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Climate variability perspective on rainfall dynamics at Mecheri sheep research station, Pottaneri, Salem District, Tamil Nadu

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Abstract
India is especially vulnerable to climate change because of its varied climate zones and reliance on monsoonal rainfall. Extreme weather events like floods and droughts have become more frequent in recent decades due to major changes in the nation's rainfall patterns. The purpose of the study was to learn more about Salem's monsoonal dynamics and rainfall extremes. The Mecheri Sheep Research Station in Pottaneri, Salem, Tamil Nadu, India, recorded significant interannual variability in rainfall and a substantial monsoonal influence over a 41-year period (1983-2024). The annual rainfall totals showed extreme wet and dry years, peaking at almost 1417.4 mm in 2022 and falling as low as 593 mm in 2002. Although there isn't a clear long-term trend, extremes have become more common in recent decades. According to monthly data, January-February is still the driest time of year (~10-15 mm), while October-November (Northeast Monsoon) is the wettest (October ≈150 mm). According to seasonal analysis, summer and winter contribute roughly 22% and 10% of the annual total, respectively, while the Southwest Monsoon (June-September) and Northeast Monsoon (October-December) contribute approximately 35% and 33%. These variations significantly impact the management of watersheds, underscoring the need for robust planning during droughts and high storage during rainy years. The frequency and variability of severe occurrences that have been recorded align with predictions of climate change, which point to longer dry spells and heavier monsoon rains. For the region's climate adaptation and sustainable water resource planning, it is imperative to comprehend these trends. The data in this study provide a scientific basis for planning that takes climate change into account. It calls on communities, water managers, and legislators to take proactive measures to guarantee ecological stability and water security for future generations.

Keywords: Seasonal rainfall distribution, rainfall trends, monthly rainfall patterns, and monsoonal variability

1. Introduction

A major worldwide problem, climate change has significant effects on agricultural output, hydrological cycles, and socioeconomic stability (Singh, 2021) [16]. India is especially susceptible to these changes because of its many climate zones and dependence on monsoonal rainfall. Variations in rainfall have an impact on a nation's drinking water supply, surface and river runoff, soil moisture, groundwater reserves, energy production, agricultural output, and, eventually, its economy. Therefore, trends in rainfall are crucial for planning and managing water resources by analyzing how climate change is affecting them (Kuttippurath *et al.*, 2021) [5]. Significant changes in the nation's rainfall patterns have occurred in recent decades, including modifications to the monsoon's onset, intensity, and distribution. Extreme weather events including droughts and floods have become more common as a result of these changes (Maharana *et al*., 2021) [6].

The large interannual variability of the Indian Summer Monsoon Rainfall (ISMR) is influenced by global climatic events like the Pacific Decadal Oscillation (PDO), Arctic Oscillation (AO), and El Niño-Southern Oscillation (ENSO).

(Roy *et al*., 2019; Bracco *et al*., 2007) [14, 1]. A shift in rainfall patterns due to climate change has been indicated by recent studies that have shown a weakening of traditional teleconnections, especially the AO-ISMR link after the 1980s (Ranade and Gurrapu, 2025) [9]. The need for region-specific research to comprehend localized effects and create adaptive measures is highlighted by these shifts. Such research will be crucial for developing effective agricultural strategies and water management practices that can mitigate the adverse effects of changing rainfall patterns. Furthermore, understanding these localized effects can enhance community resilience in the face of increasing climate variability. A thorough examination of rainfall patterns over the previous forty years is essential, given the crucial reliance of Salem's water supplies and agriculture on monsoonal rainfall. Such a study will influence watershed and catchment management techniques, offer insightful information about the effects of climate change at the local level, and aid in the creation of adaptable measures to protect the socioeconomic well-being of the area.

2. Methodology

2.1 Study Area

The Mecheri Sheep Research Station (MSRS), Pottaneri was started on 05.06.1978 at Pottaneri Panchayat of Mecheri Block in Salem district by the Government of Tamil Nadu, Chennai and is functioning under the control of Tamil Nadu Veterinary and Animal Sciences University, Chennai. This research station is situated in Salem-Mettur highway about 35 km west of Salem and 15 km east of Mettur at a longitude of 77° 56’E, latitude of 11° 45’N and altitude of about 650 feet above MSL. Its geography is marked by a mix of plains and hills, particularly the Shevaroy Hills, which modulate the district’s rainfall through orographic effects (Kumar and Neelakantan, 2016) [4]. This station lies in northern-western agro-climatic zone of Tamil Nadu and the climate is generally hot, semiarid and tropical in nature.

2.2 Data Collection

The rainfall data were obtained from the rain gauge available at the Mecheri Sheep Research Station, Pottaneri, and will be utilized. The dataset spans a 41-year period (1983-2024), ensuring a robust temporal scale for analysis. Additional ground-based data and observations were integrated from regional meteorological departments.

Data Categorization: To facilitate a comprehensive temporal analysis, the rainfall dataset was categorized as follows:

- **Monthly Rainfall:** Data were compiled for each calendar month to identify intra-annual rainfall fluctuations and determine peak and lean months.
- **Seasonal Contribution:** The contribution of each season to the total annual rainfall was calculated using percentage analysis. This helped in identifying the dominance of monsoonal contributions and variations in summer and winter precipitation patterns.
- **Seasonal Rainfall:** Rainfall was grouped according to Tamil Nadu’s four climatological seasons:
  - **Winter:** January-February
  - **Summer:** March-May
  - **Southwest Monsoon (SWM):** June-September
  - **Northeast Monsoon (NEM):** October-December
- **Annual Rainfall:** Computed by aggregating monthly rainfall values for each calendar year.

3. Results

3.1 Annual Rainfall Analysis

A) From 1983 to 1990

The data on rainfall particulars from 1983 to 1990 recorded at this station is presented in Table 1. The rainfall during this time period ranged from 658.90 to 970.9 mm, with an average of 831.4 mm. The tract received the most rainfall in September (204.50 mm), followed by October (105.10 mm) and May (103.00 mm), according to the average monthly rainfall collected over the period. With the exception of 1984 and 1988, when maximum rainfall was recorded in July and May, respectively, the tract typically saw its highest rainfall in September and October. Month-wise examination of rainfall found that in the year 1983, the tract received no rainfall from January to April months, however, the following months had above normal precipitation in most of the months with maximum in the month of September. However, in the year 1984, though the rainfall was lesser than the previous year, the tract got precipitation throughout the year. In the years 1985, 1987, 1988, 1989 and 1990, precipitation observed in all the months except February month. The examination of average yearly rainfall of the different years demonstrated that heavy rainfall in one year was followed by low rainfall in the succeeding year (Figure 1). The average yearly rainfall received in the monsoon season was 75.97 per cent of the total annual rainfall.

Table 1: Monthly rainfall (mm) from 1983 to 1990

Months	1983	1984	1985	1986	1987	1988	1989	1990	Average
January	0.0	8.0	37.4	6.4	7.4	0.0	0.0	6.7	8.24
February	0.0	71.2	0.0	11.6	0.0	0.0	0.0	0.0	10.35
March	0.0	55.7	6.0	0.0	67.2	6.0	20.0	34.0	23.61
April	0.0	44.4	72.2	51.0	55.0	79.0	87.0	48.0	54.58
May	114.6	31.0	31.4	68.3	49.9	221.0	109.0	199.0	103.00
June	83.2	3.5	138.4	42.2	70.1	28.2	22.0	30.0	52.20
July	108.6	184.4	101.2	43.4	8.5	102.0	166.0	25.0	92.39
August	104.1	15.6	73.4	72.4	50.3	169.2	48.0	119.0	81.50
September	297.1	86.3	277.3	128.7	174.0	147.2	271.0	254.0	204.50
October	102.6	108.2	48.0	146.2	268.4	15.4	114.0	38.0	105.10
November	16.2	26.2	75.2	105.0	137.6	6.2	55.0	89.0	63.80
December	144.5	24.4	9.0	21.8	41.1	6.1	0.0	10.0	32.11
Total	970.9	658.9	869.5	697.0	929.5	780.3	892.0	852.7	831.4

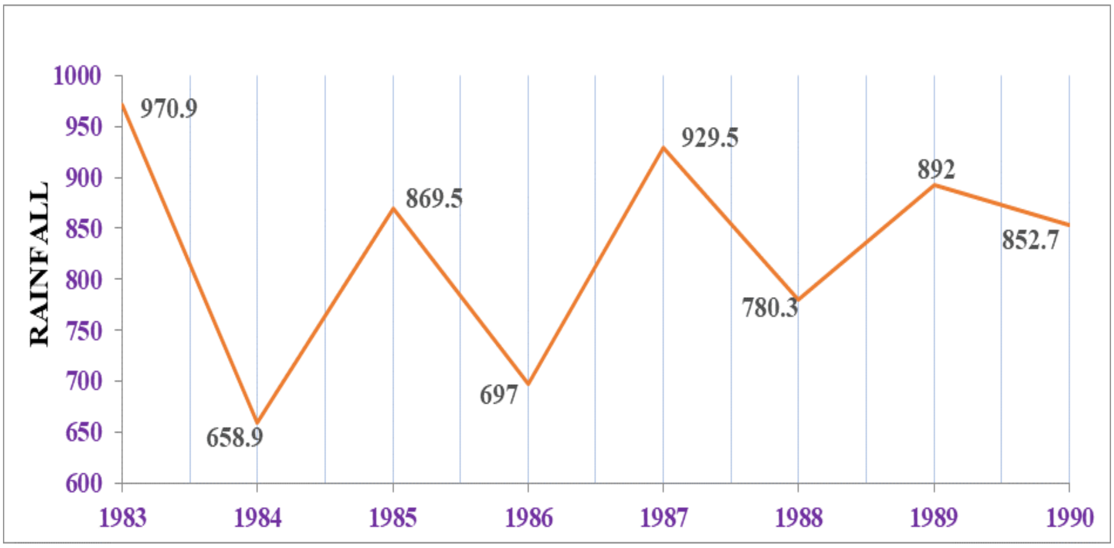

Fig 1: Annual rainfall pattern from 1983 to 1990

A) From 1991 to 2000

The monthly rainfall from 1991 to 2000 is presented in Table 2. The rainfall during this time period ranged from 721.1 to 1209.4 mm, with an average of 986.79 mm. While September and October typically had the most rainfall in the tract, November, July, April, and August saw the most rainfall in 1991, 1995, 1996, and 1998, respectively. The months of June through December accounted for around 83.95% of the total rainfall, according to the average annual rainfall totalled over the years. The majority of the years in this year saw good rainfall in this tract, and the yearly rainfall pattern showed no discernible trend. The tract experienced higher rainfall from 1992 to 1996 (Fig. 2), followed by a decrease.

Table 2: Monthly rainfall (mm) details from 1991 to 2000

Months	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Average
January	11.0	0.0	0.0	0.0	5.3	0.0	0.0	0.0	0.0	0.0	1.63
February	0.0	0.0	7.2	0.0	0.0	0.0	0.0	0.0	3.2	18.2	2.86
March	29.0	0.0	0.0	0.0	27.0	23.1	13.0	0.0	0.0	29.0	12.11
April	88.0	4.0	0.0	48.0	59.0	206.3	82.1	36.0	55.2	9.2	58.78
May	76.0	23.0	99.3	201.0	142.0	73.3	21.1	72.3	53.3	68.4	82.97
June	118.0	70.0	75.0	12.0	73.0	124.3	66.0	25.3	50.4	51.3	66.53
July	65.0	47.0	62.0	99.4	246.4	52.0	87.0	174.3	43.4	0.0	87.65
August	32.0	62.4	130.0	55.5	175.3	165.2	116.0	262.0	76.4	190.1	126.49
September	149.0	239.1	128.3	103.0	104.2	185.4	131.2	101.3	57.2	284.4	148.31
October	175.0	143.2	204.1	284.8	124.3	184.3	281.4	198.0	343.3	220.1	215.85
November	265.0	105.4	129.0	151.2	148.0	32.1	164.4	135.0	96.4	128.1	135.46
December	0.0	27.0	79.0	0.0	0.0	163.4	76.4	77.3	35.0	23.4	48.15
Annual Rainfall	1008.0	721.1	913.9	954.9	1104.5	1209.4	1038.6	1081.5	813.8	1022.2	986.79

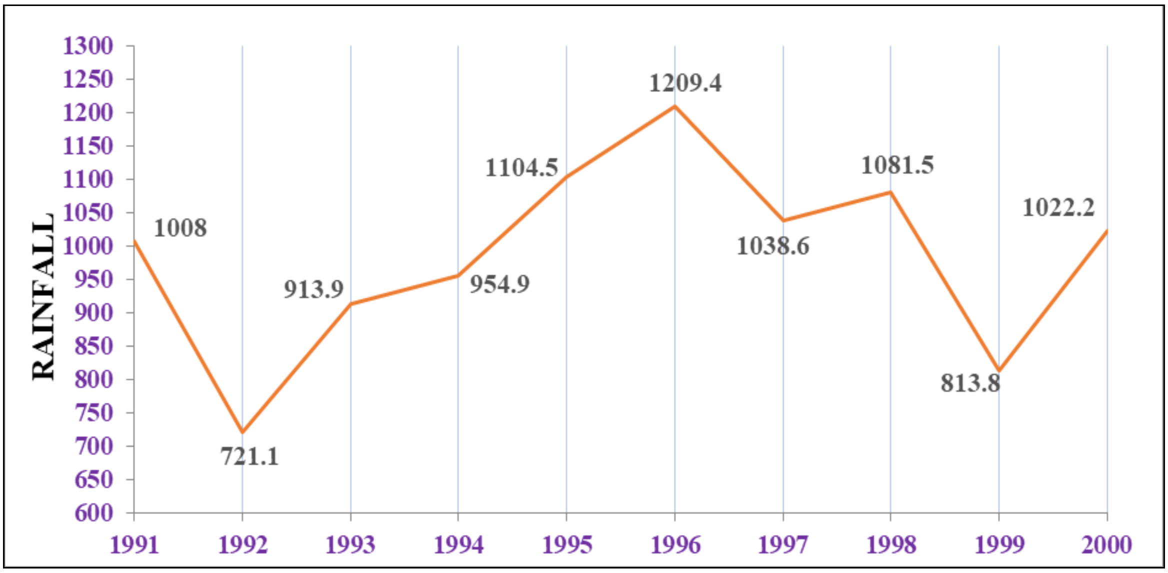

Fig 2: Annual rainfall pattern from 1991 to 2000

B) From 2001 to 2010

The details of rainfall from 2001 to 2010 based on averages for monthly is presented in Table 3. The measured annual rainfall ranged from 593.0 to 1213.60 mm, with an average of 910.86 mm. The tract received the most rainfall in various months in various years (e.g., April in 2001; May in 2004; August in 2003, 2005, and 2007; September in 2002 and 2009; October in 2006 and 2008, and November in 2010). The month-wise rainfall pattern did not show any particular pattern. The months of June through December accounted for 77.56% of the total yearly rainfall. The yearly rainfall trend for each month showed (Figure 3) a rise in rainfall from 2002 to 2005 (593.00 mm to 1213.6 mm), followed by a decrease in 2006 (844.7 mm). During this time, the graphical representation showed no discernible pattern. During this time, significant variations in rainfall were seen between years. The average yearly rainfall during this time frame (910.86 mm) was 7.69 percent lower than the average rainfall during the preceding period (1991-2000).

Table 3: Monthly rainfall (mm) details from 2001 to 2010

Months	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Average
January	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	2.0	0.0	0.32
February	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
March	0.0	75.5	57.4	0.0	63.8	49.4	0.0	91.7	24.8	0.0	36.26
April	244.0	7.4	15.0	52.9	53.2	17.8	67.0	18.2	57.4	38.8	57.17
May	5.2	101.3	47.8	338.3	84.5	49.8	29.6	142.4	191.6	115.8	110.63
June	24.4	31.2	69.8	58.6	34.1	106.2	82.4	94.2	58.2	83.5	64.26
July	176.4	7.0	67.6	89.8	72.4	0.0	93.6	76.0	7.2	94.0	68.40
August	95.9	48.9	192.3	15.6	286.2	99.3	251.3	180.4	138.2	152.3	146.04
September	108.9	164.3	131.6	264.3	100.8	179.0	161.0	79.0	209.5	41.0	143.94
October	134.5	123.6	160.1	128.3	272.2	240.0	131.6	201.4	17.0	123.2	153.19
November	52.8	33.8	31.7	40.8	197.6	103.2	39.0	121.0	81.0	311.3	101.22
December	24.8	0.0	8.4	0.0	48.8	0.0	136.0	3.0	11.0	62.3	29.43
Annual Rainfall	866.9	593.0	781.7	988.6	1213.6	844.7	991.5	1008.5	797.9	1022.2	910.86

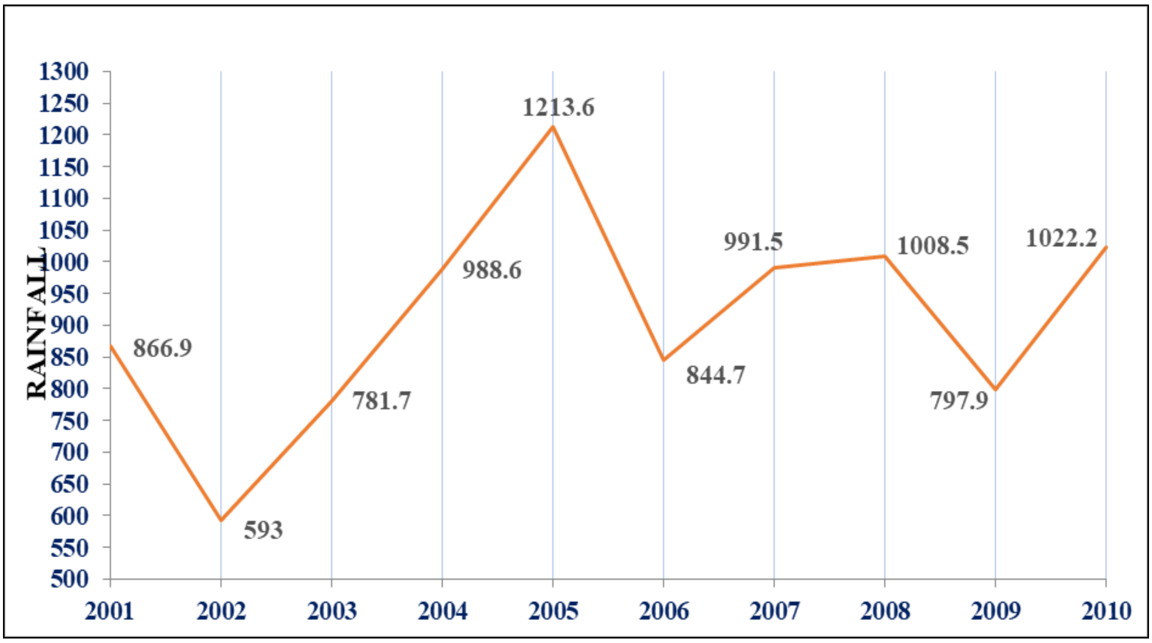

Fig 3: Annual rainfall pattern from 2001 to 2010

D) From 2011 to 2017

The data on rainfall particulars from 2011 to 2017 is presented in Table 4. The tract received the most rainfall in July (2016), August (2011 and 2017), September (2013 and 2014), October (2012), and November (2015). In most years, January and February received no rainfall or very little rainfall. This tract received 78.14 percent of the total rainfall from June to December months; the analysis of the annual rainfall pattern revealed no clear pattern (Figure 4), and the tract received less rainfall that was below average for three years in a row. i.e., from 2012 to 2014 and then there was a sharp increase in rainfall in the year 2015 followed by a below average rainfall of 668.6 mm in the subsequent year. The average annual rainfall for the years 1983-1990, 1991-2000, 2001-2010, and 2011-2017 was 831.4 mm, 986.79 mm, 910.86 mm, and 810.8 mm, respectively. From 2011 to 2017, the average yearly rainfall in this area was extremely low. Between 2011 and 2017, the average annual rainfall was 10.98% lower than it was between 2001 and 2010.

Table 4: Monthly rainfall (mm) details from 2011 to 2017

Months	2011	2012	2013	2014	2015	2016	2017	Average (2011 to 2017)	Average (1983 to 2017)
January	0.0	0.0	0.0	0.0	24.0	0.0	11.2	5.03	3.45
February	20.2	0.0	2.3	0.0	0.0	0.0	0.0	3.21	3.83
March	45.0	0.0	0.0	0.0	39.3	0.0	13.2	13.93	22.00
April	187.1	11.4	35.9	13.0	149.0	0.0	9.0	57.91	57.19
May	42.7	73.5	50.4	115.1	138.0	110.3	150.2	97.17	98.30
June	27.3	37.8	18.4	61.1	58.1	121.0	13.4	48.16	58.93
July	105.0	47.8	31.7	13.0	48.3	200.2	106.8	78.97	81.50
August	193.3	71.0	140.2	42.2	153.3	138.4	215.7	136.3	123.75
September	137.1	93.0	258.8	172.2	61.4	41.0	189.5	136.1	157.46
October	85.2	244.7	79.8	171.8	122.6	25.0	185.1	130.6	155.58
November	43.4	43.2	59.0	29.3	258.7	2.0	30.7	66.61	95.53
December	20.2	43.2	19.2	85.0	29.3	30.7	30.0	36.8	36.87
Annual Rainfall	906.5	665.6	695.7	702.7	1082.0	668.6	954.8	810.8	894.38

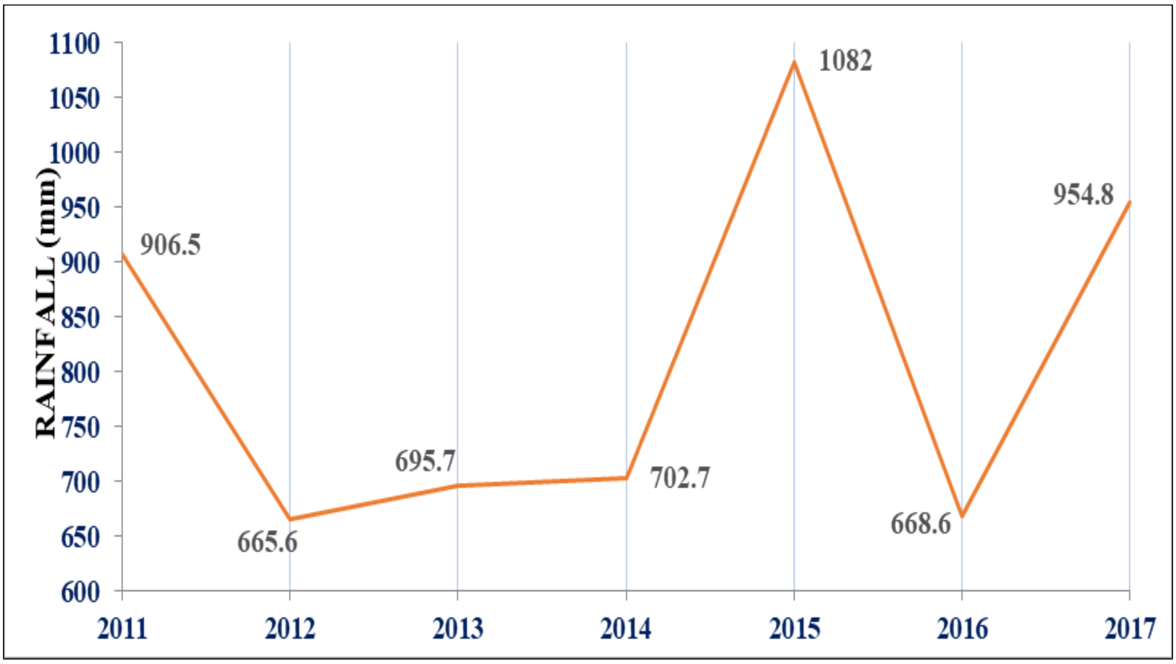

Fig 4: Annual rainfall pattern from 2011 to 2017

E) From 2018 to 2024

The data on rainfall particulars from 2018 to 2024 recorded is presented in Table 5. During this time, the average annual rainfall was 982.81 mm, with a range of 653.40 to 1417.4 mm. The average monthly rainfall averaged across the period revealed that the tract received greatest rainfall in the month of October (168.84 mm) followed by September (147.97 mm) and May (121.79 mm) months accordingly. With the exception of 2018, 2020, and 2021, when maximum rainfall was recorded in May, July, and November, respectively, the tract got the most rainfall in September and October in the majority of years (Figure 5).

Table 5: Monthly rainfall (mm) details from 2018 to 2024

Month	2018	2019	2020	2021	2022	2023	2024	Average (2018 to 2024)	Average (1983 to 2024)
January	0.0	21.2	3.2	32.0	0.0	0.0	3.6	8.57	6.01
February	20.0	0.0	0.0	20.0	0.0	0.0	0.0	5.71	4.77
March	20.2	0.0	3.2	0.0	19.0	38.2	0.0	11.51	16.76
April	10.0	94.5	112.2	122.0	49.2	9.2	2.4	57.07	57.13
May	203.2	51.0	98.7	60.4	171.9	106.7	160.6	121.79	110.05
June	98.8	100.9	88.7	127.8	279.2	45.6	84.0	117.86	88.40
July	49.2	73.5	257.8	134.8	101.3	59.4	94.1	110.01	95.76
August	54.0	126.8	64.3	16.0	252.4	13.5	196.9	103.41	113.58
September	124.8	232.5	148.6	145.5	80.3	278.8	25.3	147.97	152.72
October	94.0	193.2	128.8	94.4	317.2	63.7	290.6	168.84	162.21
November	50.2	83.3	88.7	224.6	98.1	35.3	30.2	87.20	91.37
December	27.0	17.1	64.7	30.2	48.8	3.0	109.2	42.86	39.87
Annual Rainfall	751.4	994.0	1058.9	1007.7	1417.4	653.4	996.9	982.81	938.60

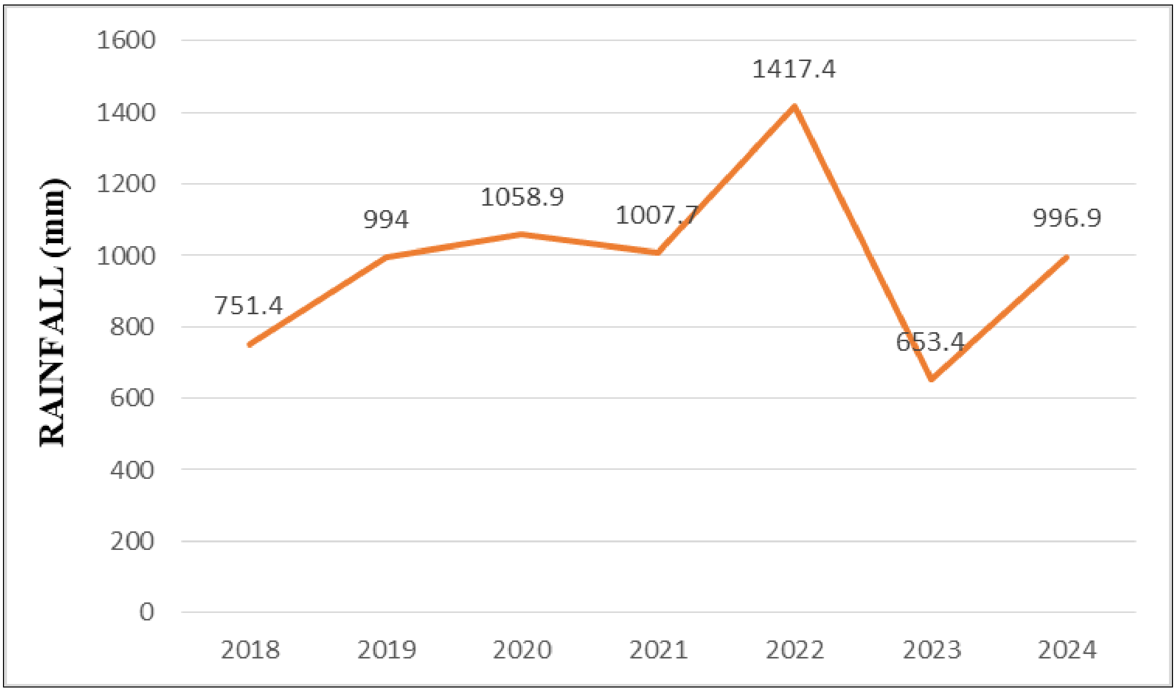

Fig 5: Annual rainfall pattern from 2018 to 2024

The month-wise study of rainfall pooled over multiple years (i.e., 1983 to 2017) revealed that the tract got greatest rainfall in month of September (Fig. 6) followed by October and August months correspondingly. January, February, March, April, May, June, July, August, September, October, November, and December all had the highest average monthly rainfall of 37.4 mm in 1985, 71.2 mm in 1984, 91.7 mm in 2008, 244.0 mm in 2001, 338.3 mm in 2004, 138.4 mm in 1985, 286.2 mm in 1995, 297.1 mm in 1983, 343.0 mm in 1999, 311.3 mm in 2010, and 163.4 mm in 1996. Between June and December, the tract received 79.34 percent of the total rainfall.

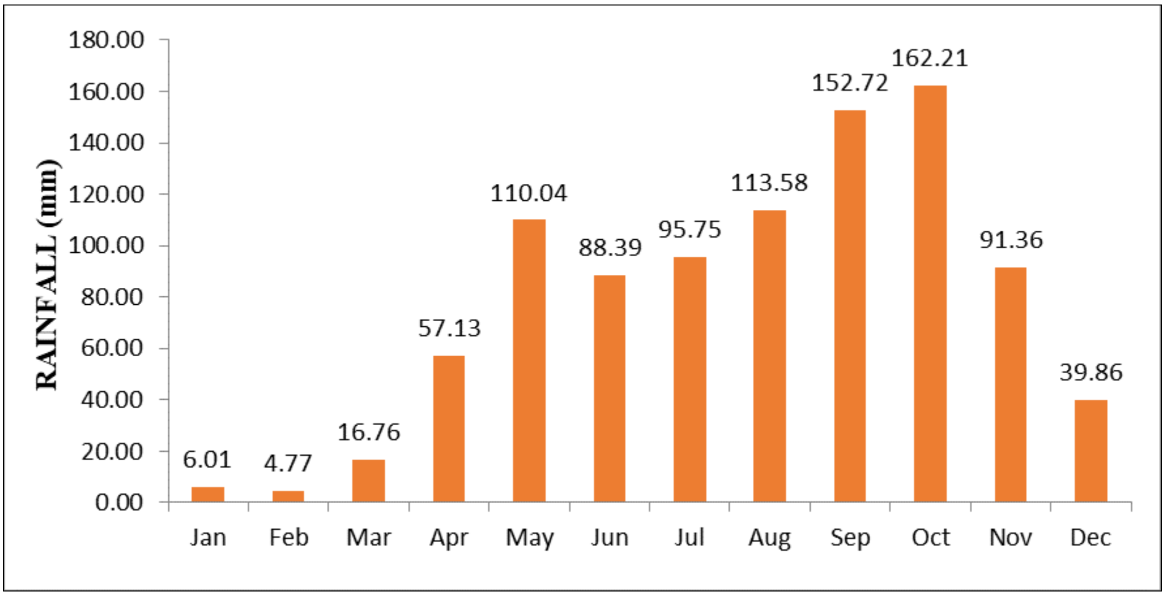

Fig 6: Average Monthly Rainfall from 1983 to 2024

The tract had the highest rainfall of more than 1200 mm in just two years, 1996 and 2005, and the lowest rainfall of 593 mm in 2002, according to the yearly rainfall data between 1983 and 2017 (Fig. 7). Additionally, the tract had less than 700 mm of rain in 1984, 1986, 2012, 2013, and 2016.

The annual rainfall in MSRS, Pottaneri, Salem from 1983 to 2024 shows considerable variation, with distinct periods of higher and lower rainfall. The most significant rainfall was recorded in 2022 (1417.4mm), reaching over 1000 mm, closely followed by 2005 (1213.6mm) and 1996 (1209.4mm), which also approached this peak. In contrast, 2002 experienced the lowest average rainfall, dropping to below 500 mm, indicating a notably dry year. These fluctuations reflect not a gradual trend but rather alternating wet and dry phases that characterize the region's climate.

Rainfall was comparatively constant in the 1980s and 1990s, typically falling between 650 and 1000 mm with fewer extreme readings. But starting in the 2000s, MSRS, Pottaneri, Salem started to see more noticeable highs and lows. For instance, rainfall totals were extremely high in 2005, 2008, and 2010, but they sharply decreased in 2002. This erratic pattern points to growing variability in the rainfall distribution of the area, which is probably caused by more significant changes in the climate. According to Raviraj *et al.* (2020) [11], who observed ~ 1200 mm in 2005 a number much beyond the typical range these data are consistent with the reported patterns of growing climate extremes throughout India. The contrasting events such as floods in 2021 and dry spells in 2016 illustrate how Salem's rainfall has become increasingly unpredictable, emphasizing the need for resilient watershed and resource management strategies.

E) Monthly Rainfall Analysis

The monsoon systems in the area have created the monthly rainfall distribution in MSRS, Pottaneri, and Salem, which has a distinct cyclical rhythm. The wettest months of the year are October and November, when average rainfall peaks at about 150 mm in October and 130 mm in November. This illustrates how the Northeast Monsoon (NEM), which normally comes in late October and lasts until December, has a significant impact on this area of Tamil Nadu. On the other hand, January and February are the driest months, with little to no rainfall (often less than 15 mm), suggesting a particularly dry winter. The pre-monsoon summer months (March through May) also experience relatively low rainfall, with April averaging around 35 mm, gradually increasing through May (~72 mm) as atmospheric moisture builds toward the onset of the monsoon.

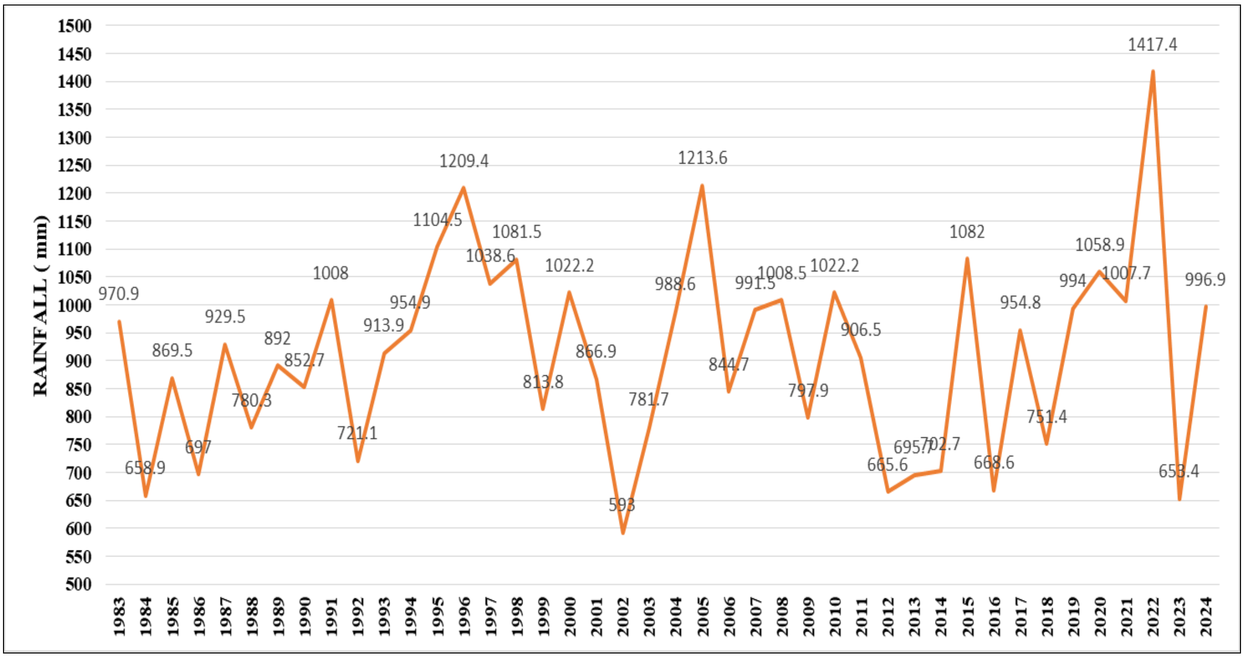

Fig 7: Annual Rainfall Pattern from 1983 to 2024

A major contributor from June to September is the Southwest Monsoon (SWM), which causes rainfall to gradually increase from June (~50 mm) to a secondary peak in September (~115 mm). August (~85 mm) contributes significantly as well, emphasizing the strength of the mid-monsoon. December is a transitional month that still experiences notable rainfall (~60 mm), although it is slightly past the Northeast monsoon peak. According to established Tamil Nadu climatological patterns, where nearly 80% of the annual rainfall falls during monsoon periods, MSRS, Pottaneri, Salem's rainfall regime is significantly skewed toward the late monsoon months, as evidenced by the precipitation's sharp increase in October and November and subsequent tapering in December (Kokilavani *et al.*, 2025) [3].

The region's agriculture greatly depends on this seasonal distribution. Rabi crops, which are grown after the monsoon season, benefit from the most rainfall in October and November, whereas Kharif crops, which are planted during the Southwest Monsoon, depend on steady rainfall from June to September. In addition to providing a bimodal opportunity for cultivation, these twin peaks in rainfall necessitate careful water management to avoid dry spells, particularly in the early and late months of the year. This pattern is supported by earlier research, such as that conducted by Raviraj *et al.* (2020) [11], which highlights Salem's significant reliance on the timing and volume of the monsoon, especially the post-monsoon rains. This trend affects the district's flood preparedness and water resource planning in addition to influencing the agrarian calendar.

3.2 Seasonal Rainfall Analysis

The seasons seen at Mecheri Sheep Research Station, Pottaneri are cold or winter (January and February), Hot-weather or summer (March to May), south-west monsoon (June to September) and north-east monsoon (October to December) seasons. Over the whole study period (i.e., from 1983 to 2025), the average annual rainfall was 931.29 mm (Table 6).

In winter, hot weather, south-west monsoon, and northeast monsoon seasons, the average rainfall was 8.65, 184.01, 441.76, and 298.87 mm, respectively (Fig. 8). Overall, the tract's yearly rainfall was 6.44% lower than Tamil Nadu's average. This tract received the most rainfall during the south-west monsoon, according to the season-wise data, while the northeast monsoon season produced the most rainfall throughout Tamil Nadu. This tract received 0.93, 19.76, 47.44, and 31.87 percent rainfall during the winter, hot weather, southwest monsoon, and northeast monsoon seasons, respectively. The comparable percentages for Tamil Nadu as a whole were 2.23, 16.28, 31.87, and 49.62 percent, respectively.

The monsoon systems' overwhelming influence is evident in the pie chart showing MSRS, Pottaneri, Salem's seasonal rainfall distribution. About 35% of the total annual rainfall is contributed by the Southwest Monsoon (SWM), which lasts from June to September. At 33%, the Northeast Monsoon (NEM), which lasts from October to December, makes up nearly the same portion. Together, these two monsoon systems provide around 68% of MSRS, Pottaneri, Salem's annual precipitation, highlighting the district's significant reliance on the seasonal monsoon cycles for its climate. On the other hand, the winter months (January-February) only contribute 10% to the annual total, while the summer months (March-May) produce a comparatively modest 22%. The seasonal disparity mirrors typical rainfall trends across Tamil Nadu, where monsoon rainfall makes up more than 75-80% of the total precipitation annually (Kokilavani *et al.*, 2025) [3].

The MSRS, Pottaneri, Salem differs from other parts of Tamil Nadu that can be more dependent on the Northeast Monsoon alone because of its balanced monsoonal dependence. Since the SW and NE monsoons are almost equally important in Salem, any change or malfunction in either system for example, a weak NE monsoon year like 2014 can have a significant effect on groundwater recharging, crop productivity, and total annual rainfall.

The management of water resources and agriculture are practically impacted by this dual-monsoon system. The Northeast Monsoon is essential for sustaining Rabi crops, filling reservoirs, and replenishing aquifers, whereas the Southwest Monsoon is essential for starting the Kharif cropping season. In order to provide resilience against intraseasonal variability, local planning must give rainwater collection and storage throughout both monsoon windows top priority because both monsoons contribute significantly. This seasonal distribution is supported by studies like those conducted by Raviraj *et al.* (2020) [11], which highlight the need of dual-seasonal readiness in Salem's rainfall management plan.

Table 6: Season wise rainfall details (1983 to 2024)

Year	Winter/Cold (Jan-Feb)	Summer/Hot-weather (Mar-May)	South west Monsoon (Jun-Sep)	North East Monsoon (Oct-Dec)	Total
1983	0.0	114.6	593.0	263.3	970.9
1984	79.2	131.1	289.8	158.8	658.9
1985	37.4	109.6	590.3	132.2	869.5
1986	18.0	119.3	286.7	273.0	697.0
1987	7.4	172.1	302.9	447.1	929.5
1988	0.0	306.0	446.6	27.7	780.3
1989	0.0	216.0	507.0	169.0	892.0
1990	6.7	281.0	428.0	137.0	852.7
1991	11.0	193.0	364.0	440.0	1008.0
1992	0.0	27.0	418.5	275.6	721.1
1993	7.2	99.3	395.3	412.1	913.9
1994	0.0	249.0	269.9	436.0	954.9
1995	5.3	228.0	598.9	272.3	1104.5
1996	0.0	302.7	526.9	379.8	1209.4
1997	0.0	116.2	400.2	522.2	1038.6
1998	0.0	108.3	562.9	410.3	1081.5
1999	3.2	108.5	227.4	474.7	813.8
2000	18.2	106.6	525.8	371.6	1022.2
2001	0.0	249.2	405.6	212.1	866.9
2002	0.0	184.2	251.4	157.4	593.0
2003	0.0	120.2	461.3	200.2	781.7
2004	0.0	391.2	428.3	169.1	988.6
2005	0.0	201.5	493.5	518.6	1213.6
2006	0.0	117.0	384.5	343.2	844.7
2007	0.0	96.6	588.3	306.6	991.5
2008	1.2	252.3	429.6	325.4	1008.5
2009	2.0	273.8	413.1	109.0	797.9
2010	0.0	154.6	370.8	496.8	1022.2
2011	20.2	274.8	462.7	148.8	906.5
2012	0.0	84.9	249.6	331.1	665.6
2013	2.3	86.3	449.1	158.0	695.7
2014	0.0	128.1	288.5	286.1	702.7
2015	24.0	326.3	321.1	410.6	1082.0
2016	0.0	110.3	500.6	57.7	668.6
2017	11.2	172.4	525.4	245.8	954.8
2018	20.0	233.4	326.8	171.2	751.4
2019	21.2	145.3	533.7	293.6	994.0
2020	3.2	214.1	559.4	282.2	1058.9
2021	52.0	182.4	424.1	349.2	1007.7
2022	0.0	240.1	713.2	464.1	1417.4
2023	0.0	154.1	397.3	102.0	653.4
2024	3.6	163.0	400.3	430.00	996.9
Average	8.65	184.01	441.76	296.87	931.29
% over annual rainfall	0.93	19.76	47.44	31.87	
Tamil Nadu (2000-01 to 2023-24)					
Average rainfall	21.29	155.62	304.63	474.36	955.91
% over annual rainfall	2.23	16.28	31.87	49.62	

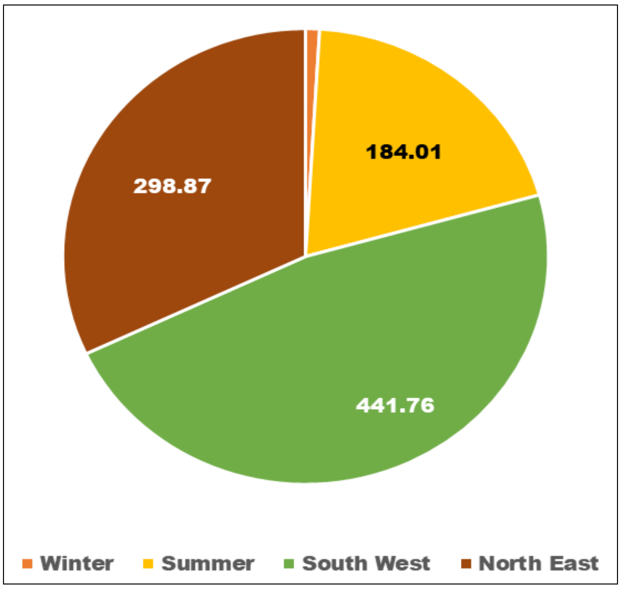

Fig 8: Average Seasonal Rainfall (mm) Pattern

In conclusion, the data clearly shows that bimodal rainfall capture and utilization is a crucial component of sustainable development in the area, as Salem's hydrological health depends on the time and intensity of both monsoonal pulses.

Rainy Days

The number of rainy days observed from 1989 to 2017 is presented in Table 7. The mean count of rainy days averaged across the years was 49.79 days, varying from 36 days (in 2002) to 67 days (in 2011) (Fig. 9). The greatest count of rainy days was noted in October, succeeded by September and August. The area experienced more rainy days than usual during 58.62 percent of the time. The count of rainy days recorded in January and February was the least when compared to all other months.

4. Discussion

4.1 Climate Change Inference

The rainfall data from the MSRS, Pottaneri, Salem area from 1983 to 2024 shows new trends that are consistent with more general signs of climate change seen in India and around the world. Although there is no discernible rising or decrease trend in the district's total yearly precipitation, there has been a noticeable increase in interannual variability and the number of extreme rainfall events in recent decades. Record-breaking rainy years (like 2021) and notable dry years (like 2002) characterize this pattern, which is in line with research on how climate change is affecting regional hydrology (Srinivasan, 2019) [17].

4.2 Increase in extreme rainfall and drought incidents

The frequency of extreme events, which are years with rainfall totals that are either much higher or lower than the climatological mean, has increased. This pattern is consistent with observations made throughout India, where during the past few decades, the frequency of both seasonal droughts and short-duration, high-intensity rainfall has increased (Srinivasan, 2019) [17]. The 2022 monsoon season in the MSRS, Pottaneri, and Salem dataset saw rainfall that was much higher than the monthly averages over the long run, especially in October and November, suggesting that the Northeast Monsoon was intensifying. On the other hand, 2016 saw one of the lowest yearly totals, with significant deficits in both the Northeast and Southwest monsoon seasons.

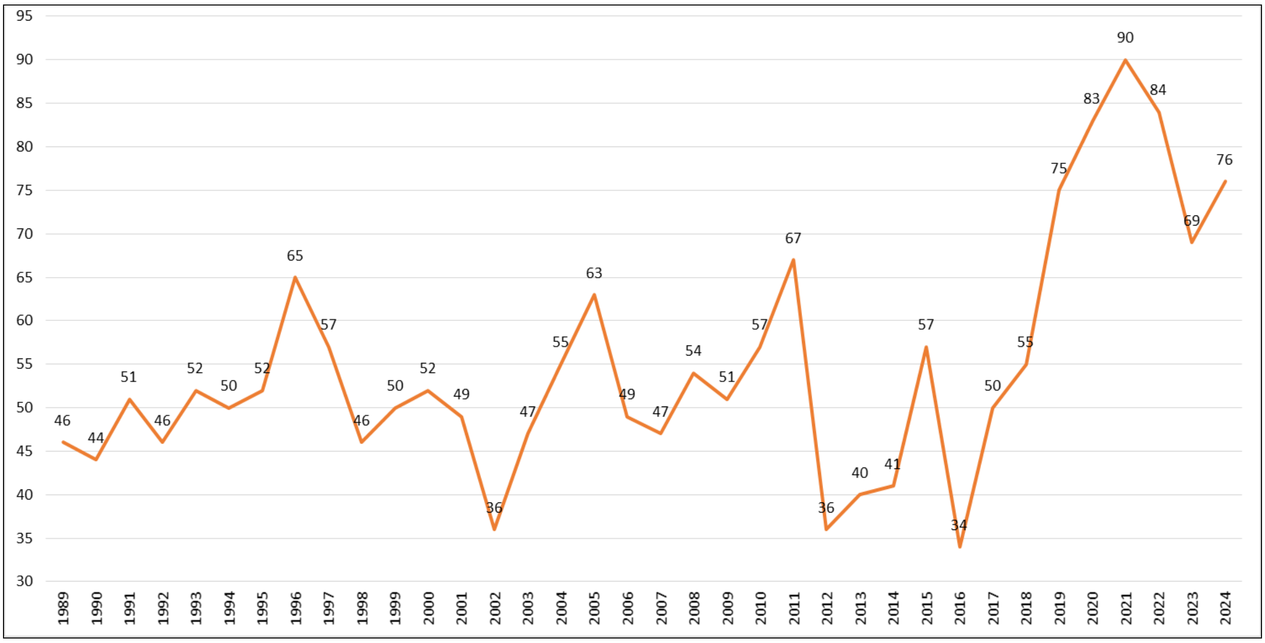

Fig 9: Number of rainy days from 1989 to 2024

Table 7: Monthly rainy days from 1989 to 2024 (numbers)

Months	1989-2003														
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
January	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0
February	0	0	0	0	1	0	0	0	0	0	1	3	0	0	0
March	1	2	1	0	0	0	1	1	1	0	0	1	0	2	3
April	5	1	3	0	0	4	2	9	3	2	4	1	5	1	1

May	6	10	6	2	6	8	6	3	2	5	7	7	1	7	4
June	3	3	8	4	5	2	3	9	6	1	4	4	3	3	3
July	13	2	4	2	4	8	8	1	6	5	3	0	7	1	3
August	3	7	4	5	4	3	10	9	5	12	4	11	8	4	11
September	10	9	7	14	7	5	7	13	7	6	6	10	8	8	6
October	3	3	9	9	12	14	8	8	10	8	14	7	9	7	10
November	2	5	8	9	10	6	6	3	13	3	5	4	4	3	5
December	0	1	0	1	3	0	0	9	4	4	2	4	4	0	1
Total	46	44	51	46	52	50	52	65	57	46	50	52	49	36	47

Months	**2003-2017**													
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
January	0	0	0	0	0	0	0	0	0	0	0	1	0	1
February	0	0	0	0	0	0	0	2	0	0	0	0	0	0
March	0	3	2	0	4	3	0	1	0	0	0	2	0	1
April	5	3	3	2	2	3	4	8	2	4	1	8	0	1
May	14	8	5	3	7	8	5	6	5	3	6	4	6	8
June	3	3	7	6	6	7	5	5	3	2	5	3	9	2
July	5	5	0	3	5	2	6	6	4	5	1	4	6	4
August	2	6	4	9	9	7	8	11	6	6	4	8	5	10
September	10	6	9	7	6	9	5	12	5	10	8	7	3	10
October	12	15	11	9	11	2	6	7	7	5	9	6	1	7
November	4	10	8	5	3	8	13	8	2	3	4	10	0	4
December	0	4	0	3	1	2	5	1	2	2	3	4.	4	2
Total	55	63	49	47	54	51	57	67	36	40	41	57	34	50

Months	**2018-2024**							
	2018	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**Average**
January	0	0	1	4	0	0	3	0.36
February	1	0	0	1	0	0	0	0.25
March	1	0	1	0	1	2	0	0.80
April	1	3	8	7	6	3	1	3.47
May	8	3	5	7	10	13	7	6.13
June	9	7	8	6	7	6	11	4.86
July	5	7	16	10	15	10	9	5.41
August	8	12	7	5	10	4	12	7.02
September	8	18	14	14	5	18	4	8.63
October	7	18	9	11	14	6	15	8.86
November	6	4	7	21	8	6	6	6.27
December	1	3	7	4	8	1	8	2.72
Total	55	75	83	90	84	69	76	54.88

These variations imply that rainfall extremes are being exacerbated by climate change, most likely as a result of increased atmospheric moisture content. Heavy but more intermittent downpours can result from warmer air's capacity to hold more water vapor. At the same time, lengthier dry spells brought on by changed monsoon circulation patterns might make conditions for agriculture and water security more difficult.

4.3 Shifts in monsoon timing and distribution

The monsoon seasons may be changing in terms of time and organization in addition to intensity. There is early indication that the Northeast Monsoon (October to December) is becoming more erratic, with a greater likelihood of delayed onset or sudden cessation, based on both national meteorological research and MSRS, Pottaneri, Salem's rainfall trends. Since Salem's agriculture mostly depends on consistent seasonal rainfall for planting and harvesting, this unpredictability has a direct impact on the Kharif and Rabi cropping cycles. Crop failures, irregular irrigation schedules, or an increase in pest pressure can result from even little changes in the monsoon's start or retreat. According to certain climate models, waning tropical circulations and rising sea surface temperatures in the Bay of Bengal a major influence on Northeast Monsoon patterns may cause late-season rainfall (October-November) to become more unpredictable and intense in the ensuing decades (Srinivasan, 2019) [17]. These forecasts support the abnormalities in Salem's recent climatology that have been noticed.

4.4 Broader climatic consistency

The dynamics of rainfall seen in MSRS, Pottaneri and Salem is not unique. They are in line with regional and international evaluations of how precipitation systems are affected by climate change. The IPCC assessments, for example, show a distinct pattern of "wet-get-wetter and dry-get-drier," especially in tropical and subtropical regions. Because MSRS, Pottaneri, Salem and Tamil Nadu are located in a climatic transition zone and receive rainfall from both of India's major monsoons, they are particularly vulnerable to even little changes in monsoon regimes. Notably, research referenced in Srinivasan (2019) [17] predicts that India will continue to see an increase in the frequency and intensity of intense daily rainfall occurrences. This is consistent with the 40-year trend in Salem that decadal extremes have been increasingly noticeable since the year 2000.

4.5 Implications for climate-adaptive planning

These evolving rainfall characteristics necessitate a paradigm shift in water and land management, moving from a stationary climate assumption to a climate-adaptive approach. Future watershed and agricultural planning in Salem must incorporate:

- Early warning systems and seasonal forecasts to prepare for extreme wet or dry events.
- Dynamic cropping calendars based on monsoon onset predictions.
- Climate-resilient infrastructure capable of handling both floods and droughts (e.g., flood storage buffers and drought relief irrigation systems).
- Continuous monitoring and research to refine local projections and adjust policies.

Moreover, climate-smart agricultural techniques, including soil moisture conservation, crop diversification, and stress-tolerant crop varieties, will be critical in minimizing the socio-economic impacts of climate variability.

5. Conclusion

A comprehensive analysis of 41 years of rainfall data for the MSRS, Pottaneri, Salem district (1984-2024) indicates that the monsoon significantly influences the region's hydroclimatic profile. The district is very seasonal, with the Northeast (October-December) and Southwest (June-September) monsoons accounting for around 68% of the total precipitation each year. Of these, the Northeast Monsoon usually produces the most rainfall each month, particularly in October and November, which are the months with the highest rainfall. The monsoon dependence of the region's water resources is highlighted by the winter and summer seasons, which, while not negligible, contribute comparatively minor portions (10% and 22%, respectively).

The long-term dataset demonstrates high inter-annual variability, with annual totals ranging from 593.0 mm in 2002 (a severe drought year) to 1417.4 mm in 2021 (an exceptionally wet year). Such large variations highlight the region's sensitivity to climate change and show how common extreme weather occurrences are. These patterns are not coincidental; rather, they are indicative of larger national and international climate trends, where climate change is contributing to an increase in rainfall variability, the frequency of extreme events, and unpredictable seasonal patterns. Considering water management, these findings have significant ramifications. Initially, the predominance of monsoon rains suggests that any interruption or postponement of monsoon activity can have a substantial effect on groundwater recharging, agriculture, and water storage. This calls for a multifaceted strategy to water resource management that prioritizes adaptability and resilience. Strategies including afforestation, check dam and percolation tank construction, regulated aquifer recharge, and rainwater collecting are essential for increasing the system's ability to withstand rainfall shocks.

Second, more adaptable and climate-resilient infrastructure development is needed due to the growing frequency of exceptional years, both rainy and dry. The ability to store excess water during rainy years while maintaining sufficient buffer capacity to lessen floods is a requirement for dynamic reservoir operations. On the other hand, to guarantee a steady supply throughout the seasons, stored resources must be effectively rationed during dry spells. In this regard, local-level resilience can be greatly increased by supporting decentralized water storage, community-based watershed treatments, and drought-resilient farming methods.

Crucially, the information also reaffirms the necessity of continuous climate forecasting and monitoring systems. According to future climate simulations, rainfall extremes in Tamil Nadu and the rest of peninsular India will only get worse. The stakes are much higher for a district like Salem, which depends on both monsoons, which is different from those that only have one. Changes in the commencement dates, the distribution of rainfall, or delayed or unsuccessful monsoons can all have repercussions for the ecology, economy, and lives of the area.

In conclusion, four decades of rainfall trends confirm that long-term climate monitoring is not only a scientific endeavour but also a strategic requirement for sustainable development. Salem can develop the adaptive capacity to deal with a future of greater uncertainty by coordinating watershed management with observed rainfall dynamics and anticipated climate hazards. In order to ensure water security and ecological stability for future generations, policymakers, water managers, and communities are urged to take proactive measures by the data offered in this study, which offers a scientific basis for climate-informed planning.

Conflict of Interest

Not available

Financial Support

Not available

Reference

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