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Research Article

Tracking the Long-term Progression of Weather Variables in West Tripura through the Lens of Climate Change

BURHAN U. CHOUDHURY[1]*, D. DASCHAUDHURI[1] AND K. GHOSH[2]

[1]ICAR Research Complex for NEH Region, Tripura Centre, Lembucherra-799001, West Tripura
[2]Agromet Division, India Meteorological Department, Shivajinagar, Pune-411005, Maharashtra

ABSTRACT

Weather variables that change over time and on a long-term basis can impact the climate of a region. Using Mann-Kendall tests and Sen's slope, we evaluated the variability, trends, and magnitudes of change in weather variables in West Tripura for 32 years (1992-2023). The rainfall experienced yearly variation (CV: 21.5%), with an average of 2320.5 mm and a non-significant decrease of 10.0 mm annually. The average number of rainy days for the past 32 years was 94 ± 11.6. West Tripura had 75 extreme rainfall events (1-day maximum >100 mm), with 16 of them being more severe (1-day maximum >150 mm), including 286 mm in June 2001. For 12 out of 32 years, the region experienced a deficit in rainfall, leading to mild to severe degrees of meteorological drought 59 times. Long-term air temperature trends yielded contradictory results. The maximum temperature went up by +0.04° C, while the minimum temperature was lower by -0.03° C. A consistent water deficit was observed in the climatic water balance (Rainfall vs. Pan Evaporation) during the peak Rabi growing season (November to March). With the evapotranspiration trend suggesting increased atmospheric demand, more water is needed to maintain optimal crop growth and yield. To enhance cropping intensity and land productivity in the studied region, it is crucial to manage water, whether through in-situ or irrigation, particularly during the Rabi season.

Key words: Climate change, Trend analysis, Water balance, Weather variables, Tripura, Northeast India

Introduction

The role of weather parameters in understanding climate patterns, forecasting extreme events, and assessing environmental changes is crucial. Long-term measured weather data analysis is a great way to identify patterns, trends, and anomalies in weather patterns in a region. Through this analysis, valuable insights into climate variability can be gained and future climate conditions can be predicted. This guide supports decision-making in various sectors, such as agriculture, water resource management, and disaster preparedness. After the IPCC projection of a rise in earth's surface temperature (at an average of 0.05° C per decade) during the period 1901-2003 (IPCC, 2007; Pörtner *et al.*, 2019), the analysis of climate variables on different spatiotemporal scales has gained increasing importance. The Indian Institute of Tropical Meteorology (IITM) used global and regional climate models with different IPCC scenarios to indicate a temperature change of about 3-5° C and an increase of 5-10% in summer monsoon rainfall. As per the study, there is likely to be a 20-30% decrease in the number of rainy days, which will result in an increase in rainfall intensity (Krishnan *et al.*, 2020).

Climate change impacts are rapidly becoming a reality in the Northeastern Region of India (NEI).

*Corresponding author,
Email: burhan3i@yahoo.com

Between 1901 and 2015, the variability in rainfall's spatial and temporal distribution in NEI (including 8 states) increased from 14.7% to 27.8%. The seasonal rainfall distribution over decades exhibited an inconsistent pattern: an upswing in the monsoon (JJAS) but a downswing in the pre (MAM) and post (ONDJ) monsoon months. Between 1951 and 1990, the maximum temperature (mean 29° C) rose to +0.04° C and the rate of rise doubled (+0.086° C) in recent decades (1990-2015). The minimum temperature (mean 19° C) decreased by -0.01° C from 1951 to 1990, but a reverse trend of increasing (@ +0.01° C) was noticed in the recent decades (1990 to 2015) (Choudhury *et al.,* 2025). The rainfall and temperature trends within the region are often conflicting. A long-term study (1986-2014) by Saha *et al*. (2015) found that there were significant decreases in post-monsoon and winter rainfalls in the NE state of Mizoram. A significant increase in annual, maximum, and minimum air temperatures was reported by them, particularly during winter months (Saha *et al.,* 2016). In another long-term study from the northeastern states of Meghalaya (Umiam), Choudhury *et al*. (2012) found a non-significant increasing trend in the annual and pre-monsoon (MAM) rains but a non-significant decreasing trend in monsoon and post-monsoon months. The maximum temperature increased (+0.086° C $year^{-1}$) significantly, while the minimum temperature decreased (-0.0116° C $year^{-1}$) non-significantly. The region is experiencing frequent weather extreme events due to such regional anomalies in rainfall occurrence and temperature trends (Kalita *et al.,* 2024).

Natural disasters like floods, landslides, and cyclones are common in Tripura and other Northeastern states of India. The state Tripura has yet to achieve a food grain surplus (current deficit at >6.0%) for the population size of over 4.2 million, with a cultivated area of only 0.27 million ha (Govt. of Tripura, 2023). Extreme weather events (flood followed by drought) are a major reason for the state's food security sustainability deficit. The intensity of such events has been on the rising trend in recent decades (Pörtner *et al.,* 2019). The result of this has been the partial to complete failure of agricultural crops, as well as significant losses for the allied agriculture sectors, such as livestock and fisheries. A state that is dominated by resource-poor farmers, 96% of whom are small and marginal, relies solely on agriculture and allied sectors for their livelihood security (Govt. of Tripura, 2023). The socio-economic, food, and nutritional security of a significant portion of the state's population is at risk due to the frequent occurrence of extreme climate events.

Region-specific climate studies on a micro-scale are essential to comprehend the local climate and devise a crop calendar that accounts for the trend in frequency and time of extreme weather events in the past few decades (Choudhury *et al.,* 2013; Saha *et al.,* 2016). This will promote crop diversification by adjusting sowing and harvesting windows of site-specific cropping patterns and crop types in a cyclical manner while minimizing the risk of crop failure (Das *et al.,* 2013; Mandal *et al.,* 2015). Micro-scale climate data can be used to efficiently manage water resources, especially during dry spells or monsoon fluctuations, to ensure sustainable water availability for agriculture and households (Mandal *et al.,* 2017). The enhancement of early warning systems and preparedness strategies can be achieved through detailed climate studies. The spread of vector-borne diseases in both plants and humans is directly influenced by climate. Disease surveillance and preventive measures are aided by micro scale climate data (Ashrith *et al.,* 2017). Thus, region-specific micro-scale climate data analysis and adequate interpretation are crucial for climate projection studies, as they enable the development of adaptation and mitigation measures, which are an integral part of climate resilient agriculture (Choudhury *et al.,* 2022).

To address this need, the present study incorporated long-term measured climate variability (1992-2023) to detect the direction of change (+/-) in climate variables and quantify the magnitude of those changes for West Tripura. For this, a non-parametric Mann-Kendall test was performed on the measured climate variables, namely rainfall, temperature, relative humidity, sunshine duration, evaporation, and rainy days. The magnitudes of the trends were estimated using Sen's slope.

Materials and Methods

Long period measured weather dataset

The measured daily weather data of 32 years (1992-2023) were collected from Agromet Observatory, located in ICAR Research Complex for NEH Region, Tripura Centre, Lembucherra, under West Tripura district of Tripura. The observatory is located at an elevation of 16.2 meters above mean sea level (MSL) and has the geographic coordinates of 25°53' N latitude and 91°55' E longitude. For duration of 32 years, weather parameters, such as rainfall, temperature (both maximum and minimum), relative humidity, sunshine duration, evaporation, and rainy days, were collected on daily basis. The analysis was conducted in accordance with the India Meteorological Department (IMD) guidelines to categorize different seasons. In the time scale, four meteorological seasons were used for annual observation, which included winter (January to February), pre-monsoon (March to May), monsoon (June to September), and post-monsoon season (October to December). According to IMD guidelines (IMD Glossary), the rainfall distributions on a weekly, monthly, and seasonal basis were classified as follows

1. Excess when percentage departure of realised rainfall from normal rainfall is more than 19%.
2. Normal when percentage departure of realised rainfall from normal rainfall is between – 19 % to + 19 %.
3. Deficient when percentage departure of realised rainfall from normal rainfall is between – 20 % to - 59 %.
4. Scanty when percentage departure of realised rainfall from normal rainfall is between – 60 % to - 99 %.
5. No rain when percentage departure of realised rainfall from normal rainfall is – 100 %

Similarly, the maximum and minimum temperatures were categorized as

1. Normal when the departure from normal is ± 1° C,
2. Above normal when the departure of normal is + 2° C,
3. Appreciably above normal when the departure of normal is +3° C to +4° C. The normal maximum temperature should be 40° C or less
4. Markedly above normal when the departure of normal is from +5° C to +6° C. The normal maximum temperature should not exceed 40^{o} C.

A drought year considered when the annual rainfall deficiency was > 26% of its long-term normal rainfall. The drought was classified as moderate if the rainfall deficiency was between 26 and 50%, and severe if the deficiency was over 50%. When there is an average weighted normal rainfall of 88 cm on a country scale, this can be termed as Indian Summer Monsoonal Rainfall (ISMR) (Shewale and Kumar, 2005).

Methodology adopted in trend analysis

A Mann-Kendall test was used to detect the changing trends of annual and seasonal weather variables in the time series (Kendall, 1995). The objective of this rank correlation test was to compare the observed number of discordances to the expected value of the same quantity from a random series. A statistically significant trend was evaluated using the 2-statistics. To detect any trends at the selected level of significance (a), we compared the absolute value of Z to the standard normal cumulative distribution. The trend is said to decrease if Z is negative, and increase if Z is positive. The true slope (magnitude) of an existing trend (change year) was estimated using Sen's non-parametric method in the second phase of analysis (Feng *et al.*, 2016; Choudhury *et al.*, 2012). The strength of the linear relationship between the variables was determined by calculating the correlation coefficient (r) values.

Results and Discussion

Long period mean monthly rainfall distribution pattern

Table 1 presents descriptive statistics, including long-term (LT: 1992-2023) trends on monthly rainfall distribution from 1992 to 2023. The average monthly rainfall for a long period varied from 5.7 (±10.8) mm in January to 442.9 (±191.1) mm in June. The wettest month was June, received a record rainfall of 442mm followed by July (405.5mm ±189.4) and

Table 1. Mann-Kendall trend statistics for mean monthly rainfall at Lembucherra, West Tripura (1992-2023)

Month	Long period average mean monthly rainfall (mm)						
	Maximum	Minimum	Mean	SD[1]	CV[2] (%)	Z[3]	Q[4]
January	51.4	0.0	5.7	10.8	190.2	-0.67	0.000
February	218.0	0.0	24.9	43.0	173.1	-1.83	-0.40+
March	290.4	0.0	69.8	64.3	92.1	-0.45	-0.45
April	506.7	0.0	178.2	125.8	70.6	-0.57	-1.07
May	941.0	59.8	394.3	205.8	52.2	0.31	1.13
June	900.0	75.4	442.9	191.1	43.2	0.18	0.30
July	908.6	108.0	405.5	189.4	46.7	-0.89	-4.35
August	707.7	108.8	324.8	143.4	44.2	-0.47	-1.12
September	558.8	74.9	252.9	131.0	51.8	-0.28	-0.37
October	324.4	40.8	168.6	78.1	46.3	-0.37	-0.69
November	224.0	0.0	37.4	55.5	148.6	0.05	0.00
December	159.7	0.0	15.7	34.9	222.2	2.49	0.00*

*Significant at 10%, ** Significant at 5%, *** Significant at 1%, [1]SD: Standard Deviation; [2]CV: Coefficient of Variation; [3]Z: Normalized test statistics; [4]Q: Sen's Slope (mm/month).

May (394.3 mm). The highest rainfall in a single month during the entire study period was recorded in May 2001 at 941.0 mm, followed by 900.0 mm in June 2004. The monthly rainfall variability ranged from 46.3% (CV) in October to 190.2% (CV) in January. The variation between March and October was still relatively low but overall, in post-monsoon/ winter months, monthly rainfall variability was very high (Table 1). A 32-year trend analysis revealed that June was the only monsoon month to experience a monthly rainfall increase of 0.30 mm. During other monsoon months, including July, August, and September, the monthly rainfall trend fell by 0.37 to 4.35 mm. The pre-monsoon month of May, which is the third highest rainfall recipient, also showed a trend of an increase of 1.13 mm per month. During post-monsoonal months, by and large, mean monthly rainfall decreased significantly (e.g. October and February) or remained unchanged (e.g. November to January) (Table 1).

Annual and seasonal rainfall distribution pattern

The seasonal and annual rainfall distribution and its trend are presented in Table 2. Over a long period of 32 years, inter-annual rainfall fluctuated (CV: 21.5%) between 1457.0 (in 1992) and 3421.7 mm (in 2001), with a mean of 2320.5 mm. The study area is currently experiencing a non-significant decrease in annual rainfall at a rate of 10.0 mm per year. During the 32-year period, the station had 22 years (68.7%) of normal rainfall, with six years (18.7%) of excess rainfall and four years (12.5%) of deficit rainfall, compared to the long-term average annual rainfall. Monsoon months (JJAS) contributed 61.5% of the total annual rainfall, while pre-monsoon months (MAM) contributed 27.7% (Table 2, Fig.1). The contribution from post-monsoon (OND) and winter months (JF) was not significant (10.9%). In 2017 alone, the station received an unprecedented rainfall of 2433mm during the 4 (JJAS) monsoon months, a 70% increase compared to the long-period normal monsoon rain. Similarly, in 1994, the station received 737.9mm monsoon rainfall, which was 48.3% less than the long period average monsoon rainfall. The Mann-Kendal test confirmed that there is a small decrease (Z-1.02) in the average annual rainfall rate of 10.0 mm per year. Similarly, winter, pre-monsoon, and monsoon also indicated a decreasing trend (Z= -1.88, -0.34 and -0.44) at the rate of 0.9, 1.4, and 3.6 mm per year, respectively. In contrast, non-significant increasing trend (Z= 0.15) in pre-monsoon months was observed in the rate of 0.4 mm per year (Table 2).

Table 2. Long term seasonal and annual rainfall patterns in Lembucherra, West Tripura (1992-2023)

Rainfall (mm)	Total Annual Rainfall	Winter (JF)*	Pre- monsoon (MAM)	Monsoon (JJAS)	Post Monsoon (OND)
Maximum	3421.7	218.0	1265.6	2433.1	368.4
Minimum	1457.0	0.0	219.0	737.9	40.8
Mean	2320.5	30.6	641.6	1426.0	221.7
SD	498.7	43.26	232.64	435.42	87.87
CV (%)	21.5	1.41	0.36	0.31	0.40
Z	-1.02	-1.88	-0.34	-0.44	0.15
Sen's Slope (mm/year)	-10.01[ns]	-0.87 [ns]	-1.38 [ns]	-3.62 [ns]	0.36 [ns]

*JF: January to February; MAM: March to May; JJAS: June to September; OND: October to December. ns: non-significant.

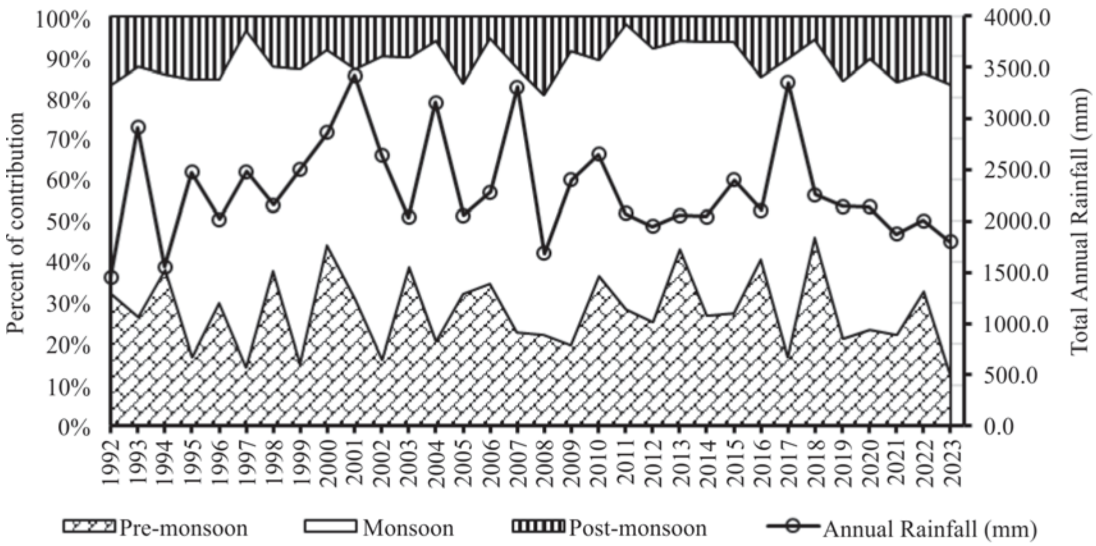

Fig. 1. Temporal variation in long period (1992-2023) annual & seasonal rainfalls

Rainy days and extreme rainfall events

Inter-annual rainy days varied widely from 77 (in 2008) to as high as 117 (in 2002) with an LPA (of 32 years) of 94 ± 11.6 days (Table 3). The pre-monsoon, monsoon, and post-monsoon months had a LPA of 24, 59 and 9 rainy days, respectively. The contribution of monsoon months (JJAS) to annual rainy days was 63%, with a relatively small inter-annual variation (CV: 16.0%). Pre-monsoon months contributed 25.6%, while post-monsoon and winter months contributed marginally (10.0%) with wide inter-annual variations (CV >28.9% and 37.6%). The trend analysis revealed a slight decrease in rainy days during the monsoon, but a significant decrease during the premonsoon months. The number of rainy days during post-monsoon and winter months almost remained constant. The decreasing trend in pre-monsoon and monsoon months led to an annual decrease in rainy days, although it wasn't significant (Table 3). The probability of extreme rainfall during this period was high as the monthly mean rainfall trend was increasing while rainy days were decreasing. Despite the annual rainfall in 2023 being 22.6% below the average, there were three instances of extreme rainfall events (more than 100 mm in 24 hours) (Joshi and Rajeevan, 2006).

The observation of extreme rainfall events showed that Lembucherra had 75 events when the

Table 3. Trend analysis of long period annual and seasonal rainy days at Lembucherra, West Tripura (1992-2023)

	Annual Rainy Days	Winter (JF)	Pre- monsoon (MAM)	Monsoon (JJAS)	Post Monsoon (OND)
Maximum	117	7	43	86	18
Minimum	77	0	12	47	3
Mean	94	2	24	59	9
SD	11.59	2.06	6.88	9.46	3.46
CV (%)	12.30	104.40	28.87	15.98	37.55
Z	-1.40	-1.15	-1.98	-1.02	-1.52
Sen's Slope (number/year)	-0.380	0.000	-0.267*	-0.182	0.093

*Significant at 10%.

1-day total rainfall exceeded 100 mm, with 16 of these events having rain exceeding 150 mm (Figs. 2 and 3). The highest amount of rain recorded was on June 6, 2001 (286.0 mm), followed by 269.4 mm on April 11, 2007. There were 16 1-day extreme rains in July, followed by May and June, each with 15 1-day extreme rains. The monsoon months experienced the highest number of 1-day extreme rainfall events with 45 times, compared to pre- and post-monsoon months with 29 times. Previous studies also reported comparable trends for the neighbouring Northeastern states of Meghalaya (Choudhury *et al.*, 2012) and Mizoram (Saha *et al.*, 2016).

Categorization of monthly rainfall distribution

The percent deviation from LPA categorizes the rainfall distribution during monsoon months for 32 years as deficit, normal, or excess events. The analysis revealed that there were 11 normal monsoon seasons (LPA±19%), 12 years with deficit (LPA-19%), and 9 years with excess (>LPA+19%) monsoon rainfall (Fig. 3). The monthly distribution of monsoon rain was also uneven. The number of normal months (17) was the highest in June, with August having the most excess months (12) and September having the most deficit months (15). The rainfall in June and July was higher than in August

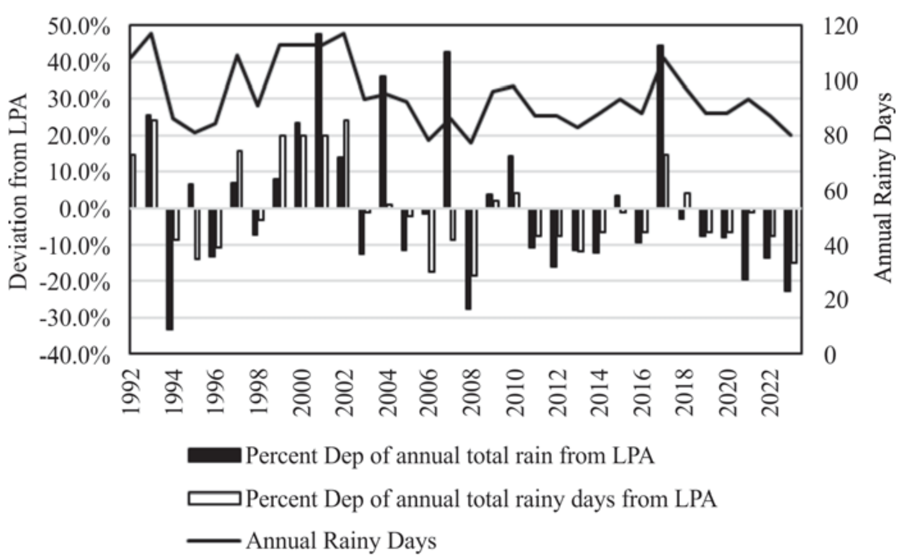

Fig. 2. Anomalies of annual rainfall, rainy days and occurrence of total annual rainy days at Lembucherra (1992-2023)

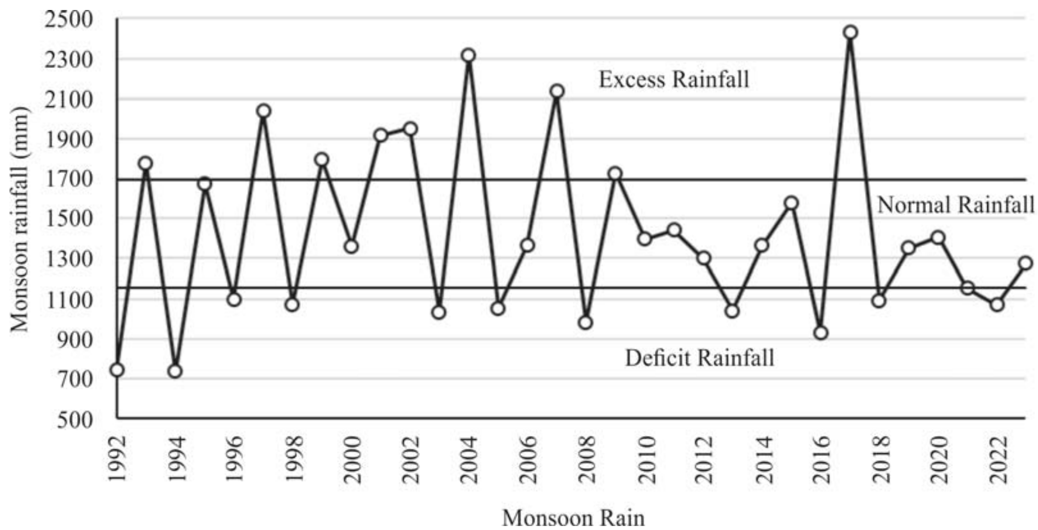

Fig. 3. Categorization of long period average (1992- 2023) monsoon rainfall as deficit, normal and excess at Lembucherra, West Tripura

and September. Table 4 presents the categorization of monthly, seasonal, and annual rainfall.

Meteorological droughts during the Southwest monsoon months

Table 5 shows the classification of meteorological drought years based on the weekly water requirements (55 mm) for rice cultivation (Choudhury *et al*., 2012). The normal window for nursery sowing of Kharif rice initiated from 23rd met week i.e. 4th to 10th June and harvested on 40th week. Lembucherra experienced various degrees of meteorological drought, from low to very severe in 59 times. The very severe meteorological drought observed in 1992, 1994, 1996, 2000, 2001, 2003, 2005, 2008, 2015, 2018, 2021, 2022 and 2023 and was caused by a weekly rainfall below 55 mm for more than 4 consecutive weeks (CWs). Severe meteorological droughts were observed in 1998, 2007, 2013 and 2023 due to 4 CWs with rainfall less than 55 mm. During the past 32 years, there have been 14 and 25 meteorological drought events that were moderate (deficit rain for 3 CWs) and low (deficit rain 2 CWs) respectively. The analysis further reveals that the meteorological drought is mostly recorded in the second half of the season when paddy is either at tillering or panicle stage. At this stage, the optimal moisture level in the soil plays a significant role in grain production. However, the dry weeks at the end of the season were advantageous for the crop to harvest. Rainfed rice production cannot be sustained due to the frequent occurrence of various degrees of droughts, which suggests that irrigation water should be ensured during the future kharif paddy cultivation.

Trend Analysis of maximum and minimum temperatures

The mean monthly maximum temperature was highest in April and May (33.3° C), and lowest in January (24.9° C). The highest maximum temperature was recorded 39.7° C on April 27, 2021 (Table 6). Mann-Kendall trend statistics exhibited a significant ($p < 0.01$) rising trend in July (Z = 3.36). The other significant rise ($p < 0.05$) was recorded during August (Z= 2.95), and June (Z= 2.59). An increasing trend can be seen in the seasonal analysis (Table 7). A significant increase was established in all seasons except for winter. Both monsoon and annual mean maximum temperature showed the most significant increase ($p < 0.01$). The significant ($p < 0.01$) rise of average annual mean maximum temperature calculated 0.041° C (Z= +4.52; Table 7).

Tables 8 and 9 display the mean monthly and season-wise maximum and minimum temperatures. The average monthly temperature fluctuated from

Table 4. Categorization of monthly, seasonal, and annual rainfall distributions in the study area

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	JF	MAM	JJAS	OND	Annual
1992	E	E	D	E	D	D	D	D	D	N	D	D	E	D	D	D	D
1993	D	E	N	D	E	N	E	D	E	D	E	D	E	E	E	D	E
1994	E	E	E	D	D	D	D	D	D	D	E	D	E	N	D	D	D
1995	D	E	D	N	D	E	N	E	N	E	E	D	E	D	N	E	N
1996	D	D	E	D	N	N	D	D	N	E	D	D	D	N	D	E	N
1997	D	D	N	D	D	E	E	N	E	D	D	E	D	D	E	D	N
1998	E	D	E	E	N	D	E	D	D	D	E	D	E	E	D	N	N
1999	D	D	D	D	N	D	E	E	E	E	D	D	D	D	E	E	N
2000	E	N	E	E	E	E	D	E	D	N	D	D	E	E	N	N	E
2001	D	E	D	D	E	E	D	E	E	E	E	D	E	E	E	E	E
2002	E	D	N	D	D	N	E	E	E	D	E	D	D	D	E	N	N
2003	D	D	E	E	N	E	D	D	D	N	D	E	D	E	D	N	N
2004	E	D	D	E	D	E	E	D	E	N	D	D	D	N	E	D	E
2005	D	E	E	D	N	D	N	N	N	E	D	D	N	N	D	E	N
2006	D	D	D	D	E	N	D	E	N	D	D	D	D	E	N	D	N
2007	D	E	D	E	D	E	E	N	D	E	E	D	E	N	E	E	E
2008	E	D	N	D	D	D	N	N	D	E	D	D	E	D	D	N	D
2009	D	D	D	D	N	N	E	N	E	N	D	D	D	D	E	N	N
2010	D	D	N	E	E	N	D	N	E	E	D	E	D	E	N	E	N
2011	D	D	N	N	D	N	N	E	D	D	D	D	D	N	N	D	N
2012	E	D	D	E	D	N	D	E	D	D	N	D	D	D	N	D	N
2013	D	D	D	D	E	N	D	D	N	D	D	D	D	E	D	D	N
2014	D	E	D	D	N	N	D	E	N	D	D	D	N	N	N	D	N
2015	D	D	D	E	D	N	E	E	D	D	D	D	D	N	N	D	N
2016	D	D	E	N	E	D	N	D	D	D	E	D	D	E	D	E	N
2017	D	D	N	E	D	E	N	E	E	E	D	E	D	N	E	E	E
2018	D	D	D	N	E	N	D	D	D	D	N	E	D	E	D	D	N
2019	D	E	N	N	D	N	E	D	D	E	N	D	E	D	N	E	N
2020	E	D	D	D	N	N	N	D	E	N	D	D	D	D	N	N	N
2021	D	D	N	D	D	N	N	D	D	D	D	E	D	D	D	E	N
2022	D	D	D	D	E	N	D	D	N	E	D	D	D	N	D	N	N
2023	D	D	N	D	D	N	D	E	D	D	E	E	D	D	N	E	D

D: Deficit, N: Normal, E: Excess, JF: Jan to Feb, MAM: Mar to May, JJAS: Jun to Sep, OND: Oct to Dec

10.20° C in January to 24.20° C in August. The lowest minimum temperature recorded 2.5° C on March 26, 2007 followed by 3.2° C on January 15, 1998. The trend analysis indicated that the trend decreased from January to May, October and November, but then increased from June to September and December. The mean monthly temperature trend in February declined (Z= -1.86) at the rate of 0.08° C per year while the June month experienced an increasing trend (Z= 0.49) at the rate of 0.015° C per year.

The annual mean minimum temperature (19.5±1.79° C) indicating a declining trend (Z= -1.22)

Table 5. Weekly monsoon rainfall pattern for categorization of meteorological drought

Year	Standard Meteorological Week																	
	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1992	N	N	D	D	N	N	N	D	N	D	D	D	D	D	D	D	D	D
1993	N	N	N	D	N	D	N	D	D	N	N	N	N	D	D	N	N	D
1994	D	N	D	N	D	N	D	D	D	D	N	D	N	D	D	D	D	D
1995	N	N	N	D	N	N	N	N	D	N	N	N	N	D	D	N	D	
1996	N	D	N	N	N	D	D	N	D	D	D	D	D	D	D	N	D	N
1997	N	D	N	N	N	N	N	N	N	D	N	D	N	N	N	N	N	D
1998	D	D	D	D	N	N	N	D	D	D	N	N	D	N	D	D	D	D
1999	D	D	D	N	D	N	N	N	N	N	D	N	N	N	N	N	D	N
2000	N	N	N	N	D	N	N	D	N	N	D	D	D	D	D	D	D	D
2001	N	N	N	D	D	D	D	D	N	D	D	N	N	D	D	N	D	N
2002	N	N	D	D	N	N	N	N	N	N	N	N	D	D	D	D	N	D
2003	N	N	N	N	D	D	D	N	N	D	D	D	D	D	N	D	N	D
2004	N	D	N	N	N	N	N	N	N	D	N	D	D	D	N	N	D	D
2005	D	D	D	D	D	N	D	N	D	D	D	N	N	N	N	N	D	N
2006	N	N	N	D	N	D	D	D	N	N	N	N	D	D	N	N	D	N
2007	N	N	D	N	D	D	N	N	N	D	D	N	N	N	D	D	D	D
2008	N	D	D	D	N	N	D	N	N	N	N	D	N	D	D	D	D	D
2009	N	N	D	N	N	D	N	N	N	N	N	N	D	N	D	N	N	N
2010	N	N	D	N	N	D	N	D	N	N	N	D	D	D	N	D	N	D
2011	N	D	D	N	N	D	D	D	N	N	N	N	D	D	N	D	D	D
2012	N	N	N	D	D	N	N	D	N	N	D	N	D	D	N	D	D	N
2013	N	D	N	D	D	D	D	N	N	N	D	D	D	N	D	N	D	N
2014	D	N	N	N	N	D	D	N	D	N	N	D	N	D	D	N	N	D
2015	N	N	N	N	N	N	N	N	N	D	N	N	N	D	D	D	D	D
2016	D	N	D	N	N	N	N	N	N	D	N	D	D	D	N	D	D	D
2017	D	N	N	D	N	N	N	N	D	N	N	N	N	N	N	N	D	N
2018	N	N	D	D	N	D	D	N	D	D	D	D	D	D	D	D	D	D
2019	D	N	D	D	N	N	D	D	N	N	N	D	N	D	D	D	N	D
2020	N	N	D	N	D	D	N	N	D	D	N	N	N	D	N	N	N	D
2021	N	N	D	N	D	D	N	D	D	N	D	D	D	D	D	D	D	D
2022	N	N	N	D	N	D	D	N	D	D	D	D	D	N	N	D	D	N
2023	D	N	N	N	N	D	D	D	D	N	N	N	D	D	D	D	D	N

D: Deficit, N: Normal, JF: Jan to Feb, MAM: Mar to May, JJAS: Jun to Sep, OND: Oct to Dec

at the rate of 0.03° C per year. Except the monsoon, all other seasons indicating a decreasing trend (Z= -0.37 to -1.22) at the rate of 0.01° C per year in the post monsoon to 0.04° C per year during winter months. During monsoon, the mean temperature showed an increasing trend (Z= 0.57) at the rate of 0.02° C per year. A decrease in temperature is a sign that crop maturity will be delayed. Low temperature negatively impacts germination, normal plant growth, development, and phonological events (Rangappa *et al.*, 2024). Over 30% decrease in yield from infertile grains and delayed 30-day maturity were observed during the rice-growing period in the region when the temperature decreased by 2° C

Table 6. Mann-Kendall trend statistics for mean monthly maximum temperature at Lembucherra (1992-2023)

Month	Mean Monthly Maximum Temperature (°C)						
	Minimum	Maximum	Mean	SD	CV (%)	Z	Q
January	22.0	28.9	24.9	1.27	5.11	+0.73	+0.01
February	24.9	29.7	27.0	1.21	4.49	+1.09	+0.04
March	28.5	33.9	31.4	1.31	4.19	+2.09	+0.04*
April	31.2	35.6	33.3	1.14	3.42	+1.96	+0.05*
May	30.6	35.3	33.3	1.04	3.13	+1.80	+0.06
June	28.2	35.4	32.7	1.25	3.80	+2.59	+0.04**
July	29.9	34.3	32.2	0.97	3.01	+3.36	+0.06***
August	30.3	34.0	32.3	0.74	2.28	+2.95	+0.04**
September	31.1	34.1	32.4	0.70	2.15	+2.77	+0.04*
October	30.6	35.9	32.0	0.98	3.07	+2.45	+0.04**
November	28.3	33.6	30.2	1.06	3.51	+2.71	+0.045*
December	25.0	33.2	27.2	1.49	5.48	+1.77	+0.04

* Significant at 10%, ** Significant at 5%, *** Significant at 1%, Q: Sen's slope (˚C per year)

Table 7. A long-term (1992-2023) trend analysis of the annual and seasonal distribution of Maximum Temperature (°C) at Lembucherra

	Winter (°C) (JF)	Pre- monsoon (°C) (MAM)	Monsoon (°C) (JJAS)	Post Monsoon (°C) (OND)	Annual (°C)
Minimum	24.0	30.9	30.7	28.4	28.4
Maximum	28.2	34.9	33.6	34.2	33.6
Mean	25.9	32.7	32.4	29.8	30.7
SD	0.90	0.90	0.70	1.00	0.60
CV (%)	3.63	2.68	2.05	3.49	1.91
Z	1.41	2.68	4.30	2.94	4.49
Sen's Slope (˚C per year)	0.03	0.04**	0.04***	0.05**	0.04***

* Significant at 10%, ** Significant at 5%, *** Significant at 1%

Table 8. Mann- Kendall trend statistics for mean monthly minimum temperature at Lembucherra (1992-2023)

Month	Mean Monthly Minimum Temperature (°C)						
	Minimum	Maximum	Mean	SD	CV (%)	Z	Q
January	5.4	13.2	10.2	1.57	15.43	-0.21	-0.01
February	7.1	15.8	12.1	1.92	15.83	-1.86	-0.08+
March	14.4	21.4	17.2	1.93	11.18	-1.05	-0.04
April	16.3	24.4	20.9	1.92	9.16	-0.60	-0.02
May	17.7	25.2	22.5	1.84	8.15	-0.08	-0.01
June	18.7	25.6	23.7	1.62	6.85	+0.49	+0.02
July	19.8	26.0	24.2	1.55	6.42	+0.44	+0.01
August	20.2	25.9	24.2	1.32	5.46	+0.31	+0.00
September	21.2	25.8	24.1	1.25	5.18	+0.00	+0.00
October	17.8	25.2	22.9	1.93	8.41	-0.18	-0.01
November	14.6	23.2	18.9	2.37	12.57	-0.71	-0.03
December	8.7	16.9	13.5	2.21	16.36	+0.05	+0.01

Q: Sen's slope (°C per year)

Table 9. Trend analysis of annual and seasonal minimum temperature (°C) distribution at Lembucherra for a long period (1992-2023)

	Winter (°C) (JF)	Pre- monsoon (°C) (MAM)	Monsoon (°C) (JJAS)	Post Monsoon (°C) (OND)	Annual (°C)
Minimum	6.3	16.4	20.2	14.2	15.2
Maximum	14.4	23.6	25.5	20.9	22.4
Mean	11.2	20.2	24.0	18.4	19.5
SD	1.60	1.60	1.30	2.02	1.79
CV (%)	14.68	7.88	5.47	10.95	9.16
Z	-1.22	-0.70	0.57	-0.37	-1.22
Sen's Slope (˚C per year)	-0.04	-0.03	0.02	-0.01	-0.03

(Choudhury *et al.*, 2013). For grain crops, the reduction in spikelet fertility and the production of infertile spikelet will increase in the region since the threshold cardinal temperature is already at a lower level. This will result in a significant decrease in crop yields, particularly during Rabi seasons.

Atmospheric evaporative demands, relative humidity, and sunshine hours

The monthly average relative humidity during 1992 to 2023 fluctuated between 63 (± 8.84) percent in February and 80 (± 4.41) percent in July (Table 10). From December to April, the humidity was below 70 percent, but it gradually increased until it hit its peak in July, and then started to decrease again. The trend analysis showed an increasing trend of humidity in all the months. A significant increasing trend (p <0.01, +0.37 percent per year) was found in October (Z= 3.57) and in December (Z= +4.07, +0.70 percent per year). Significant trend (p <0.05) of increase were found in January (Z= +2.87), July (Z= +2.77), September (Z= +3.13) and in November (Z= +2.79) with varying rate of increase from 0.23 to 0.60 percent per year (Table 10).

The seasonal and annual variations of mean relative humidity had a similar trend to that of mean monthly relative humidity (RH). The monsoon remained the most humid (79 ±4.63 percent), followed by the Post monsoon (73 ±6.65 percent) and the Pre monsoon (69 ±4.48 percent), while

Table 10. Mann-Kendall trend statistics for mean monthly average relative humidity (%) at Lembucherra (1992-2023)

Month	Mean monthly Relative Humidity (%)						
	Minimum	Maximum	Mean	SD	CV (%)	Z	Q
January	43.0	82.0	64.0	10.88	17.0	+2.87	+0.60**
February	42.0	79.0	63.0	8.84	14.0	+1.41	+0.22
March	51.0	75.0	65.0	5.68	8.8	+1.96	+0.21*
April	57.0	78.0	69.0	4.67	6.8	+0.79	+0.08
May	59.0	83.0	73.0	5.31	7.2	+0.76	+0.07
June	52.0	87.0	77.0	6.72	8.7	+1.90	+0.19
July	66.0	88.0	80.0	4.41	5.5	+2.77	+0.23**
August	65.0	90.0	79.0	5.08	6.4	+2.16	+0.22*
September	64.0	88.0	79.0	5.40	6.8	+3.13	+0.31**
October	56.0	870	77.0	6.45	8.3	+3.57	+0.37***
November	57.0	85.0	72.0	6.34	8.8	+2.79	+0.33**
December	45.0	82.0	680	9.56	14.1	+4.07	+0.70***

* Significant at 10%, ** Significant at 5%, *** Significant at 1%, Q: Sen's slope (% per year)

during winter, humidity remained the lowest (64 ±9.49 percent). The trend analysis showed a significant (at *p*= 0.01 level) increase in mean monthly RH (Z=+3.88) during the post-monsoon season, at a rate of 0.47 percent per year. The annual mean RH (Z =+2.87) experienced a significant increase (*p* <0.05) at a rate of 0.33 percent per year. The seasonal and annual variations of mean RH had shown a similar trend as mean monthly RH.

The mean monthly, seasonal, and annual variation of bright sunshine hours (hrs/ day) presented in Tables 11 and 12. The trend analysis showed a significant (at *p*=0.01 levels) decreasing trend of mean monthly sunshine hours particularly from January to June, October, and December. The mean monthly bright sunshine hour during the entire period (1992- 2023) ranged from 3.7 (±1.2) hrs per day in the month of July to 7.2 (±1.2) hrs per day in the month of March (Table 11). The trend analysis of seasonal and annual sunshine hours showed a significant decrease (at p=0.01 level) (Table 12). During winter, the declining trend (Z= -3.91) was 0.11 hours per day, while in pre-monsoon, the trend (Z= -4.52) was -0.07 hours per day from normal. Similarly, both the monsoon (Z= 3.09) and post-monsoon (Z= -3.98) were also declining at the rate of 0.04 and 0.06 hours per day respectively. The average bright sunshine hour was found to be highest

Table 11. Mann- Kendall trend statistics for mean monthly average bright sunshine hour (hrs/day) at Lembucherra (1992-2023)

Month	Mean monthly average relative humidity (%)						
	Minimum	Maximum	Mean	SD	CV (%)	Z	Q
January	1.6	8.3	5.7	1.7	29.6	-3.52	-0.12***
February	3.6	8.7	6.8	1.3	19.6	-3.91	-0.08***
March	4.8	9.4	7.2	1.2	16.5	-3.44	-0.09***
April	5.1	11.6	7.1	1.4	19.2	-3.48	-0.08***
May	4.2	8.5	6.4	1.1	17.0	-2.38	-0.05*
June	1.9	7.1	4.4	1.4	31.8	-2.48	-0.07*
July	1.2	6.0	3.7	1.2	31.9	-1.29	-0.03
August	2.0	9.4	4.7	1.6	33.4	-1.56	-0.04
September	2.1	6.9	4.6	1.1	23.7	-1.33	-0.03
October	3.5	8.5	5.7	1.2	21.0	-2.58	-0.07**
November	6.0	8.5	7.1	0.7	9.6	-0.61	-0.01
December	4.5	8.8	6.6	1.3	20.1	-4.18	-0.11***

* Significant at 10%, ** Significant at 5%, *** Significant at 1%, Q: Sen’s slope (% per year)

Table 12. Trend analysis of long period annual and seasonal mean monthly average bright sunshine hour (hrs/ day) distribution at Lembucherra (1992-2023)

	Winter (JF)	Pre- monsoon (MAM)	Monsoon (JJAS)	Post Monsoon (OND)	Annual
Minimum	3.5	5.6	2.5	5.2	4.7
Maximum	8.3	9.4	6.1	8.2	8.2
Mean	6.2	7.0	4.4	6.5	5.9
SD	1.35	0.96	0.84	0.76	0.83
CV (%)	21.6%	13.8%	19.4%	11.7%	14.2%
Z	-3.91	-4.52	-3.09	-3.98	-4.62
Sen’s Slope (hrs per year)	-0.11***	-0.07***	-0.04***	-0.06***	-0.07***

* Significant at 10%, ** Significant at 5%, *** Significant at 1%.

during pre-monsoon (7.0 ±0.96 hours per day) and lowest during monsoon (4.4 ± 0.8 hours per day).

The study showed a significant decline in the daily sunshine hours during the Rabi and pre-Kharif periods. In a finding of effect of sunshine hour in maize crop, Song *et al.* (2020) found that the decline in sunshine hour reduced the average maize yield by 8% due to limited root growth. Through a simulated model, it was found that the shortage of production could be attributed to the replacement of cultivars with longer growth periods. The annual mean bright sunshine hours were found to be 5.9 (±0.83) hours per day, with a variation of 14.2 percent. Simon *et al.* (2023) reported that a decrease in the hours of sunshine during the pre-blooming period of maize leads to disturbances in the formation of its reproductive organs.

The average monthly total pan evaporation (TPE) fluctuated between 89.8±34.07 mm in December and 126.7± 21.19 mm in March (Fig.4). The average monthly TPE was above 100 mm from March to October, but it fluctuated between 90 and 100 mm during the remaining months. According to the trend analysis, 9 out of 12 months had a decreasing trend while 3 had an increasing trend. The trend of total pan evaporation during November and December decreased significantly (*p* = 0.1) (Z = -2.16 to -2.25). The annual loss of 1255.8 (± 221.2) mm showed a non-significant decrease (Z =-1.087) at a rate of 6.02 mm per year. With an increasing trend in mean annual temperature (0.027° C per year), the total evaporative loss was expected to increase. In the present study, however, there was a reverse trend.

Changes in climate variables like temperature, wind speed, and humidity are often indicated by a decrease in pan evaporation during non-rainy months (Mandal *et al.*, 2015). In humid weather like in West Tripura, we observed downward trend might be the effect of global dimming effect as evident from the decreasing trend in sunshine hour (Tables 11 and 12). This phenomenon has been a dominant trend in reducing pan evaporation in many parts of the world (Anand, 2023). The reduction in solar radiation and vapour pressure deficit effectively reversed the effect of rising temperature on pan evaporation (Jin *et al.*, 2023). Choudhury *et al.* (2012) reported similar observations on the strong influence of sunshine duration followed by wind speed on evaporative demand in mid-altitude Meghalaya. It might suggest an increase in cloud cover, reduced solar radiation, or higher atmospheric moisture. Lower pan evaporation can affect crop water requirements. The reduced evaporation means reduced evapo-transpiration, which further means that the atmospheric demand for water is lower, potentially affecting crop growth and yield if the soil stays too moist.

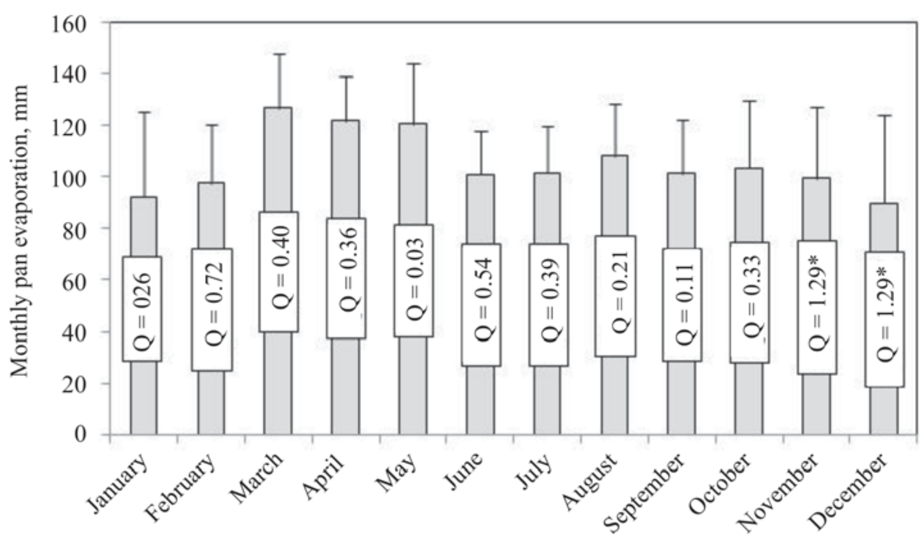

Fig. 4. Mann- Kendall trend statistics for mean monthly total pan evaporation (mm) at Lembucherra (1992-2023)

Table 13. Mann-Kendall trend statistics for mean monthly average ET_0 (mm/day) at Lembucherra (1992-2023) using the Blenny Criddle method.

Month	Mean daily average ET_0 (mm/ day)						
	Maximum	Minimum	Mean	SD	CV (%)	Z	Q
January	4.1	3.6	3.9	0.12	3.20	+0.83	+0.00
February	4.6	3.9	4.2	0.14	3.35	-0.71	-0.00
March	5.5	4.9	5.2	0.16	3.10	+0.54	+0.00
April	6.2	5.6	5.9	0.17	2.82	+0.68	+0.00
May	6.8	6.1	6.5	0.18	2.71	+1.05	+0.01
June	7.0	6.2	6.7	0.18	2.68	+1.67	+0.01
July	6.7	6.1	6.5	0.15	2.31	+1.93	+0.01
August	6.5	5.9	6.3	0.12	1.86	+1.64	+0.01
September	6.0	5.6	5.9	0.09	1.45	+2.25	+0.01*
October	5.7	5.0	5.4	0.14	2.62	+1.15	+0.00
November	4.9	4.4	4.6	0.16	3.43	+0.54	+0.00
December	4.4	3.7	4.0	0.17	4.16	+1.22	+0.01

* Significant at 10%, Q: Sen's slope (mm per year)

Climatic water balance studies

The reference evapotranspiration (ET_0) calculated through the Blaney Criddle method showed an increasing trend in every month, except February of the year (Table 13). The monthly normal ET_0 was found at its maximum in June (6.7 ± 0.18 mm/day) and its minimum in January (3.9± 0.12 mm/day). From March to October, the ET_0 remained above 5 mm per day. The trend analysis shows a significant (p <0.1%) increase in the trend of ET_0 (Z= 2.25) in September, at nominal increase. Only in February, the trend shows a declining trend (Z= 0.71). The annual average ET_0 calculated at 5.23 mm ± 0.09 mm/day, while ET_0 remained high during the monsoon (6.35±0.11 mm/ day) (Table 14). Both during the post-monsoon and winter seasons, ET_0 remained below 5 mm per day. Annual ET_0 showed an increase (Z= 0.73) at a nominal rate. Similar increasing trends were observed in all the seasons (Table 14).

The increasing trend of ET_0 indicates a greater atmospheric demand for water, leading to increased water requirements for crops to maintain optimal growth and yield. Long-term water stress can lead to a decrease in photosynthesis, nutrient uptake, and overall plant health. Under higher ET_0, the plant may balance the stress by reducing carbon dioxide uptake, potentially affecting growth and productivity.

Figure 5 shows the correlation between rainfall and ET_0. The shortage of water was observed from

Table 14. Trend analysis of long-term annual and seasonal ET_0 (mm/day) distribution at Lembucherra (1992-2023) using the Blenny Criddle method.

	Winter (JF)	Pre- monsoon (MAM)	Monsoon (JJAS)	Post Monsoon (OND)	Annual
Minimum	4.30	6.11	6.48	4.97	5.38
Maximum	3.76	5.58	6.03	4.42	4.97
Mean	4.05	5.86	6.35	4.66	5.23
SD	0.11	0.13	0.11	0.14	0.09
CV (%)	2.76	2.20	1.79	3.04	1.71
Z	0.15	0.89	1.86	1.7	0.73
Sen's Slope (mm/year)	0.004	0.002	0.009	0.006	0.004

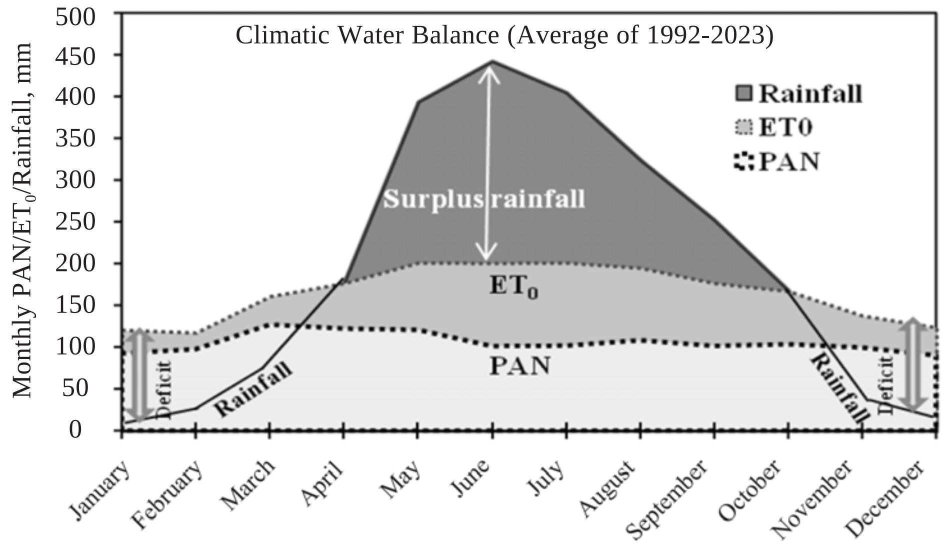

Fig. 5. Climatic Water Balance (mean monthly rainfall – mean monthly PAN evaporation and reference ET) at Lembucherra

January to March and then again from November to December. During this period, the monthly evapotranspiration demand was not met due to insufficient rain. Between December and February, there was a deficit of more than 80 percent of the demand. The water scarcity persisted maximum during winter (87.2%) followed by post-monsoon (48.3%). Annual rainfall was 17 percent above the demand for evapotranspiration. By modifying agronomic management practices such as the type of crops grown, sowing window, and growing short-duration varieties, etc., the potential water surplus period (April to October) can be utilized to intensify and diversify agricultural production systems in the region.

Conclusions

The present study revealed that rainfall in West Tripura declined eight out of 12 months. The decline was more prominent during the monsoon and pre-monsoon periods. On the other hand, the rain in post-monsoon was trending upwards. Monthly, seasonal, and annual rainy days were also following the same trend of rainfall. Extreme rainfall mostly occurred during the monsoon, but a good number of similar events were also recorded during the post-monsoon period. Analyzing rainfall data, it was found that out of 32 monsoons, there were 12 deficit monsoons and 9 surplus monsoons. A downward trend in rainfall during the last two months of monsoon, August and September, may have a negative impact on kharif crop cultivation, particularly rice. The reason is that the cultivation during this period is almost entirely dependent on rain. Furthermore, at this time, rice is usually either in its maximum tillering or panicle emergence phase, which requires a specific amount of standing water for rice crops. In addition, the farmers in this region commence the cultivation of boro season by making use of the moisture residue left over from the monsoon. The crops of both this and next seasons will be negatively impacted by a reduction in rainfall during this season.

However, a slight inclination in the trend of rains in the post-monsoon season may be helpful for the crop. The inclining trend of the number of extreme rainfall events during this season may cause crop loss, especially for winter vegetables. The inclining trend of mean air temperature may shorten the growing period, thus reducing photosynthesis and impacting yield. However, the impact of elevated temperature can be both positive and negative depending on the crop type and the extent of rice's temperature. The increase in temperature can alter the timing of critical phenological stages such as flowering and fruiting, pollination success, and overall reproductive performance. The increasing trend of evapotranspiration indicates climatic water stress for the crop in the state, particularly during the non-rainy season. The significant increase in relative humidity may lead to an increase in specific pests and diseases. The infestation may further accelerate due to the decreasing tendency of daily sun shine hours. These changes in long-term weather parameter can be mitigated by adaption strategies such as breeding heat-resistant crop varieties, site-specific re-visit of crop calendar, including altering planting schedules, and improving irrigation efficiency.

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