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Assessing climate variability impacts on the productivity of major crops in Krishna District, Andhra Pradesh (1997-2020)

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सार – जलवायु परिवर्तनशीलता एक वैश्विक चिंता का विषय बन गई है, जिसमें बढ़ती हुई गर्मी की लहरों की आवृत्ति गर्मियों के मानसून की वर्षा में परिवर्तनशीलता को बढ़ा रही है। यह परिवर्तनशीलता भारत में कृषि के लिए महत्वपूर्ण खतरे पैदा करती है, जिससे कुछ क्षेत्रों में बाढ़ और अन्य में गंभीर सूखे के कारण फसल उत्पादन में क्षेत्रीय असमानताएं होती हैं। यह अध्ययन कृष्णा जिले, आंध्र प्रदेश में प्रमुख फसलों: अरहर/तुअर, कपास, मूंगफली और चावल की उत्पादकता पर विभिन्न मौसम मापदंडों के प्रभाव की जांच करता है। डेट्रेंडिंग, सहसंबंध और महत्व परीक्षण जैसे सांख्यिकीय तरीकों को नियोजित करते हुए, हम पिछले 23 वर्षों (1997-98 से 2019-20) में मौसम के मापदंडों (वर्षा, तापमान और हवा की गति) और फसल उत्पादकता (टन प्रति हेक्टेयर) के बीच संबंधों का विश्लेषण करते हैं। हमारे निष्कर्ष फसल की पैदावार पर जलवायु कारकों के महत्वपूर्ण प्रभाव को उजागर करते हैं और जलवायु-संबंधी कृषि जोखिमों को कम करने के लिए अनुकूली रणनीतियों की आवश्यकता को रेखांकित करते हैं।

ABSTRACT. Climate variability has become a global concern, with an increasing frequency of heat waves contributing to heightened variability in summer monsoon precipitation. This variability poses significant threats to agriculture in India, leading to regional disparities in crop production due to floods in some areas and severe droughts in others. This study examined the impact of various weather parameters on the productivity of major crops: Arhar/Tur, cotton, groundnut, and rice in Krishna District, Andhra Pradesh. Employing statistical methods such as detrending, correlation, and significance tests, we analyze the relationships between weather parameters (rainfall, temperature, and wind speed) and crop productivity (Tons/Hectare) over the past 23 years (1997-98 to 2019-20). Crop Weather Calendars are utilized to understand stage-wise water requirements, identify favorable and unfavorable weather conditions, and assess the statistical significance of various parameters at the 95% and 99% confidence levels. Our findings highlight the critical influence of climatic factors on crop yields and underscore the need for adaptive strategies to mitigate climate-related agricultural risks.

Key words - Crop productivity, Weather parameters, Growth stage, Crop weather calendar.

1. Introduction

Climate variability is increasingly recognized as a global threat, with a marked rise in the frequency of heat waves contributing to heightened variability in summer monsoon precipitation (Habib-ur-Rahman *et al*., 2022). This variability poses significant challenges to agriculture, particularly in India, where the agriculture sector is highly susceptible to climate change (Kumar & Gautam, 2014). The effects are manifested through regional inequalities in crop production, with some areas experiencing floods while others face severe droughts. Understanding the impact of these climatic changes on crop productivity is essential for developing strategies to mitigate these adverse effects and ensure food security (Feng *et al.,* 2021). This study investigates the impact of weather parameters-rainfall, maximum and minimum temperature, and wind speed-on the productivity of major crops (Arhar/tur, Cotton, Groundnut, and Rice) in Krishna District, Andhra Pradesh, over the past 23 years (1997-98 to 2019-20). The aim is to understand the variability of these parameters in relation to the crop life cycle and their correlation with crop productivity. Previous studies have shown that long-term climatic variability significantly affects crop phenology and yield across agro-climatic regions (Massano *et al*., 2023). To explore this, the study examines historical data, climate projections, and their influence on grapevine phenology, growth, and yield. Kumar *et al.* (2004) consider factors such as temperature, precipitation, and extreme weather events, assessing their cumulative effects on grape productivity over time. For instance, rainfall during the sowing, vegetative growth, and flowering stages of Arhar crops is beneficial, whereas it is detrimental during the germination, grain formation, and harvesting stages. Similarly, in cotton crops, rainfall is favorable during the sowing, germination, vegetative growth, and flowering stages but unfavorable during the initial boll maturity stages. Groundnut crops benefit from rainfall during the flowering and grain formation stages. For rice, rainfall is advantageous during the vegetative growth and flowering stages but adverse during grain formation and harvesting. Extreme events during the summer have the most significant impact on plant productivity. However, research documenting these effects is limited, as noted by Kumudini *et al.* (2014). Barlow *et al*. (2015) conducted a recent review on the impact of temperature extremes, such as frost and heat, on wheat (*Triticum aestivum* L.). They found that frost leads to sterility and the abortion of grains, while excessive heat reduces the number of grains and shortens the grain-filling period. Meehl *et al*. (2007) analyzed temperature trends and discovered that daily minimum temperatures are rising faster than daily maximum temperatures. This increase in daily mean temperatures makes extreme weather events more likely, potentially harming grain yield. High maximum temperatures are generally unfavorable during the sowing and germination stages but can be beneficial during grain formation and harvesting (Hatfield & Prueger, 2015). Singh *et al.* (2014) noted that variations in June to September rainfall adversely affect rice production in Bihar, India, illustrating the broader relevance of these findings. Additionally, the analysis of minimum temperature and wind speed also provided valuable insights into their impact on crop productivity.

This study employs various statistical methods to analyze the relationships between weather parameters and crop productivity, including de-trending, correlation, and significance tests. Crop weather calendars were used to understand stage-wise water requirements, identify favorable and unfavorable weather conditions, and assess the statistical significance of various parameters at the 95% and 99% confidence levels. By enhancing our understanding of the crop-weather relationship and facilitating yield estimation, this study aims to aid in crop planning and ultimately increase crop productivity in Krishna District. The findings underscore the critical influence of climatic factors on crop yields and highlight the need for adaptive strategies to mitigate climate-related agricultural risks.

2. Data and Methodology

This study focuses on Machilipatnam, a prominent city in the Krishna District, located in the Coastal Andhra region of Andhra Pradesh, India. Historically, Machilipatnam served as a significant trading port for the Portuguese, British, Dutch, and French during the 17^{th} century. Geographically, the city is positioned at 16.17° N latitude and 81.13° E longitude on the southeast coast of India, with an average elevation of 14 meters (45 feet). The Meteorological Observatory Station code for Machilipatnam is 43185. The primary data for this study includes daily maximum temperature, minimum temperature, wind speed, and rainfall for Machilipatnam, spanning the period from January 1980 to December 2020. This meteorological data was obtained from the National Climate Data Centre, CRS Office, India Meteorological Department, Pune. Crop data for the study was collected from the Ministry of Agriculture and Farmers Welfare website (https://upag.gov.in/). Table 1 outlines the crops selected for the study, including their respective start and end years. The crops chosen are Arhar/tur, cotton (Lint), groundnut, and rice. Each crop has been studied over the same period, from the 1997-98 agricultural year to the 2019-20 agricultural year. This consistent timeframe allows for a comprehensive analysis of how past and future climate variations impact the productivity of these major crops in the Krishna District of Andhra Pradesh. To focus on technological trends, crop productivity data was

TABLE 1

Crops chosen for the study are as tabulated

Crop	Start Year	End Year
Arhar/tur	1997-98	2019-20
Cotton (Lint)	1997-98	2019-20
Groundnut	1997-98	2019-20
Rice	1997-98	2019-20

detrended using methods outlined by Lobell and Burke (2009). Monthly and yearly averages, maximum values of maximum temperatures, minimum values of minimum temperatures, maximum and average wind speeds (km/hr), total and maximum rainfall were calculated. Trend analysis was conducted for maximum temperature, minimum temperature, rainfall, and average wind speed over the study period. The study employs several statistical methods to analyze the relationship between weather parameters and crop productivity.

2.1. *Detrending*

This method removes the technological trends from the crop productivity data, allowing for a clearer analysis of the impact of weather variables.

2.2. *Correlation analysis*

Correlation coefficients were calculated to measure the relationship between crop productivity (measured in tons per hectare) and various weather parameters, including rainfall, maximum and minimum temperatures, and wind speed. This analysis was performed for crop productivity data for the Kharif season (June to September) over the past 23 years (1997-98 to 2019-20).

$$r = \frac{\sum(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum(x_i-\bar{x})^2 \sum(y_i-\bar{y})^2}} \quad (1)$$

r = correlation coefficient

x_i = values of the x-variable in a sample

$\bar{x}$ = mean of the values of the x-variable

y_i = values of the y-variable in a sample

$\bar{y}$ = mean of the values of the y-variable

2.3. *Test of significance*

The statistical significance of the relationships between weather parameters and crop productivity was assessed using the Student's t-test. The significance levels were tested at 95% and 99% confidence intervals to ensure robust results.

$$t = \frac{m_A - m_B}{\sqrt{\frac{S^2}{n_A}+\frac{S^2}{n_B}}} \quad (2)$$

mA and mB represent the means of groups A and B, respectively. nA and nB represent the sizes of group A and B, respectively. S^2 is an estimator of the common variance of the two samples

$$S^2 = \frac{\sum(x-m_A)^2+\sum(x-m_B)^2}{n_A+n_B-2} \quad (3)$$

2.4. *Crop life cycle analysis*

Detailed correlation analyses were performed for the major crops: Arhar/tur, Cotton (Lint), Groundnut, and Rice-based on their crop life cycle data. This involved assessing the impact of rainfall, maximum and minimum temperatures, and wind speed during different growth stages (sowing, vegetative growth, flowering, grain formation, and harvesting) on crop productivity.

2.5. *Significance testing*

The statistical significance of the relationships between weather parameters and crop productivity was ascertained by testing the significance for the 23-year period. This helps understand the extent to which weather parameters influence crop yields, providing insights for better crop planning and management.

By integrating historical climate data, crop productivity records, and rigorous statistical methods, this study aims to enhance our understanding of the impact of climate variability on agriculture in Krishna District. The findings will contribute to developing adaptive strategies to mitigate climate-related agricultural risks and improve crop productivity in the region.

3. Results and discussion

3.1. *Climatic and meteorological insights for Krishna District*

3.1.1. *Crop Weather Calendar and rainfall patterns*

The *Kharif* season in Krishna District is meticulously mapped out in Table 2, detailing crucial stages from sowing to harvesting for crops like Arhar/tur, cotton (lint), groundnut, and rice. Each crop follows a distinct timeline marked by stages such as sowing (deep red), vegetative growth (orange), flowering (yellow), grain formation (olive green), and harvesting (green). Meanwhile, Table 3 and Figure 1 underscores the region's rainfall dynamics over 41 years, revealing significant variability. From a mean low of 5.4 mm in March to a high of 193.4 mm in October, the district experiences pronounced dry spells from January to April and December, contrasting with robust monsoon months from May to November. Extreme events, like November's peak of 993.1 mm and frequent

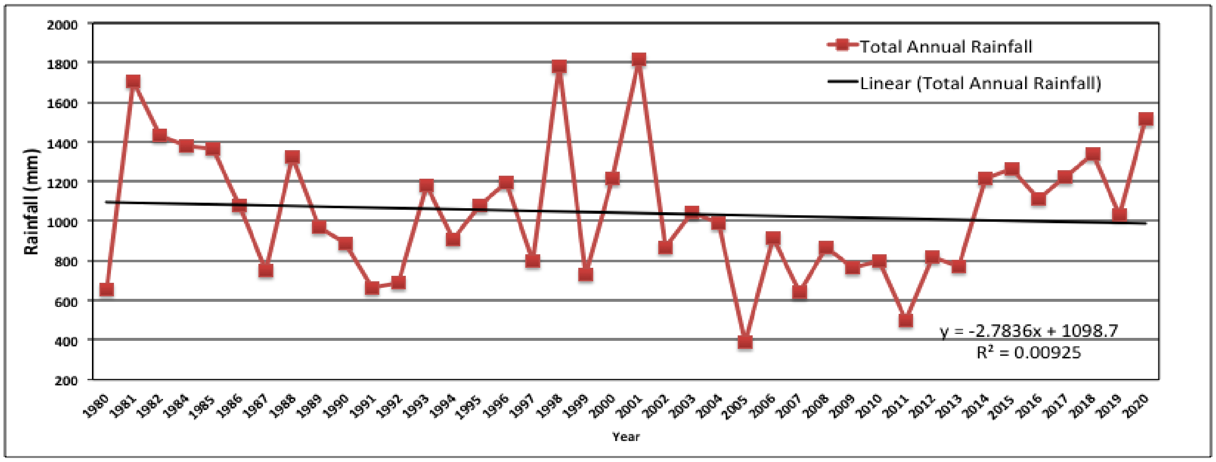

Fig. 1. Year-wise rainfall at Machilipatnam (1980-2020)

TABLE 2

Crop Weather Calendar (Crop Life History Kharif Season in Krishna District)

CROP WEATHER CALENDAR (CROP LIFE HISTORY) *KHARIF* SEASON IN KRISHNA DISTRICT												
Crop	**Jan**	**F**	**M**	**A**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Arhar/tur						SOWING						
						GERMINATION						
								VEGITATIVE GROWTH				
								FLOWERING				
									GRAIN FORMATION			
											HARVESTING	
Cotton (Lint)						SOWING						
						GERMINATION						
								VEGITATIVE GROWTH				
									FLOWERING			
										BOLL MATURITY		
	PICKING UP											PICKING UP-
Groundnut						SOWING						
						GERMINATION						
							VEGITATIVE GROWTH					
								FLOWERING				
									GRAIN FORMATION			
										HARVESTING		
Rice					SOWING							
						TRANSPLANTING						
							VEGITATIVE GROWTH					
								FLOWERING				
									GRAIN FORMATION			
										HARVESTING		

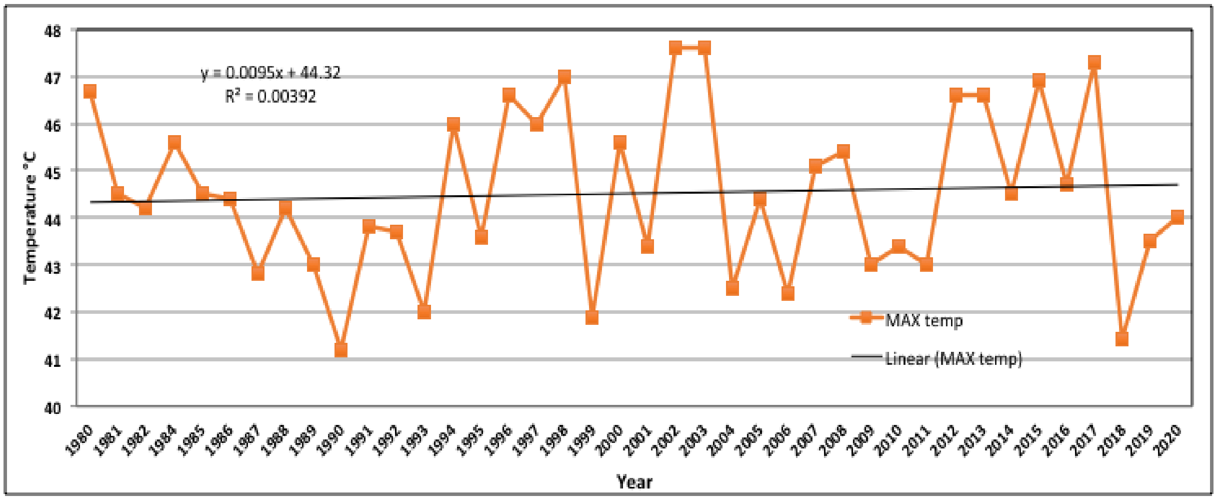

Fig. 2. Year-wise maximum temperature at Machilipatnam (1980-2020)

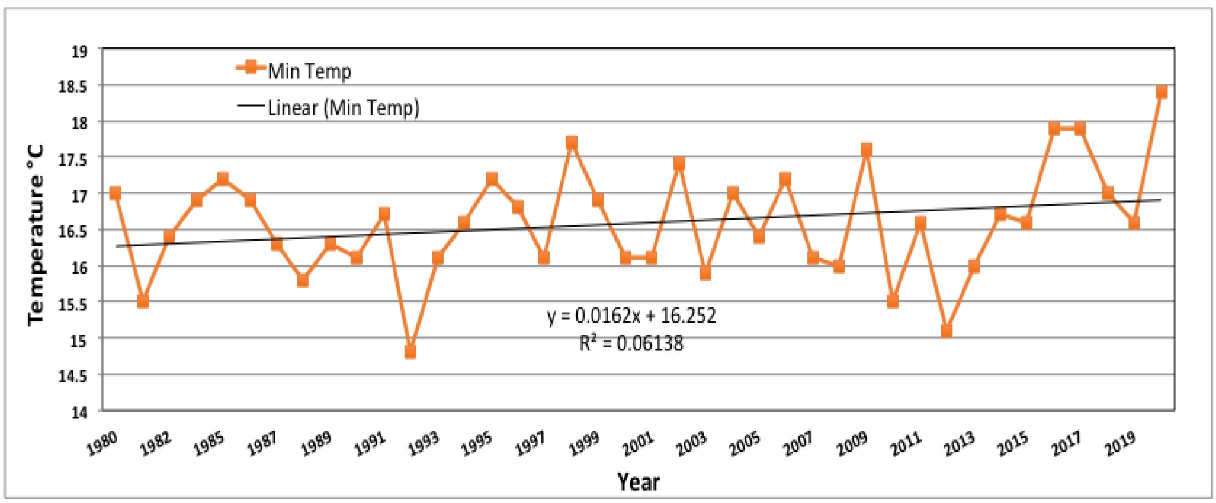

Fig. 3. Year-wise minimum temperature of Machilipatnam from 1980-2020

TABLE 3

The month-wise rainfall descriptive statistics

Months Particulars	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Average rainfall	6.3	14.7	5.4	9.2	42.7	111.9	190.6	175.7	178.6	193.4	122.2	19.8
Highest rainfall	48.4	96.1	67.7	78.7	248	329.5	449.9	414.7	526.5	447.5	993.1	110.4
Relevant Year(s)	2009	1987	2005	1998	1987	2013	1985	1997	2007	1991	1991	1982
Lowest rainfall	0	0	0	0	0	20.5	45.3	36.2	9.5	18.9	0.6	0
Relevant Year(s)	20 out of 41 years	23 out of 41 years	26 out of 41 years	19 out of 41 years	2 out of 41 years	2019	2016	1984	2011	1988	1999	11 out of 41 years

zero-rainfall occurrences in various months, underscore the area's vulnerability to climatic fluctuations.

3.1.2. *Temperature extremes and trends*

Table 4 and Fig. 2 highlights temperature variations in Krishna District, ranging from a peak of 47.6° C in scorching May to cooler averages of 29.5° C in January and December. Notable years, such as 2012 and 2017, recorded extreme maximum temperatures, emphasizing seasonal patterns crucial for agricultural planning. Similarly, Table 5 illustrates monthly temperature ranges, from January's low of 14.8° C to August's high of 22.3° C, reflecting stable patterns across decades. Figure 3 presented the annual temperature of the said region. These insights are essential for understanding how temperature impacts crop growth and phenology, shaping agricultural strategies across the district.

3.1.3. *Wind dynamics and agricultural implications*

Table 6 and Fig. 4-5 delve into wind speed variability, with August recording the highest speeds at 39.0 km/h and December the lowest at 21.0 km/h. Monthly averages peak at 19.7 km/h in May, influencing pollination and evapotranspiration rates critical for crop health. Stable minimum speeds from 5.0 km/h in winter to 9.0 km/h in summer underscore consistent environmental conditions affecting crop stress and resilience. These wind dynamics are pivotal in agricultural management and infrastructure planning in Krishna District. These insights collectively provide a comprehensive understanding of the complex climatic and meteorological factors shaping agricultural productivity and resilience in Krishna District, which are crucial for sustainable development and adaptation strategies in the face of climate change.

3.2. *Correlation between rainfall and crop productivity for Machilipatnam, Krishna district, AP state*

The statistical analysis of Table 7 revealed the relationship between monthly rainfall and the productivity of four major crops (Arhar/tur, Cotton (Lint), Groundnut, and Rice) in Machilipatnam, Krishna District, Andhra Pradesh, over the period from 1997-98 to 2019-20. For Arhar/tur, significant positive correlation with June rainfall ($r = 0.544$, $p<0.01$) suggests that higher rainfall in June benefits productivity, whereas negative correlations in July ($r = -0.431$, $p<0.05$), September ($r = -0.427$, $p<0.05$), October ($r = -0.354$, NS), and November ($r = -0.388$, $p<0.05$) imply detrimental effects from excessive rainfall during these months. For Cotton (Lint), a significant negative correlation in October ($r = -0.428$, $p<0.05$) indicates reduced productivity due to excessive rainfall, while a significant positive correlation with the monsoon season (June July August and September [JJAS], $r = 0.493$, $p<0.05$) highlights the importance of adequate rainfall during these months. Groundnut shows a significant positive correlation in September ($r = 0.582$, $p<0.01$), indicating that higher rainfall benefits productivity. However, negative correlations in August ($r = -0.272$, NS) and mixed non-significant results for other months suggest a complex relationship. For Rice, a significant positive correlation in August ($r = 0.431$, $p<0.05$) indicates that higher rainfall supports productivity, while negative correlations in July ($r = -0.019$, NS), September ($r = -0.262$, NS), October ($r = -0.213$, NS), and November ($r = -0.457$, $p<0.05$) suggest detrimental effects from excessive rainfall. Overall, positive correlations during key months emphasize periods where adequate rainfall boosts crop productivity, while negative correlations highlight the detrimental effects of excessive rainfall, stressing the need for balanced water management. Statistically significant correlations underscore the substantial impact of rainfall on crop productivity during specific periods, offering valuable insights for optimizing agricultural practices.

3.3. *Correlation between temperature extremes and crop productivity and crop productivity for Machilipatnam, Krishna district, AP state*

The analysis of Table 8 examines the correlation between maximum temperature and crop productivity in Machilipatnam, Krishna District, Andhra Pradesh, from 1997-98 to 2019-20. For Arhar/tur, high temperatures in July negatively affect productivity ($r = -0.466$, $p<0.05$), while November shows a positive impact ($r = 0.529$, $p<0.05$). Cotton (Lint) benefits from higher temperatures in December ($r = 0.373$, $p<0.05$). Groundnut shows negative correlations with high temperatures in January ($r = -0.405$, $p<0.05$) and October ($r = -0.398$, $p<0.05$). For Rice, November's higher temperatures positively impact productivity ($r = 0.562$, $p<0.01$). These findings underscore the variable effects of temperature on different crops and highlight the need for targeted temperature management strategies to optimize productivity in Krishna District. Table 9 examines the correlation between minimum temperatures and crop productivity in Machilipatnam, Krishna District, Andhra Pradesh, from 1997-98 to 2019-20. Arhar/Tur shows negative correlations in June ($r = -0.346$, NS) and November ($r = -0.504$, $p<0.05$). Cotton (Lint) exhibits significant negative correlations in January ($r = -0.547$, $p<0.01$) and during JJAS ($r = -0.588$, $p<0.01$). Groundnut displays significant negative correlations in June ($r = -0.583$, $p<0.01$) and August ($r = -0.454$, $p<0.05$). Rice demonstrates significant positive correlations in July ($r = 0.416$, $p<0.05$) and August ($r = 0.454$, $p<0.05$), with a significant negative correlation in November ($r = -0.238$, NS). These findings

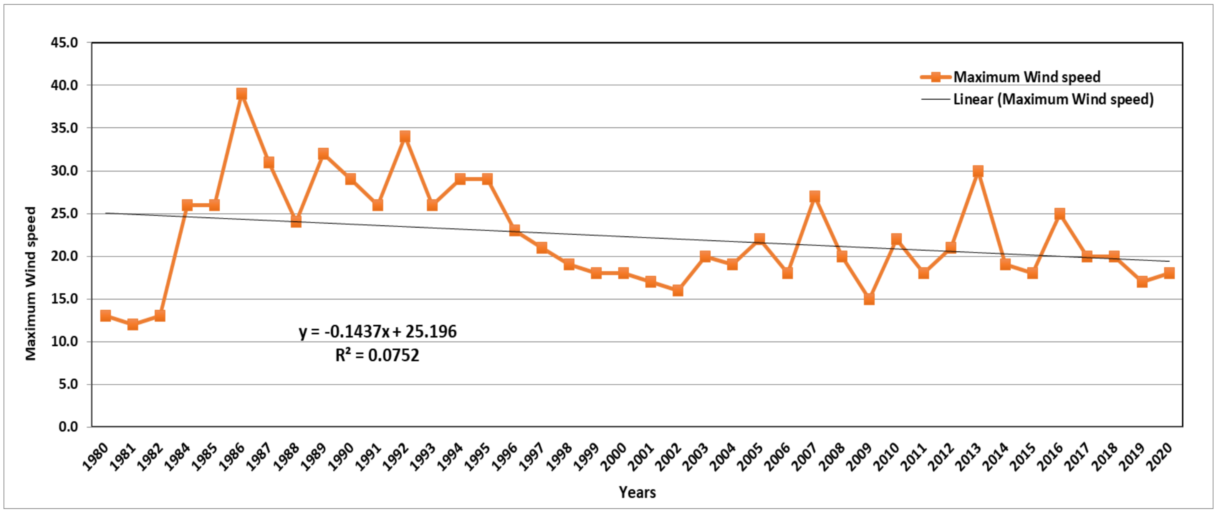

Fig. 4. Year-wise maximum wind speed at Machilipatnam (1980-2020)

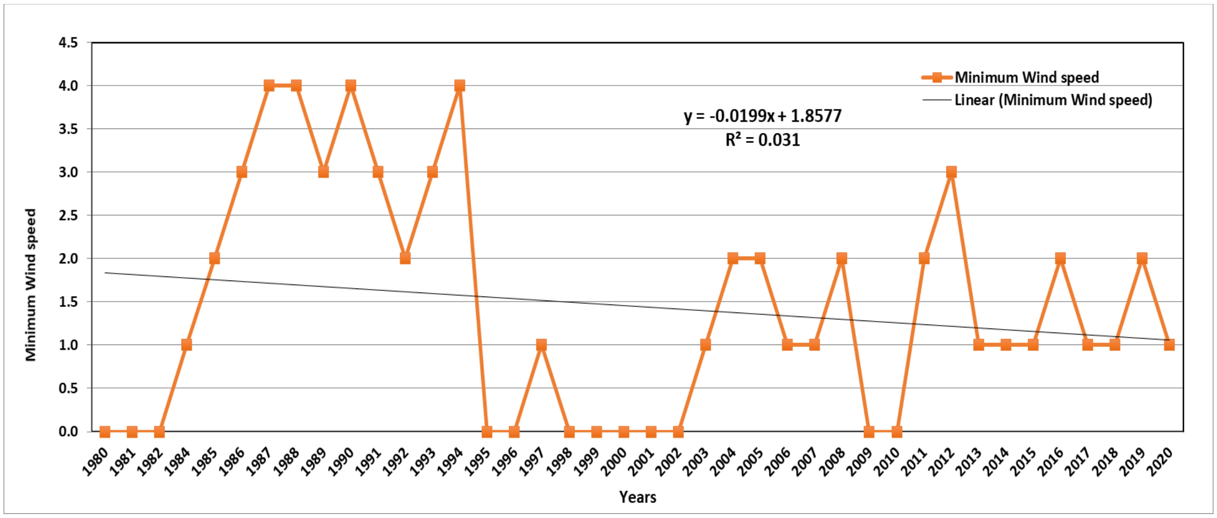

Fig. 5. Year-wise minimum wind speed of Machilipatnam from 1980-2020

TABLE 4

Average temperatures and the month-wise maximum temperature recorded between 1980-2020

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Highest Max. Temperature	**34.5**	**37.4**	**38.6**	**42.0**	**47.6**	**47.0**	**42.8**	**39.6**	**38.2**	**37.8**	**35.4**	**34.6**
Relevant year(s)	2006	2012	2016 & 2017	1987	2002 & 2003	1998	2014	2009	2002	2011	2017	2008
Average Max. Temperature	**29.5**	**29.7**	**33.9**	**35.4**	**38.4**	**37.6**	**35.9**	**34.6**	**33.5**	**33.0**	**30.2**	**29.5**

TABLE 5

Monthly Average temperatures and the monthly minimum temperature recorded in 1980-2020

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Minimum Temperature	14.8	15.3	16.1	20	19.5	22	21.4	22.3	22.0	19.2	15.5	15.5
Relevant Year(s)	1992	2014, 2017	2000	1987	2014, 2017	1989, 2013, 2016	1985	1999	1989, 2014, 2017	1985	1981, 1982	1981, 1982, 2010, 2012, 2015
Average Temperature	17.5	18.4	20.4	23.0	23.4	23.4	23.2	23.3	23.4	22.2	19.0	17.5

TABLE 6

Average and the month-wise maximum wind speed recorded in 1980-2020

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Max Wind Speed	23.0	27.0	29.0	30.0	34.0	27.0	32.0	39.0	26.0	26.0	31.0	21.0
Aver. Wind Speed	11.1	13.2	15.3	17.6	19.7	17.8	15.8	15.7	13.9	13.9	14.1	12.5
Min Wind Speed	5.0	5.0	8.0	9.0	9.0	8.0	8.0	7.0	8.0	8.0	6.0	6.0

TABLE 7

Correlation between Rainfall and Crop Productivity for Machilipatnam, Krishna District, AP State for the period of 1997-98 to 2019-20 is tabulated below

Crop	*Arhar/tur*		Cotton (Lint)		Groundnut		Rice	
Jan	-		-0.129	NS	0.008	NS	-	
Feb- Apr	-		-		-			
May							0.042	NS
Jun	0.544	**	0.35	NS	-0.055	NS	0.209	NS
Jul	-0.431	*	-0.154	NS	0.053	NS	-0.019	NS
Aug	0.38	*	0.14	NS	-0.272	NS	0.431	*
Sep	-0.427	*	0.01	NS	0.582	**	-0.262	NS
Oct	-0.354	NS	-0.428	*	-0.173	NS	-0.213	NS
Nov	-0.388	*	0.151	NS	0.259	NS	-0.457	*
Dec	-0.223	NS	0.111	NS	-	-		
JJAS	0.277	NS	0.493	*	0.206	NS	0.089	NS
OND	-0.364	*	0.026	NS	-	-		

TABLE 8

Analysis of correlation between maximum temperature and crop productivity for Machilipatnam, Krishna district, AP state for the period of 1997-98 to 2019-20

Crop	*Arhar/Tur*		Cotton (Lint)		Groundnut		Rice	
Jan	-		-0.164	NS	-0.405	*	-	
Feb- Apr	-		-		-			
May							-0.037	NS
Jun	-0.07	NS	-0.111	NS	0.23	NS	-0.263	NS
Jul	-0.466	*	0.029	NS	-0.073	NS	-0.065	NS
Aug	0.054	NS	0.231	NS	0.081	NS	0.046	NS
Sep	-0.066	NS	0.104	NS	-0.082	NS	0.087	NS
Oct	0.039	NS	0.019	NS	-0.398	*	-0.152	NS
Nov	0.529	*	-0.155	NS	-0.297	NS	0.562	**
Dec	-0.019	NS	0.373	*	-	-		
JJAS	-0.083	NS	-0.05	NS	0.086	NS	-0.093	NS
OND	0.364	*	0.241	NS	-	-		

TABLE 9

Correlation between Minimum Temperature and Crop Productivity for Machilipatnam, Krishna District, AP State for the period of 1997-98 to 2019-20 is tabulated below:

Crop	*Arhar/tur*		Cotton (Lint)		Groundnut		Rice	
Jan	-		-0.547	**	0.002	NS	-	
Feb- Apr	-		-		-			
May							-0.14	NS
Jun	-0.346	NS	-0.583	**	0.348	NS	0.014	NS
Jul	0.024	NS	-0.194	NS	-0.102	NS	0.416	*
Aug	-0.234	NS	-0.047	NS	0.065	NS	-0.454	*
Sep	-0.14	NS	-0.353	*	-0.167	NS	0.081	NS
Oct	-0.049	NS	-0.08	NS	0.031	NS	-0.331	NS
Nov	-0.504	*	-0.177	NS	0.306	NS	-0.238	NS
Dec	0.051	NS	-0.102	NS	-	-		
JJAS	-0.327	NS	-0.588	**	0.089	NS	0.047	NS
OND	-0.329	NS	-0.157	NS	-	-		

TABLE 10

Correlation between Minimum Wind Speed and Crop Productivity for Machilipatnam, Krishna District, AP State for the period of 1997-98 to 2019-20 is tabulated below:

Crop	*Arhar/tur*		Cotton (Lint)		Groundnut		Rice	
Jan	-		0.062	NS	0.401	*		
Feb- Apr			-		-			
May							-0.076	NS
Jun	-0.465	*	-0.088	NS	0.374	*	-0.093	NS
Jul	-0.501	*	0.262	NS	0.421	*	-0.196	NS
Aug	-0.003	NS	0.395	*	0.378	*	0.007	NS
Sep	-0.305	NS	-0.133	NS	0.413	*	0.234	NS
Oct	-0.228	NS	-0.034	NS	0.357	*	-0.008	NS
Nov	0.235	NS	0.237	NS	0.264	NS	-0.053	NS
Dec	-0.37	*	0.007	NS	-	-		
JJAS	-0.515	*	0.108	NS	0.594	**	-0.029	NS
OND	-0.111	NS	0.065	NS	-	-		

highlight the varying impacts of minimum temperatures on crop productivity, emphasizing the need for precise temperature management strategies in Krishna District agriculture.

3.4. *Correlation between wind speed (minimum-maximum) and crop productivity for Machilipatnam, Krishna District, AP State*

Tables 10 and Table 11 analyze the correlation between minimum and maximum wind speed and crop productivity in Machilipatnam, Krishna District, Andhra Pradesh, from 1997-98 to 2019-20. Minimum wind speed reveals significant trends where Arhar/Tur shows negative correlations in June (r = -0.465, p<0.05) and July (r = -0.501, p<0.05), indicating reduced productivity with lower wind speeds. Conversely, Cotton (Lint) benefits from higher minimum wind speeds in January (r = 0.401, p<0.05), June (r = 0.374, p<0.05), July (r = 0.421, p<0.05), and August (r = 0.395, p<0.05). Groundnut demonstrates positive correlations in May (r = 0.413, p<0.05), June (r = 0.374, p<0.05), July (r = 0.421,

TABLE 11

Correlation between Maximum Wind Speed and Crop Productivity for Machilipatnam, Krishna District, AP State for the period of 1997-98 to 2019-20 is given below

Crop	*Arhar/tur*		Cotton (Lint)		Groundnut		Rice	
Jan	-		-0.184	NS	0.347	NS		
Feb- Apr	-		-		-			
May	-		-		-		-0.248	NS
Jun	-0.005	NS	0.05	NS	0.207	NS	0.328	NS
Jul	-0.165	NS	0.073	NS	0.343	NS	-0.064	NS
Aug	0.056	NS	0.552	*	0.295	NS	-0.036	NS
Sep	0.143	NS	-0.158	NS	0.376	*	0.004	NS
Oct	-0.249	NS	-0.231	NS	-0.088	NS	-0.246	NS
Nov	-0.345	NS	0.109	NS	0.179	NS	-0.121	NS
Dec	-0.168	NS	0.072	NS	-	-		
JJAS	0.157	NS	0.126	NS	0.417	*	0.155	NS
OND	-0.441	*	0.055	NS	-	-		

$p<0.05$), August ($r = 0.378$, $p<0.05$), and notably high in JJAS ($r = 0.594$, $p<0.01$), suggesting enhanced productivity with increased wind speeds during these periods. Rice shows varied correlations, with positive effects noted in June ($r = 0.234$, NS) and October ($r = 0.357$, $p<0.05$), but non-significant impacts in December. Maximum wind speed (Table 11) highlights that Arhar/Tur exhibits negative correlations in OND ($r = -0.441$, $p<0.05$), indicating reduced productivity with higher maximum wind speeds during these months. Conversely, Cotton (Lint) benefits significantly in August ($r = 0.552$, $p<0.05$) from increased wind speeds. Groundnut shows positive correlations in June ($r = 0.328$, NS), July ($r = 0.343$, NS), and September ($r = 0.376$, $p<0.05$), indicating favorable conditions for productivity with higher wind speeds. Rice benefits notably in JJAS ($r = 0.417$, $p<0.05$), emphasizing the positive impact of higher maximum wind speeds during these months. These findings underscore the complex and variable effects of wind speed on different crops throughout the year in Krishna District. They highlight the necessity for targeted wind management strategies to optimize agricultural productivity, considering each crop's specific needs and sensitivities to wind conditions.

Bhattacharyya *et al.* (2021) investigated the change in meteorological parameters that affect crop production and productivity. They found that yields of crops were significantly dependent on climatic variables, and more or less, the area plays a significant role in crop yield for most crops like rice, maize, oilseeds, vegetables, citrus, and turmeric. Gyamerah *et al.* (2021) reported the impacts of climate variability indicators (maximum and minimum temperatures) and the marginal effect of climate variables on crop (maize) yields in the northern region of Ghana. Climatic indicators such as temperature, precipitation, wind speed, solar radiation, and humidity potentially affect sustainable food production (Simanjuntak *et al.*, 2022). Zhang *et al.* (2017) reported that high wind speeds, for instance, could damage crops and infrastructure, while low humidity increases water stress.

4. Conclusions

This study examined meteorological factors (rainfall, temperatures, and wind speed) and their correlations with crop productivity in Krishna District, Andhra Pradesh, India. Noteworthy associations between weather parameters and crop productivity were found, highlighting the importance of favorable weather conditions during specific crop growth stages. For Arhar/Tur, positive rainfall impacts were observed during sowing, vegetative growth, and flowering, while unfavorable conditions affected germination, grain formation, and harvesting stages. Cotton faced challenges with initial boll maturity rainfall but benefited from rainfall during sowing, germination, vegetative growth, and flowering. Groundnuts showed heightened productivity with favorable rainfall during flowering and grain formation. Rice thrived with favorable rainfall during vegetative growth and flowering but experienced productivity decline during grain formation and harvesting. Elevated maximum temperatures were unfavorable during sowing and germination but advantageous during grain formation and harvesting. These insights can guide refined crop planning, understanding the weather-crop interplay, and predicting crop yields in Krishna District. Positive correlations supported crop growth, while negative correlations hindered development. Integrating these findings into agricultural strategies can inform decisions for enhancing crop productivity and mitigating the impacts of climate variability. The climatic and meteorological data for Krishna District reveals significant variability impacting agriculture. Rainfall ranges from 5.4 mm in March to 993.1 mm in November, with dry spells from January to April and December and heavy monsoons from May to November. Temperature extremes peak at 47.6 °C in May, with cooler averages of 29.5 °C in January and December, highlighting seasonal variability critical for crop growth. Wind speeds, varying from 21.0 km/h in December to 39.0 km/h in August, influence pollination and evapotranspiration rates. These insights underscore the need for adaptive agricultural strategies. Effective water management, heat stress mitigation, and wind resilience are crucial for maintaining productivity. Understanding these climatic patterns is essential for sustainable agricultural development in the face of climate change, ensuring long-term resilience and productivity in Krishna District.

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No funding was received for the current study. The authors declare that they have no conflict of interest. This manuscript does not contain any studies involving animals performed by any authors.

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