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VARIATIONS OF RAINFALL PATTERN IN MANAS RIVER BASIN, ASSAM

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Abstract:
Hydrological and water quality models rely heavily on precipitation data since it affects the rate and magnitude of flow and mass transfer.Analysing the rainfall patterns of a watershed, river catchment, or drainage basin can help with water management and water efficiency. The potential of crop production, farming systems, and patterns of agricultural productivity can all be determined through an understanding of the nature and characteristics of rainfall,this is then used in reservoir planning, flood control engineering, drainage system design, soil and water conservation, and other similar fields of study and practice. Understanding the features of rain in relation to its temporal variation is crucial for long-term sustainability. The industrialization has altered global and regional climate, which in turn alters hydrologic conditions and the responses of runoff in watersheds. Given its significance to local economies, it's vital to study rainfall variability at the regional level. The rainfall trends of the Manas River basin have been outlined in this research.From 2005 through 2018; the yearly rainfall trend of the Manas river basin before, during, and after the monsoon has been studied.

Keywords: Manas River, Rainfall pattern, Seasonal variation, watershed, rainfall variability

Introduction:

The increased temperature and precipitation variability that characterize the global climate changes have a significant impact on interconnected earth systems, particularly hydrology and water resources (Fu et al., 2007). The hydrological cycle in a watershed and on a regional scale is altered by climatic factors, such as total precipitation, rainfall, and temperature, which have an impact on every aspect of hydrology and water resources, changes the hydrological series in the Manas River Basin (陈伏龙 et al. 2019; Li et al., 2020). The primary cause of its sudden shift is the variability displayed by hydrological and climatic variables (Chen et al., 2015; Ling et al., 2011).

Vegetation cover in a watershed area has a direct or indirect impact on rainfall because it absorbs and stores some of the precipitation that falls on its surface during the early stages of a storm, before letting the rest of it evaporate or run off. Net precipitation is determined by the sum of the water lost through evaporation and water lost via transpiration, both of which vary over a period of 78 days (Shahin, 2002). It's not easy to put a number on a rainfall event because it might have many different characteristics (how much rain fell, what kinds of rain fell, how long it rained, how hard it rained, and so on) and these characteristics change over time (Lan et al., 2005). It is emphasized that long-term daily rainfall data is crucial since it allows for statistical analysis at daily, weekly, and seasonal scales of time (Aris et al., 2010). For flood study in a specific location, the daily unit of rainfall observation is a crucial temporal unit for revealing seasonal and spatial-temporal variability and uneven distribution of rainfall (Chu et al., 2010).

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Intricate climatic events rely heavily on precipitation (Narkhedkar et al., 2010). Therefore, in order to comprehend the nature of variable rainfall, experts from various fields, such as meteorologists, hydrologists, soil scientists, agronomists, geographers, etc., describe rainfall differently. Air pressure, temperature, and humidity all play a role in determining rainfall patterns, all of which have knock-on effects on the river catchment's evaporation, precipitation, soil moisture, surface and sub-surface flow, and discharge (Al Huda and Singh, 2016). However, orography and terrain features exert substantial control over rainfall totals, intensities, and occurrences (Starkel, 1972a; Starkel, 1972b; Starkel, 2002). As a result, elevation and surface slope are two of the most important determinants of precipitation (Singh, & Syiemlieh, 2010).

In general, it is true that the Indian subcontinent receives more than 80% of its annual rainfall between June and September due to the summer monsoon rains (Kripalani et al., 2004). The hydrological system in the north-eastern parts of India relies heavily on the summer season rainfall, as this is when the majority of the year's precipitation falls. This is because the average annual rainfall in these regions is significantly lower than the amount of rain that falls during the summer (May-August) (Goswami et al., 2010). The river basins in north-east India are prone to flooding at this time of year. Changes in river basin water level and discharge are amplified by heavier downpours. Heavy monsoon rainfall (Jamir et al., 2008), insufficient river bank ability to contain high flow, erosion, silting of riverbeds, landslides, and inadequate drainage facilities in flood-prone areas are the primary causes of flooding (Mohapatra et al., 2003).

The hydrology of rivers and the diversity of ecosystems in protected areas are both directly impacted by climate change. Because of climate change, the global hydrological cycle is expected to become more intense, which will have a significant effect on local water supplies (Amell,1999). Surface and subsurface water balances are significantly impacted by the shifting geographical and temporal patterns of precipitation brought on by global climate change (Kunstmann et al., 2004). Therefore, scientists, environmentalists, planners, policymakers, and others will pay close attention to the extent of climate change and its implications in order to maintain ecological equilibrium in the long run. The hydrology of a river can be significantly impacted by climatic, land-use, and human-use variations (Singh, 2020).

Rainfall is a key component of climate and has been characterized in a variety of ways by experts from various fields, including meteorologists, hydrologists, soil scientists, agronomists, and geographers. It fundamentally affects the hydrological cycle and modifies the nature and properties of hydrographs. The key factors affecting the hydro-tropes of the catchment landscape are the extreme rainfall circumstances, which have an impact on the evapotranspiration regimes, soil moisture and sub-surface flow, surface runoff, and trends of base flow. On the other hand, the macro-regional atmospheric conditions and the micro-regional orographic impacts of the Indian monsoon climate govern the amount, intensity, and frequency of precipitation (Starkel, 1970; Starkel, 1972a). The Inter Tropical Convergence Zone (ITCZ) shift is an atmospheric factor that affects the monsoon climate and causes irregularities in the seasonal distribution of rainfall. Thus, this paper discusses the study of variations of rainfall patter of the Manas River basin.

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Study Area:

Eastern Bhutan and northeast India are drained by the 41,350 square kilometres watershed that is the Manas River, a major tributary of the Brahmaputra River. Out of its total length of 376 kilometres, 272 kilometres flow through Bhutan and the remaining 104 kilometres run through Assam to the point where the river meets the mighty Brahmaputra at Jogighopa. A total of 18,300 km2 of Bhutanese territory is drained, between the coordinates of 26°10′ to 26° 50′ N Latitudes and 90°00′ to 91°00′ E Longitudes, while a total of 23,000 km^2 of Assam, India is drained (Fig.-1). Some of the river's main stem originates in southern Tibet and flows into India over the Bumla pass in Arunachal Pradesh's north-western region.

The Manas River travels from the southwest via Bhutan and into the south-central foothills of the Himalayas in India's Assam. This route follows the river's original course as it was carved out by glaciers.The Aie River begins its journey into India at the village of Agrong in the Goalpara district of Assam after flowing roughly 29 kilometers south-westward through Bhutan. The next 75 kilometers or so of its winding path take it to the Brahmaputra, not far from Jogigopa. The Black Mountains provide the source of the 110-kilometer-long Aie River, which begins at an elevation of around 4,915 meters near the village of Bangpari; the Manas is 376 kilometers long along the course of its longest tributary, the Kur, of which roughly 104 kilometers are located in the Indian state of Assam.

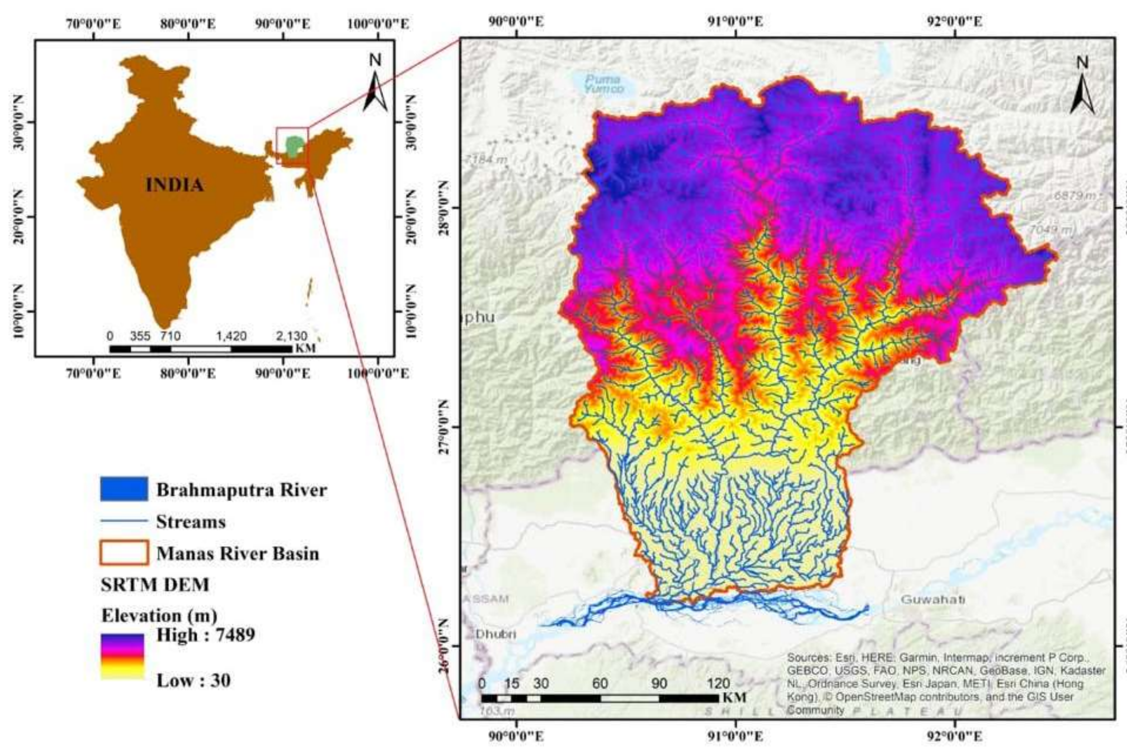

Fig.-1: Location of Manas River Basin, Assam

When it exits the western side of Manas National Park, it divides into the Beki and the Bholkaduba. The Manas National Park is located on a vast low-lying alluvial terrace below the foothills of the outer Himalaya, and is traversed by the Manas River as well as five other smaller rivers. Besides serving as a natural boundary between India and Bhutan, the river is also a recognized international boundary. There is not a single flat area within the watershed's 140-kilometer radius; the catchment rises from an elevation of 100 meters near the Indian border to the Great Himalayan peaks at over 7,500 meters along the major Himalayan range bordering Bhutan and Tibet. It is one of the world's most biodiversity regions because of the convergence of several different types of ecosystems, including the Sub-Himalayan Bhabar Terai formation and the riverine succession that continues up to the Sub-Himalayan Mountain Forest. It gets as low as around 150 C and as high as about 370 C. May through September sees the heaviest rains, with an average of 333 cm (13 feet) every year.

The main vegetation types found along the Manas River are:

- In the northern regions, Sub-Himalayan Light Alluvial Semi-Evergreen woods
- Mixed moist and dry deciduous woods in the East Himalayas (the most common type)
- Woodland on a low-lying savanna, and
- Nearly 50 percent of Manas National Park is made up of Assam Valley Semi-Evergreen Alluvial Grasslands.

Materials and Methods:

The following database and statistical methods, which will serve as the basis for the entire project, will be needed to perform the research.

- ➢ Daily rainfall data is gathered from the CWC office at Adabari, Guwahati and CWC office in Shillong for the 14-year period (2005-2018).
- ➢ The temporal variations of rainfall in Manas River Basin were categorised into Annual variations, seasonal variations, and storm variations for the 14 years period (2005-2018) and have been calculated with the help of various statistical techniques like Mean, standard deviation, Coefficient of variation and Z score.
- ➢ The toposheets of the research areahas been used in the mapping, which is done at a scale of R.F.1/50,000, from Survey of India.

Results and Discussion:

The Manas basin receives rainfall from both the boreal winter and summer monsoon circulations since the area is impacted by both monsoonal and mid-latitude weather systems. The land-sea temperature difference and its associated thermal circulations have previously been thought to be responsible for monsoon circulation. The main precipitation sources in the area during the winter

and early spring are synoptic weather systems that originate in the Mediterranean and migrate eastward toward South Asia.
One important hydro-meteorological factor that helps control the hydrological response in a river watershed is rainfall. The meteorological, atmospheric, geo-hydrological, and land surface factors all have an impact on the rainfall-runoff interaction. In order to determine which model is appropriate for such humid conditions of the land surface and relatively large seasonal rainfall intensities, the present chapter focuses on two key methodological aspects: generation of data of hydrological parameters and its spatio-temporal variations and, secondly, the establishment of rainfall-runoff relationship in Dikrong river catchment (Al Huda, 2013).
In general, the greatest, most fundamental and most immediate threat to the local population in a region is the unpredictable variability of rainfall – the dimensions of which can only be appreciated by understanding the historical record on various time scales. While most of the rainy days have low intensity, but most of the annual rainfall total is contributed by the fewer, high intensity events majorly associated with deep convection into the troposphere. Here we have discussed the various parameters that contribute for the overall study of rainfall variability in the Manas river catchment.

Annual Variations:

Annual variation in rainfall occurs mainly due to the changes in precipitation, evaporation and transpiration, soil moisture and ground water levels. In India the variability of annual rainfall is affected mainly by monsoon winds, topography, ocean currents, etc.
Here we can observe that the annual variations of rainfall for the years 2005 to 2018. The total amount of rainfall received during each year, indicating fluctuations in annual rainfall amounts over time. For instance, the highest total rainfall was observed in 2017 (3247.00 mm), while the lowest was recorded in 2006 with 1376.52 mm.Years with higher standard deviation, like 2012 (48.05 mm/day), experienced more variable rainfall patterns compared to others. The year 2005 had a Coefficient of Variation of 134.57%, indicating a high degree of variability in rainfall relative to the mean for that year. Thus we can say that the study provides valuable insights into the annual fluctuations, average patterns, and variability of rainfall, aiding in the understanding of rainfall patterns and trends in the specified region over the studied period (Table-1 & Fig.-2 & 3).

Table-1: Annual Variations of Rainfall in Manas River Basin (2005-2018)

Year	Total Rainfall (mm)	Average Rainfall (mm)	STD (mm/day)	CV (%)	No of Rainy Days	Rainfall Intensity (mm/day)
2005	1401.80	12.41	16.69	134.57	80	17.52
2006	1376.52	11.77	17.13	145.58	78	17.65
2007	1882.65	15.06	17.57	116.64	91	20.69
2008	2767.50	20.20	25.48	126.13	121	22.87
2009	2709.00	25.80	26.82	103.94	97	27.93
2010	2527.40	22.37	24.88	111.22	101	25.02
2011	1493.20	19.65	23.65	120.36	59	25.31

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2012	3013.80	37.21	48.05	129.14	80	37.67
2013	1618.20	23.45	31.04	132.36	67	24.15
2014	2699.60	29.03	35.76	123.21	83	32.53
2015	2978.50	30.39	37.52	123.44	97	30.71
2016	2142.40	23.04	26.18	113.66	75	28.57
2017	3247.00	25.77	33.48	129.91	106	30.63
2018	3031.50	24.85	30.21	121.57	106	28.60

N.B. The day which has more than 2.5 mm of rain from 8.00 am has been counted as a rainy day as per the definition given by the Indian Meteorological department, Pune.

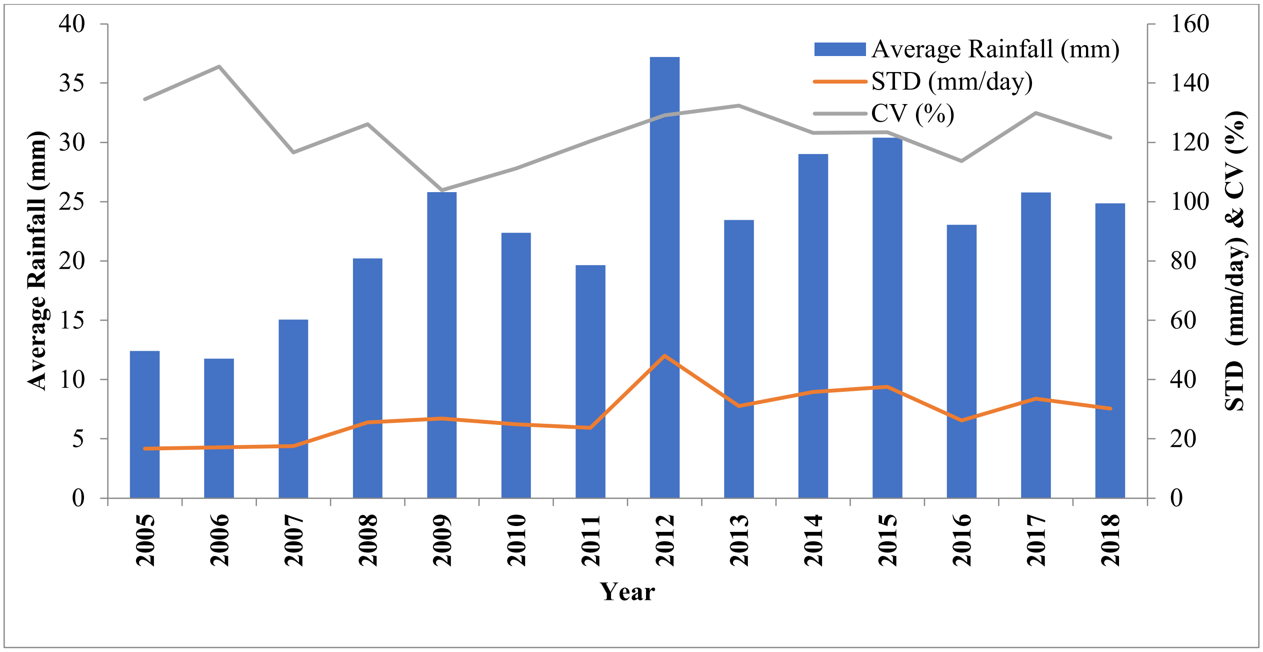

Fig.-2: Annual Variations of Rainfall in Manas River Basin (2005-2018)

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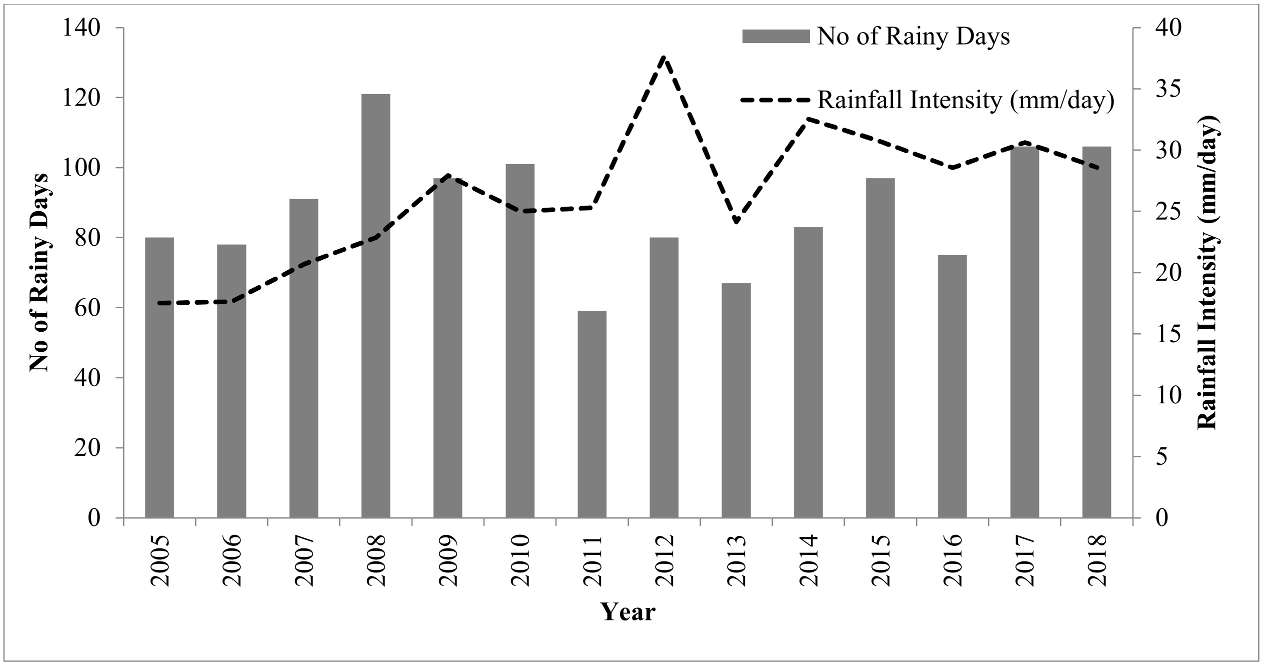

Fig.-3: Rainfall Intensity and No of Rainy Days

Rainfall intensity is the ratio of the total amount of rain (Rainfall Depth) falling during a given period to the duration of the period. It is expressed in depth units per unit time, usually as mm per hour (mm/hr). The "Number of Rainy Days" indicates the count of rainy days for each occurrence. For the specific study area, the first occurrence had 80 rainy days; the second had 78, and so on. On the other hand, the "Rainfall Intensity (mm/day)" reveals the amount of rainfall experienced per day during the rainy days. The values for rainfall intensity vary across the occurrences, indicating fluctuations in the amount of rainfall per day during different rainy periods. The highest rainfall intensity was observed during 2012, with a value of 37.67 mm/day, while the lowest was recorded during the 2006, with 17.65 mm/day. Analyzing this data provides valuable insights into the patterns and characteristics of rainfall in the specified region or time frame. Occurrences with a higher number of rainy days may indicate prolonged rainy seasons, while those with high rainfall intensity suggest intense and heavy rainfall in shorter periods.

Overall, understanding the distribution of rainy days and the corresponding rainfall intensity is essential for various applications, including water resource management, agricultural planning, and environmental studies. This data contributes to a better comprehension of the region's rainfall patterns and variability, aiding in decision-making and planning for activities that are influenced by weather and precipitation.

Seasonal Variation of Rainfall (2005-2018)

The study area has a warm, humid climate with up to 76% relative humidity. The majority of the rain falls between June and September during the monsoon season, flooding the western side of the park, and it rains from mid-March to October. The smaller rivers dry up from November to February, and the Manas River's water level declines during this time. The average high temperature in the summer is 37 °C, and the average low temperature in the winter is 5°C. Based

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on variations in rainfall, temperature, and wind, this region's climate can be split into four separate seasons. Winter (December–February), pre-monsoon (March–May), monsoon (June–September), and retreating monsoon are these (October– November). Climate change and human meddling pose serious threats to the park's sustainability and environmental safety. Over the past century, this region's rainfall has been noticeably declining at a rate of about 5 mm each decade (Bora, 2018).

It's been observed that the forest environment, especially the marsh, and grassland, along the Manas River's banks and across the park are undergoing change. The environment, which is characterized by factors like temperature, soil moisture, and humidity, could be severely impacted by this. There is no doubt that the hydrology of the Manas River and the local flora and fauna have been affected by these alterations. Variations in water output and environmental changes in the upper section of the river affect the sediment load on the river flow, which in turn affects downstream environments. Sedimentation in the Manas River rises in tandem with the melting of the ice caps that fed it. Countless wild animals perished in the river's flash floods, which also caused substantial damage to the park's vegetation and infrastructure.

Usually the trend of daily rainfall in Manas river catchment follows the same as general trend of monsoon climate. The winters are dry, the stormy rain summers have thunderstorms and sudden rain i.e. April, setting monsoon has continuous rain and then occasional rains in the last phase of monsoon, probably in October with occasional storms, 10-days moving average also shows high fluctuation of rainfall during the continuous heavy rain period. During this period, the intensity of rainfall varies significantly and makes more fluctuations in the rainfall pattern. This may be one of the main causes of flash floods in these areas of foot-hill topography.

As far as temporal variation in daily rainfall pattern is concerned, in spite of such higher rainfall intensity during the post-monsoon period, the degree of its fluctuation is marginally lesser (CV=29%) than the pre-monsoon period (CV=19.10%) as there are more numbers of occasional rains that fluctuate the rainfall trends. But the intensive rains for shorter period recharge the soil and sub-surface stratum in this areas of deep loamy and sandy soils. However, such fluctuating nature of rainfall intensity is also seen in post-monsoon season of retreating monsoon when there are cases of flash floods due to soil-water discharge conditions (Table-2, Fig.-4 & 5).

Table-2: Seasonal Variations of Rainfall in Manas River Basin

Seasons	Total Rainfall (mm)	Mean Rainfall (mm)	STD (mm/day)	CV (%)	No of Rainy Days	Rainfall Intensity (mm/day)
Pre Monsoon	2980.27	15.13	17.09	112.96	156	19.10
Monsoon	27675.65	23.72	30.28	127.68	964	28.71
Post Monsoon	2233.15	21.47	36.83	171.54	77	29.00

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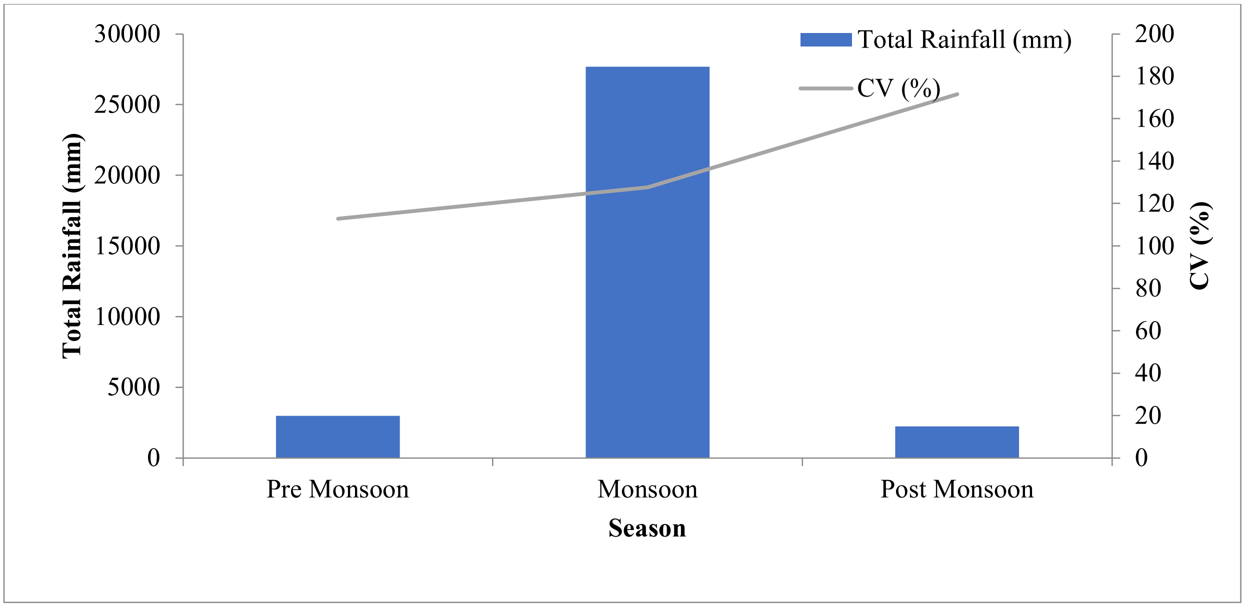

Fig.-4: Total rainfall and Coefficient of Variation of rainfall in Various Seasons

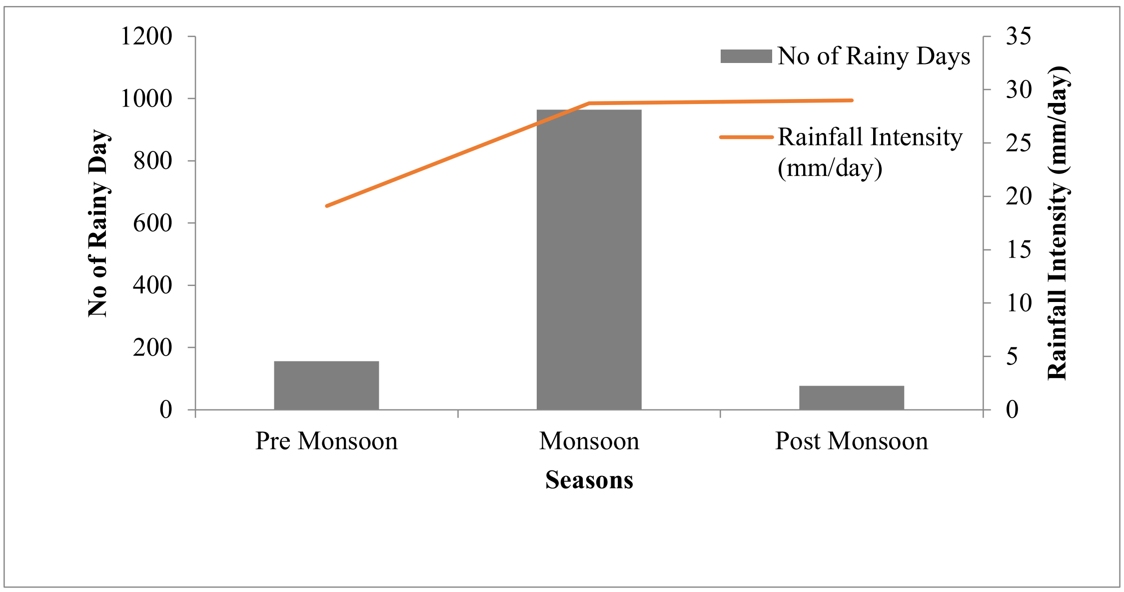

Fig.-5: Rainfall intensity during various seasons

Identification of Stormy Days:

Storm intensity is classified into different categories based on the Z value, representing the amount of rainfall. Extremely low storms, with a Z value below 0, recorded a total rainfall of 8079.62 mm, with an average of 8.02 mm. Slightly more rainfall was observed in very low storms (Z value: 0-0.5), with a total of 5467.10 mm and an average of 29.24 mm. Low storms (Z value: 0.5-1.5) exhibited even higher rainfall, reaching 8788.55 mm in total, with an average of 49.37 mm. Moving up the intensity scale, moderate storms (Z value: 1.5-2.5) had a total rainfall of 3678.10 mm, averaging 78.26 mm. High storms (Z value: 2.5-3.5) was further increases in rainfall of

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2077.80 mm, and an average of 109.36 mm. Very high storms (Z value: 3.5-4.5) experienced significantly high rainfall, amounting to 2497.60 mm on the whole, with an average of 138.76 mm. Finally, the most intense category, extremely high storms (Z value: Above 4.5), witnessed the highest amount of rainfall, with a total of 2470.90 mm and an average of 190.07 mm. In that particular study area we can observe a consistent trend of rising rainfall levels with increasing storm intensity, highlighting the importance of understanding these variations for climate monitoring and disaster preparedness in storm-prone regions (Fig.-6).

Table-3: Characteristics of Different Rainstorm Events in Manas River Basin during 2005-2018

Storms	Z Value	Total Rainfall (mm)	Mean Rainfall (mm)	STD (mm/day)	CV (%)	No of rainy Days	Rainfall Intensity (mm/day)
Extremely Low	Below 0	8079.62	8.02	6.34	78.96	736	10.98
Very Low	0-0.5	5467.10	29.24	4.22	14.45	187	29.24
Low	0.5-1.5	8788.55	49.37	8.50	17.21	178	49.37
Moderate	1.5-2.5	3678.10	78.26	7.92	10.12	47	78.26
High	2.5-3.5	2077.80	109.36	9.58	8.76	19	109.36
Very High	3.5-4.5	2497.60	138.76	8.40	6.05	18	138.76
Extremely High	Above 4.5	2470.90	190.07	18.88	9.93	13	190.07

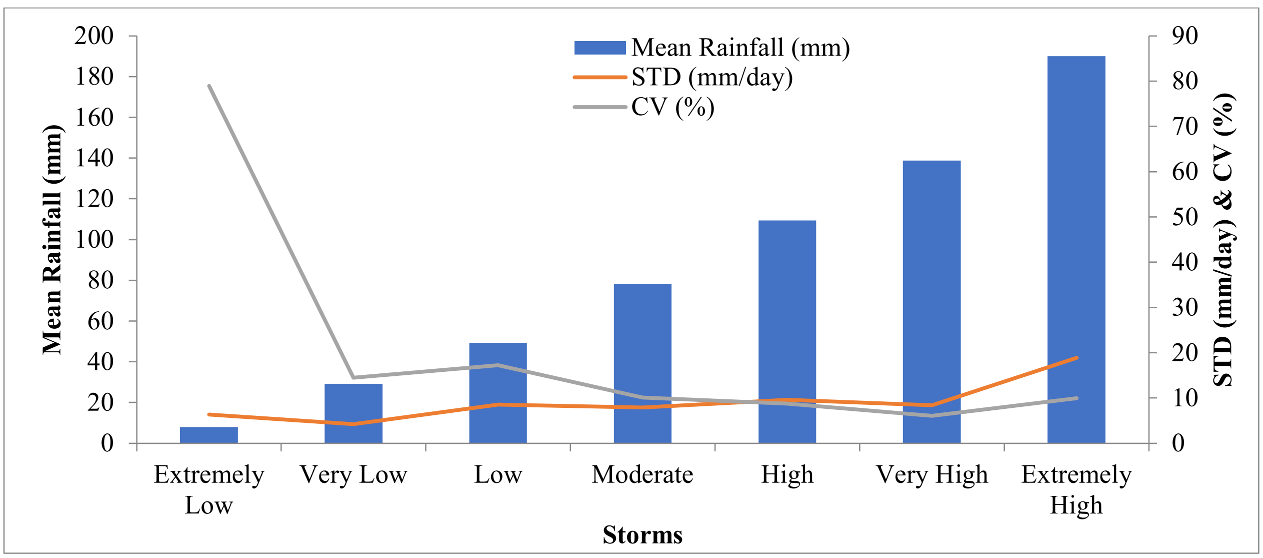

Fig.-6: Stormy Variations of Rainfall in Manas River Basin (2005-2018)

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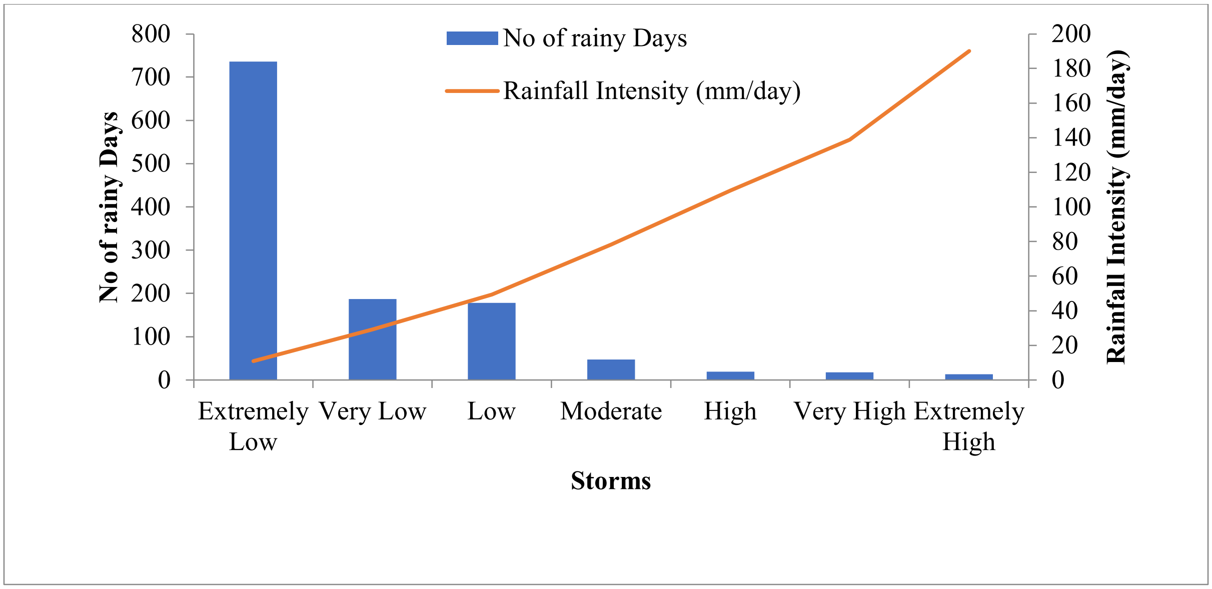

Fig.-7: No of Rainy Days and Rainfall intensity of different Storms in Manas River Basin

Over the observed period, there were 736 rainy days with a relatively low rainfall intensity of approximately 10.98 mm per day. Moving up the intensity scale, there were 187 rainy days with a moderate rainfall intensity of around 29.24 mm per day, and 178 rainy days experienced a higher intensity of about 49.37 mm per day. As we further ascend, 47 rainy days had a significant rainfall intensity of approximately 78.26 mm per day. More infrequent but impactful, there were 19 rainy days with an intense rainfall of about 109.36 mm per day. Additionally, 18 rainy days experienced even higher intensity, with approximately 138.76 mm of rainfall per day. At the top of the scale, there were 13 rainy days with the most substantial intensity, reaching approximately 190.07 mm per day (Table-3 and Fig.-7). The data indicates that higher rainfall intensities are less frequent but can result in significant volumes of rainfall within a single day. This information is essential for understanding local hydrology, managing water resources, and preparing for potential impacts on infrastructure and agriculture, allowing for more effective planning and response to extreme weather events.

Storm Duration:

A rainfall event is the basic unit used for infiltration, runoff, and soil erosion. It is defined as a specific rainfall depth distributed in time according to a specific temporal rainfall distribution. This particular study provides an insight into the duration and frequency of rainfall events. The majority of events are of shorter duration, with one-day events being the most prevalent, constituting 44.26% of the occurrences, followed by two-day events at 18.64%. As the duration increases, the frequency of rainfall events gradually decreases. Longer events, such as 9 day and 14 day events, are comparatively rare, each representing only 4 days and 2 days of occurrence (Table-4). This information is crucial for effective planning and preparation against weather-related impacts, such as flooding and droughts, and for ensuring the resilience of communities and infrastructure to varying rainfall patterns. Understanding the distribution of rainfall event durations aids in implementing appropriate strategies to manage water resources and mitigate potential risks associated with extreme weather conditions. This information offers valuable insights into the duration and frequency of rainfall events in the observed period. Understanding the distribution of rainfall event durations is essential for various sectors, including agriculture, water resource management, and urban planning, as it can help prepare for potential flooding, droughts, and other weather-related impacts. By recognizing the prevalence of shorter-duration events and the rarity of longer-duration events, authorities can develop appropriate strategies for mitigating risks associated with rainfall patterns and ensuring the resilience of communities and infrastructure to weather fluctuations.

Table-4: Total Number, Total Stormy Rainfall and Average Rainfall Depth per storm in Different Duration during 2005-2018

Duration of Rainfall Event (Days)	No of Event		Rainfall of Events (mm)		Mean Rainfall (mm)	STD (mm/day)	CV (%)	No of Rainy Days	Rainfall Intensity (mm/day)	Average Rainfall Depth (mm/event)
	Total	%	Total	%						
1	235	44.26	3182.1	9.66	13.54	20.04	148	159	20.01	13.54
2	99	18.64	3401.1	10.33	17.18	19.56	113.87	165	20.61	34.35
3	57	10.73	3374.82	10.25	19.74	26.84	135.99	133	25.37	59.21
4	44	8.29	3293.8	10	18.71	25.5	136.25	147	22.41	74.86
5	33	6.21	3761.05	11.42	22.79	28.33	124.29	139	27.06	113.97
6	23	4.33	4453.3	13.52	32.27	38.98	120.79	177	25.16	193.62
7	9	1.69	1694.9	5.15	26.9	31.97	118.84	50	33.9	188.32
8	12	2.26	3529.9	10.72	36.77	42.99	116.92	87	40.57	294.16
9	4	0.75	734.1	2.23	20.39	20.52	100.64	32	22.94	183.52
10	7	1.32	1981.1	6.02	28.3	39.31	138.9	63	31.45	283.01
11	3	0.56	729.4	2.21	22.1	23.94	108.33	29	25.15	243.13
12	1	0.19	513.8	1.56	42.82	42.64	99.59	10	51.38	513.8
14	2	0.38	700.2	2.13	25.01	20.53	82.1	26	26.93	350.1
16	1	0.19	243.6	0.74	15.23	23.42	153.81	11	22.15	243.6
38	1	0.19	1337.8	4.06	35.21	37.23	105.77	35	38.22	1337.8

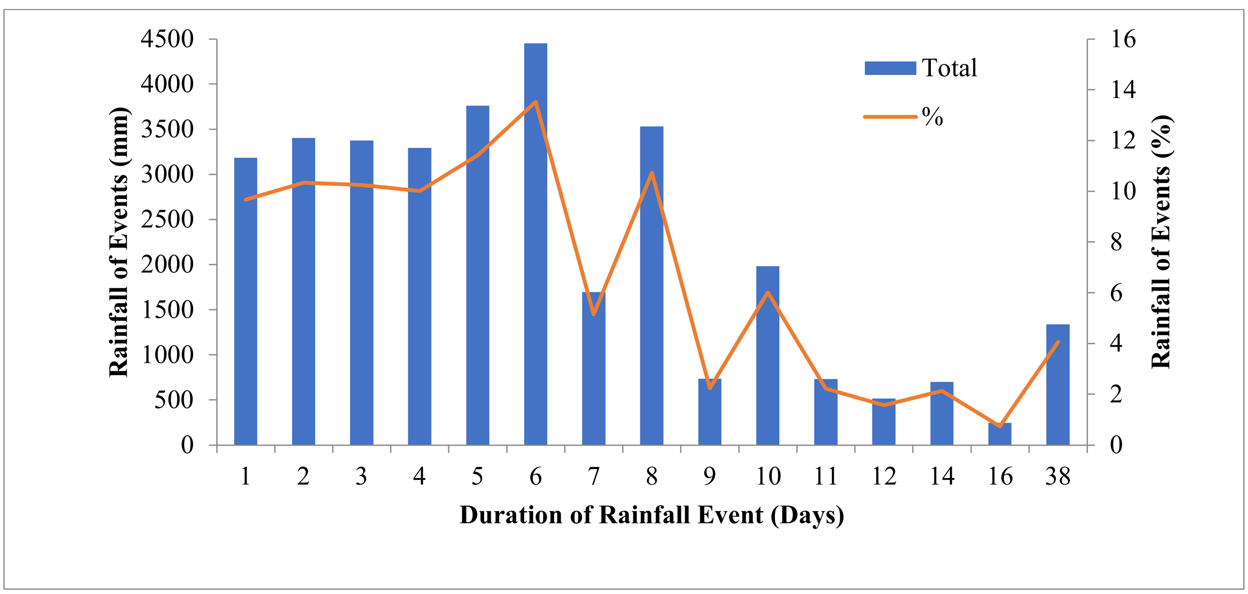

Fig.-8: Rainfall measurements for various events

The highest recorded rainfall is 4453.30 mm, making up 13.52% of occurrences in 6 days rainfall event.There are other significant events around 3761.05 mm, 3529.90 mm, and 3401.10 mm, each accounting for over 10% of the overall rainfall recorded. Moderate to lower rainfall events are also present, ranging from 1981.10 mm to 243.60 mm, representing 6.02% to 0.74% of the total rainfall (Fig.-8). The observation indicates that extreme rainfall events with values above 3000 mm are more common, collectively accounting for approximately 51.47% of the totalrecorded rainfall,

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while moderate to low rainfall events make up the rest. Understanding the distribution of rainfall amounts is vital for various sectors, including agriculture, water resource management, and disaster preparedness. By recognizing the prevalence of different rainfall intensities, authorities can develop appropriate strategies to manage water resources efficiently, prepare for potential flooding or droughts, and ensure the resilience of communities and infrastructure to varying weather conditions

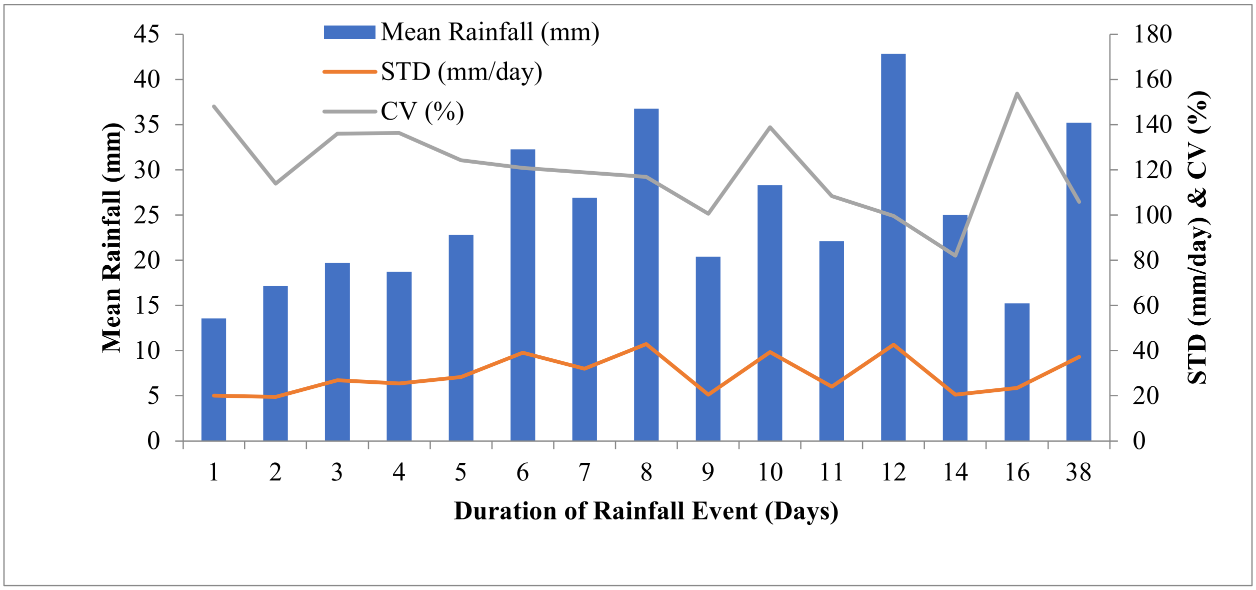

Fig.-9: Standard Deviation and Coefficient of Variation of Rainfall Events

Thereforewe receive information on mean rainfall (in mm), standard deviation (STD) in mm/day, and the coefficient of variation (CV) as a percentage for various rainfall observations. Analyzing the data, we observe varying patterns in rainfall characteristics across the recorded instances.

The mean rainfall ranges from 13.54 mm to 42.82 mm, indicating different average rainfall amounts for each observation. The standard deviation, which measures the dispersion or variability of the data, shows variations from 19.56 mm/day to 42.99 mm/day. This indicates that some instances have higher variability in rainfall compared to others. The coefficient of variation (CV) expresses the standard deviation as a percentage of the mean, offering insights into the relative variability of each dataset. The Coefficient of Variationvalues range from 82.10% to 153.81%, (Table-4 & Fig.-9) indicating diverse levels of relative variability in rainfall patterns. Notably, some instances have high Coefficient of Variationvalues, suggesting substantial fluctuations in rainfall compared to their mean values. On the other hand, instances with lower Coefficient of Variation values have relatively more stable and consistent rainfall patterns around their respective means. Higher valueCoefficient of Variations may indicate the potential for extreme weather events, leading to floods or droughts, whereas lower values Coefficient of Variation suggest more predictable rainfall patterns. Such information is essential for water resource management, agriculture, and disaster preparedness, helping authorities make informed decisions and prepare for weather-related impacts effectively.

The presented research provides a comprehensive analysis of rainfall patterns in the Manas River basin over a 14-year period, from 2005 to 2018. The study explores various meteorological aspects,

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including the annual variations of rainfall, storm intensity, distribution of rainy days, and characteristics of rainfall events. The data reveals valuable insights into the region's climate and precipitation trends, which have significant implications for water resource management, agriculture, and environmental conservation.The analysis of annual variations in rainfall indicates fluctuations in total rainfall amounts and average rainfall patterns over the studied years. These variations can have implications for water availability, agricultural productivity, and flood risks in the region. The standard deviation and coefficient of variation demonstrate the variability of rainfall data, with some years experiencing more erratic patterns compared to others. Understanding such variations is crucial for preparing communities and infrastructure for extreme weather events, such as heavy rainfall and droughts.The classification of storm intensity based on the Z value provides a comprehensive overview of different rainfall scenarios during storms. The data highlights the prevalence of low to moderate-intensity storms, with higher intensity storms being less frequent but potentially more impactful. Identifying such patterns is essential for disaster preparedness and response planning, as intense storms can lead to flooding, landslides, and other natural hazards.The distribution of rainy days and corresponding rainfall intensity gives valuable insights into the nature of rainfall events in the region. The majority of rainy days exhibit lower rainfall intensity, while fewer rainy days experience intense rainfall. This information is crucial for managing water resources, agricultural planning, and infrastructure development to cope with varying rainfall patterns.The characteristics of rainfall events, including their duration and corresponding rainfall amounts, provide a comprehensive understanding of the variability in rainfall occurrences. The data highlights the prevalence of shorter-duration events, with one-day events being the most common. However, extreme rainfall events with values above 3000 mm are also relatively common, indicating the potential for heavy precipitation and flooding in the region.

Conclusion:

The research on rainfall patterns in the Manas River basin provides essential information for water resource management, agriculture, and environmental conservation in the region. The analysis of annual variations in rainfall indicates fluctuations in total and average rainfall amounts, emphasizing the need for adaptive water management strategies to cope with changing precipitation patterns.The classification of storm intensity helps identify potential risks associated with heavy rainfall and extreme weather events. Understanding storm intensity patterns is critical for disaster preparedness and mitigation measures to safeguard communities and infrastructure.The distribution of rainy days and rainfall intensity assists in planning agricultural activities and managing water resources effectively. By recognizing the prevalence of lower-intensity rainy days, farmers can optimize irrigation practices and enhance water use efficiency.The characteristics of rainfall events, such as duration and rainfall amounts, provide valuable insights into the variability of precipitation in the region. This information is crucial for designing resilient infrastructure and disaster response strategies to mitigate the impacts of extreme weather events.In conclusion, the study on rainfall patterns in the Manas River basin is essential for long-term water resource planning, flood control engineering, agricultural productivity, and

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climate change adaptation. The findings presented here serve as a valuable point of reference for policymakers, water managers, and researchers in making informed decisions and developing sustainable strategies for the region's water management and environmental conservation.

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