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Changing Rainfall Pattern in Pokhara Valley, Nepal

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Abstract

Pokhara valley lies on the southern slope of the Annapurna Range in the Himalayas, Nepal. The mountain range blocks the monsoon originating from the Bay of Bengal in the monsoon season. Based on the observed rainfall data from 1991 to 2021 AD from the Department of Hydrology and Meteorology (DHM), Government of Nepal (GoN), this study aims to assess the monthly, seasonal, and annual pattern of rainfall in Pokhara. Trend analysis for annual rainfall as well as seasonal and monthly rainfall was performed and a regression method was used to find the rate of increase or decrease of the rainfall. Pre-monsoon and monsoon seasons indicate both an upward and a downward trend, whereas post-monsoon and winter seasons illustrates the exact opposite. However, the average monthly rainfall indicates an upward trend, despite the fact that the annual rainfall exhibits both an increasing and a decreasing trend. According to the research, there are rising (+ve) and falling (-ve) trends for the different stations. Although both stations are very near, the precipitation varies broadly. Such massive variation within the short distance might be due

to climate change, local wind effects, outflanking of hydraulic structures, and monsoon patterns.

Introduction

In most cases, Precipitation is referred to as Rain or Rainfall. It is the water in solid or liquid forms falling to the earth and is perhaps the most important phase of the Hydrological cycle. Rain is formed when saturated air gets heated (air that cools down at the dew point) and rises either by mountains, conventional currents, or frontal actions. The amount of Rainfall recorded at a place is measured using a *Rain Gauge*. Rainfall is important for maintaining the water cycle by depositing the fresh water on Earth, for agriculture, irrigation purpose, and hydropower project. Similarly, the rainfall pattern is generally referred to as the distribution of rainfall in a specific region over a given period, such as a year or a season. Rainfall patterns are very complex and are influenced by a variety of factors, including geographic location, climate, topography, and weather. During the summer monsoon, rain-bearing winds approach Nepal from the southeast, so heavier rainfall occurs in the Churiya range's foothills, increasing with altitude on the windward side and sharply decreasing on the leeward. The heaviest rainfall is in Hilly Regions, especially in the Pokhara region. Also, the monsoon season in Nepal contributes roughly 60- 90% of the country's annual rainfall during the summer months from June to September (Nayava, 1980). The spatio-temporal variation in the intensity and frequency of precipitation is exposed to extreme weather events such as flood, drought, erosion, landslides, and sedimentation often leading to damage to life and property and also valuable infrastructures (Chalise & Khanal, 2002; Karki et al., 2017).

Pokhara valley is surrounded by high mountains in the east, north, and north-west which function as a barrier causing precipitation from both mountain valley flow and orographically raised humid air (Aryal et al., 2015). June, July, and August are the wettest months while November, December, and January being the driest ones. The study shows that there is no significant trend in all available stations in Pokhara i.e., there are both increasing and decreasing trends for different stations with the greatest amount of rainfall in the month of July and August with maximum value at Lumle where Pokhara Airport exhibits the highest variability while Nirmal Pokhari has the lowest one. Furthermore, the finding shows that rainfall is significantly higher in areas near water bodies or in catchment areas (Kharel & Basnet, 2021). Moreover, a recent study (Paudel, 2020) reported that the trend of rainfall is decreasing in Pokhara while the temperature is increasing.

Pokhara is located in the Western Hill region and also receives the highest rainfall. Although this area gets higher rainfall, there is no uniform pattern which is a matter of importance for further research. The climate of Pokhara is classified as subtropical, but due to its elevation, the weather is generally quite mild. Even the rainfall pattern of Pokhara valley is influenced by the location of the city (in the foothills of the Annapurna range), causing local variations in rainfall depending on topography and altitude. In addition, thunderstorms and other weather events can cause day-to-day localized variations in rainfall. Since Pokhara is the valley with higher rainfall, changes in the rainfall patterns there have had a major impact on the local ecosystem, agriculture, and way of life. Climate change, urbanization, deforestation, and changes in land use are just a few of the variables that have an impact on the rainfall patterns in the Pokhara Valley. The natural hydrological cycle of the area has been changed by these factors, leading to more frequent and intense rainfall events that have led to flooding, landslides, and soil erosion. As climate is an unavoidable factor, the study of climate and climatic factors is a must for Pokhara to be developed with all the infrastructures. Thus, data from the Pokhara Airport station, situated in the middle of Pokhara Valley, could be employed to depict the entire study region while data from Malepatan station are also collected from the DHM for the study of rainfall to understand how the local wind influences the distribution of rainfall even over a short distance.

Methods and Materials

Study area

Pokhara valley, the second largest valley in the hilly region, lies in the western part of Nepal. Pokhara, the city of lakes is situated in the Gandaki province with an area of 464.24 km^2, latitude of 28°16'0.8", and longitude of 83°58'6.64". It is located 200 kilometers west of Kathmandu at an altitude of about 822m. Due to its altitude, the city experiences a humid subtropical climate with moderate temperatures. According to the Department of Hydrology and Meteorology, Pokhara receives the second-highest amount of rainfall in the country, while Lumle, 23.9km from Pokhara City, receives the maximum amount of rainfall in the nation (roughly 5000mm). High mountains that are to the east, north, and northwest of the Pokhara valley act as a barrier and produce precipitation from orographically lifted moist air as well as mountain-valley flows that are drawn into the region every day. Because of these characteristics, Pokhara is a moisture convergence zone that receives some of Nepal's heaviest rains (Aryal et al., 2015). Although it rarely snows in the valley during the winter, it does sporadically on the surrounding slopes.

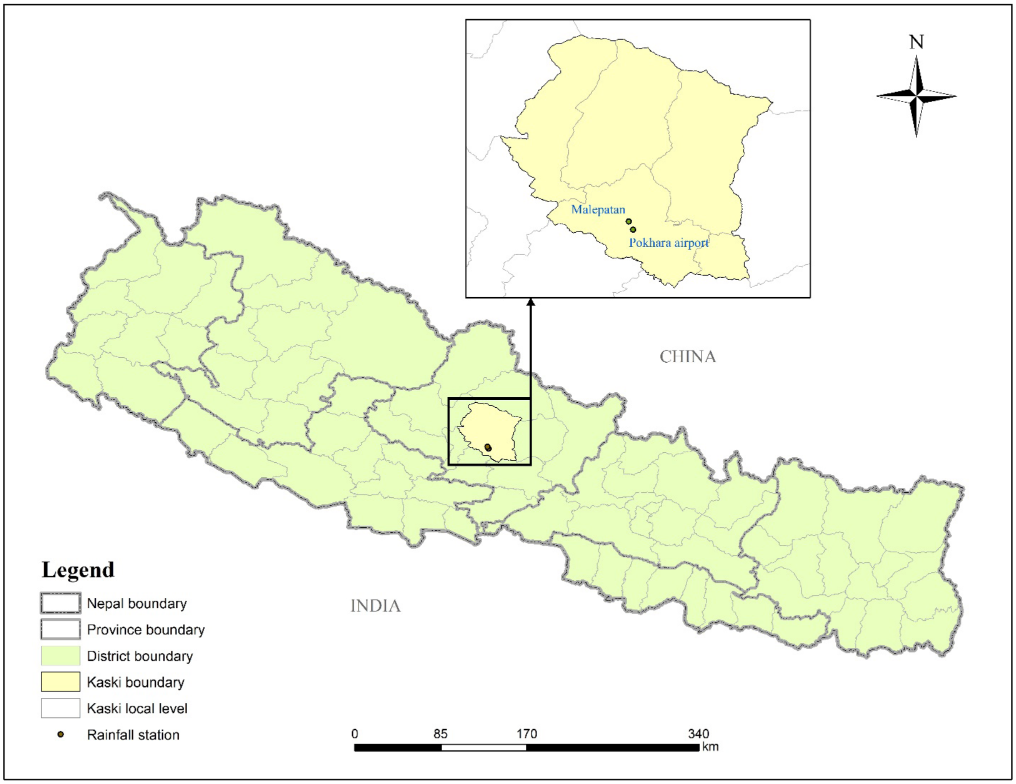

Figure 1. Map of the study area

Sources of data

The study is based on the secondary data which has been collected from the Department of Hydrology and Meteorology (DHM), Government of Nepal (GoN). Data obtained from DHM is the climate data from which the rainfall data has been extracted and analyzed. As the data are secondary, the monthly rainfall data of the last 30 years from 1991AD to 2021 AD from two different stations (Pokhara Airport and Malepatan) has been taken into account to analyze the distribution of rainfall. Pokhara Airport Station and Malepatan Station have been selected by judging approach out of the different stations existing in the Pokhara valley since they are both relatively close to one another also Pokhara Airport lies in the central part which may represent the climate of the entire region. Malepatan station had some issues with data quality and quantity for two years (1991 and 2005), which caused problems with analysis, but no appropriate method was considered for handling missing data.

Table 1. Rain gauge station

Station	Index No.	Types of Station	Latitude	Longitude	Elevation (m)
Pokhara Airport	0804	Aeronautical	28.20090°	83.98210°	827
Malepatan	0811	Agrometeorology	28.2181°	83.9731°	856

And lastly, the collected data was integrated into Ms. Excel, and the monthly, seasonal, and annual trend of rainfall in Pokhara was analyzed using the following formula,

$$(y - \overline{Y}) = b\,(x - \overline{X})$$

where b = r. $\frac{s_y}{s_x}$

Results and Discussion

Monthly rainfall situation

While analyzing the mean monthly rainfall data of Pokhara Airport from 1999 to 2021 it has found that the highest rainfall occurred in July with 954.13 mm followed by August with 849.81mm and June with 657.23 mm while the lowest rainfall is recorded in December with 12.5 mm followed by November 16.6 mm as shown in Figure 2, whereas in Malepatan, it is found that highest rainfall occurred in July with 1019.89 mm followed by the August with 864.74 mm and the lowest occurred in November and December with 14.33 mm and 11.82 mm as shown in Figure 3.

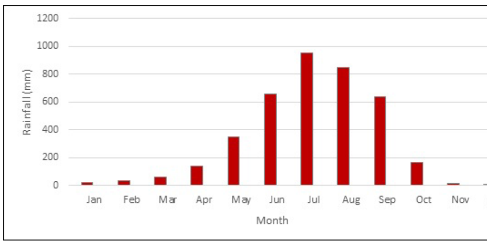

Figure 2. Monthly rainfall situation of Pokhara Airport from 1991 to 2021

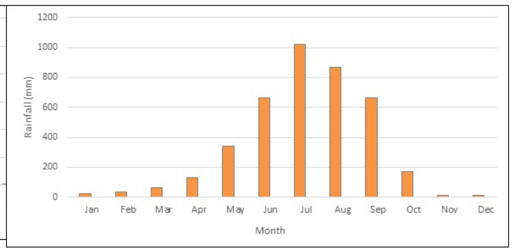

Figure 3. Monthly rainfall situation of Malepatan from 1991 to 2021

Seasonal rainfall situation

Pre-monsoon season

After the data analysis of Pokhara Airport, it is seen that the maximum rainfall in pre-monsoon season is recorded in the year 2000 at 933.9 mm followed by the year 1999 at 920.3 mm while the lowest rainfall is recorded in 2014 with 247.7 mm followed by the year 1992 and 2009 with 301.4 mm and 331.1 mm as presented in Figure 4. It is seen that there is no uniform pattern i.e. there is fluctuation in rainfall amount received during the pre-monsoon season, whereas, in Malepatan station the maximum rainfall is recorded in the year

2020 with 834.9 mm followed by the year 2000 with 811.8 mm while the lowest rainfall is recorded in 2014 with 276.2 mm followed by the year 2009 with 312.5 mm as presented in Figure 5. Lastly, it can be observed from Figures 4 and 5 that the precipitation is rising in Malepatan station during the pre-monsoon season at a rate of 1.998 mm (R^2 = 0.008) while falling in Pokhara Airport at a rate of 1.749 mm (R^2 = 0.0081).

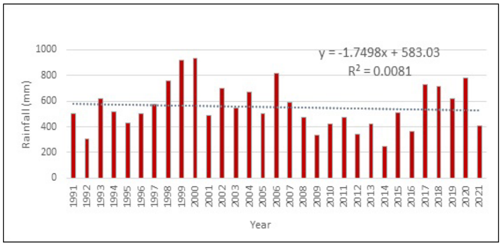

Figure 4. Pre-monsoon rainfall situation for Pokhara Airport from 1991 to 2021

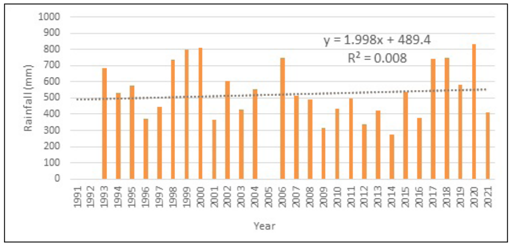

Figure 5. Pre-monsoon rainfall situation for Malepatan from 1991 to 2021

Monsoon season

While analyzing the variation of rainfall in the monsoon season of 30 years time period in Pokhara Airport station, it is seen that the maximum rainfall in the monsoon season is recorded in the year 2020 with 4524.6 mm followed by the year 2021 and 1995 with 4269.57 mm and 4068.9 mm of rainfall while the lowest rainfall is recorded in 2006 with 1866.5 mm followed by the year 2005 and 2019 with 2069 mm and 2083.3 mm of rainfall as shown in Figure 6, while in Malepatan station the maximum rainfall in monsoon season is recorded in the year 2020 with 4817.7 mm followed by the year 2021 and 1995 with 4422.11 mm and 4310.5 mm of rainfall while the lowest rainfall is recorded in 2006 with 1969.7 mm followed by the year 1997 and 1992 with 2270.3 mm and 2313.7 mm of rainfall as shown in Figure 7 respectively. Finally, Figures 6 and 7 show that during the monsoon season, precipitation is falling at a rate of 5.588 mm (R^2 = 0.0059) at Pokhara Airport station while increasing at a rate of 4.8924 mm (R^2 = 0.0042) at Malepatan station.

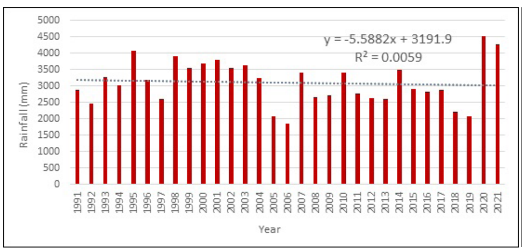

Figure 6. Monsoon rainfall situation for Pokhara Airport from 1991 to 2021

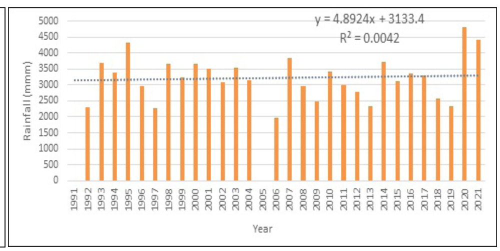

Figure 7. Monsoon rainfall situation for Malepatan from 1991 to 2021

Post-monsoon season

After the rainfall data analysis of Pokhara Airport, it is seen that the maximum rainfall in post-monsoon season is recorded in the year 2021 at 473.91 mm followed by the year 2016 with 335.4 mm while the lowest rainfall was recorded in 2003 with 34.1 mm followed by the year 2020 and 1991 with 51 mm and 53.8 mm as shown in Figure 8, whereas in the analyzation of rainfall data of Malepatan station, the maximum rainfall in post-monsoon season is recorded in the year 2021 with 541.3 mm followed by the year 1992 and 2016 with 317.2 mm and 315.7 mm while the lowest rainfall is recorded in 2020 with 53.3 mm followed by the year 2003 and 2008 with 60.4 mm and 64.5 mm as shown in Figure 9 respectively. Also, Figures 8 and 9 show that precipitation is rising at Pokhara Airport station at a rate of 1.560 mm (R^2 = 0.0206) and Malepatan station at a rate of 2.378 mm (R^2 = 0.0457) throughout the post-monsoon season.

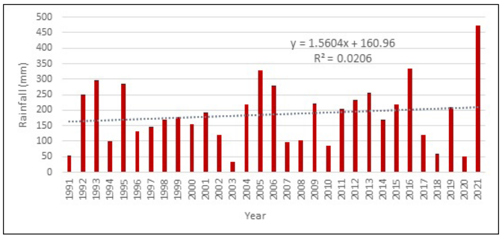

Figure 8. Post-monsoon rainfall situation for Pokhara Airport from 1991 to 2021

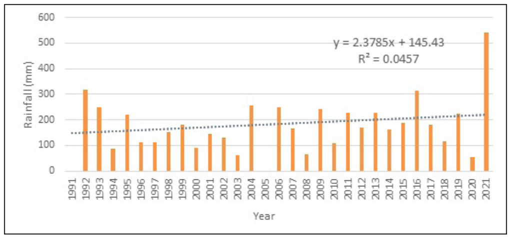

Figure 9. Post-monsoon rainfall situation for Malepatan from 1991 to 2021

Winter season

With the analysis of 30 year's rainfall data from Pokhara Airport, the maximum rainfall in winter is observed during 2007 at 176.6 mm followed by the year 1998 at 158.7 mm while the lowest rainfall is recorded in 2009 with 0 mm followed by the year 2018 and 2016 with 1.4 mm and 2.4 mm as presented in Figure 10. In Malepatan station, it is seen that the maximum rainfall in the winter season is recorded in the year 2015 at 215.4 mm followed by the year 2007 at 171.4 mm while the lowest rainfall is recorded in 2009 at 0.5 mm followed by the year 2017 at 6.2 mm as presented in Figure 11 respectively. In the end, Figures 10 and 11 show that throughout the winter, precipitation is decreasing at a rate of 0.8679 mm in Pokhara Airport station (R^2 = 0.0231) and at a rate of 0.676 mm in Malepatan station (R^2 = 0.011).

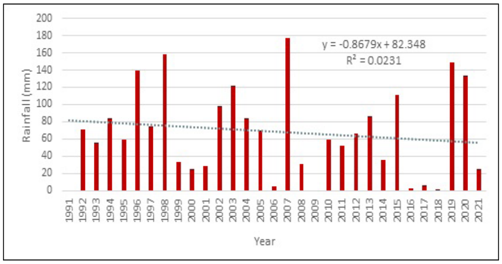

Figure 10. Winter rainfall situation for Pokhara Airport from 1991 to 2021

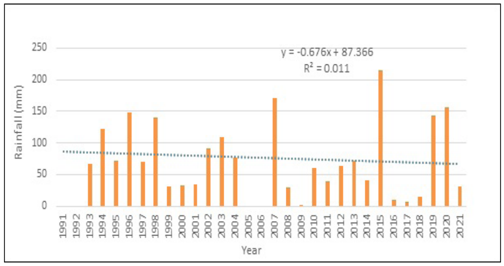

Figure 11. Winter rainfall situation for Malepatan from 1991 to 2021

Annual rainfall situation

While analyzing the annual rainfall data for 30 years (1991-2021) of Pokhara Airport station it is found that the most precipitation was recorded in the year 2020 with 5453.2 mm followed by the year 2021 with 5216.6 mm and the lowest one recorded in the year 2005 and 2006 with 2966.8 mm and 2984.5 mm as shown in Figure 12. It can be seen in Figure 12 that the rate of precipitation is in decreasing order at 6.22 mm respectively with no uniform pattern in annual rainfall while in Malepatan station it is found that the highest rainfall occurred in the year 2020 with 5815.6 mm followed by the year 2021 with 5454.61 mm and the lowest occurred in the year 2006 and 1997 with 2982.5 mm and 3011.6 mm as shown in Figure 13. Therefore, from analyzation of Figure 13, it can be said that the rate of precipitation is in increasing order at 0.461 mm respectively with no uniform pattern in annual rainfall.

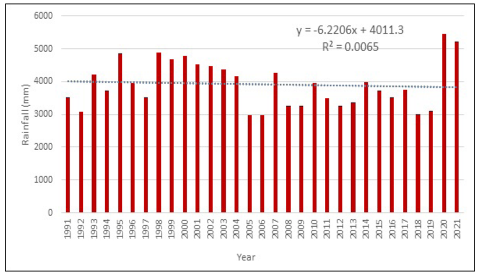

Figure 12: Annual rainfall situation for Pokhara Airport from 1991 to 2021

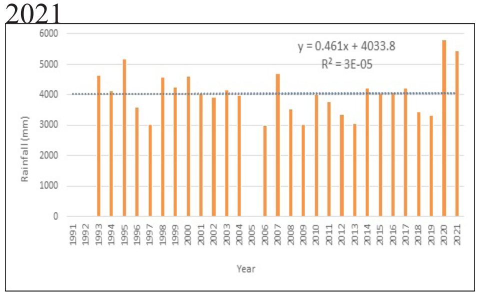

Figure 13. Annual rainfall situation for Malepatan from 1991 to 2021

The south-easterly monsoon dominates Nepal's climate, providing the majority of precipitation during the wet summer months (June to September). However, the amount of summer monsoon rains generally declines from southeast to northwest. Summer monsoon rain intensities in Nepal and the onset of the monsoon both are important factors in the economy of a nation because it is the key climatic factor in the growth of the country's water resources. Additionally, it actively and substantially affects inter-annual variability, including the Southern Oscillation Index (SOI) (DHM, 2014; Shrestha, 2000).

Both stations show an increasing trend of monthly precipitation. Furthermore, the result also indicates that the highest rainfall through the year occurred during the monsoon season (peak months July and August) with the lowest one during post monsoon season (November and December). This phenomenon is similar to the other previous studies as they show the peak month of rainfall in July and August for all the regions and areas near or close to water sources or with larger catchment areas experience or receive significantly more rainfall (Kharel & Basnet, 2022; Paudel, 2020). Furthermore, even in the study of trend analysis of Rainfall, Temperature, and Relative Humidity of Kathmandu the periods of highest rainfall, temperature, and relative humidity are between June or July, or August for TIA (Regmi et al., 2021). Study for the whole of India no significant trend was observed for monthly rainfall as rainfall in June, July, and September declined while in August it increased (Kumar et al., 2010). Meanwhile, in a recent study, it was found that maximum precipitation was observed in the monsoonal month, that is, June to September, and also during pre and post-monsoon months, susceptible to climate variability mainly rainfall variability as rainfall is the main driver of agriculture growth in the study region (Panda & Sahu, 2019). Similarly, the study of the monthly precipitation trend over the Nethravathi Basin showed a negative trend of precipitation in June, July, and August while the positive trend in September indicated overall changes in precipitation trend during the southwest monsoon (Babar & Ramesh, 2013).

The amount of rainfall shows the difference in the seasonal rainfall situation as well (in both the stations) where the trend for the pre-monsoon season and monsoon season is increasing as well as decreasing. In contrast, the rainfall trend for the post-monsoon season increased while for the winter season, it declined. Reference (Panthi et al., 2015) showed that monsoon rainfall is increasing throughout the Gandaki Basin while the Pre-monsoon, Post-monsoon, and winter monsoon are decreasing in most of the zones with no change in the arrival of Monsoon in the basin while the retreat is delayed. Moreover, the intensity and frequency of rainfall extremes in India increased significantly during boreal summer after 1980 affecting urban transportation, agriculture, and infrastructures (Mukherjee et al., 2018; Nikumbh et al., 2019). Similarly, rainfall intensity over Singapore also tends to increase over the year though found insignificant statistically and with a significant decrease in factor of safety referring to a climate change that existed after 2009 possibly causing effects on slope stability (Kristo et al., 2017). Studies in Saudi Arabia showed a decrease in the overall trend of rainfall with large variability on both an annual and seasonal basis due to IOD (annual) and ENSO (seasonal) and also the dominancy of extreme rainfall events (Athar, 2015).

The rainfall trend for the Malepatan station shows increasing order for annual precipitation while the Pokhara airport shows decreasing order. Previously, (DHM, 2017) analyzed the climate trend of the whole country which shows that the average annual rainfall of the country has not changed much. Mustang is the lowest rainfall area while Lumle is the highest rainfall area and also concentrated in some pocket areas such as the Makalu-Barun area in the Eastern part, Lumle in the Northern-central part, and Langtang area in the Central Part. Furthermore, during the analysis of seasonal and annual weather data of Lower Kaski, annual precipitation is seen maximum at Lumle station while minimum in Malepatan Station (2001-2007) and Panchase Station (2008-2017) though the annual rainfall shows a decreasing trend (Basnet et al., 2020).

Conclusion

The study concluded that July has the most rainfall, with August following in second and the least rainfall in December followed by November from 1991 to 2021 with an increasing trend. However, for Pokhara valley, it is found that the seasonal rainfall trend for the post-monsoon season is increasing while the winter season is decreasing and the seasonal rainfall trend for the pre-monsoon season and monsoon season is increasing as well as decreasing. The higher rainfall occurred in the years 2020 and 2021 with annual rainfall showing both an increasing as well as decreasing trend. Therefore, from the trend analysis study, we can conclude that there are rising (+ve) as well as falling (-ve) patterns for the various stations. The eastern part of Pokhara receives more amount of rainfall in summer. As the southeast part of Pokhara is open and has got the mountain in the southern part it receives the highest amount of rainfall in Nepal.

The findings of this study indicate that though both stations are very near, the precipitation varies broadly. Such massive variation within the short distance might be due to climate change, local wind effect, outflanking of hydraulic structures and monsoon patterns, and unusual precipitation which needs further research.

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