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Study on Relationship between Climate Variability and Turmeric Production in Manipur, India

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ABSTRACT

Background: Turmeric is a vital crop in Manipur, but its production is increasingly influenced by changing climatic conditions. Understanding the relationship between climate variables and turmeric output is essential for sustainable agricultural planning in the region.

Methods: This study analyzes the causal relationship between climate factors and turmeric production in Manipur using secondary data from 2001-02 to 2020-21. Key climate variables examined include minimum temperature (°C), relative humidity (RH%), wind speed (m/s), solar radiation (W/m²) and rainfall (mm). Statistical tools such as compound annual growth rate (CAGR), mean, standard deviation, standard error and the Cuddy Della Valle Index (CDVI) were used to assess variability and trends. Additionally, the Correlogram and Augmented Dickey-Fuller (ADF) test was applied to data from 2013 to 2022 to evaluate the stationarity of climate and production variables.

Result: The findings indicate high instability in turmeric cultivation area during Periods I and III, alongside moderate fluctuations in production and significant variability in rainfall and wind speed. The ADF test revealed stationary behavior in variables such as turmeric area, production, productivity, maximum RH and wind speed. Conversely, temperature, wind direction, solar radiation and rainfall exhibited non-stationary patterns. A strong positive correlation was found between turmeric production and factors like cultivation area, solar radiation and maximum temperature. This study highlights the significant influence of climate variability on turmeric production in Manipur. The insights can guide policymakers and farmers in developing climate-resilient agricultural strategies to ensure stable turmeric yields in the future.

Key words: ADF test, CAGR, CDVI, Climate variables, Correlation, Turmeric.

INTRODUCTION

Climate change is one of the most significant and challenging threats facing the world today, with profound effects on ecosystems, biodiversity and the environment as a whole. The impacts of climate change are widespread and often unpredictable, affecting everything from weather patterns to ocean health, agriculture and human livelihoods. The Intergovernmental Panel on Climate change (IPCC, 2021) observed significant changes in the temperature, precipitation patterns and extreme events in all regions in future. At present, it is already affecting agricultural production and its impacts are expected to worsen. And panel state that if global temperature rises by 1.5 to 2.0°C in the ensuing decades, there will likely be an increase in heat waves, longer warm and shorter cold seasons. Climate variability is one of the most significant elements affecting crop output, accounting for over 60% of yield variability (Osborne and Wheeler, 2013; Matiu *et al*., 2017). Globally, previous studies have shown a connection between climate change and its impact on crop productivity, Particularly in South East Asia (Lasco *et al*., 2011; Aryal *et al*., 2020).The actual impact of climate change on crop production, however depends on the type of crop, its location and its ability to adapt to climate vagaries (Vermeulen *et al*., 2012; Rohith *et al*., 2020).

The North eastern hilly region, green belt of India which comprises states namely Assam, Arunachal Pradesh, Meghalaya, Mizoram, Nagaland, Tripura and Sikkim harbours rich flora on account of its varied topography, climates altitudes and has great potential for the development of horticultural crops including spices. The state's agrarian activities are heavily dependent on climatic conditions, with the majority of rainfall occurring between April and mid-October, primarily due to the South Westerly Monsoon. This rainfall pattern enriches the soil, making it conducive for various crops, including turmeric. State is the hub for major spices like large cardamom, ginger, turmeric, black pepper, chilli, bay leaf *etc*. which are in great

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demand and has tremendous potential (Hnamte *et al*., 2012). The region also has niche spice crops like Lakadong turmeric, Bird's eye chilli, King Chilli and Nadia ginger which has high market demand for their unique features (Momin *et al*., 2018). Turmeric (*Cucurma longa* L.) is commercially important spice of India in general and Manipur in particular is the most extensively cultivated spice. It belongs to the family Zingeberaceae. The rhizome has yellow pigment curcumin which is the main active compound and colouring agent. Cucurmin has certain therapeutic properties. Traditionally it is also an important ingredient in curry, dishes, religious observances, cosmetic and dye. It is extensively used in preparations of indigenous medicines. Turmeric is closely related to ginger since it is dried rhizome herbaceous plant (Dahal and Idris, 1999). The spices also sometimes called "Indian saffron" attributed to its yellow colour. It has highest diversity comprising 40 spices (Ashraf *et al*., 2017) and some important varieties exported outside.

In India, 11 lakh tonnes of turmeric are produced in the agricultural year 2019-2020. This production primarily comes from the states of Tamil Nadu, Andhra Pradesh, Karnataka, Odisha and West Bengal, with Tamil Nadu being the largest producer. Turmeric occupied approximately 2.54 lakh acres, or 6% of the entire area in India devoted to spices. Turmeric is an essential crop in India, not just for its culinary uses but also for its medicinal and cultural significance (Navyashree *et al*., 2024). Manipur, a pivotal region for organic turmeric production, is increasingly experiencing the adverse effects of severe climatic conditions. These conditions negatively impact the quality of rhizomes and heighten susceptibility to pest and disease infestations, thereby affecting turmeric yields. Despite the crop's climatic preferences, there is a paucity of long-term studies examining the impact of climate change on turmeric cultivation in this significant region. Understanding the relationship between climate variables and turmeric production is crucial for developing adaptive strategies.

Previous studies have emphasized the importance of analyzing rainfall variability and probability for effective crop planning. For instance, Dharani *et al*. (2023) conducted a comprehensive study in Madurai district, Tamil Nadu, utilizing 40 years of rainfall data to inform crop planning decisions. Their findings highlighted the necessity of aligning crop choices with rainfall patterns to enhance productivity and mitigate risks. Similarly, Neenu *et al*. (2013) reviewed the impact of climatic factors on crop production, underscoring the sensitivity of agriculture to climatic fluctuations. In the context of turmeric, Khawale and Chinchmalatpure (2023) investigated the adoption of cultivation practices among growers, revealing that a significant proportion had medium to low adoption levels, indicating room for improvement in agronomic practices. Furthermore, Rajanbabu *et al*. (2022) analyzed the growth and instability of significant spices in India, including turmeric and found notable fluctuations in production and yield, attributed to various factors including climatic variability.

Given these insights, this study aims to explore the relationship between climate variables and turmeric production in Manipur. By examining the effects of climatic factors on turmeric yields, the research seeks to contribute to the development of resilient agricultural practices tailored to the region's unique climatic challenges.

METRIALS AND METHODOS

The study collected, analyzed and tabulated secondary data on detailing the area under turmeric cultivation, production volumes and productivity rates in Manipur obtained from authoritative sources such as the Department of Agriculture, GoM and GoI and climatic variables such as temperature, relative humidity, rainfall, wind speed and solar radiation has been collected from India Meteorological Department (IMD). The 2013-2022 period was chosen due to significant climatic events or trends that could affect agricultural patterns, such as extreme weather, droughts, or rainfall shifts. Another reason due to the availability of reliable and consistent data on specific agricultural indicators, which is crucial for a high-quality and consistent analysis. The various analytical tools to achieve its objectives, which are briefly discussed in the following sub-sections.

Compound annual growth rates

Compound annual growth rates were calculated using exponential form/semi log model for area, production, productivity and climate variables such as temperature, relative humidity, rainfall, solar radiation *etc*. The exponential form of the model is as below:

$$Y_t = \alpha\ (1 + r)^t u_t \qquad ...(1)$$

For the purpose of estimation, above equation was transformed into log linear form and parameters were estimated using Ordinary Least Square (OLS) technique after log transformation.

$$\text{Log } Y_t = \log_a + t\log_b + u_t$$

$$\text{Log } Y_t = \beta_1 + \beta_2\ (t) + u_t$$

The compound growth rate (g) in percentage was then computed from the following relationship:

$$\text{Growth rate} = \{\text{Antilog } (\beta_2) - 1\} \times 100$$

Where,

Y = Explained variable or dependent variable.

β_1 = Intercept or constant term.

β_2 = Regression coefficient.

t = Explanatory or independent variable (years which taken the value 1, 2, 3, n).

u_t = Disturbance term.

Cuddy Della Valle instability index

The simple co-efficient of variation (CV) overestimates instability in time series data with long-term trends. CDVI, unlike other instability indices that focus on variance or deviation from a mean, considers the magnitude and direction

of changes, providing a more comprehensive view of production volatility over time. The formula for CDVI is provided.

$$\text{Instability index (II)} = CV \times \sqrt{(1-R^2)}$$

Where,
CV = Co-efficient of variation.
R^2 = Co-efficient of multiple determination (adjusted).

The ranges of CDVI are given as follows 1. Low instability = 0 to 15 2. Medium instability = 15 to 303. High instability = 30 and above.

Correlogram

A correlogram is a visual representation of a time series autocorrelation function (ACF) or partial autocorrelation function (PACF). However, the correlogram may look distinct from a stationary series for a non-stationary time series, where the statistical properties change over time. In particular, non-stationary time series may exhibit slow or absent decay in autocorrelations, indicating trends or seasonality in the data. As a result, the correlogram of a non-stationary time series may display high and persistent autocorrelations, making it difficult to detect the proper signal or pattern within the data.

Correlation

A correlation is an examination of the relationship between two or more variables. When the relationship between two variables is quantifiable, correlation is the statistical instrument used to measure and represent the relationship in a concise formula. The two variables are linked if one causes a commensurate change in the other.

Augmented Dickey-Fuller (ADF) test

In order to check for a trend in the data by testing for a unit root, the augmented Dickey-Fuller (ADF) test is a statistical technique used to assess if a time series data set is stationary or non-stationary. A time series' statistical characteristics, such as the mean, variance and autocorrelation, remain constant if stable. A time series that is non-stationary, on the other hand, has a trend or pattern that evolves. In order to account for any serial correlation in the data, the ADF test extends the Dickey-Fuller test by including additional lagged factors in the regression equation. The ADF test yields a test statistic as well as a p-value. A series is termed stationary if the test statistic is less than the critical value and the p-value is less than a predetermined

Table 1: Compound annual growth rates for area, production and productivity of turmeric in Manipur state.

Years	Turmeric in Manipur state		
	Area (in 000′ Ha)	Production (in MT)	Productivity (in kg/ha)
CAGR-I (2001-02 to 2010-2011)	18.95	19.94	6.03
CAGR-II (2011-12 to 2011-2021)	4.29	5.14	9.97
Overall CAGR-III (2001-02 to 2020-21)	10.07	10.92	0.30
CDVI-I (2001-02 to 2010-2011)	190.17	22.62	35.63
CDVI-II (2011-12 to 2011-2021)	24.63	20.57	31.15
Overall CDVI (2001-02 to 2020-21)	133.22	21.50	38.03

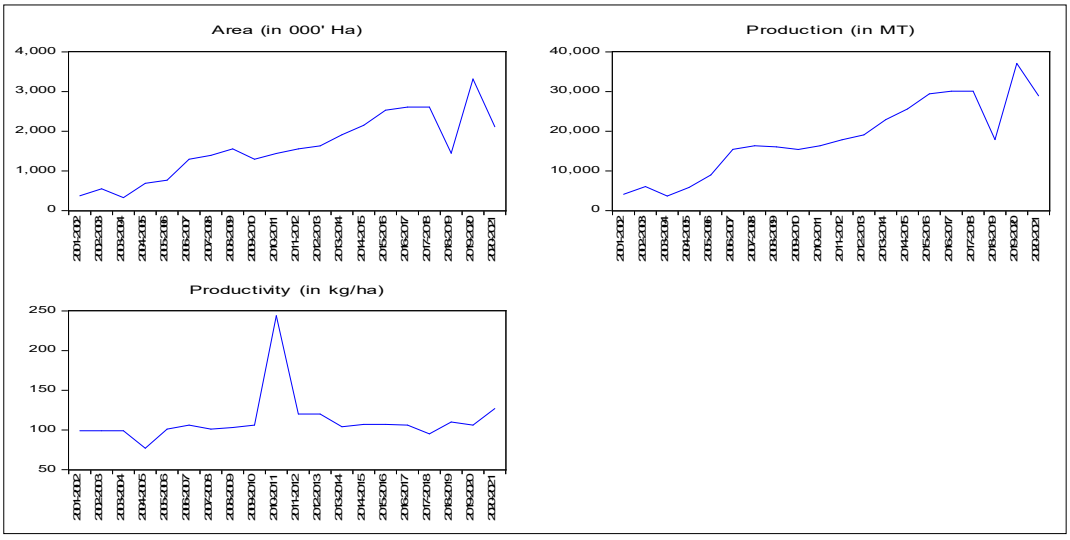


Fig 1: Trends of area, production and productivity of turmeric in the Manipur over time.

significance level, often 0.05. However, if the test statistic is more than the critical value and the p-value is more significant than the significance level, we fail to reject the null hypothesis and conclude that the series is non-stationary.

RESULTS AND DISCUSSION

Table 1 displays the CAGR in area, production and productivity of turmeric over three phases (2001-2010, 2011-2021 and 2021-2021). The results reveal incredible growth rates in the area (18.95%), production (19.91%) and even productivity (6.04%) over the first 2000-2011 decade. The growth rate was favourable at 4.29% and 5.14% in areas and productivity, with a significant increase in productivity (10.12%) from 2011 to 2022 compared to period I (2001 to 2011). Between period III, 2000-01 and 2020-21, the overall period saw an 8.74% increase in area and 10.92% increase in production and modest annual increase in productivity of 0.30 per cent annually. It shows there has been a rapid increase in area, production and productivity after MOMA (Manipur Organic Mission Agency) began in 2016 in Manipur. Their studies also observed the increasing trends in area, production and productivity in various parts of the state, including vegetable crops. The study revealed high instability in the area under turmeric in Manipur during period I (2001-02 to 2010-2011) at 190.17 which replicated in period III overall (2001-02 to 2020-21) at 133.22. Productivityshowed some moderate instability, ranging from 31.15 to 38.63 and medium instability, around 20.57 to 22.62 in productionindicating volatility in the area (period I) and productivity throughout the period (Table 1 and Fig 1).

Table 2 reveals a decrease in annual trends in climate variables in Manipur, with the maximum trend in rainfall being -6.07% and the minimum trend at wind direction being - 0.09%. The temperature during that period was averaged at 20.02°C, with maximum temperatures at 30.91°C and minimum temperatures at 12.29°C. The relative humidity level was averaged at 77.13%, with maximum and minimum values of 96.29% and 23.12%, respectively. The wind speed was 2.16 meters per second, with a wind direction of 175.04 and the solar radiation was 899.42 Watts/mtr^2. From 2013 to 2022, the average annual rainfall was 95.25 mm. The solar radiation showed the highest standard deviation, followed by rainfall, which showed significant variation, with a standard deviation of 43.44 and 34.98 respectively. The wind speed, maximum relative humadity and maximum temperature displayed a lesser standard deviation, indicating a meager d*evia*tion from the mean value. The revealed high instability in rainfall at 37.94, indicating higher volatility persistence and medium

Table 2: Compound annual growth rates of different climate variables in Manipur during the period of 2013-2022.

Variables	Manipur state				
	CAGR	Mean	S. deviation	S. error	CDVI instability index
Temp (°C)	-2.31	20.02	2.14	0.68	9.21
Max. temp. (°C)	-0.78	30.91	1.95	0.62	6.32
Min. temp. (°C)	-5.6	12.29	2.62	0.83	18.23
RH (%)	-0.25	77.13	2.01	0.64	2.64
Max. RH (%)	-0.42	96.29	1.92	0.61	1.63
Min. RH (%)	-1.68	32.12	2.85	0.90	7.92
Wind speed (mtrs/sec)	-2.62	2.16	0.47	0.15	21.67
WindDir. (°)	-0.09	175.04	12.06	3.81	7.31
Solar Rad. (Watts/mtr²)	-0.49	899.42	43.47	13.75	4.93
Rainfall (mm)	-6.04	95.25	34.98	11.06	37.94

Table 3: Trends of different climatic variables over the period in the Manipur.

Years	Temp (°C)	Max. temp (°C)	Min. temp (°C)	RH (%)	Max. RH (%)	Min. RH (%)	Wind speed (mtrs/sec)	Wind dir (°)	Solar rad (Watts/mtr²)	Rainfall (mm)
2013	20.99	29.88	14.37	74.72	94.8	35.88	2.63	185.43	885.76	81.09
2014	21.08	31.37	12.76	76.34	98.95	31.86	2.37	183.67	919.4	78.53
2015	20.47	31.75	12.7	79.31	98.89	31.07	2.07	174.33	901.19	101.35
2016	21.06	31.82	13.44	80.19	98.14	32.52	1.94	175.26	912.57	93.13
2017	20.87	31.46	13.55	79.55	97.25	34.15	1.58	164.78	875.19	149.9
2018	19.83	31.6	12.14	77.89	96.67	32.18	3.00	166.43	941.06	119.29
2019	20.82	32.45	12.95	76.3	95	32.41	2.58	155.76	923.51	108.59
2020	20.49	31.54	13.18	76.78	94.11	34.01	1.61	170.62	935.52	127.6
2021	20.59	31.58	12.74	75.35	94.39	32.05	1.93	175.55	909.81	68.32
2022	14.04	25.66	5.02	74.83	94.71	25.07	1.84	198.6	790.18	24.71

instability in wind speed at 21.67, while low in temperature, relative humidity, wind direction and solar radiation.

Table 3 display the trends of various climate variables from 2013 to 2022. According to the findings, the average temperature ranges between 14.04°C and 21.08°C in 2022 and 2016, respectively. And the maximum temperature fluctuated from 25.66°C to 32.45°C in 2022 and 2019 respectively where as the minimum temperature fluctuated from 5.02°C in 2022 to 14.37°C in 2013. The relative humidity in Manipur state ranged from 74.72% to 80.19% in 2013 and 2016, respectively. The maximum relative humidity was highest during 2014 was 98.95%, while the lowest was 94.11% in 2020. The minimum relative humidity ranged from 25.07 to 35.88% in 2022 and 2013, respectively. In 2018, the highest wind speed of 3 metres per second was recorded and during 2022, recorded the highest wind direction at 198.60, whereas 2020 had the solidest sun radiation at 935.52 watts per m^2. The state experienced varying rainfall levels in 2022 and 2018, with less rainfall in 2022 (24.71 mm) and the highest in 2018 (108.59 mm), with an average rainfall of 95.25 mm, indicating significant rainfall fluctuations.

The autocorrelation function (ACF) of a time series is represented visually by a correlogram for stationarity. The ACF has been computed for climate variables for time series data with lag (-1) between 2013-14 and 2021-22. Result in Fig 2 shows the eight lags that were found for that period. The results of the correlogram for several climate variables, including temperature (°C), maximum temperature (°C), minimum temperature (°C), relative humidity (%), wind speed (mtrs/sec), wind direction (°), solar radiation (Watts/ mtr^2) and rainfall (mm) reveals that there are distinct and more fluctuations and making it difficult to detect the true signal or pattern within the data over the period for all the variables. It clearly shows that, time series data is non stationary (Fig 2).

Results of Augmented Dickey-Fuller test to determine whether climate variable and turmeric production time series are stationary or non-stationary for Manipur state have been worked out and represented in Table 4. The results show that turmeric crops' area, production and productivity were determined to be stationary and also indicating that 1 per cent significance and does not depend on their time-dependent structure. Among the climate variables, RH (%), Wind speed (mtrs/sec), WindDir. (°), Solar Rad. (Watts/mtr^2) and rainfall (mm) were non-stationary in nature and not statistically significant except wind speed which is significant at 10%. The maximum and minimum relative humidity were stationary and the maximum relative humidity is significant at 1%.

Table 5 shows the results of causal relationship between the area, production and productivity of the turmeric crops and the main meteorological variables. The findings indicate that the area and production are both significantly positively corrected, with a value of 0.970. The study found a significant positive correlation between solar radiation and productivity, with a value of 0.737, indicating its significant role in enhancing productivity. Solar radiation significantly influences turmeric productivity in state due to its seasonal impact on photosynthesis and rhizome development unlike temperature and humidity, is crucial for turmeric to thrive and produce high-quality rhizomes. Although, the maximum temperature is moderately correlated with area and production of turmeric, which have values of 0.586 and 0.588, respectively, which shows mild temperature is crucial for the production of turmeric.

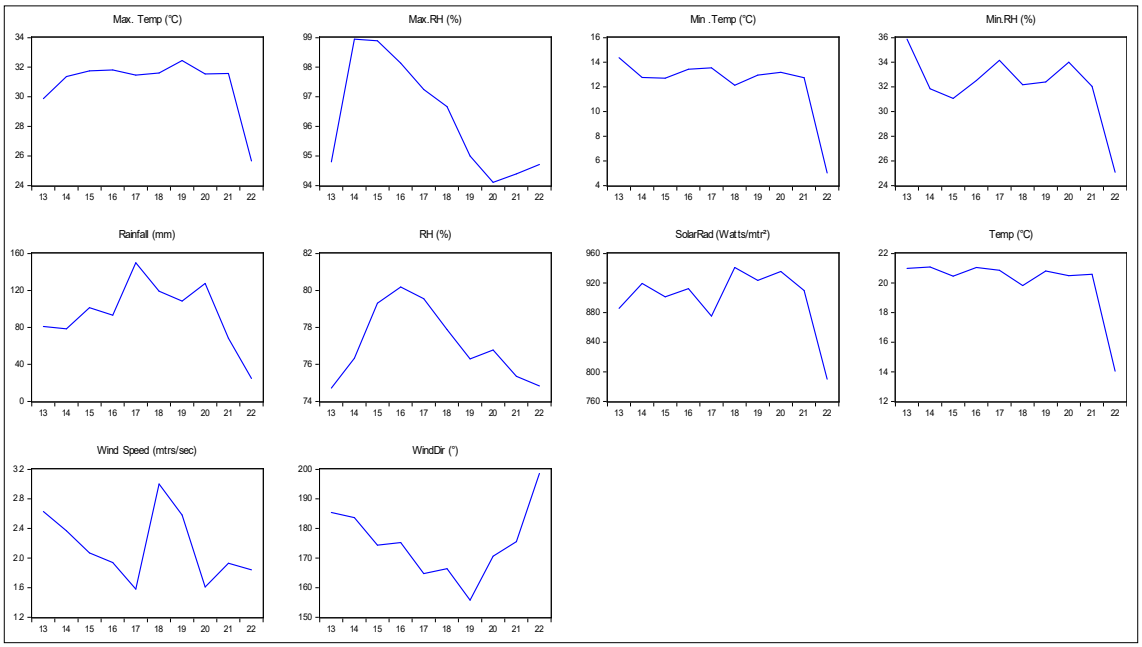


Fig 2: Picturization of correlogram for stationarity of climate variables in Manipur state.

Table 4: Augmented dickey-fuller test results for climate variables and turmeric in Manipur.

Variables	Augmented dickey-fuller test statistic		
	t-statistics	Probability	Remarks
Turmeric area	-6.677	0.000	Stationary
Turmeric production	-7.894	0.000	Stationary
Turmeric productivity	-5.601	0.003	Stationary
Temp. (°C)	-1.3286	0.5603	Non-stationary
Max. temp. (°C)	0.2408	0.9514	Non-stationary
Min. temp. (°C)	-0.6841	0.7951	Non-stationary
RH (%)	-1.562	0.4547	Non-stationary
Max. RH (%)	-6.015	0.0021	Stationary
Min. RH (%)	-1.5933	0.4352	Non-stationary
Wind speed (mtrs/sec)	-2.866	0.0969	Stationary
WindDir. (°)	1.0178	0.9890	Non-stationary
Solar Rad. (Watts/mtr^2)	-1.9935	0.2830	Non-stationary
Rainfall (mm)	-2.5163	0.4352	Non-stationary

*Stationary means it does not have time dependent structure.

Table 5: Relationship between climatic factors and the production, area and productivity of turmeric in Manipur.

Variables	Correlation coefficient		
	Productivity	Area	Production
Productivity			
Area	-0.295^{NS}		
Production	-0.087^{NS}	0.970**	
Temp (°C)	-0.385^{NS}	0.507^{NS}	0.479^{NS}
Max. temp (°C)	0.115^{NS}	0.584*	0.588*
Min. temp (°C)	-0.260^{NS}	0.133^{NS}	0.147^{NS}
RH (%)	-0.265^{NS}	0.222^{NS}	0.183^{NS}
Max. RH (%)	-0.442^{NS}	0.039^{NS}	-0.079^{NS}
Min. RH (%)	-0.038^{NS}	-0.210^{NS}	-0.151^{NS}
Wind speed (mtrs/sec)	-0.110^{NS}	-0.344^{NS}	-0.480^{NS}
WindDir (°)	0.024^{NS}	-0.494^{NS}	-0.491^{NS}
Solar rad (Watts/mtr^2)	0.737*	-0.242^{NS}	-0.155^{NS}
Rainfall (mm)	0.014^{NS}	0.096^{NS}	0.167^{NS}

SUMMARY

Three phases (I, II and III) are seen in this research investigation, covering 2000-01 to 2020-21. Turmeric cultivation area, production and productivity increased at 24.04%, 19.91% and 6.04%, respectively, from 2000-01 to 2010-11. During Period II (2011-12 to 2020-21), growth rates in area (4.29%), production (5.14%) and productivity (10.12%) were all positive. For the overall period III (2000-01 to 2020-21), favourable growth rates were observed for the area (8.74%), production (10.92%) and a modest rise in productivity (0.30%). Following the launch of MOMA in Manipur in 2016, there has been a quick rise in area, production and productivity. The study revealed high instability in the turmeric area (190.17 and 133.22) in Manipur during periods IandIII, with moderate (31.15 to 38.63) and medium production (20.57 to 22.62) fluctuations, high rainfall (37.94) and wind speed instability (21.67). Manipur's climate variables also displayed remarkable changes, with rainfall experiencing the highest decrease in compound annual growth rate (-6.07) and wind direction having the lowest (-0.09). The study investigated numerous climate indicators and discovered that they fluctuated, making it difficult to establish regular trends, showing the non-stationarity of the time series data. The Augmented Dickey-Fuller test found that certain climate variables were non-stationary, whereas turmeric crop-related indicators were stationary. The study also found substantial relationships between meteorological variables and turmeric cultivation, especially regarding area, production and productivity. Sun radiationshowed a substantial positive link with productivity, whereas maximum temperature showed a modest correlation with turmeric area and production.

RECOMMENDATION

❖ **Climate-resilient agriculture policies**

It is critical to implement policies concentrating on climate-resilient agricultural practices to assist farmers in Manipur

in adapting to shifting climate patterns. These policies should help farmers alter their turmeric farming methods to reduce the adverse effects of climate change. Implementing irrigation practices to combat water scarcity during droughts, for example, or altering planting schedules to meet shifting rainfall patterns.

❖ **Weather monitoring and early warning systems**

It is critical to build an efficient weather monitoring system combined with early warning mechanisms to improve climate resilience. This device will assist farmers in Manipur in receiving warnings about extreme weather events like storms or heavy rainfall. Farmers can take appropriate measures to protect their turmeric crops, such as harvesting early or guarding the fields if timely warnings are issued.

❖ **Community engagement and participation**

Community engagement and participation among Manipur's farmers is essential for encouraging knowledge-sharing and cooperative activities. Promoting teamwork and a feeling of community can help best practices for turmeric cultivation be adopted successfully. Farmers may cooperatively explore and apply creative solutions to increase the resilience and productivity of the turmeric sector by exchanging experiences and expertise.

If effectively implemented, these policy measures can significantly enhance the resilience and productivity of the turmeric sector in Manipur. By empowering farmers with knowledge, providing timely weather alerts, promoting sustainable agricultural practices and facilitating market linkages, the overall agricultural economy in Manipur stands to benefit, leading to improved livelihoods and sustainable growth.

CONCLUSION

This study gives insight into the long-term growth trends in turmeric farming in Manipur. The study revealed three periods of expansion, each with a different area, production and productivity growth rate. Notably, the MOMA initiative's implementation 2016 resulted in a rapid increase in these indicators, indicating the favourable impact of strategic interventions. Furthermore, the study included an investigation of climate variables, indicating their shifting nature and the difficulty in establishing stable patterns across time. The study used statistical tests such as the Augmented Dickey-Fuller test to determine stationarity in both climate variables and turmeric production. The data revealed substantial relationships between meteorological elements and turmeric cultivation, emphasising the necessity of considering environmental factors when optimising crop outcomes. A comprehensive plan that incorporates climate adaptation, sustainable farming methods, enhanced infrastructure and climate-resilient farming is required to increase turmeric output in Manipur and India. This plan must also include market access, government backing and agricultural technology.

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Disclaimers

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Conflict of interest

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