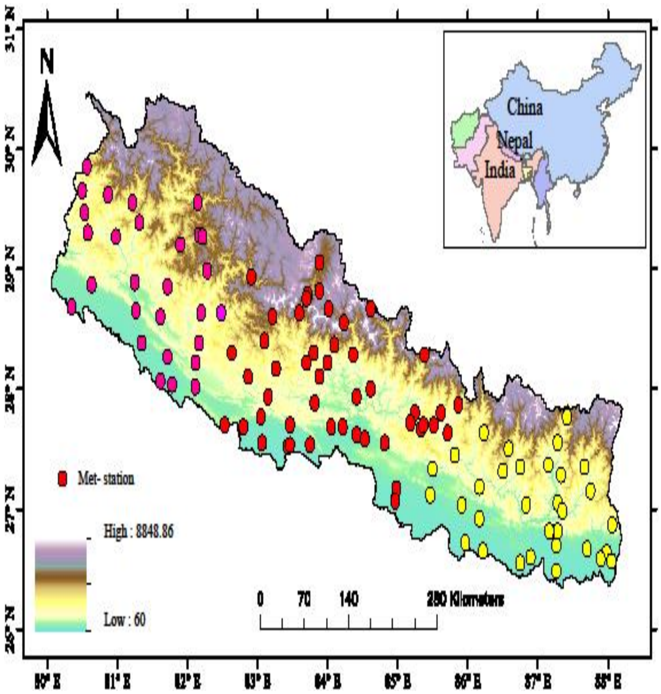

Figure 1: Spatial distributions of the met-stations with rainfall time series (1977-2018) over the study area; the stations for the western, central, and eastern regions are represented by the colors pink, red, and yellow respectively.

2.2 Data and Methods

The Department of Hydrology and Meteorology, Government of Nepal, provided the monthly precipitation data for 107 meteorological stations, which were used in the study. The locations of the meteorological stations are displayed in Fig.1. Monthly, seasonal, and annual rainfall data covering the year between 1977 and 2018 were considered. To determine this time range, as many station records as possible were examined. The daily rainfall data was added up to get the monthly total rainfall values. The arithmetic mean approach was used to obtain the annual, seasonal, and monthly means for each station. The stations were selected based on less than 10 % missing records. Ninety percent of the stations had observed values that were less than three percent of the total number of annual observations. A few high-altitude stations with a 30-year time record that contains 5–10% missing values are used for spatial coverage. To estimate the missing rainfall values in the climate dataset from neighboring weather stations, we used the Normal Ratio approach (Myronidis and Nikolaos, 2021; Bagale et al., 2023b).

From the meteorological perspective; observed monthly rainfall datasets were used to formulate their standardized departures using the historical means and standard deviations for the period 1977 to 2018. Standardized rainfall anomalies were used to identify the dry and excess episodes. Additionally, this analysis identified the severe extreme events using the percent deviation from the long-term mean winter rainfall. This paper applied the Student's t-test and found to be statistically significant at a 95% confidence interval with p-value < 0.05. The inverse distance weighted (IDW) technique was used in this study to interpolate and depict rainfall (Patel, et al., 2007).

3. Results

3.1 Rainfall Statistics

In comparison to the yearly rainfall, rainfall was reported in December (0.8%), January (1.2%), and February (1.6%), according to monthly rainfall measurements from 1977 to 2018. Nonetheless, winter precipitation, which occurs from December to February, makes up around 3% of Nepal's yearly precipitation total (Fig. 2a). Furthermore, more than 80% of the country's annual rainfall occurs during the monsoon season, with 13% occurring before and 4% occurring after (Fig. 2). Furthermore, the regional rainfall metrics are depicted in (Table 1).

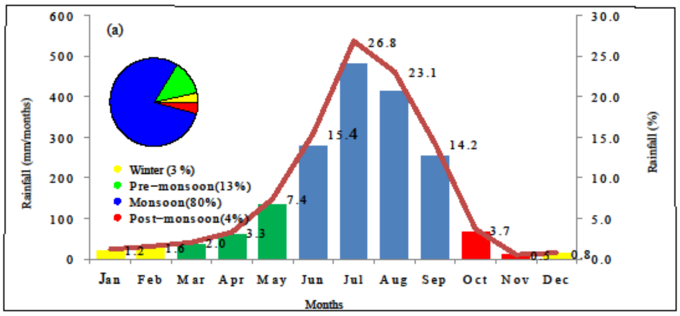

Figure 2 : The seasonal amount of rainfall (%) is displayed in a pie chart along with the variability of monthly rainfall averaged from 1977 to 2018; updated from (Bagale et al., 2023).

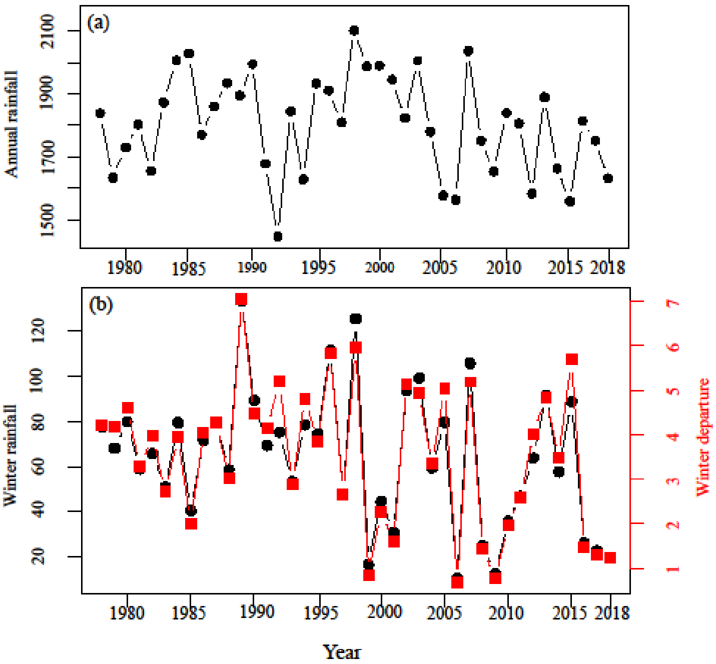

Figure 3: Temporal variability observed for (a) annual rainfall, (b) winter rainfall, and percentage departure of winter rainfall anomaly.

With strong rainfall from June to September, the monsoon season dominates Nepal's rainfall, with the remaining eight months of the year receiving only 20% of the country's yearly total and experiencing water scarcity.

Table 1: Regional rainfall (mm) in the western, central and eastern (WCE) regions

Region	Western	Central	Eastern
December	16.51	14.85	10.08
January	32.71	20.17	12.43
February	40.49	27.44	17.80
winter	91.40	61.46	40.28

Table 1 shows that the western region of Nepal got more rainfall in winter compared to other regions. Additionally, rainfall decreases from the western to the eastern regions in December, January, and February.

Different years had different winter rainfall contributions to the annual total. Figure 3 (a, b) displays the annual and winter rainfall for each year. The annual percentage of winter rainfall varied from 0.78% in 2006 to 7.04% in 1989. According to Fig. 3b, 26 seasons supplied less than 3% of the yearly rainfall, while 15 winter seasons contributed more than 3%. Furthermore, the yearly rainfall during the big winter dry spell was less than 1%. In eight seasons, there were excess winter episodes with more than 5% of the annual rainfall.

3.2 Spatial Variability

Rainfall pockets of more than 100 mm were found in Nepal's northeast, upper mountainous center area, and far western region. While dry rainfall zones in the middle and eastern regions, which are located at lower land, got relatively little rainfall, the west-east mountain range had naturally occurring strong rainfall patterns. In general, Nepal's far western region saw more rainfall than other parts of the country. In various locations, the 16 (14.96%) stations record more than 100 mm. The isohyetal map (Fig. 4) clearly illustrates the regional heterogeneity of rainfall across the nation. In various parts of the nation, the study has discovered both rainy and dry zones. In general, winter rainfall averages decline from the western to the eastern regions. However, there is a lot of winter rainfall in the hilly stations in the central and eastern regions. Rainfall in the far west of Nepal was higher than in the central and eastern regions. The research area has seen significant regional diversity in winter rainfall, with the eastern lowlands experiencing 12 mm and the western and central high mountains experiencing over 150 mm.

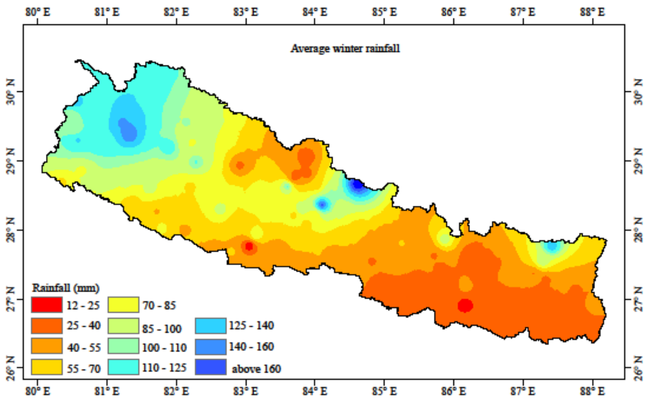

Figure 4: Spatial distributions mean winter rainfall (mm) over Nepal.

The complex mountain terrain in the winter rainfall study clearly illustrates that while the low area of eastern Nepal exhibits dry rainfall patterns, the higher topography of the central and eastern Himalayan ranges has extremely intricate heavy rainfall patterns. In Nepal, winter precipitation generally rises with elevation (Fig. 4).

3.3 Temporal Variability

The average rainfall observed in the winter season is 63.97 mm. The rainfall was observed under the average rainfall during 19 seasons and above the average rainfall in the 23 seasons. The rainfall variability varied from 10.66 mm in the major dry year 2006 to 133.51 mm in the major excess year 1989 which is clearly shown in Fig. 5(a). Large dry winter rainfall was observed in the years 2006, 2009, 1999, 2018, 2017, 2008, 2016, and 2001, and wet years 1989, 1998, 1996, 2007, and 2003 (Fig 5a,b, and table 2). Winter rainfall has decreased frequently in the last two decades. In the years 1979, 2006, and 2009 the average winter rainfall recorded less than 18 mm. During these episodes large areas over Nepal observed low rainfall.

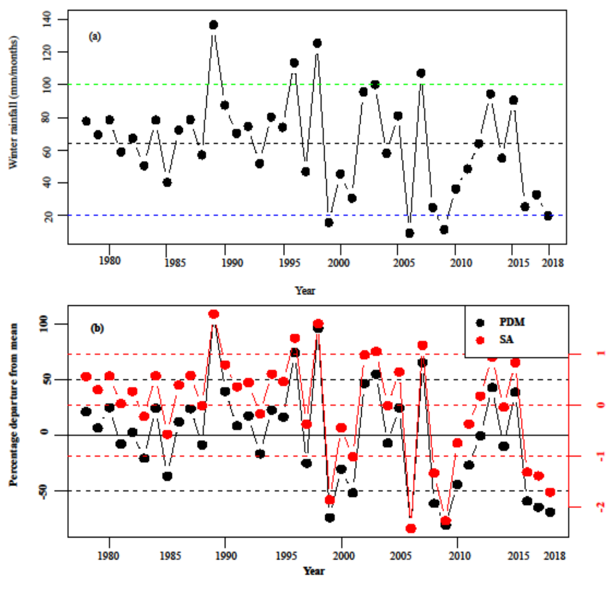

Figure 5: Temporal variability of (a) rainfall and (b) rainfall anomalies.

From this statistical analysis, the five major wet and eight major dry episodes were identified (Fig 5a, b, and Table 2). The winter standardized anomaly fluctuation is clearly shown in Fig. 5b. The major dry year's anomalies and rainfall of each episode are depicted in Table 2. It shows the rank of dry years based on rainfall anomalies from long-term rainfall climatology.

This study observes the rainfall in the major dry years from 1977 to 2018, as well as the shortfall rainfall below average winter rainfall and the declining percentage rainfall anomalies. The first and second-rank dry seasons in 2006 and 2009 had respective average monthly rainfalls of 10.76 and 12.69 millimeters. In addition, winter episodes in 2006 recorded rainfall of 10.76 mm, which was lower than the long-term average of 53.31 mm. In Table 2, rainfall information for other significant dry winter events are provided.

Table 2: Winter dry years rainfall variability in different years over Nepal from 1977-2018

Rank	Year	Average rainfall (mm)	Negative Anamoly (%)	Deficit rainfall below long-term average (mm)
1	2006	10.76	88.33	53.31
2	2009	12.69	80.35	51.40
3	1999	17.02	73.63	47.10
4	2018	20.25	68.67	43.92
5	2017	22.25	64.19	41.06
6	2008	25.12	60.96	38.99
7	2016	26.47	58.84	37.64
8	2001	31.29	51.50	32.94

Rainfall throughout the year-average deficit was almost 43.30 mm (67.69%) less than the normal winter rainfall from 1977 to 2018. Recently, the years 2016 to 2018 were three successive years of severe winter dry episodes. During the last couple of decades, the winter rainfall observed to drier frequently in the years; 2008, 2009, 2016, 2017, and 2018. The consecutive years 2016 to 2018 observed less than 27 mm in winter.

3.4 Regional Temporal Variability

For the western, central, and eastern (WCE) areas, we selected stations 28, 47, and 32 for the regional study. Winter rainfall averages in WCE regions were approximately 92.93 mm, 61.68 mm, and 42.75 mm, respectively. Winter rainfall in the western region varies from 172.68 mm in 2013 to as little as 24.28 mm in 1999, which was a dry year. The central region also had variations in winter rainfall, with a minimum of 6.27 mm in 2006 and a maximum of 149.44 mm in 1989. The eastern area saw variations in rainfall, with a minimum of 2.18 mm in 2006 and a maximum of 101.38 mm in 2007. In comparison to the center regions, the western region experienced higher rainfall in 95% of the 40 years of the study period. The western region experienced higher regional rainfall than the central and eastern regions, as seen in Fig. 6a. There were clear rainfall patterns during the dry winter season, according to the rainfall variability in WCE zones. The winter seasons of 1999, 2006, 2009, 2017, and 2018 saw the least amount of rainfall in eastern Nepal—less than 11 mm—while 1982, 2001, and 2008 saw less than 21 mm. Table 3 lists the main dry-year rainfall for the central and eastern regions. Overall, compared to the central and western regions, the eastern region received less rainfall.

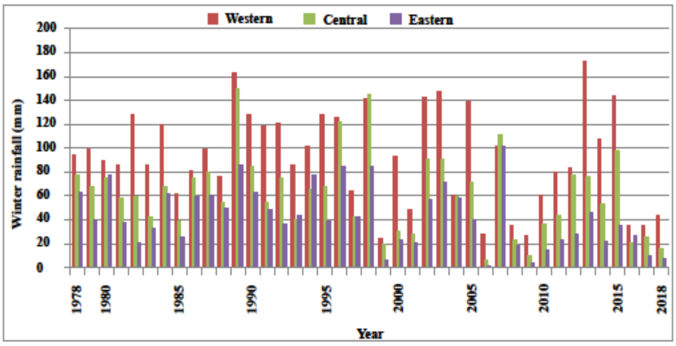

Figure 6: Temporal variability of WCE regions winter rainfall.

A comparison of the area-wise data showed that the eastern region had more dry signals than the middle and western regions. Table 3 displays the percentage decrease in departure rainfall anomalies in specific years in the central, eastern, and western areas. Compared to the central and eastern parts of Nepal, the western area had more winter rainfall. The WCE regions of Nepal observed seven, nine, and nine major dry winter episodes respectively (Table 3).

Table 3: Regional major winter dry episodes in years from 1977 – 2018 with rainfall (mm) statistics

Rank	Year	Eastern rainfall (mm)	Negative anomaly(%)	Year	Central rainfall (mm)	Negative anomaly (%)	Year	Western rainfall (mm)	Negative anomaly (%)
1	2006	2.18	94.9	2006	6.27	89.84	1999	24.28	73.8
2	2009	3.75	91.22	2009	10.25	83.39	2009	26.86	71.1
3	1999	6.92	83.81	2018	15.66	74.61	2006	28.04	69.83
4	2018	8.02	81.23	1999	19.43	68.5	2017	34.8	62.55
5	2017	10.49	75.47	2016	20.43	66.87	2008	34.98	62.36
6	2010	14.56	65.93	2008	23.48	61.94	2016	35.5	61.8
7	2008	18.62	56.45	2017	25.24	59.08	2018	43.28	53.43
8	2001	20.7	51.57	2001	28.18	54.32			
9	1982	20.95	50.99	2000	30.57	50.44			

Generally, the regional winter season rainfall dynamics are in similar nature however only the amount of rainfall is remarkable.

3.5 Spatial overview of eight major winter dry years

There was a large spatial variability of winter rainfall in eight major dry years. There was a general downward trend in winter rainfall from west to east. Different rainfall patterns were seen throughout different significant dry periods [Fig. 7 (a-h)]. Rainfall in 2006 and 2009 had comparable spatial variability to the previous years. The worst incidents in the previous forty years occurred during these dry years. The eastern and central regions suffered more damage during these occurrences than the western ones. The rainfall magnitudes for each major drought year are shown in Table 3, and the interpolated isohytal maps are shown in [Fig.7 (a-h)]. There was insufficient average rainfall of less than 27 mm in the last three consecutive winter dry years, which were 2016, 2017, and 2018. 2018 was drier in the east and center than it was in 2017. Similar to previous years, we saw poor winter rainfall in the eastern region during the dry years of 2016 and 2018. The far western region saw greater rainfall throughout these years. From the far western to the mid-western to the central and eastern regions, the winter rainfall in 1999 progressively declined. Although there was little rainfall in the eastern region in 1979 and 2001, the trend was consistent with previous years. The far western region saw greater rainfall throughout these years. The central and eastern areas are drier during these years.

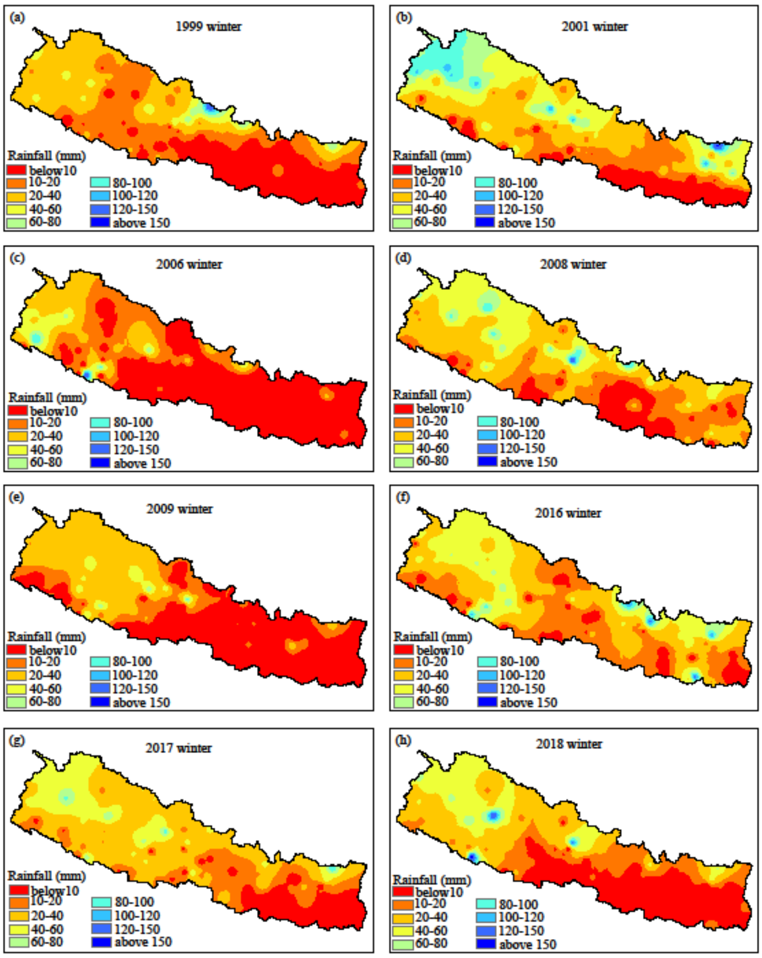

Figure 7: Spatial distributions of winter rainfall in the years (a)1979, (b) 1999, (c) 2001, (d) 2006, (e) 2009, (f) 2016, (g) 2017, and (h) 2018.

Additionally, for the past forty two years, the average monthly rainfall during each of the eight major dry winter occurrences has been less than 31.29 mm. Although some pocket stations are located in the central and northeast high ranges, the rainfall generally falls from the western to the eastern region in each occurrence. Water for irrigation and drinking is a problem in Nepal's hilly areas during the winter. In general, eastern Nepal endures more severe dry weather than other regions during the major eight dry winter years.

Each episode has its own dynamics of winter rains. An overcrowded metropolis like Nepal's capital, Kathmandu, depends heavily on the winter rainfall to replenish its water supplies. Additionally, according to the spatial and temporal analysis, Nepal's western region receives more rainfall than the other regions. The lowlands of Nepal's eastern parts were particularly drier than the rest during eight significant dry winter rainfall years. In addition, the far west receives more winter precipitation on average and during significant drought years. The regional variability of the winter rainfall over Nepal in individual dry years is depicted in the spatially interpolated maps [Fig. 7 (a-h)].

3.6 Large Deficit Winter Episodes

The westerly circulation system develops and supplies winter rainfall through the western region to the eastern region of Nepal. The average of eight dry rainfall episodes indicates that the eastern region's lowlands were extremely dry in the winter season, which accumulates less than 10 mm. However, there are intrinsic heavy rainfall patterns observed in west-to-east mountainous ranges. However, the northwest mountainous regions measured higher rainfall than other regions. The Chepuwa station in Northeast Nepal is the main winter pocket rainfall area in eastern Nepal. The rainfall observed gradually increases with elevation in the Eastern region clearly shown in Fig.8. The far western areas of the Western region observed more heavy rainfall than the other regions.

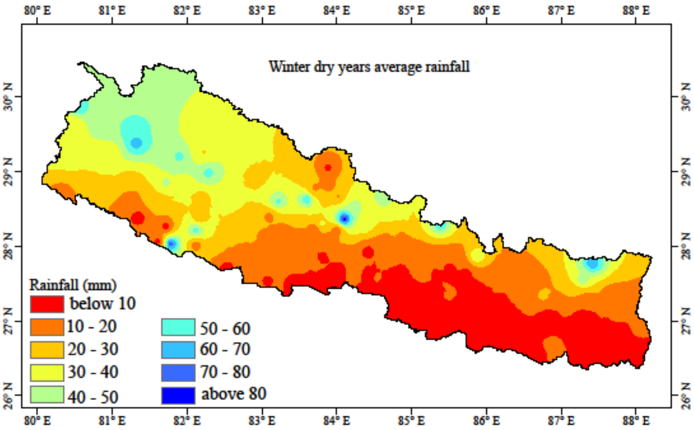

Figure 8: Spatial variability of an average of 8 winter dry years.

Moreover, the Mountainous region of the far western region observed high rainfall and the lowlands of the eastern region observed minimum rainfall.

4. Discussion

Winter receives about 3 percent of the yearly rainfall (Karki et al., 2017). The present study recognized winter rainfall contributed 0.68 % in 2006 and 7.04 % in 1989. The winter season contributes approximately 3 % of Nepal's annual precipitation. However, the average winter rainfall of Nepal was observed at 63.97 mm during the years (1977-2018).

Using standardized rainfall anomalies variation from the mean using Aphrodite datasets for five decades (1960-2015) in Nepal, earlier research revealed years of winter seasonal precipitation that were surplus or deficient (Dawadi et al., 2021). The years after 2000 the dry events are frequently identified to be deficient years. This study identified the severe dry years observed significant negative departures of winter rainfall observed in years 1999, 2001, 2006, 2008, 2009, 2016, 2017, and 2018 implying great deficiencies in rainfall or dry conditions supported by the previous studies (Wang et al., 2013; Dahal et al., 2016). During these eight large winter deficient years eastern regions recorded comparatively lower rainfall than central and western regions.

Varied parts of Nepal have varied dynamics of winter rainfall. The lower part of eastern Nepal is drier than other parts of the country, according to the average winter rainfall. The outcomes are comparable to those of the earlier study (Kansakar et al., 2004).

The analysis indicated that the western region of Nepal recorded more rainfall during the winter in comparison with the central and eastern regions (Karki et al., 2015). The findings of this study are similar to this study finding the western regions are wetter than other regions due to western disturbances entering Nepal from west to east.

Wang et al., (2013) identified that the severe dry condition observed in 2005-2006 and 2008-2009 for the period November to February of winter episodes received less than 50 % of the average precipitation in Western Nepa. Similarly, the findings of present study identified that in years 2006 and 2009 were the first and second rank extremely drier winter seasons in the last four decades. The mean rainfall observed in these years was less than 18 mm. Moreover, this study identified that each drought event received less than 51 % of the average rainfall.

Dahal et al. (2015) identified the worst drought episodes in 2006 and 2009 central regions of Nepal based on SPI indices for the periods (1977-2010). Similarly Dahal et al. (2021) observed the dry episodes based on SPI indices and noticed the dry seasons in eastern Nepal. The central and eastern regions' reductions of rainfall in respective years are similar to the present study findings shown in Fig. 6(a, b).

According to Wang et al. (2013); Gentle and Maraseni, (2012) dry spells have a significant influence on agriculture and way of life. The consecutive large deficit winter episodes made livelihood more difficult for the local mountainous people for their life habitat. This study has identified successive winter drought episodes in Nepal was 2008-2009 and 2016-2018.

In winter generally, the low land of the eastern region measured the severe drought conditions compared with the other regions. The dry events of 2006 and 2009 were the worst winter drought events in Nepal. Moreover, in years 1979, 2001, 2009, and 2018 the winter rainfall measures low rainfall in large areas of Nepal. In these years eastern and central Nepal were affected by severe dry conditions. However, the far western region of western Nepal was wetter comparatively. The findings are similar in line with previous researchers such as; Ichiyanagi et al., 2007. Similarly, previous researchers observed short rainfall in the lowlands and plains and snowfalls in the high-altitude areas (Kalsi, 1980; Dimri et al., 2015).

The average of major large deficit episodes of winter rainfall, spatial variability indicates that west to east decreases of rainfall. The drier and wetter areas in large deficit episodes of winter seasons indicated that the lower Terai region of eastern Nepal records low rainfall (Fig.8).

5. Conclusion

This study provided concise knowledge about the national and regional temporal and spatial variability of major dry winter seasons rainfall from 1977–2018. Winter rainfall contributes about 3 percent of the annual rainfall. Among the dry episodes, the year 2006 was the worst dry rainfall year, followed by 2009 in the last four decades. The major dry winter episodes in 2006 and 2009 observed more than 72 percent of stations below average rainfall, so large areas over Nepal were affected by dry conditions.

The eastern region frequently showed the winter dried signals in recent years compared with other regions. Moreover, the all-Nepal and regional analysis identified that, after 2000 dry events evolved frequently. Present study observed rainfall of less than 31.29 mm in all eight major dry winter seasons.

The regional winter rainfall showed that the eastern region records less rainfall in all years than the central and western regions. Generally, the winter rainfall increases with elevation over WCE regions and observed intrinsic heavy rainfall patterns in west to east mountainous ranges. Average winter rainfall, and major dry winter seasons spatial variability of rainfall showed that high rainfall pockets areas are observed in western Nepal and high mountain belt of central and northeast regions.

Author Contributions

Damodar Bagale designed the study and wrote original draft, and prepared a paper with significant input from Madan Sigdel, Deepak Aryal and Binod Dawadi.

References

Bagale, D., Devkota, L, Adhikari, T. and Aryal, D., 2023. Spatio-Temporal Variability of Rainfall over Kathmandu Valley of Nepal. Journal of Hydrology and Meteorology, 11(2): https://doi.org/10.3126/jhm.v11i1.59661

Barros, A. P., Kim, G., Williams, E., and Nesbitt, S. W., 2004. Probing orographic controls in the Himalayas during the monsoon using satellite imagery. Natural Hazards and Earth System Science, 4(1), Pp. 29–51. https://doi.org/10.5194/nhess-4-29-2004

Dahal, N. M., Xiong, D., Neupane, N., and Belayneh, Y., 2021. Spatiotemporal analysis of drought variability based on the standardized precipitation evapotranspiration index in the Koshi River Basin, Nepal. https://doi.org/10.1007/s40333-021-0065-6

Dahal, P., Shrestha, N. S., Shrestha, M. L., Krakauer, N. Y., Panthi, J., Pradhanang, S. M., … Lakhankar, T., 2016. Drought risk assessment in central Nepal: temporal and spatial analysis. Natural Hazards, *80*(3), Pp. 1913–1932. https://doi.org/10.1007/s11069-015-2055-5

Dawadi, B., Sharma, S., Reynard, E., and Shahi, K., 2023.Climatology, variability, and Trend of the Winter Precipitation over Nepal. Earth Syst, Environ 7, Pp. 381-391. https://doi.org/10.1007/s41748-023-00338-0

Dimri, A. P., 2007. The transport of momentum, sensible heat, potential energy and moisture over the western Himalayas during the winter season. Theoretical and Applied Climatology, 90(1–2), Pp. 49–63. https://doi.org/10.1007/s00704-006-0274-0

Dimri, A. P., 2006. Surface and upper air fields during extreme winter precipitation over the western Himalayas. Pure and Applied Geophysics, 163(8), Pp. 1679–1698. https://doi.org/10.1007/s00024-006-0092-4

Dimri, A. P. and Mohanthy, U.C., 2009. Simulation of mesoscale features associated with intense western disturbances over western Himalayans. Metrological applications, 16(8), Pp. 289–308.https://doi.org/10.1002 met.117

Dimri, A. P., Niyogi, D., Barros, A. P., Ridley, J., Mohanty, U. C., Yasunari, T., and Sikka, D. R., 2015. Western Disturbances: A review. Reviews of Geophysics, 53(2), Pp. 225–246. https://doi.org/10.1002/2014RG000460

Gentle, P., and Maraseni, T. N., 2012. Climate change, poverty and livelihoods: Adaptation practices by rural mountain communities in Nepal. Environmental Science and Policy, 21(October 2017), Pp. 24–34. https://doi.org/10.1016/j.envsci.2012.03.007

Hamal, K., Sharma, S., Baniya, B., Khadka, N., and Zhou, X., 2020. Inter-Annual Variability of Winter Precipitation Over Nepal Coupled With Ocean-Atmospheric Patterns During Pp. 1987–2015. Frontiers in Earth Science, 8(May). https://doi.org/10.3389/feart.2020.00161

Ichiyanagi,K., Yamanaka,M.D.,Muraji, Y., & Vaidya,B.K. (2007). Precipitation in Nepal Between 1987 to 1996. *International Journal of climatology*, 27 :1753-1762. doi:10 :1002/joc.1492.

Kalsi, S. R., 1980. On some aspects of interaction between middle latitude westerlies and monsoon circulation. Mausam 38: Pp. 305-508.

Kansakar, S. R., Hannah, D. M., Gerrard, J., and Rees, G., 2004. Spatial pattern in the precipitation regime of Nepal. Int.J.Climatol., Pp. 1645–1659. https://doi.org/10.1002/joc.1098

Karki, R., Hasson, S., Schickhoff, U., & Scholten, T., 2017. Rising Precipitation Extremes across Nepal, Pp. 1–25. https://doi.org/10.3390/cli5010004

Karki, R., Talchabhadel, R., Aalto, J., and Baidya, S. K., 2016. New climatic classification of Nepal. Theoretical and Applied Climatology, 125(3–4), Pp. 799–808. https://doi.org/10.1007 /s00704-015-1549-0

Lang, T. J., and Barros, A. P., 2002. An investigation of the onsets of the 1999 and 2000 monsoons in central Nepal. Monthly Weather Review, 130(5), Pp. 1299–1316. https://doi.org/10.1175/1520-0493 (2002)130<1299: AIOTOO>2.0.CO; 2

Lang, T. J., and Barros, A. P., 2004. Winter Storms in the Central Himalayas, *82*(3), Pp. 829–844.

Li, G., Wang, Y., Lee, K. H., Diao, Y., and Zhang, R., 2008. Increased winter precipitation over the North Pacific from 1984-1994 to 1995-2005 inferred from the Global Precipitation Climatology Project. Geophysical Research Letters, 35(13), Pp. 1–5. https://doi.org/10.1029/ 2008GL034668

Myronidis, D., and Nikolaos, T., 2021. Changes in climatic patterns and tourism and their concomitant effect on drinking water transfers into the region of South Aegean, Greece. Stochastic Environmental Research and Risk Assessment, 35(9), Pp, 1725–1739. https://doi.org/10.1007/s00477-021-02015-y

Sigdel, M., and Ikeda, M., 2012. Summer Monsoon Rainfall over Nepal Related with Large-Scale Atmospheric Circulations. Earth Science & Climatic Change, 3(2), https://doi.org/10.4172/2157-7617.1000112

Sigdel,M and Devkota, L.P., 2013. Connection of wintertime precipitation system in and around Nepal with Pacific and Indian Ocean Indices. Pakistan Journal of Meteorology, 10(19), Pp. 11-18.

Wang, S. Y., Yoon, J. H., Gillies, R. R., and Cho, C., 2013. What caused the winter drought in western Nepal during recent years? Journal of Climate, 26(21), Pp. 8241–8256. https://doi.org/10.1175/JCLI-D-12-00800.1

Webster, P. J., Magaña, V. O., Palmer, T. N., Shukla, J., Tomas, R. A., Yanai, M., and Yasunari, T., 1998. Monsoons: processes, predictability, and the prospects for prediction. Journal of Geophysical Research: Oceans, 103(C7), Pp. 14451–14510. https://doi.org/10.1029/97jc02719