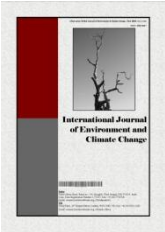

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Drought Analysis in Southern Agroclimatic Zone of Tamil Nadu using Standardized Precipitation Index

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Drought differs from other natural hazards in the fact that the initiation and the termination is extremely difficult to determine and that its drastic effects continue to persist well after the cessation of the event which adds to the complexity as well as the casualties. The Southern Agro Climatic Zone (ACZ) of Tamil Nadu is heavily rain shadowed during the South West Monsoon Season, several complications arise with respect to drought, causing crop failures and depleted moisture concentration in certain cases. With that idea in perspective, a study was conducted in Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore, India to study the frequency of drought over the Southern Agro-Climatic Zone of Tamil Nadu, India. Since precipitation that occurs over a region determines mainly the occurrence and cessation of drought events, precipitation-based Rainfall Deviation and Standardized Precipitation Index (SPI) was used to quantify the extent of rainfall deficit or surplus over the region. The analysis of 30 years (1991 – 2020) historical rainfall data of various districts of the Southern Agroclimatic Zone of Tamil Nadu using SPI showed that the annual SPI value ranged from +3.3 to -4. The study showed that Tirunelveli and Thoothukudi districts were most prone to moderate drought and severe drought. The region showed more frequency of Moderate drought than Severe and Extreme drought.

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Keywords: Drought; standardized precipitation index; rainfall deviation; southern agro-climatic zone.

1. INTRODUCTION

Drought is the recurring periods of relatively long durations of abnormally dry weather conditions that leads to moisture deficit in the atmosphere and ultimately influences the lithosphere and the biosphere [1,2]. It is an extreme event where in water scarcity and global warming have a negative influence on crop growth and grain yield [3]. Drought is the most crucial yet least understood natural hazard [4,2]. Drought occurs more frequently in the semi-arid and arid areas. In recent decades, India has had frequent and severe droughts (once every three years) [5]. The frequency and intensity of drought is expected to increase especially during 2020 to 2050 [6]. Drought risk in India is rising due to an increase in total dry days, longer dry periods, and fewer light precipitation days. According to a quantitative study of data, India is experiencing a 49 percent rise in lengthy dry periods and a 33 percent increase in overall dry days [7]. Between 1950 and 1990, there were ten drought years. Six drought years have occurred since 2000: 2002, 2004, 2009, 2014, 2015, and 2016. At the moment, the drought in India has grown very severe that Cherrapunji, one of the world's highest rainfall places in the north east of India, with over 11,000 mm of rainfall, is considered to be in a drought for nearly nine months of the year [8]. Drought hit 330 million people in India in 2016, affecting ten states following two years of poor monsoons [9]. Since a majority of the Indian agriculture largely depends on the monsoon season, this sector is indeed the first to be influenced by drought. Besides agriculture, droughts also effect other sectors including the tourism, environment, health, marketing and ultimately the economy of the country. It brings forth various complications ranging from food crisis, various health risks, social conflicts and in the worst-case scenario, compels the farmers to commit suicide [10].

Drought is further classified into different categories: i) Meteorological Drought ii) Hydrological Drought iii) Agricultural Drought and iv) Socio-Economic Drought [11]. Drought differs from other natural hazards in the fact that it is a slowly creeping phenomenon. The effects of drought accumulate for a considerable period of time and the effects may persist for a long time after the cessation of the event. The initiation and the termination of the drought event is difficult to determine [12,13]. Droughts usually affect agriculture first, as soil moisture levels quickly decline. In the presence of high temperatures and heavy winds, the process is accelerated [2]. Proper monitoring and assessment of drought events especially in those regions with highly vulnerable areas need to be undertaken so as to reduce the losses and damages. As a result, a greater understanding of drought climatology and the establishment of a coherent and holistic drought surveillance approach that combines climate, soil, and water supply aspects are crucial [2,14,15]. It is important to examine agricultural drought and its possible consequences on food supply in sensitive parts, particularly in drought-prone areas. Agricultural droughts' effects on food supplies may be measured, allowing governments to make more sustainable policies. It needs a comprehensive assessment of the links between spatiotemporal drought variations, farming systems, irrigation impacts, and the available water resources [16]. Drought-prone locations have a wide multitude of issues in terms of intensity, spatial and temporal scales. As a result, drought risk assessment is required to deal with this terrible drought, which has a significant impact on society. Because they simplify complicated inter-relationships between various climatic factors, drought indices are among the most significant instruments for monitoring and assessing drought [17]. Guhathakurta [18] evaluated the risk of district-wide droughts across India using PNP from the southwest monsoon season (June to September) for 424 districts over 14 years (1988–2001) and found the highest chance (>60 percent) in various districts in northern India.

Drought indices have been devised by meteorologists and agriculturalists to accurately match the climatology of certain parts of the world in order to gauge the current type and extent of drought and to monitor drought risks across a particular region on a routine basis [19]. Several studies related to drought with the help of various drought indices have been conducted by many researchers in India. Since the majority of the Indian Peninsula receives its rainfall during the South West Monsoon, majority of the studies have used precipitation-based indices like Percent Normal Precipitation, Standardized Precipitation Index, Enhanced Drought Index and Palmer Drought Severity Index. [14,20-22]. Drought-prone areas and persistently drought-affected areas were defined by [23], who discovered that the majority of the drought-prone areas were in dry or semiarid regions, where droughts occur frequently. During the monsoon season in India, categories based on rainfall deviations were utilized to monitor and evaluate patterns of precipitation across the country [24]. The main driver of drought is precipitation [25,26]. Thus, Precipitation based standardized precipitation index (SPI) has been used intensively for the quantification and assessment of drought [1,20,22,24,25,27]. Standardized Precipitation Index has been recommended by WMO as the standard meteorological drought index [24]. Rainfall pattern of 100 years (1918 to 2017) was analyzed by [28] wherein the rainfall pattern of Coimbatore district of Tamil Nadu was studied and the spatio-temporal pattern of drought was analysed using SPI. SPI is used to quantify the extent of rainfall excess or deficit over a certain time-scales which may range from 1-month time-scale to several years [26]. SPI has been used to assess drought events over time in various countries [27,29,30-32]. With this in perspective, this study was conducted with the objective of assessing the spatial and temporal extent of drought in the Southern Agro-Climatic Zone (ACZ) of Tamil Nadu (TN), India using SPI.

2. MATERIALS AND METHODS

2.1 Study Area

The Southern Agroclimatic zone of Tamil Nadu is geographically located between 8°9' and 10°50' North Latitude and 77°10' and 79°25' East Latitude. The area extends from the high mountain regions in the west up to the coastal regions in the East. This area of Tamil Nadu lies under the rain shadow region. The elevation varies from the mean sea level at the eastern coast and up to 300m in the hilly region. The mean annual rainfall in the region is about 857mm. The major crops grown in the region include Rice, Maize, Cucumber, Sorghum, Ragi, Black Gram, Green Gram, Groundnut, Fodder Crops, Gingelly, Castor, Cotton, Chillies, Banana, Jasmine, Coriander, Onion, Lime, Cashew and Amla. The study area map is depicted in Fig. 1.

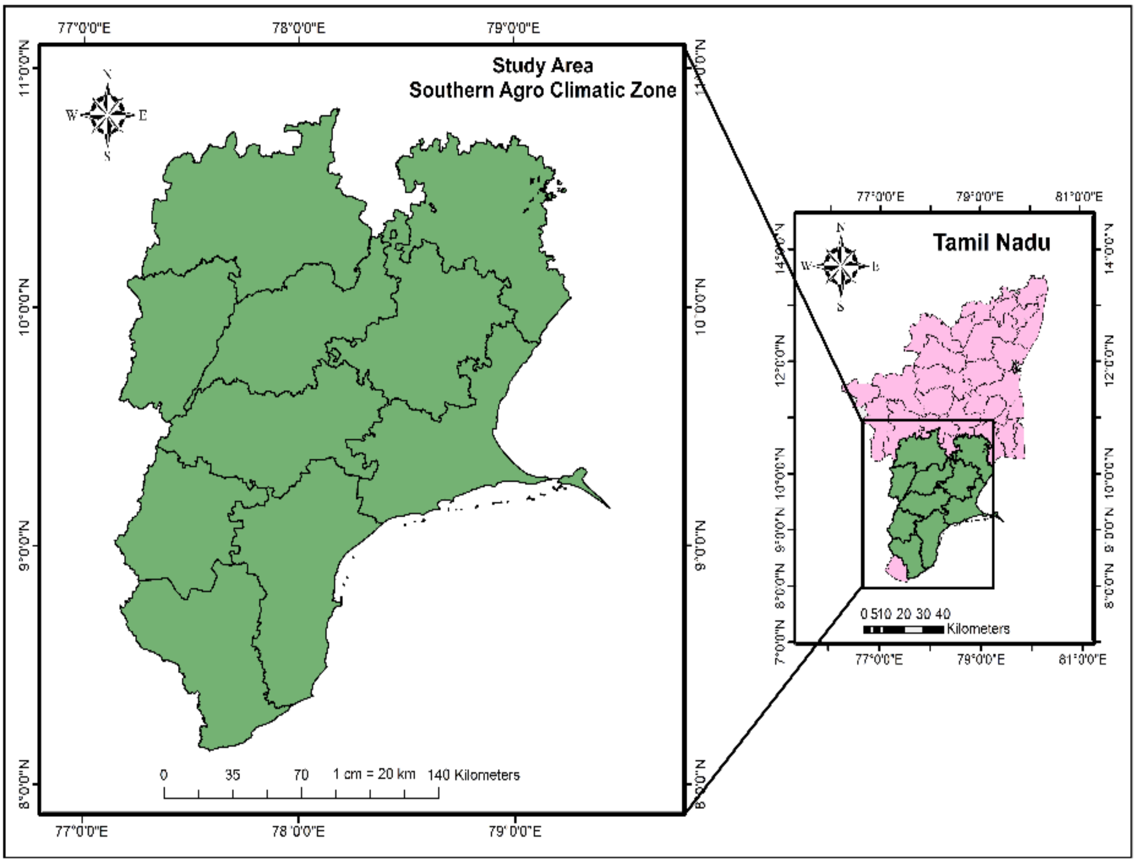

Fig. 1. Study area showing the southern agro climatic zone of Tamil Nadu, India

2.2 Data

The district-wise historical rainfall data from 1991-2020 (30 Years) was collected from the respective research stations under Tamil Nadu Agricultural University located within the study area viz., Madurai, Thirunelveli, Thoothukudi, Virudhunagar, and Theni. Additional data for districts viz., Dindigul, Pudukkottai, Tenkasi, Ramanathapuram and Sivagangai and for those districts where the long-term historical data was insufficient were obtained from India Meteorological Department, Pune.

The rainfall data was further classified into various seasonal periods in order to have a better perspective *viz.,* Cold Weather Period (CWP) which lies between January to February, Hot Weather Period (HWP) from March to May. South West Monsoon (SWM) from June to September and Northeast Monsoon (NEM) starting from October to December.

2.3 Methodology

Rainfall deviation from the normal rainfall for the study area was computed as below:

Rainfall Deviation = [(Actual Rainfall-Normal Rainfall) / Normal Rainfall] ×100

The Rainfall deviation of less than -20 per cent is considered as a drought condition (IMD, Pune). The classification of rainfall deviation as given by the India Meteorological Department; Pune is given on table 1. The minimum value of the rainfall deviation is -100 per cent, which indicates that there was no rain, and the highest value is undefinable. The rainfall deviation is 100 per cent if the actual rainfall is twice the rate of the normal rainfall, 200 percent if the actual rainfall is thrice the quantity of normal rainfall, and so on [26].

Table 1. Categories of Rainfall Deviations (IMD)

Deviation from Normal Rainfall	Category
≥+19	Excess
+10.1 to +19	Above Normal
-10 to +10	Normal
-10.1 to -19	Below Normal
≤-20	Deficit

Standardized Precipitation Index (SPI) was formulated by [33]. This index was proposed to quantify the deficit as well as the surplus of the precipitation on varying time scales. Eg. 1, 3, 6, 12, 24 and 48-month time-scales. The time-scales show how the precipitation for a certain period compares to the entire record, perhaps 30 or 50 or 100 years, for a given station [34]. SPI over various time scales, such as 1- or 3-month SPI of a certain month, reflects variance in precipitation totals for that month and the preceding two months, respectively. As a result, SPI values are reported in standard deviations, with a positive number indicating above-average precipitation and a negative value indicating below-average precipitation [35]. It is important to remember that when evaluating the SPI data, the "wetness" or "dryness" is measured relative to historical averages instead of the absolute sum of precipitation for the given region [25].

Table 2. Classification of Standard Precipitation Index (SPI) values and the corresponding drought intensities [33]

SPI Value	Intensity
≥ 2.00	Extremely wet
1.99 to 1.50	Very Wet
1.49 to 1.00	Moderately Wet
-0.99 to 0.99	Near Normal
-1 to -1.49	Moderate drought
-1.50 to -1.99	Severe drought
≤ -2.00	Extreme drought

The 3-month SPI was calculated from the 30 years (1991-2020) historical datasets using the SPEI package in R Studio [36]. The criteria as defined by [33] to determine the drought events and the classification of SPI for defining drought intensities at various time-scaled was used for interpretation and is given in Table 2.

3. RESULTS AND DISCUSSION

3.1 Drought Analysis Based on Rainfall Deviation

The analysis done based on the past 30 years (1991-2020) rainfall deviation for the constituent districts in the Southern Agroclimatic Zone is shown in Figs. 2 and 3. The study revealed that among all the districts within the study area, Thoothukudi district have the highest extreme rainfall deficit years where there are 15 years under drought years within 30 years. This is followed by Tirunelveli and Virudhunagar at 12 years under drought out of 30 years. Similar findings have been made regarding the rainfall variability analysis [14]. An intriguing result obtained was that despite Thoothukudi district despite having the highest average rainfall among the districts (1057.9mm) shows the highest frequency of deficit years (15 years), and also shows the greatest number of excess rainfall events with 12 years as excess. This is so because the district shows a decreasing trend in the annual total rainfall since 2001 with a brief excess in 2011-12. Pudukkottai district also shows a decreasing trend in the annual total rainfall. This raises a concern because of the fact that since the rainfall pattern of these regions shows a declining trend, the rainfall normal will get affected which in turn may put additional risks to various sectors including agriculture.

3.2 Drought Frequency and Intensity Analysis from Standardized Precipitation Index

The frequency of drought along with the intensity based on the 3 Month Standardized Precipitation Index (SPI) was determined. The criteria developed by [33] was used to classify the intensity of drought. The annual and seasonal drought frequency of the districts under the Southern Agro-Climatic Zone of Tamil Nadu are

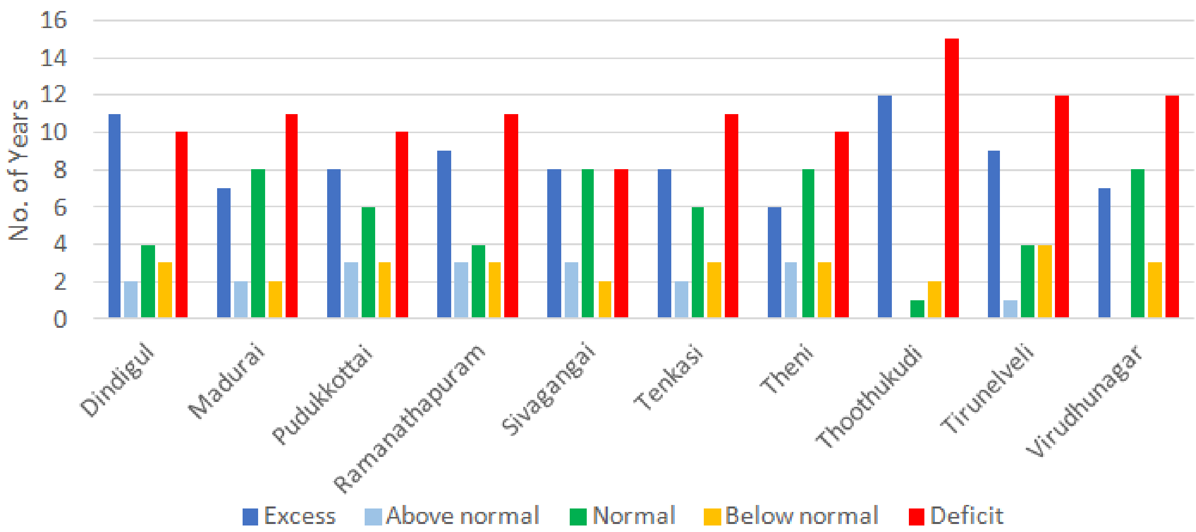

Fig 2. Rainfall Deviation of Southern Agroclimatic Zone of Tamil Nadu

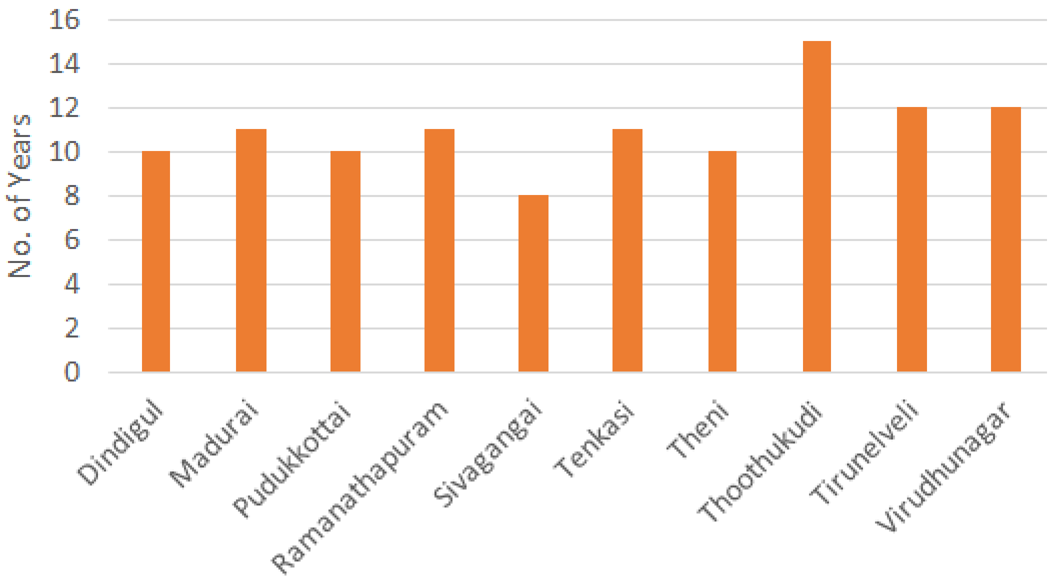

Fig 3. Frequency of drought years in Southern Agroclimatic Zone as per Rainfall Deviation

Table 3. Drought frequency based on 3 month SPI values

Drought	Dindigul	Madurai	Pudukkottai	Ramanathapuram	Sivangai	Tenkasi	Theni	Thoothukudi	Tirunelveli	Virudhunagar
Moderate Drought										
Annual	15	15	14	12	15	13	13	16	17	14
SWM	4	8	4	3	7	5	3	8	3	7
NEM	6	6	5	4	3	8	7	2	6	8
Severe Drought										
Annual	5	8	5	5	6	6	8	15	5	10
SWM	3	3	3	4	2	1	3	4	3	3
NEM	0	2	0	2	3	3	4	2	3	3
Extreme Drought										
Annual	5	3	5	4	4	4	5	5	5	2
SWM	1	1	3	0	1	0	2	1	1	1
NEM	3	2	3	2	2	2	3	4	3	2

Table 4. Annual and seasonal 3 Month SPI ranges

Districts	Annual		SWM		NEM	
	Max	**Min**	**Max**	**Min**	**Max**	**Min**
Dindigul	2.6	-3.5	2.6	-2.1	2.1	-3.5
Madurai	3.1	-3.8	3.1	-2.6	2.1	-3.8
Pudukkottai	2.6	-3.6	2.6	-3.4	1.5	-3.6
Ramanathapuram	2.5	-2.6	2.5	-1.9	1.7	-2.6
Sivangangai	2.9	-3	2.9	-2.2	1.9	-2.9
Tenkasi	2.7	-2.5	2.7	-1.6	1.9	-2.3
Theni	2.7	-2.9	1.7	-2.6	2.1	-2.6
Thoothukudi	2.4	-3.3	2.5	-2	2.2	-2.5
Tirunelveli	2.5	-2.8	2.7	-2.6	1.9	-2.8
Virudhunagar	2.9	-3.1	2.9	-2.1	2	-2.2

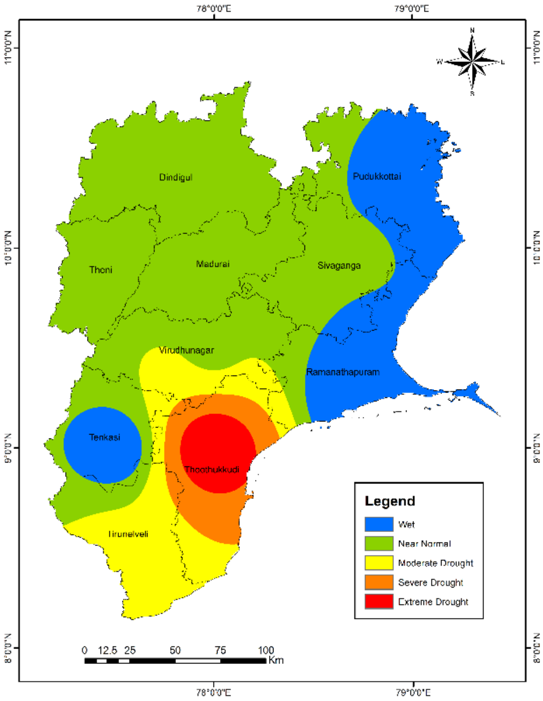

Fig. 4. Spatial distribution of drought based on 3-month SPI

on Table 3 and the annual and the Seasonal 3-Month SPI ranges are given on Table 4.

The assessment of 3-month SPI over the southern agroclimatic zone of Tamil Nadu showed that the study area was prone to moderate droughts with Tirunelveli and Thoothukudi having the highest frequency at 17 years and 16 years respectively on an annual time scale while Ramanathapuram district recorded the lowest occurrence (12 years). On a seasonal scale, Thoothukudi and Madurai showed the highest frequency during the SWM, while Tenkasi and Virudhunagar showed the highest frequency during NEM. Severe drought had the highest frequency in Thoothukudi (15 years) and Virudhunagar (10 years) while other districts showed comparatively low frequency. Extreme drought intensity had the least occurrence in the study area. The region showed a significant variation of both extreme wet and dry periods in both the seasonal and annual comparison (Table 4). Both extreme wet and severe drought conditions were observed during both the NEM and SWM.

The rainfall deviation analysis showed a highest deficit in the district of Thoothukudi which is followed by Virudhunagar and Tirunelveli. The annual 3-months SPI analysis revealed that the southern agroclimatic zone is more prone to moderate droughts especially in the districts of Tirunelveli and Thoothukudi. Thus, the SPI and rainfall deviation from the mean shows the same observation which signifies a strong inter-relationship between these two parameters. Previous studies also reported a similar observation for the variability of monsoons across the study area [17,37]. The seasonal SPI also showed a comparatively higher drought events during the North East Monsoon.

4. CONCLUSION

The 3-month SPI analysis provides an in-depth perspective of the monsoon seasons of the Southern Zone of Tamil Nadu. It gave a brief information about the occurrence and variation of both wet and drought conditions which helps in planning and development of different agricultural activities. The study region has faced drought conditions during 2002-2003 and again in 2016-17 and shows a distinct variation in the spatial extent of drought across the region. The temporal analysis of drought showed some intriguing outputs regarding the incidence of drought conditions over the regions studied. Thus, it can be concluded that Standardized Precipitation Index and rainfall can be a useful tool to assess drought conditions over a region. SPI alone can be quite limiting as it relied on the observation data which can be scarce and may not be readily available to portray the spatial extent of drought. Hence, remote sensing-based assessment of drought using various vegetative indices may be done so as to obtain more information about the spatio-temporal extent of drought and to formulate effective counter-measures to tackle the adverse effects of drought.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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