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Research Article

Statistical Analysis of Rainfall Distribution in Biratnagar, Nepal: A case study

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Abstract

Rainfall is a key component in the construction of many engineering projects, including canals, bridges, culverts, and road drainage systems. The primary goal of this study is to ascertain the annual, monthly and seasonal fluctuations in rainfall in Biratnagar, Nepal over a period of 10 years (2010-2019). The mean, standard deviation, coefficient of variation, skewness, kurtosis, Precipitation Concerntration Index (PCI), normal rainfall along with Mann-Kendall test were calculated to check the rainfall variations. The annual data showed the biggest varieties in rainfall, with an average annual rainfall of 1542.43 mm during a ten years period. Furthermore, an erratic monthly rainfall pattern was found by the non-parametric Mann-Kendall test. However, the test value for each month was non-significant at the 5% level of significance. We also found that the rainfall is least in the winter and most during monsoon season. Based on these calculations, It is seen that the pattern of rainfall is inconsistent or unpredictable. However, present study will aid in the understanding of rainfall variations and trends, assisting in the management of water resources, ecosystems, irrigation, sustainable agricultural planning, engineering structural design, and other areas.

Keywords: Statistical analysis, Biratnagar, Precipitation Concentration Index, Mann-Kendall test, normal rainfall

Introduction

The foundation of sustainable development of any country is water, which is also essential for human survival, environmental health, and socioeconomic growth. It is essential to lowering the global disease load and enhancing population health, welfare, and productivity. Rainfall is the primary source of water (Satheeshkumar et al. 2017). It is the total amount of precipitation that falls on Earth's surface over a given period of time. Amount of rainfall is affected by many factors. Main factor is atmospheric temperature. Pressure is also a factor. Wind speed and direction are the two other important factors that determines the type, occurrence and amount of precipitation. Also, the characteristics of particular land influence the rainfall. Mountains, plateaus, forests all of these have influence in rainfall (Penin et al. 2022). Regional geomorphology and monsoonal winds have a considerable impact on Nepal's climate. Pre-monsoon (March through May), summer monsoon (June through September), post-monsoon (October through November), and winter (December through February) are the four climatological seasons of Nepal (Nayava 1980).

The pre-monsoon season is hot, dry, and occasionally rainy. By the end of this period, there are westerly winds that range from moderate to strong across the country, and it is humid with thunderstorms. During the summer monsoon, a southwesterly air mass with a lot of moisture is coming from the Bay of Bengal. The monsoon typically begins on June 10 and travels westward for a week before reaching all of Nepal (Kansakar et al. 2004). In contrast, the post-monsoon often begins from September 21st. After the monsoon season, crops and paddy are harvested, and the dry winter months bring chilly weather. The summer monsoon season in Nepal accounts for 80% of all yearly precipitation (Nayava et al. 1980, Shrestha et al. 2000, Dahal 2012, Karki et al. 2017, Karki et al. 2012), whereas the winter, pre- and post-monsoon seasons account for only a small portion of precipitation—3.5%, 12.5%, and 4.0%, respectively (Department of H & M 2015). Nepal has lately seen a series of natural disasters due to heavy monsoonal rains, including flooding, landslides, soil erosion, etc. A 200 mm heavy rainfall in August 1987 caused floods and inundation in the Eastern Terai (Adhikari 2013). Furthermore, according to studies, 49% of all disaster incidences in Nepal between 2000 and 2017 were brought on by flooding (SEEDS & CRECD 2021). The country has an average height rise of 45 meters per kilometer, with altitudes ranging from 90 meters above mean sea level in the south to 8848 meters above mean sea level in the north (Islam et al. 2010). Rainfall strongly depends on geographical location such that higher elevations experience less intense rainfall than lower elevations (Ichiyanagi et al. 2007). A slight difference in rainfall can have a big influence on the socioeconomic circumstances of the nation because agriculture remains the mainstay of Nepal's economy. An abundance of rain can hinder agricultural productivity and cause flooding and landslides (Idowe et al. 2011), while a lack of rain can limit the production of agricultural products, which causes food shortages, water shortages, and power outages (Hanjra & Qureshi 2010). In order to manage water resources, ecosystems, prepare for sustainable agriculture, avert natural disasters like landslides and floods, and generate hydropower, it is helpful to have an understanding of the distribution of rainfall in advance. This is the primary purpose of present study.

The variability of the rainfall can be predicted using a variety of models (Gilbert 1987). However, due to a dearth of meteorological stations and incomplete data, there have only been a few studies to anticipate the variability in rainfall in Nepal. Nayava (Nayava 2004) studied temporal variation of rainfall at a few rainfall stations in Nepal during 1971-2000 using statistical analysis. Except for the Far-Western region of Nepal, where there was a tiny declining trend in the annual rainfall, the results showed no definite trend in Nepal's annual rainfall. The data also revealed that as the monsoon months progressed, the number of wet days decreased and rainfall intensity increased. Karki (Karki 2005) used Mann-Kendall approach to investigate the daily rainfall pattern in the Kathmandu valley during the summer monsoon season from 1971 to 2005. The outcome showed a considerable upward tendency in the daily rainfall pattern, with a rainfall rate of 0.1-10 mm/day. The overall monsoonal rainfall, however, remained the same. Baidya *et al. (*Baidya *et al.* 2008) examined the daily trends of extreme precipitation and temperature in Nepal using the software RclimDex. The findings revealed rising temperature trends for 36 years, from 1971 to 2006, and rising precipitation trends for 46 years, from 1961 to 2006, with high rainfall events at the majority of the sites. Shrestha and Sthapit [21] applied Mann-Kendall test, Spearman’s Rho and a linear regression to analyze the temporal variation of rainfall in the Bagmati river basin, Nepal. They discovered a significantly increasing upward trend in annual mean rainfall and the summer monsoon season (June and July). Shah *et al.* [22] studied the monthly, seasonal, and annual variability of rainfall and temperature in Morang district from 30 years (1982–2011) data using the Mann–Kendall test together with Sen's Slope estimator. The findings revealed irregular rainfall patterns on a monthly and seasonal basis, but it was discovered that annual rainfall was increasing. Chhetri and Kumar [23] examined rainfall variability in 17 field stations of Nepal's hilly regions between 1987 and 2016 using statistical measures like mean, median, standard deviation, coefficient of skewness, and coefficient of variation. The findings demonstrated that there was a substantial difference in rainfall at each location. The hilly study area saw 80.87% monsoon rainfall and 3.29% winter precipitation. Sharma *et al*.[24] used the Kriging linear interpolation method to study the precipitation and its extremities in seven Provinces of Nepal between 2001 and 2016. With the exception of Province 6 (Karnali), the precipitation trended downward.

Here, we concentrate on analyzing the rainfall distribution pattern in Biratnagar and its overall effects on the country using statistical tools such as mean, standard deviation, coefficient of skewness, Kurtosis, coefficient of variation, Precipitation Concertation Index (PCI), normal rainfall, Mann-Kendall test, etc. using data from the Department of Hydrology and Meteorology (DHM) of Nepal.

Theory and Method

Study Area

Biratnagar is located in morang district of eastern Nepal which covers 58.48 square kilometers of the country. Its precise location is between the latitudes of 26°232 and 26°302 N and the longitudes of 87°142 and 87°182 E[25]. It is bounded on the north by Budhiganga Rural Municipality, on the south by Jogbani in the Bihar district of Araria, on the east by the Singhia River, and on the west by the Kesalia River.

Biratnagar is one of the industrial hubs of Nepal, with a number of businesses located in and around its suburbs. Biratnagar has a tropical monsoon climate with three distinct seasons: summer (March–June), rainy (July–October), and winter (November–February) (Oli et al. 2019). The average monthly rainfall is 5.9 millimetres in November and 530.8 mm in July, with an annual average of 1891.8 mm, the most of which falls during the monsoon season (DHM, 2020). Ordinarily, the temperature of Biratnagar ranges from a minimum of 10.5°C in December to a maximum of 33.9°C in April (DHM 2020).

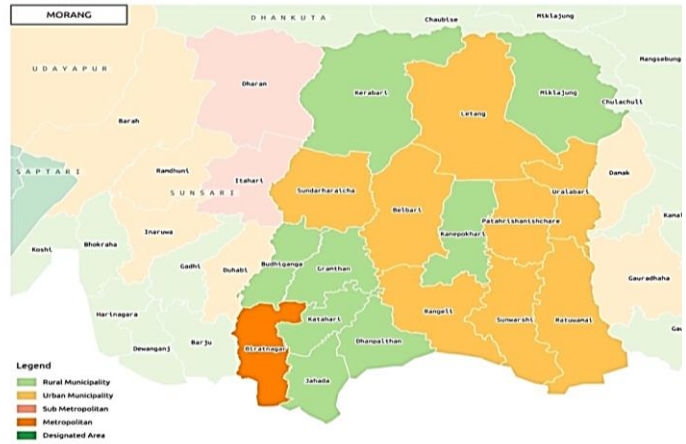


Figure 1 : Map of the Study Area (Biratnagar, Nepal) [26]

Theoretical detail

To analyze the rainfall distribution impact following statistical calculations has been performed to obtain the data as,

(i) Coefficient of Variance

The coefficient of variance is defined as,

$$CV = \frac{\sigma}{\bar{x}} \times 100$$

Where $\bar{x}$ is mean and σ is standard deviation. Coefficient of variation is used to indicate the degree of variability of rainfall [29] as $CV < 20,$ less variability, $20 < CV < 30$, Moderate, and $CV > 30$, High.

(ii) Coefficient of Skewness

Skewness measures the asymmetry of the distribution. The coefficient of Skewness is calculaed as, $S_k = \frac{n}{(n-1)(n-2)} \sum_{i=1}^{n} (x - \bar{x})^3$

If $S_k = 0$, distribution is symmetrical (non-Skewed), $S_k > 0$, distribution is positively skewed, and$S_k < 0$, distribution is negatively skewed.

(iii) Kurtosis

The Kurtosis can be calculated as,

$$K = \frac{(n^2 - 2n + 3)}{(n-1)(n-2)(n-3)} \frac{\sum_{i=1}^{n} (x|i - \bar{x})^4}{\sigma^4}$$

It is used to mesure the peakedness or flatness of a probality distribution around the the mean. If $K = 3$, the distribution is mesokurtic (normal), $K > 3$, the distribution is leptokurtic (more peaked), and $K < 3$, very high rainfall (concerntration).

(iv) Precipitation concerntration Index (PCI)

The Precipitaion Concerntration Index (PCI) defined as the uniformity or nonuniformity of rainfall over a period. PCI may be reprensented as,

$$PCI = \frac{\sum_{i=1}^{12} P_i^2}{(\sum_{i=1}^{12} P_i^2)^2} \times 100$$

Where P_i is the rainfall amount in the i^{th} month, and $\sum P_i$ is summation over 12 months. If $PCI < 10$, uniform distribution, $11 < PCI < 15$, moderate, $16 < PCI < 20$, highest rainfall, and $PCI > 20$, very high rainfall.

(v) Normal Annual Rainfall

The normal annual rainfall for 10 years may be calculated as, $N = \frac{\sum_{i=1}^{n} P_i}{10}$

Where, P_i is the rainfall in the i^{th} year.

(vi) Mann-Kendall Test

Mann-Kendall test is a non-parametric test widely used to detect the trends in hydrology and meteorology. The advantages of using MK test is that it does not require the data to be distributed normally and has low sensitivity to abrupt the breaks due to inhomogeneous time series (Tabari et al. 2011). The Mann-Kendall statistic S is given by,

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i)$$

where x_j and x_i are time series and n is the number of observations. The 'sgn' is the sign function can be expressed as,

$$sgn(x_j - x_i) = \begin{cases} 1 if x_j - x_i > 0 \\ 0 if x_j - x_i = 0 \\ -1 if x_j - x_i < 0 \end{cases}$$

The variance (σ^2) for the S statistics is given by,

$$\sigma^2 = \frac{n(n-1)(2n+5) - \sum_{t=1}^{n} t_i(t_i - 1)(2t_i + 5)}{18}$$

where, t_i represents the number of ties (equal-values) upto sample i. The Mann-Kendall statistics Z_c is given by,

$$Z_c = \begin{cases} \frac{S-1}{\sigma} for S > 0 \\ 0 for S = 0 \\ S + 1 for S < 0 \end{cases}$$

Here, Z_c follows a standard normal distribution, a positive Z_c represents an upward trend and negative Z_c represents downward trend. If $Z_c < Z_{1-\alpha/2,}(H_0)$ is rejected, a statistically significant trend exists in the hydrologic time series. Where α repsents the level of significance at 5% with $Z_{0.025} = 1.96$.

Results and Discussion

Table1: Summary of annual rainfall variation in Biratnagr, Nepal (2010-2019).

Year	Rainfall (mm)						
	Total	$\bar{x}$	σ	$CV(\%)$	S_k	K	PCI
2010	1870.1	155.84	204.76	131.39	1.12	2.99	21.95
2011	1919.6	159.97	183.93	114.98	0.74	2.16	18.43
2012	1058	88.17	110.97	125.87	1.46	4.59	20.44
2013	1471.4	122.62	179.25	146.19	1.64	4.32	24.66
2014	1547.5	128.96	164.52	127.57	1.10	3.04	20.77
2015	940.1	78.34	82.83	105.73	0.24	1.66	16.87
2016	1826.5	152.21	187.72	122.33	1.03	2.91	19.95
2017	1038.2	86.52	103.52	119.66	0.84	2.27	19.27
2018	1739.5	144.96	167.92	115.84	0.93	2.93	18.58
2019	2013.4	167.78	251.54	149.92	2.12	6.83	25.50

Table 2: Summary of monthly rainfall variation in Biratnagr, Nepal (2010-2019)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total	38.6	96.4	259.1	709.4	1653.2	3039.6	4157	2861.2	2272.8	320.6	9.2	7.2
Mean	3.86	9.64	25.91	70.94	165.32	303.96	415.7	286.12	227.28	32.06	0.92	0.72
Zc	0	0.927	1.543	0.537	-0.179	-0.894	0	-0.537	0.179	-0.716	-1.044	-1.813

Table 3: Summary of seasonal rainfall variation in Birtatnagar, Nepal (2010-2019)

	Pre-monsoon	Monsoon	Post-monsoon	Winter
Total	2621.7	12330.6	329.8	55.2
Mean	87.39	308.27	16.49	1.84

(i) Annual Analysis

Table 1 displays the statistical characteristics of the annual precipitation time series data for each year starting from 2010 to 2019. According to the computed statistics, Biratnagar's mean annual precipitation varied from 78.34 millimeters in 2015 to 167.78 millimeters in 2019. In order to examine the spatial variability of yearly precipitation for each year, the coefficient of variation, (a measure of dispersion around the mean) which shows correlation fluctuated from 105.73% to 149.92%. Over the whole time period, the average variation in precipitation was 125.95%. According to the PCI results, the years 2011, 2015, 2016, 2017 and 2018 saw modest rainfall, whereas the years 2010, 2012, 2013, 2014, and 2019 saw the largest amounts. During these periods of time maximum rainfall was measured to be 845.5 mm in 2019 and minimum to be 198.3 mm in 2015. The annual rainfall received by the years 2010, 2011, 2016, 2018, and 2019 are comparable. Similarly, annual rainfall received by the years 2012, and 2015 are comparable. Moreover, 2013 and 2014 receive more significant annual rainfall. Additionally, the Kurtosis ranged from 1.66 to 6.83 and the coefficient of skewness ranged from 0.24 to 2.12. To be classed as regularly distributed, time series data must have a coefficient of Skewness and Kurtosis of 0 and 3, respectively. Therefore, Table 1 shows that the data are positively skewed and not normally distributed. The annual distribution data reveals that the average annual rainfall, which was determined to be 1542.43 mm, indicates that Biratnagar has considerable rainfall with significant variance over a period of 10 years. Figure 2 illustrates the strong rainfall trend that was identified as the rainfall anomaly for these drought years. As a result, of heavy rainfall, floods and landslides caused greater economic loss in 2010 than 2013 and

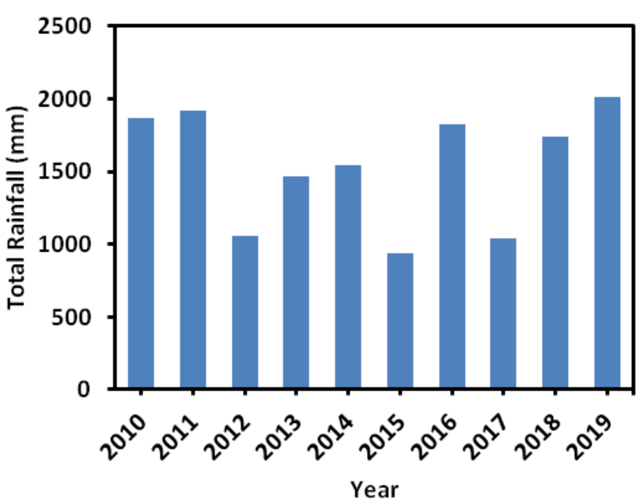
2014 (NDR 2011, NDR 2015). In addition, it has been stated that in 2015 and 2016, the total economic loss was only around 88 millions rupees (NDR 2011), which is very less during our research period. On the otherhand, from 2011 to 2017 report, floods and land slides claimed maximum lives of 248 people in 2016, and minimum lives of 77 people in 2012 in the nation (Tiwari et al. 2018). Therefore, we can notice that how the rainfall is varying annually and causing significant effects on human lives. Every year, there is large fluctuation in rainfall, which contributes to a number of disasters and is one of the significant lowering factor of Gross Domestic Product (GDP) of country.

(ii) Monthly Analysis

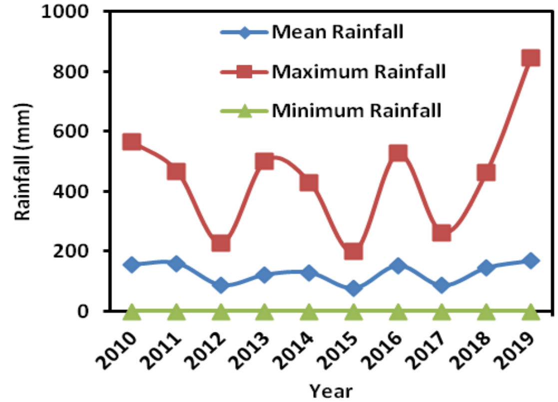
The mean and Mann-Kendall (MK) test were used to discover rainfall patterns in the monthly precipitation series. The monthly precipitation trends for the region are shown in Table 2. The average monthly rainfall was found to range between 0.72 mm and 415.7 mm, with July recording the highest average rainfall and December the lowest. The non-parametric Mann-Kendall test calculations for each particular month over a period of ten years revealed diverse rainfall trends (normal, upward, and decreasing). Calculations of January and July reveals a usual trend in rainfall. There is an upward trend for the months of February, March, April, September, and December while the tests value show a declining tendency for the months of May, June, August, October, and November. However, at 5% level of significance, the test values show no difference between an increasing or downward trend for each month. Figure 3 depicts a variation in the monthly rainfall time series for Biratnagar from 2010 to 2019. Furthermore, Figure 5 demonstrates how unpredictable Biratnagar's rainfall tendency is.

(iii) Seasonal Analysis

Additionally, we determined the seasonal fluctuation in rainfall, which is depicted in table 3. The monsoon season (June to September) has the most rainfall overall (12330.6 mm), and the winter season has the least rainfall (55.2 mm) (December-February). Monsoon was reported to have the greatest rainfall, with 845.5 mm in July, 2019. Figure 4 depicts the fluctuation in seasonal rainfall.

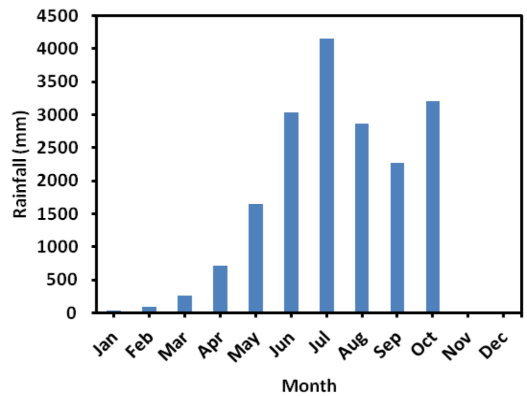


(a)

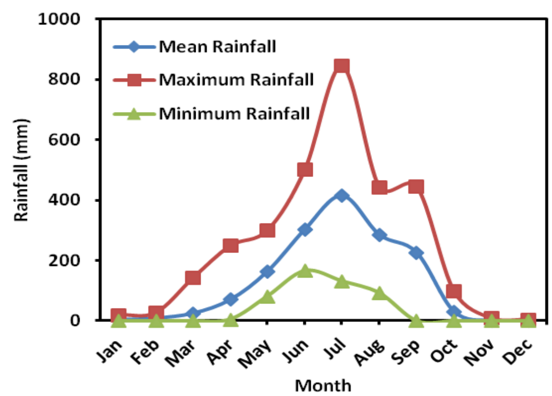


(b)

Figure 2: Annual Rainfall Variation

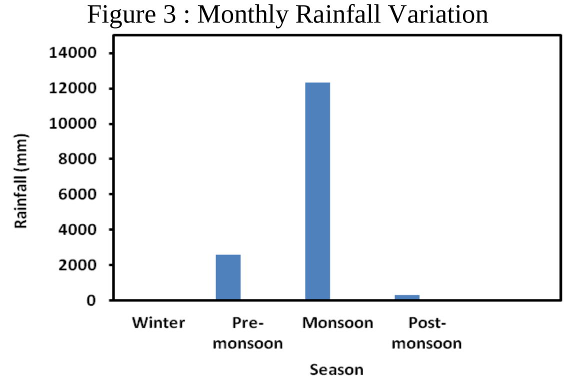


(c)

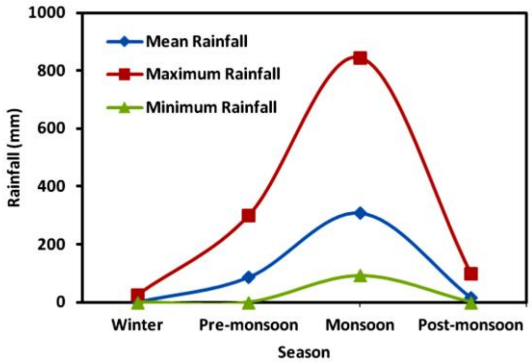


(d)

Figure 3 : Monthly Rainfall Variation



(e)



(f)

Figure 4: Seasonal Rainfall Variation

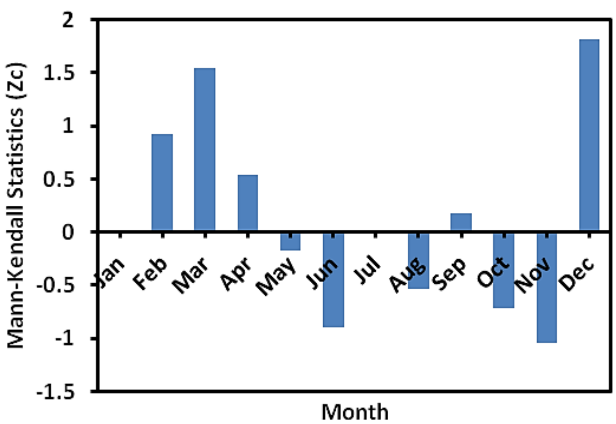


Figure 5 : Rainfall Trend

Conclusions

This paper contains the calculation and analysis of monthly, seasonal, and yearly precipitation trends over the 10 year study period of Biratnagar, Nepal. The rainfall pattern within study periodic is erratic or unpredictable. The rainfall variability is mainly due to the geographical location in lower altitude and the wind blowing from the Bay of Bangal. Another reason is that Biratnagar is an industrial area which affect the environment causing variability in weather. During monsoon season (June-September) heavy rainfall causes risk of flood and inundation in Biratnagar in the lack of embankments in Singhia and Kesalia River. Occasionally, floods take away agricultural land, allowing river water to invade human areas and causing damage to roads, buildings, and infrastructure as well as risks to human and animal lives. This monsoonal rainfall is the main cause of economic loss which lowers the Gross Domestic Product (GDP) of the country. Therefore, if the current pattern of rainfall persists during the monsoon with the same intensity and dispersion, the situation will get more dire and worse. This study will aid in the understanding of rainfall variations and trends, assisting in the management of water resources, ecosystems, irrigation, sustainable agricultural planning, engineering structural design, and other areas.

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