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Rainfall trends and their influence on crop production in Tamil Nadu, India - A 33-year analysis

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सार – : इस अध्ययन का उद्देश्य तमिलनाडु में वार्षिक और मौसमी वर्षा के फसल उत्पादकता पर पड़ने वाले प्रभावों का अध्ययन करना था। तमिलनाडु के ऋतु एवं फसल रिपोर्ट (1990 से 2023 तक) से वार्षिक वर्षा, मौसमी वर्षा, फसल उत्पादन, उपज, बुवाई और कटाई संबंधी दीर्घकालिक आंकड़े प्राप्त किए गए। 33 वर्षों के मौसमी और वार्षिक वर्षा विश्लेषण के लिए मान-केंडल और थिल-सेन प्रवृत्ति विश्लेषण के परिणामों से उत्तर-पूर्वी मानसून को छोड़कर सभी मौसमों में सकारात्मक प्रवृत्ति पैटर्न का पता चला। अध्ययन से पता चलता है कि तमिलनाडु में उत्तर-पूर्वी मानसून में वर्षा का वितरण और मात्रा अन्य मौसमों की तुलना में अधिक है। तमिलनाडु में 50% वर्षा उत्तर-पूर्वी मानसून में होती है। अध्ययन से पता चलता है कि उत्तर-पूर्वी और दक्षिण-पश्चिमी मानसून में अक्षांश के साथ वर्षा बढ़ती है। कोयंबटूर और नीलगिरी में दक्षिण-पश्चिमी मानसून, उत्तर-पूर्वी मानसून की तुलना में अधिक वर्षा लाता है। 1990 से 2023 तक सभी वर्षों में वार्षिक वर्षा 500 मिमी से अधिक रही है। तमिलनाडु में 1990-2023 के दौरान क्रमशः 5, 22 और 6, अधिक, सामान्य एवं कम वर्षा वाले वर्ष रहे। वार्षिक वर्षा तटीय क्षेत्रों की तुलना में भूमि पर अधिक होती है। हालाँकि, उत्तर-पूर्वी मानसून के दौरान, तटीय क्षेत्रों में भूमि क्षेत्रों की तुलना में अधिक वर्षा होती है। फसल उत्पादन का संबंध भूजल की तुलना में वर्षा से अधिक है। फसल उत्पादन और वर्षा तथा उपज के बीच कार्यात्मक संबंध स्थापित किए गए हैं। इनके बीच उच्च आर-स्क्वायर के साथ महत्वपूर्ण सहसंबंध पाया गया है, जो कि कुम्बु, लाल चना, बंगाल चना और तिल को छोड़कर अधिकांशतः 0.7 से 0.96 के बीच है। वर्षा की मात्रा और फसल बोने के मौसम के बीच एक महत्वपूर्ण संबंध है। इन फसलों को उस विशेष मौसम में बोने से वर्षा आधारित कृषि भूमि पर फसल उत्पादकता और उपज में वृद्धि हो सकती है। इस अध्ययन के निष्कर्ष तमिलनाडु में जल संसाधनों के उपयोग के माध्यम से फसल उत्पादन पर वर्षा के प्रभाव की बेहतर समझ विकसित करने और फसल उपज बढ़ाने में सहायक हो सकते हैं।

ABSTRACT. The purpose of this study was to investigate the effects of annual and seasonal rainfall on crop productivity in Tamil Nadu. From the Tamil Nadu Season and Crop Report for the years 1990 to 2023, the long-term data of annual rainfall, seasonal rainfall, crop production, yield, crop sowing, and harvesting report was obtained. Mann-Kendall and Theil-Sen trend analysis results for seasonal and yearly rainfall over 33 years revealed positive trend patterns, except for NE monsoon. The investigation reveals that the distribution and quantity of rainfall are higher in NE monsoon than in other seasons in Tamil Nadu. Tamil Nadu receives 50 % of rainfall in NE monsoon. The study reveals that the rainfall increases with latitude in NE and SW monsoon. The SW monsoon brings more rainfall than the NE monsoon over Coimbatore and the Nilgiris. The annual rainfall is higher than 500 mm in all years from 1990 to 2023. Tamil Nadu has experienced 5, 22, and 6 excess, normal, and deficit rainfall years during 1990-2023. The annual rainfall is more on land than on the coast. Nevertheless, during the Northeast monsoon, coastal areas receive more rainfall than land areas. Crop production is positively associated with the rainfall than that at groundwater. The functional relations have been established for crop production with rainfall and yield. A significant correlation exists between them with high R-squared, varying mostly from 0.7-0.96, except for cumbu, red gram, Bengal gram, and gingelly. There is a strong relationship between the amount of rainfall and the crop-planting season. Planting these crops at that particular season can thereby increase crop

productivity and yield on rain-fed agricultural land. These study findings may enhance the understanding of rainfall's influence on crop production more effectively and increase crop yield through the utilization of water resources in Tamil Nadu.

Key words – Rainfall trend analysis, Crop production trend analysis, Statistical approach, Linear regression, Seasonal rainfall, Annual rainfall.

1. Introduction

The rainfall in Tamil Nadu is categorized into four rainfall patterns viz. southwest monsoon (SW), northeast monsoon (NE), winter season (WS), and hot weather period (HW). The rainfall that falls between June and September is referred to as SW monsoon; October to December is NE monsoon, January and February is the winter season; and March to May is HW season. The NE monsoon is essential to agriculture and other water resources in Tamil Nadu and Andhra Pradesh (Samui *et al.,* 2013) even though India's major reason falls during the SW monsoon. Rainfall varies with time and space and is a distinct meteorological hydrologic phenomenon. Its change has a significant impact on the economies of all nations, including India (Yadav *et al.,* 2014). Among the various atmospheric elements that influence when crops should be sown, rainfall plays a significant role.

According to the IPCC 2018 assessment, reducing global warming to 1.5 °C instead of 2 °C will guarantee the sustainability of the earth's resources (IPCC 2018). Trends in rainfall are closely linked to changes in the climate (Rao *et al.,* 2023). All over the globe, the agriculture sector primarily depends on the period of occurrence and quantity of rainfall and also it plays a significant role in meeting the increasing needs of commercial and household water supplies. For agricultural productivity, farmers primarily rely on the monsoon rains. Because crop productivity, especially in rain-fed areas, is dependent on rainfall patterns, it is critical to use statistical analysis to forecast the likelihood of rainfall based on historical data records (Arvind *et al.,* 2017). Several researchers (Pingale *et al.,* 2016; Panda and Sahu, 2019; Elbeltagi *et al.,* 2020) have analyzed trends and rainfall variability in extreme circumstances using both parametric and non-parametric methods to study the temporal and spatial trends of rainfall variability in India. Rao *et al.* (2023) analyzed the trend of 31 years of rainfall data using statistical methods over Andhra Pradesh and found that there were both positive and negative trends in different months. Weber and Stewart (2004) analyzed groundwater and rainfall using a cumulating departure analysis of rainfall approach. In rain-fed agriculture, seasonal rainfall distribution and its quantity are more important than yearly total rainfall. Crop production considerations are based on seasonal variations of the rainfall. The timely commencement and abatement of rain in a certain place determine the span of the growing period for the production of crops (Robinson *et al.,* 2013). The unpredictable start and stop of the seasonal rains may lead to lower yields (Torres *et al.,* 2019). Therefore, it is essential to comprehend the characteristics of seasonal rainfall in the growing season for rain-fed agriculture (Guido *et al.,* 2020). The rainfall seasons have significantly different patterns and distributions.

Thus in this study the time series seasonal and annual rainfall, crop production, and crop planting season were analyzed to investigate the following objectives: statistical analysis of rainfall and crop production to evaluate the trend of rainfall and crop production in NE, SW, HW, WS and whole year from 1990-2023; the impact of rainfall and groundwater on crop production over 36 districts in Tamil Nadu; variation of rainfall and crop production in land and coastal regions of Tamil Nadu, and to know the correlation of crop production with rainfall and yield.

2. Data and methodology

The author obtained the time series rainfall, crop production, yield, area, crop sowing, and harvesting season from Tamil Nadu Season and Crop Report (2024) for all the districts for the period 1990 to 2023. The analysis of seasonal and annual variations of rainfall and crop production has been done. The variability of seasonal rainfall in land and coastal locations of Tamil Nadu and its impact on crop production has been studied. Also, how crop production is associated with rainfall and groundwater has been investigated. Table 1 shows the locations used in this study.

The statistical analysis of rainfall and crop production has been done using non-parametric tests viz. Mann-Kendall's test, Theil-Sen test, and departure analysis of rainfall.

2.1. *Mann-Kendall test*

Mann (1945) developed the Mann-Kendall (MK) test as a non-parametric test for detecting trends, and Kendall (1975) provided an evaluation of statistical distributions to analyze non-linear trends and transitions. It is obtained by,

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Sgn(X_j - X_i) \quad (1)$$

TABLE 1

List of districts in Tamil Nadu used in this study

S. No.	Districts	Latitude (°)	Longitude (°)	MSL (m)	Geography
1	Ariyalur	11.14	79.07	80	Land
2	Chengalpattu	12.7	80.01	36	Coast
3	Coimbatore	11	77	427	Land
4	Cuddalore	11.71	79.81	6	Coast
5	Dharmapuri	12.13	78.21	450	Land
6	Dindigul	10.36	78	265	Land
7	Erode	11.33	77.76	172	Land
8	Kallakurichi	11.73	78.96	175	Land
9	Kancheepuram	12.83	79.75	83.2	Land
10	Kanniyakumari	8.08	77.54	30	Coast
11	Karur	10.96	78.11	101	Land
12	Krishnagiri	12.53	78.26	300	Land
13	Madurai	9.96	78.16	101	Land
14	Nagapattinam	10.76	79.84	9	Coast
15	Namakkal	11.21	78.21	218	Land
16	Perambalur	11.23	78.93	143	Land
17	Pudukkottai	10.43	79.36	116	Coast
18	Ramanathapuram	9.36	78.86	2	Coast
19	Ranipet	12.95	79.32	208	Land
20	Salem	11.65	78.2	278	Land
21	Sivagangai	9.84	78.48	102	Land
22	Tenkasi	8.96	77.35	143	Land
23	Thanjavur	10.78	79.16	59	Coast
24	Theni	10	77.47	339	Land
25	The Nilgiris	11.49	76.73	900	Land
26	Thoothukudi	8.8	78.18	2	Coast
27	Tiruchirapalli	10.83	78.76	78	Land
28	Tirunelveli	8.73	77.73	47	Coast
29	Tirupathur	12.49	78.56	388	Land
30	Tiruppur	11.08	77.33	295	Land
31	Tiruvallur	13.15	79.95	72	Coast
32	Tiruvannamalai	12.25	79.11	200	Land
33	Tiruvarur	10.76	79.63	3	Coast
34	Vellore	12.91	79.18	220	Land
35	Villupuram	11.95	79.53	71	Coast
36	Virudhunagar	9.58	77.95	102	Land

Two-time series are analyzed using the trend test: x_i, ranked from i = 1, 2 …n-1, and x_j, ranked from j = i + 1, 2 ….n. Every data point (x_i) is considered a reference point and is compared to all other data points (x_j) to assign the following values:

$$Sgn(X_j - X_i) = \begin{Bmatrix} +1 \; if \; (X_j - X_i) > 0 \\ 0 \; if \; (X_j - X_i) = 0 \\ -1 \; if \; (X_j - X_i) < 0 \end{Bmatrix} \quad (2)$$

2.2. *Theil-Sen test*

One method for quantifying trends is the Theil-Sen technique (TS). The TS is a non-parametric method employed to determine the trend's magnitude (Theil 1950; Sen 1968). The test calculates the median value of all the slopes (T_i) for the data pairs (Sen 1968) by,

$$T_j = median\left(\frac{X_j - X_k}{j-k}\right) \quad (3)$$

The values at moment j and k (j>k) are denoted by the variables x_j and x_k, respectively. Sen's slope, which is the median among these N values of T_i, is calculated from:

$$\beta = \begin{Bmatrix} Q_{n+1/2} & if \; N \; is \; odd \\ 1/2(Q_{\frac{n}{2}} + Q_{n+\frac{2}{2}}) & if \; N \; is \; even \end{Bmatrix} \quad (4)$$

In a time series, a positive β value denotes a rising trend while a negative β value denotes a decreasing trend.

2.3. *Departure analysis of rainfall (DAR)*

According to the India Meteorological Department's classification, a region is deemed drought-affected if it experiences seasonal precipitation that is below 75 percent of its normal (Appa Rao,1986). DAR calculates the yearly rainfall deviation for a given year from its mean. It was computed by (Rao *et al.*, 2023, Rangarajan *et al.*, 2019),

$$DAR\ (\%) = \frac{(x_i - x_m)}{x_m} \times 100 \quad (5)$$

where x_i is the total yearly rainfall for a particular year, and the mean yearly rainfall is represented by x_m.

3. Results and discussion

3.1. *Rainfall time series from 1990 to 2023*

The author studied the distribution of rainfall in southwest monsoon (SW), northeast monsoon (NE), winter season (WS), hot weather season (HW), and whole year (WY) from 1990-2023 over Tamil Nadu, India. Fig. 1 shows the seasonal and annual variation of rainfall in Tamil Nadu from 1990-2023. Fig. 1 shows that the occurrence of rainfall in NE monsoon is maxima followed by SW, HW, and WS. In 87.88 % of cases, the rainfall in

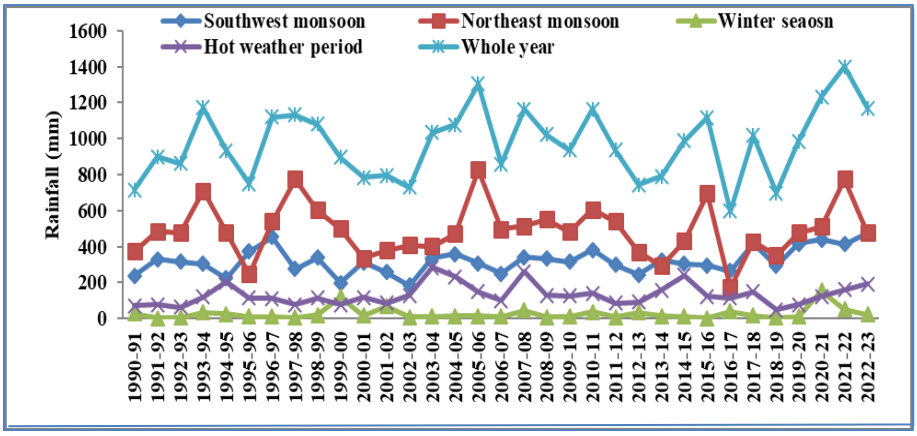
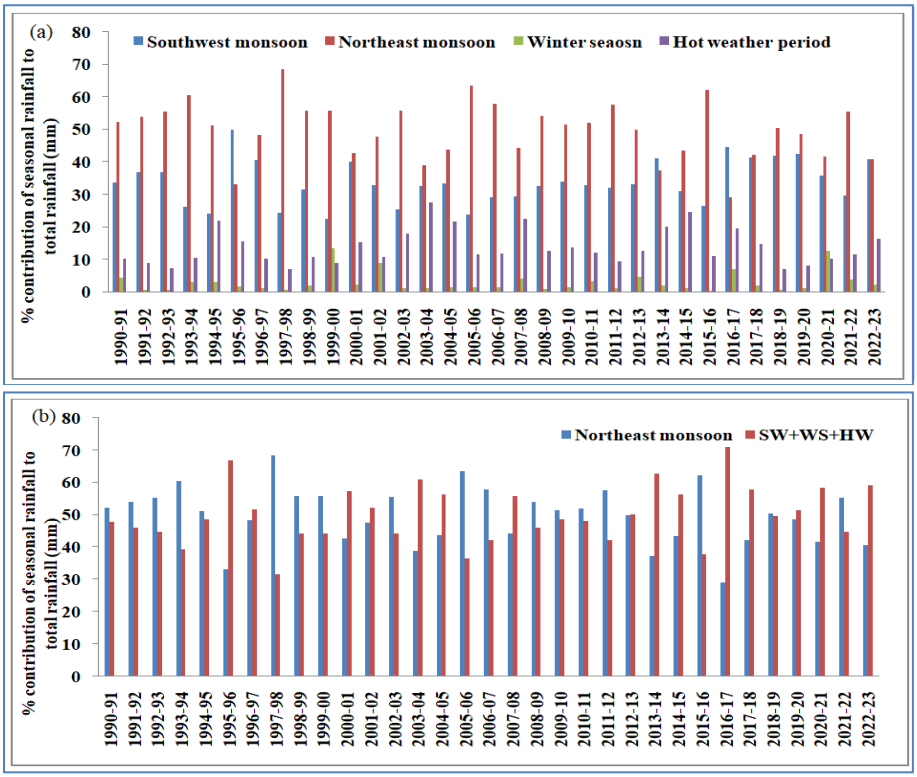


Fig. 1. Annual and seasonal variation of rainfall from 1990-2023 in Tamil Nadu



Figs. 2(a&b). Contribution of rainfall in each season to the total rainfall

NE monsoon is greater than SW, HW, and WS. The upward trend is observed from 1990-2023 in all seasons, except for NE monsoon.

Fig. 2 (a) shows the contribution of rainfall in each season to the total rainfall in a particular year. In every year, the contribution of NE monsoon rainfall is more, except for 1995-96, 2013-14, and 2016-17. The rainfall in the NE and SW monsoons in 2022–2023 differs by 1.5 mm. Furthermore, the analysis shows that NE rainfall contributes little bit more than SW, WS, and HW (Fig. 2 (b)). It is observed from Fig. 2(b) that in 18 years (54.54 %), the NE monsoon rainfall is higher than that at SW+WS+HW, and in 15 years (45.46 %), the latter is greater than former. The long-term average seasonal rainfall from 1990 to 2023 reveals that, in NE, SW, WS, and HW, the percentage of rainfall that contributes to the overall rainfall is 49.84 %, 33.67%, 2.853%, and 13.64% of cases, respectively (Fig. 3). Consequently, the rain-fed agriculture system in Tamil Nadu depends heavily on the NE monsoon. Manivannan (2024) stated that the rain-fed agriculture can be done from August to November because rainfall during these months is favourably correlated with crop yield.

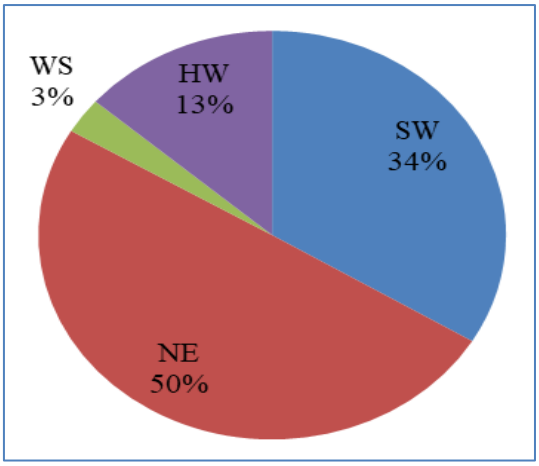


Fig. 3. Long-term average seasonal rainfall for SW, NE, WS, and HW in Tamil Nadu during 1990-2023

TABLE 2(a)

MK and TS test value for time series rainfall and crop production from 1990-2023 in Tamil Nadu

Crop	z-value (MK test)	β-value (TS test)
Food grains	2.33	113451.2
Paddy	0.73	17309.17
Cholam	-1.50	-4699.15
Cumbu	-3.52	-4566.86
Ragi	-1.04	-1614.5
Maize	7.26	95723.65
Total Cereals	2.40	106957.5
Red gram	-1.28	-500.14
Bengal gram	-1.44	-31
Green gram	1.75	621.96
Black gram	2.74	5189.37
Horse gram	-0.23	-89.66
Total Pulses	1.47	5540
Groundnut	-4.19	-24884.7
Gingelly	-3.95	-1028.13
Potato	-1.37	-544.58
Onion	2.74	2678.86
Cotton	-0.92	-1715.69
Rainfall	z-value (MK test)	β-value (TS test)
SW monsoon	1.68	2.99
NE monsoon	-0.07	-0.02
WS season	0.496	0.17
HW season	1.828	1.51
Whole year	1.007	4.45

3.2. Statistical analysis of rainfall and crop production during 1990-2023

Several researchers (Kumar *et al*., 2021; Rao *et al*., 2023; Rangarajan *et al*., 2019; Jain *et al*., 2013) used Mann-Kendall's test for trend analysis. A non - parametric test based on rank termed the MK test is used to find significant trends in time series data (Pingale *et al*., 2016; Suryavanshi *et al*., 2014, Rangarjan *et al*., 2019). Table 2 (a) shows the results of MK and Sen's slope (TS) test for rainfall and crop production. If the value of β is positive (negative) then it indicates an upward (downward) trend. The seasonal and annual rainfall analysis of MK and β shows an upward trend, except for NE monsoon. In the NE monsoon, a downward trend has been seen. The investigation shows that the food grains, paddy, maize, total cereals, green gram, black gram, total pulses, and onion show an upward trend in both MK and TS tests. The author attempted to know how the rainfall trend association with crop production for the entire period. Table 2(b) shows the trend analysis of rainfall and crop production. The finding shows that the rainfall associates well with the following crops production: food grains, paddy, cholam, horse gram, total cereals, black gram, maize, green gram, onion, and total pulses. For these crops, both rainfall and crop production shows upward trend. This implies that as rainfall increases the production of these crops also increases.

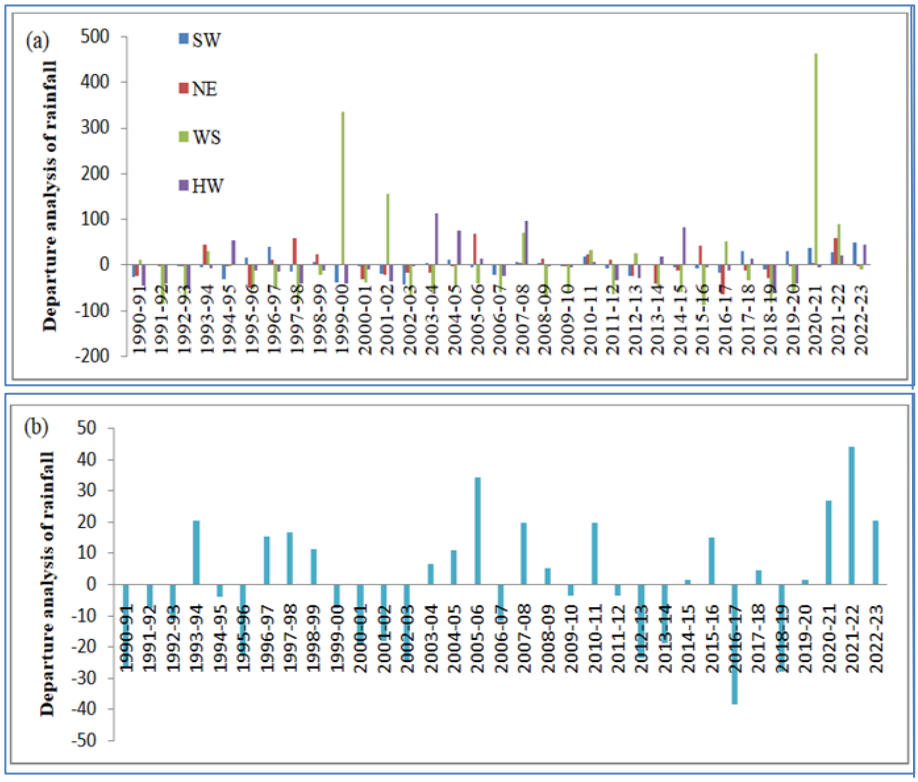
TABLE 2(b)

Trend analysis of rainfall with crop production

Crop	Rainfall	Production
Food grains	I	I
Paddy	I	I
Cholam	I	I
Cumbu	I	D
Ragi	I	D
Maize	I	I
Total Cereals	I	I
Red gram	I	D
Bengal gram	I	D
Green gram	I	I
Black gram	I	I
Horse gram	I	I
Total Pulses	I	I
Groundnut	I	D
Gingelly	I	D
Potato	I	D
Onion	I	I
Cotton	I	D

I: Increasing trend; D: Decreasing trend

Table 3 shows the percentage analysis of seasonal and annual rainfall from 1990 to 2023. The rainfall quantity varies between 400 and 900 mm in 75.75 % and 18.18 % of cases in NE and SW monsoon. In WS and HW seasons the amount of rainfall is less than 200 mm in 100 % and 84.84 % of cases, respectively. The annual rainfall is higher than 500 mm in all years from 1990 - 2023 in Tamil Nadu.



Figs. 4 (a&b). Departure analysis of rainfall (a) seasonal and (b) annual

TABLE 3

Percentage analysis of seasonal and annual rainfall from 1990 to 2023

Rainfall	SW	NE	WS	HW	WY
< 100	-	-	93.93	30.30	-
100 <RF≥200	6.06	3.03	6.06	54.54	-
200 <RF≥400	75.75	21.21	-	15.15	-
400 <RF≥500	18.18	39.39	-	-	-
500 <RF≥600	-	15.15	-	-	3.03
600 <RF≥800	-	18.18	-	-	24.24
800 <RF≥900	-	3.03	-	-	12.12
900 <RF≥1100	-	-	-	-	30.30
1100 <RF≥1300	-	-	-	-	24.24
1300 <RF≥1500	-	-	-	-	6.06

-not available; RF: rainfall; SW: southwest; NE: northeast; WS: winter season; HW: hot weather; WY: whole year

Table 4 shows the departure analysis of seasonal and annual rainfall during 1990-2023, 1990-2000, 2001-2010, and 2011-2023 time series. The number of years with excess, normal, deficit, scanty, and no rainfall categories under seasonal and annual rainfall is shown in Table 4. It shows that there is no scanty and no rain category exhibit during 1990-2010 from March to December. During 2011-2023, the scanty case occurs in 4 years in WS season, and 1 year in HW and NE monsoon. The analysis of whole year (WY) rainfall shows that the excess rainfall occurs in 1, 1, and 3 years in the time series of 1990-2000, 2001-2010, and 2011-2023, respectively. Also, it is to be noted that the rainfall is normal in 7 years during 1990-2000, 8 years during 2001-2010, and 7 years during 2011-2023. Thus in the entire period 1990-2023, the normal rainfall occurs in 22 years. It is to be noted that the excess rainfall occurs in the winter season in 1999-2000, 1993-1994, 2001-2002, 2007-2008, 2010-2011, 2012-2013, 2016-2017, 2020-2021, and 2021-2022, and the maximum deficit in winter season is observed in 2020-2021.

Fig. 4(a-b) shows the departure analysis of seasonal and annual rainfall from 1990-2023, respectively. Fig. 4(a) shows that Tamil Nadu has experienced excess rainfall for 6 years, normal rainfall for 21 years, and deficit rainfall for 6 years in SW monsoon; excess rainfall for 7 years, normal rainfall for 18 years, and deficit rainfall for 7 years in NE monsoon; excess rainfall for 9 years, normal rainfall for 3 years, deficit rainfall for 11 years, and scanty rainfall for 10 years in WS season; and excess rainfall for 7 years, normal rainfall for 15 years, deficit rainfall for 10 years, and scanty rainfall for 1 year in HW season. The analysis of WY rainfall shows that the Tamil Nadu has experienced excess rainfall for 5 years, normal rainfall for 22 years, and deficit rainfall for 6 years

TABLE 4

Departure analysis of rainfall

DAR categories (%)	Rainfall regimes	1990-2023					1990-2000				
		SW	NE	WS	HW	WY	SW	NE	WS	HW	WY
≥20	Excess	6	7	9	7	5	1	3	2	1	1
19 to -19	Normal	21	18	3	15	22	6	5	2	4	7
-20 to -59	Deficit	6	7	11	10	6	3	2	3	5	2
-60 to -99	Scanty	0	1	10	1	0	0	0	3	0	0
≤-100	No rain	0	0	0	0	0	0	0	0	0	0
DAR categories (%)	Rainfall regimes	2001-2010					2011-2023				
		SW	NE	WS	HW	WY	SW	NE	WS	HW	WY
≥20	Excess	0	1	2	3	1	5	3	5	3	3
19 to -19	Normal	8	7	0	5	8	7	6	1	6	7
-20 to -59	Deficit	2	2	5	2	1	1	3	3	3	3
-60 to -99	Scanty	0	0	3	0	0	0	1	4	1	0
≤-100	No rain	0	0	0	0	0	0	0	0	0	0

SW: southwest; NE: northeast; WS: winter season; HW: hot weather; WY: whole year

for the period 1990-2023 (Fig. 4(b)). Fig. 4 (a&b) shows that the maximum deficit is 48.09 % (2022-2023), 68.83 % (2005-2006), and 43.92 % (2021-2022) in SW, NE, and annual rainfall.

3.3. *Variation of crop production, rainfall, and yield from 1990-2023*

In India, agriculture plays a vital role in the country's economy, employing more than 70% of households in rural areas, and it is a vital sector of the Indian economy that accounts for 17% of the country's GDP (Insights 2024; Dhivya *et al.*, 2017; Khan, 2021; Dwivedi, 2014). Tamil Nadu produced 2.35 million tons of maize in 2020. Tamil Nadu's production of maize grew at an average yearly rate of 54.98% (Knoema, 2023). It is anticipated that by 2030, 45 million tons of maize could be produced (DMR, 2024). According to Agricultural Research Data Book 2024 (TNAU, 2024), Tamil Nadu is the third largest state in the production of groundnut during 2021-2022; plantation crops, and coconut in 2022-2023.

Rainfall is the primary source of crop production on agricultural land, particularly on unirrigated land. Generally speaking, the likelihood of negative consequences rises as climate change accelerates. Agronomic research indicates that prolonged temperatures may cause a notable decrease in yield (Geethalakshmi and Deepakaran, 2008). It is anticipated that climate change will negatively impact agriculture, even though certain crops benefit from it in particular regions of the world. The study finds that some crops benefit more than others since rainfall is linked to high yields and productivity. To know the impact of rainfall on crop production, the Spearman Rho correlation (Spearman, 1904) analyses has been done. A study by Muthiah *et al.* (2025) stated that the environmental data is a good fit for the non-parametric Spearman's tests because of its robustness. Table 5 shows

TABLE 5

Spearman Rho correlation test between crop production and rainfall

Crop	Rainfall
Food grains	0.987
Paddy	0.879
Cholam	0.921
Cumbu	0.845
Ragi	0.796
Maize	0.956
Total Cereals	0.832
Red gram	0.802
Bengal gram	0.765
Green gram	0.865
Black gram	0.793
Horse gram	0.924
Total Pulses	0.865
Groundnut	0.912
Gingelly	0.862
Potato	0.914
Onion	-2.54
Cotton	0.735
Sugarcane	-3.548

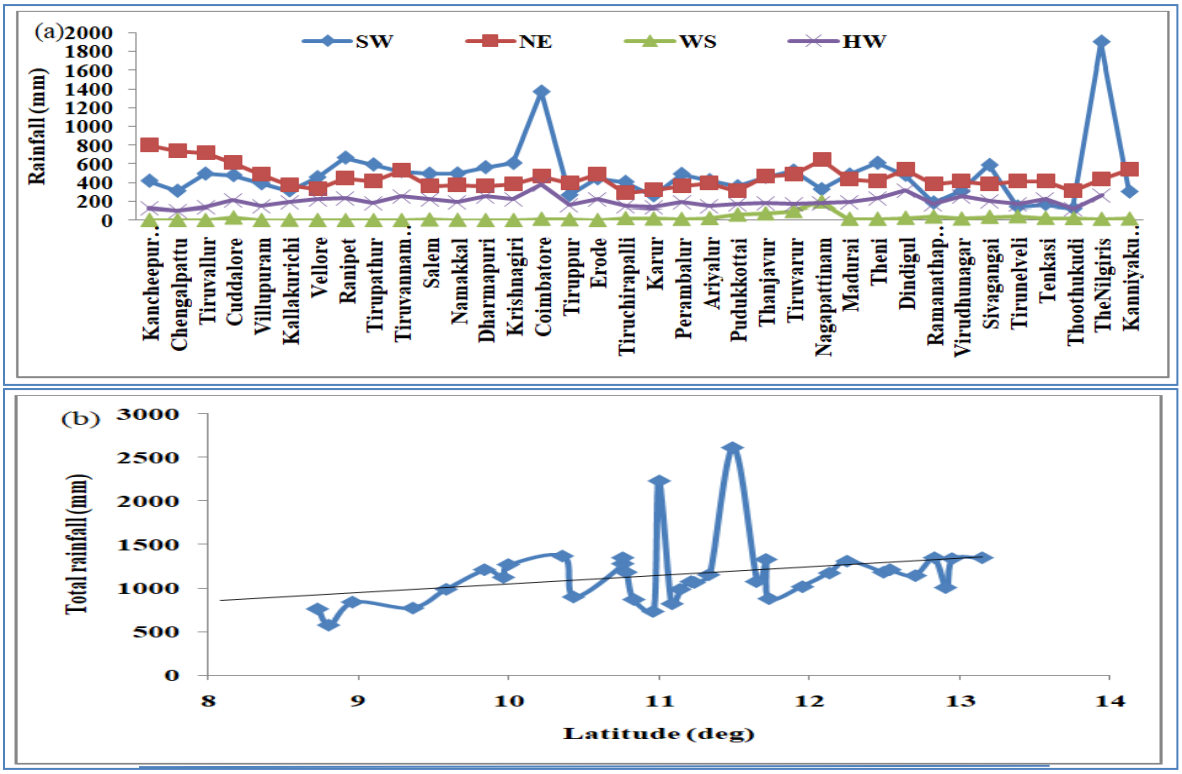
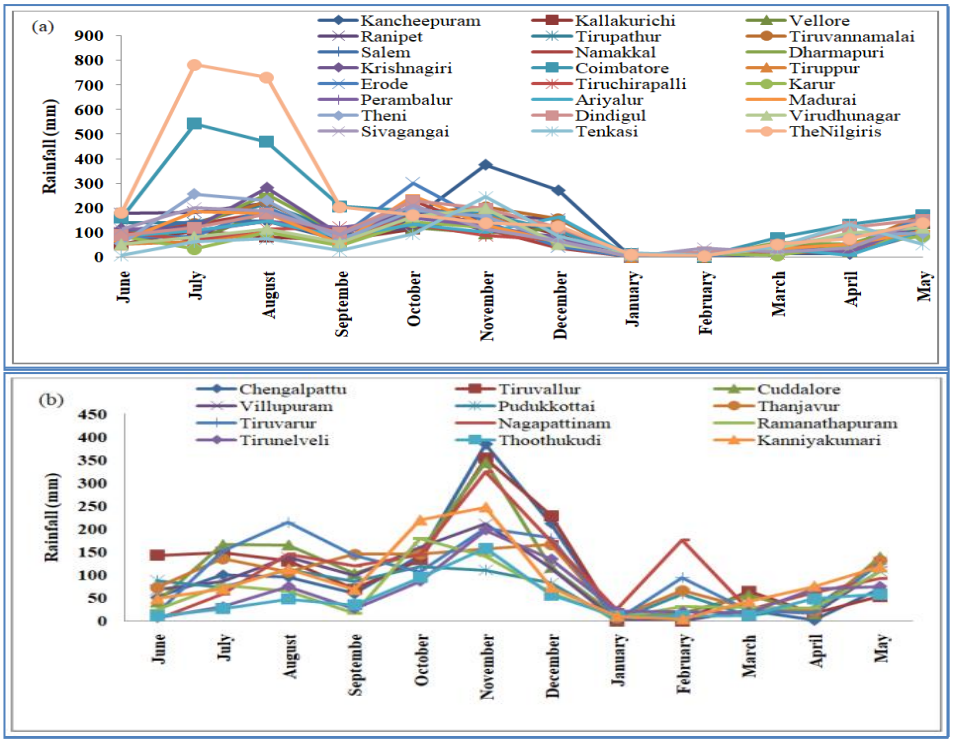


Fig. 5(a&b). (a) Seasonal variation of rainfall in district wise (b) Latitudinal variation of rainfall from June 2022 to May 2023

the statistical Spearman Rho correlation test of all crops with rainfall. The strength and trend of the association between the rainfall and crop production rankings are measured by the Spearman rank correlation coefficient. It can have any value between -1 and 1, and the stronger the link, the closer the coefficient's absolute value is to 1. The absolute positive associations are represented by 1, antagonistic correlations by -1 and zero indicates no association between rainfall and production. The investigation shows that during 1990-2023, the food grains, rice, cholam, horse gram, total cereals, black gram, maize, green gram, total pulses, cumbu, ragi, groundnut, gingelly, Bengal gram, potato, and cotton are positively associated with rainfall. This implies that the rainfall raises the productivity of these crops production and yield. Muthiah *et al.*, (2025) shows that during 2001-2011, the crop production increases with rainfall over few districts in Tamil Nadu. However, it is to be noted from Table 5 that the production of onion and sugarcane shows negative correlation with rainfall thus as rainfall increases, the production of onions and sugarcane declines.

The seasonal variation of rainfall in district wise over Tamil Nadu from June 2022 to May 2023 is shows in Fig. 5 (a). The amount of rainfall during the SW monsoon is significantly larger than the NE monsoon in Coimbatore and the Nilgiris. The investigation shows that with latitude the rainfall in NE and SW monsoon increases, whereas WS and HW period decreases. Fig. 5 (b) shows that the upward trend is seen between the latitude and total rainfall. The total rainfall and the latitude show a positive correlation. The annual rainfall is maxima in The Nilgiris (2613.6 mm) followed by Coimbatore (2231.9 mm) and minima in Thoothukudi (570.1 mm) followed by Karur (734.3 mm) in 2022-2023.

The rainfall variations in Tamil Nadu's land and coastal regions between June 2022 and May 2023 are depicted in Fig. 6(a-b), respectively. The rainfall is more on land than in coastal areas. The districts on land receive more rainfall during the SW monsoon (Fig. 6(a)), while the coastal districts receive more rainfall during the NE monsoon (Fig. 6(b)). Also, land receives more rainfall than coastal areas during the hot weather months of March through May. Among Tamil Nadu's coastal locations, Tiruvarur, Thanjavur, and Pudukottai receive most of the rainfall during the SW monsoon. Coimbatore and Dindigul receive higher rainfall (approximately 370 mm) even during hot weather periods. Rainfall ranged from 308 mm to 739 mm in the NE monsoon and 307 mm to 525 mm in the SW monsoon, except in Thoothukudi (120 mm), Ramanathapuram (182 mm), and Tirunelveli (140 mm). Farmers in coastal areas can start agricultural sowing during this time because there is a probability of substantial rainfall from June to December. It is observed from Fig. 6(b) that from September through December,



Figs. 6(a&b). Variation of rainfall in Tamil Nadu from June 2022 to May 2023 (a) Land and (b) Coast

the rainfall is at peak over Chengalpattu, Thiruvallur, Cuddalore, and Nagapatinam. Over Nagapatinam and Tiruvarur, rainfall occurs in the winter season too.

3.3.1. *Impact of rainfall on crop-planting season*

The analysis shows that there is a strong correlation between the amount of rainfall and the crop-planting season. The analysis indicates that the southwest monsoon is the best time to sow cholam in all of Tamil Nadu's districts. The peak sowing season for cumbu is the NE monsoon in southern coastal sites and the SW monsoon in northern coastal locations. The NE and the SW monsoon, respectively, are the prime gingelly-sowing seasons for coastal and land locations. For most coastal areas, the NE monsoon is the peak sowing season for groundnuts; for land-based places, it is the SW monsoon. With a few exceptions, the peak planting season for ragi, maize, red gram, and cotton indicates the SW monsoon for both land and coastal regions. Thus, on rain-fed agricultural land, planting these crops during that specific season can boost crop productivity and yield.

In rain-fed agricultural land, the production of cumbu, cotton, groundnut, cholam, ragi & gingelly is higher in northern than in southern coastal locations, but the production of maize is higher in southern coastal locations. According to research by Chattopadhyay & Ganesan,1995, the production of gingelly, cumbu, cholam

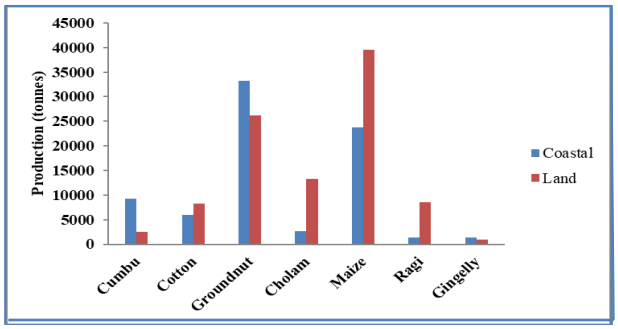


Fig. 7. Variation of crop production in land and coastal regions of Tamil Nadu

& groundnuts was higher in the northern region than in the southern region. Because of rainfall, coastal regions produce more cumbu and gingelly than land areas. Fig. 7 shows the variation in crop production in land and coastal locations. Fig. 7 shows that more maize, ragi, cotton and cholam are produced on land than in coastal areas. Cumbu, cholam, maize & ragi production quantities exhibit more variation in coastal & land locations (Fig. 7).

3.4. *Correlation of crop production and yield with groundwater and rainfall*

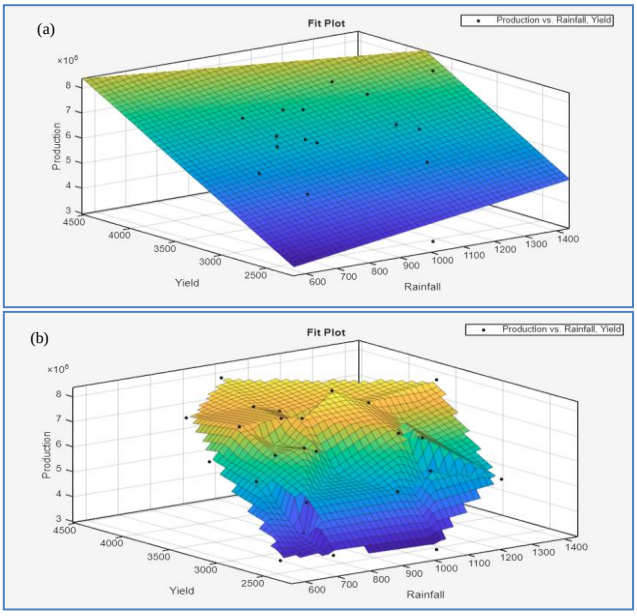
Crop productivity is dependent on both rainfall and groundwater for the agricultural land that is not irrigated and those that are, respectively. To ascertain how crop productivity varied based on irrigation and non - irrigation

TABLE 6

Range of rainfall and groundwater

S. No	Mean annual rainfall (mm)	Districts	Mean annual ground water (m)	Districts
1	< 600	Thoothukudi	< 3	Kancheepuram, Thanjavur, Tiruvarur, Nagapattinam, The Nilgiris
2	600≥RF <800	Karur, Tirunelveli, Ramanathapuram	3≥GW<4	Chengalpattu, Tiruvallur, Cuddalore, Ranipet, Tirupathur, Tiruvannamalai, Krishnagiri, Ariyalur, Sivagangai, Villupuram
3	800≥RF <1000	Tiruppur, Tenkasi, Tiruchirapalli, Kallakurichi, Pudukkottai, Virudhunagar, Ariyalur	4≥GW<5	Kallakuruchi, Vellore, Salem, Erode, Tiruchirapalli, Karur, Pudukottai, Madurai, Ramanathapuram, Thoothukudi
4	1000≥RF <1200	Vellore, Villupuram, Perambalur, Namakkal, Salem, Madurai, Chengalpattu, Erode, Dharmapuri, Thanjavur Tirupathur	5≥GW<6	Dharmapuri, Perambalur, Dindigul, Virudhunagar, Tirunelveli, Tenkasi, Kanniyakumari
5	1200≥RF <1300	Sivagangai, Krishnagiri, Theni, Tiruvarur	6≥GW<7	Namakkal, Tiruppur, Theni
6	1300≥RF <1400	Tiruvannamalai, Cuddalore, Ranipet, Kancheepuram, Nagapattinam, Tiruvallur, Dindigul	>7	Coimbatore (9.7 m)
7	2000≥RF ≤2500	Coimbatore, The Nilgiris	-	-

RF: rainfall; GW: groundwater



Figs. 8(a&b). Polynomial surfaces fit for crop production with rainfall and yield (a) paddy and (b) maize

techniques, the author investigated groundwater. Table 6 shows the mean annual rainfall and groundwater for a location used in this study. While the northern coastal regions have very high mean annual rainfall (>1000 mm), they also have minimal groundwater (<4 m). Rainfall is less than 1000 mm and groundwater is deeper than 4 m in southern coastal regions. Thus, farmers in coastal regions can plant crops depending on rainfall availability in the northern coastal locations and groundwater availability in the southern coastal locations. The mean annual rainfall of Thoothukudi is quite low, but the groundwater is 4.5 m, according to a trend analysis of rainfall and groundwater. Rainfall and groundwater levels remain high in Coimbatore. The seasonal analysis of groundwater and rainfall shows that both are increasing in all the months.

The author is intrigued to know the correlation between crop production and its yield with rainfall and groundwater. For this purpose, at first, the rainfall and the yield are entered as independent parameters, whereas the crop production is a dependent parameter in the linear regression technique. Then, instead of rainfall, groundwater has been entered as an independent parameter to know how the groundwater is associated with crop production. Table 7 shows the correlation of crop production with rainfall and yield. Fig. 8 (a-b) shows the correlation of crop production with rainfall for paddy and maize, respectively. A fair correlation is found between them for all crops except for cumbu, red gram, Bengal gram, and onion. There is no significant correlation between these four crop productions with rainfall. However, the food grains, paddy, maize, total cereals, green gram, black gram, and total pulses show a very good correlation with rainfall. The R-squared varies between 0.7-0.96 for these crops. It is observed from Table 7 that the rainfall shows a negative correlation with the crop production for ragi, horse gram, total pulses, potato, sugarcane, and cotton. The constant and coefficient of rainfall and yield is varying from one crop to another. There is no significant correlation between crop production and groundwater. A quadratic relation has been seen between groundwater and rainfall with 0.56 R-squared.

TABLE 7

Functional relations of production with yield and rainfall

S. No.	Crop	R-squared	Functional relations
1	Food grains	0.896	P=-2430570.15+1340.79RF+3961.67Y
2	Paddy	0.792	P=-2467399.56+1807.4RF+2174.93Y
3	Cholam	0.669	P=-78558.57+13.3RF+430.76Y
4	Cumbu		NC
5	Ragi	0.880	P=135380.9-48.43RF+63.42Y
6	Maize	0.958	P=-719828.61+166.38RF+428.22Y
7	Total Cereals	0.884	P=-1979161.23+1892.37RF+2837.17Y
8	Red gram		NC
9	Bengal gram		NC
10	Green gram	0.791	P=-64368.92+22.9RF+247.2Y
11	Black gram	0.876	P=-111996.1+14RF+505.7Y
12	Horse gram	0.470	P=17141.15-16.1RF+77.33Y
13	Total Pulses	0.941	P=-171049.37-6.5RF+1076.34Y
14	Groundnut	0.801	P=1478434.3+350.4RF-328.55Y
15	Gingelly	NC	
16	Potato	0.533	P=-4601.44-4.76RF+5.23Y
17	Onion		NC
18	Sugarcane	0.545	P=-4342344.12-809.93RF+761.8Y
19	Cotton	0.311	P=113260.04-48.05RF+761.8Y

P: production, RF: rainfall; Y: yield

4. Conclusions

The investigation of time series annual and seasonal rainfall with crop production has been done for the period 1990-2023. Tamil Nadu receives more rainfall in the NE monsoon than in the SW, WS, and HW seasons. There is a strong correlation between the rainfall distribution and the crop-planting season. Because the northeast monsoon brings more rainfall to Tamil Nadu than the southwest monsoon does, the NE monsoon has a stronger effect on the growth of agriculture. The seasonal analysis of groundwater and rainfall shows that both are increasing in all the months. The study reveals that with latitude the rainfall in NE and SW monsoon increases in Tamil Nadu. The rainfall is more on land than in coastal areas, but the coastal districts receive more rainfall during the NE monsoon than that on land. Farmers in coastal areas can start agricultural sowing during this time because there is a probability of substantial rainfall in the NE monsoon.

Rainfall and crop productivity are positively correlated. Land areas yield less gingelly and cumbu than coastal regions do due to rainfall. Based on the data, the optimal period to seed cholam in all districts of Tamil Nadu is during the southwest monsoon. Coastal farmers can plant crops based on the availability of rainfall in the northern coastal regions and groundwater in the southern coastal regions. Thus, in rain-fed agricultural land, planting these crops in that particular season can thereby increase crop productivity and yield.

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Data Availability

Available on request basis

Authors' Contributions

Dr. K. Thirumala Lakshmi contributed to the study's conception & design, performed material preparation, data collection, analysis & wrote the manuscript. Conceptualization, Methodology, Execution of calculations, plotting of graphs, preparing Tables, Formal analysis and investigation, Writing - original draft preparation, review and editing: *(e-mail: lakshminho@gmail.com).*

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