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RESEARCH ARTICLE

Agricultural drought propagation across major sorghum growing districts in Tamil Nadu, India

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Abstract

Quantifying the response time between meteorological and agricultural drought is vital to understanding the drought evolution and to improve monitoring. The present investigation used the % of normal precipitation and the soil moisture deficit index at a weekly scale to know spatial variations in the frequency of meteorological and agricultural drought and propagation time between these droughts in major sorghum growing districts of Tamil Nadu state. Results showed that the frequency of extreme meteorological drought was 34-68 % and 40-55 % in the first and second sorghum growing seasons, respectively. However, moderate and severe dry conditions occurred for 1-2 weeks in both seasons. In case of agricultural drought, the highest moderate drought frequency (50 %) was noticed in Ramanathapuram and Thoothukudi districts during the first season and in Coimbatore and Thoothukudi districts in the second season. The shortest drought response time of 4-5 weeks was seen in western, southern and central parts of the state, while north-western and north-eastern districts showed the longest response time of 17-18 weeks. The shorter transition time in western, southern and central regions could be attributed to low seasonal rainfall, higher frequency of extreme dry conditions during the first growing season and the presence of fine textured black and brown soils with shallow rooting depth These districts require careful planning and quick interventions to curtail the agricultural drought impact, as regional and global climatic models projected a rise in occurrence and severity of drought events in the coming yr.

Keywords: drought transition time; percent normal of precipitation; soil moisture deficit index; Pearson correlation; sorghum; Tamil Nadu

Introduction

Prolonged dry spells lead to drought conditions and the occurrence of drought is common in all climates, though it is more prevalent in arid, semi-arid and dry sub-humid climates. Drought is regarded as a slow, creeping phenomenon and indeed, it is very difficult to find its start and end point. It is estimated that around 550 lakhs people are being affected every year by drought impact across the world, affecting crops and livestock (1). The frequent drought-prone arid and semi-arid regions of India cover around 53 % of the land cover and make it one of the most vulnerable countries in the world to drought (2). It was estimated annual loss to the Indian agriculture sector will be around seven billion US dollars by 2030 (3). Similarly, research indicates drought is the expensive natural hazard that begins with a precipitation deficit that propagates through the water cycle, which affects natural ecosystems, including activities of mankind (4).

Meteorological drought is the precursor for agricultural, hydrological and socioeconomic droughts. A dearth of precipitation than the normal in a particular region leads to meteorological drought, while agricultural drought starts when soil moisture stress develops and reaches a certain threshold level, which in turn impacts the crop production. Even though there is a close relation between meteorological and agricultural drought, crop plants show a response to soil moisture deficit straight away rather than to deficit precipitation. There is a time lag for the conversion of meteorological to agricultural drought and this period is regarded as drought propagation, which was first used by (5). Across the globe, numerous studies were conducted to understand the mechanisms involved, spatial and temporal characteristics and factors affecting the propagation from meteorological to hydrological drought (6-8). Studies to find the response of agricultural drought to meteorological drought have been taken up in the recent past in many parts of the world and in India (9-13). However, most of the studies are carried out using indices at a monthly time scale and at a wider spatial scale, like an agro-climatic region. The importance of employing drought indices at a sub-monthly time scale (10 days/week) was emphasised for illustrating the agricultural drought within the crop growing period of 3-5 months and to find response time between meteorological and agricultural drought (14-15).

Tamil Nadu is one of the major agrarian states located in the south-eastern part of India, contributing 8. 9 % to the Gross Domestic Product of India (16). Sorghum is one of the major cereal crops cultivated in Tamil Nadu state and according to area and production data (2017-18 to 2021-22) of Ministry of Agriculture and Farmers' Welfare, Government of India, this state ranks fourth in terms of area (covering 8 % country's area) and production (sharing 9 % production at national level). Though sorghum is tolerant to soil moisture stress and high temperatures when compared to other cereals like maize, rice and wheat, it is also vulnerable to long dry spells. Tamil Nadu state is receiving a considerable amount of rainfall from both the southwest (June-Sept) and northeast monsoon (Oct-Dec) seasons, but is also vulnerable to many natural calamities, especially drought. For instance, a study revealed that drought has occurred once in four year in Tamil Nadu and its occurrence in consecutive year led to a severe impact on crop production and the livelihood of the farmers of the state (17). Studies were conducted to find the frequency and intensity of meteorological drought over the Tamil Nadu region using monthly drought indices (18-20). However, it is understood that studies that quantify the time lag from meteorological to agricultural drought at finer temporal resolution (weekly time scale) and spatial resolution (25 km) are rare and would aid in better drought monitoring and in reducing crop loss due to agricultural drought. Keeping the recurrent nature of drought and its ill effects on agricultural production in view, understanding the transition nature of meteorological drought to agricultural drought at finer spatial and temporal scales is important for developing strategies to reduce the drought impact. Therefore, the present investigation aims to find spatial variations in meteorological and agricultural drought frequency and to quantify the transition time between them over the major sorghum growing districts of Tamil Nadu state.

Materials and Methods

Study area

Tamil Nadu state, located in the south-eastern part of India is extends over 1. 3 lakh sq. km, which falls under the tropical climate (Fig. 1). The state's weather is influenced by the Western Ghats during the southwest monsoon period as well as by the Bay of Bengal during the northeast monsoon. Though there is spatial variation in seasonal rainfall over different districts, the state is receiving rainfall mainly from the northeast monsoon (around 48 %) while the southwest monsoon contributes 36 % of the annual rainfall (21). Abnormal situations like late onset of monsoon, extended period of dry spell during crop growing season, extreme weather events and early withdrawal of monsoon rains heavily impact the agriculture and allied sectors in the state.

Precipitation data

The daily gridded rainfall data (0.25° × 0.25°) provided by the India Meteorological Department was used to work out meteorological drought (22). The daily rainfall data was extracted for the major sorghum growing districts of Tamil Nadu for the period of 34 year (1991-2024) and was converted into to weekly format.

Soil moisture data

Soil moisture data for three layers *viz*., layer 1 (up to 7 cm), layer 2 (up to 28 cm) and layer 3 (up to 100 cm) for a period 1991-2024 were retrieved from the fifth-generation ERA5 Land reanalysis dataset (0. 25° × 0. 25°) available at The Copernicus Climate Change Service portal maintained by the European Centre for Medium-Range Weather Forecasts. Under a rainfed situation, crop plants' production capability is determined mainly by characteristics of roots that absorb soil moisture at a deeper layer during dry spells (23). CERES-Sorghum crop simulation results revealed that the ideal root depth for rainfed sorghum was 110-140 cm, while another study indicated a positive relation between photosynthetic rate and root length (up to 90 cm) of rainfed sorghum crop (24, 25). Therefore, in the present study, soil moisture till the third layer (up to 100 cm) was considered, assuming root length up to this depth could provide sufficient soil moisture. The total root zone soil moisture was calculated by adding the first three layers (up to 100 cm) data and then the daily soil moisture data was converted into weekly (26).

$$\text{Root zone soil moisture (RZSM)} = \sum_{i=1}^{3} (Di \ x \ \theta i) \qquad \text{(Eqn. 1)}$$

where, Di denotes D1 = 7 cm, D_2= 21 cm and D_3 = 72 and θ_i refers to volumetric soil moisture content (m^3/m^3).

Efficient sorghum growing districts

District-wise area, production and yield data of sorghum for the latest ten-year period (2014-2023) were collected from the Season and Crop Report published by the Department of Economics and Statistics, Government of Tamil Nadu, India (27). Time series data on sorghum area and productivity in different districts showed inter-annual variation and it is not appropriate to consider all the districts, especially districts with insignificant area and yield. Hence, an approach of efficient cropping zones was followed (28). Accordingly, the Relative spread index (RSI) and Relative yield index (RYI) were worked out using the formula given below.

$$\text{RSI} = \frac{\text{Area of the crop expressed as \% of the total}}{\text{Area of the crop expressed as \% of the total}} \times 100 \qquad \text{(Eqn. 2)}$$

$$\text{RYI} = \frac{\text{Mean yield of a particular crop in the district (kg/ha)}}{\text{Mean yield of a particular crop in the state (kg/ha)}} \times 100 \qquad \text{(Eqn. 3)}$$

Based on the RSI and RYI values, *i. e.* higher or lower than 100 %, districts were classified into the most efficient (both RSI and RYI are high), area efficient (RSI is high while RYI is low), yield efficient (RYI is high while RSI is low) and not efficient districts (both RSI and RYI are low). Accordingly, districts with the most efficient, area efficient and yield efficient were only considered for the analysis (Fig. 1). The duration of the sorghum varieties cultivated in this region is around 120 days. It is understood from the Season and Crop report statistics that sorghum is cultivated in two seasons, *i. e.* July to October and September to December, with peak sowing in July and September, respectively. Accordingly, the first season was considered from 27th to 44th standard meteorological week, with 27th week as sowing week and the second season from 35th to 52nd week, with 35th week as sowing week. Therefore, in the present study, spatial variations in rainfall, meteorological and agricultural drought occurrence and drought propagation time were carried out for these two sorghums growing seasons.

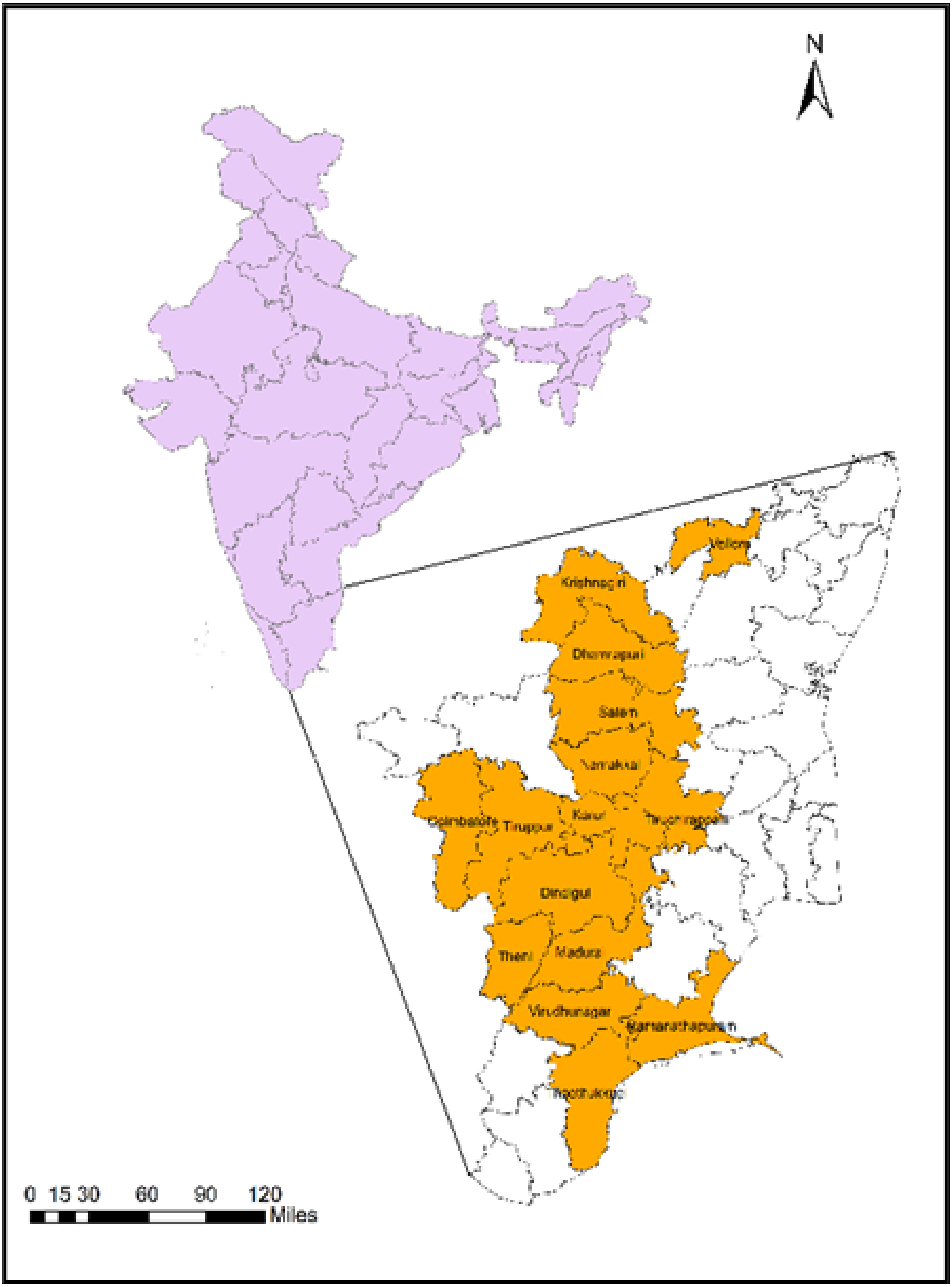


Fig. 1. Study area showing major sorghum growing districts of Tamil Nadu.

Computing drought indices and quantification of drought propagation time

Meteorological drought was characterised by Percent of Normal Precipitation (PNP) and was calculated by dividing the actual weekly rainfall by the long-term average rainfall for the corresponding week and expressed as a percentage. The drought severity classification is furnished in Table 1.

$$PNP_{i,j} = \frac{P_{i,j}}{\text{Average } P_i} \times 100 \qquad \text{(Eqn. 4)}$$

Where, PNP_{ij} = PNP for the i^{th} week and j^{th} yr; P_{ij} = Precipitation for the i^{th} week and j^{th} yr; Average P_i = Average Precipitation for the i^{th} week.

PNP requires rainfall data only and can be worked out quickly at different timescales according to the requirement for monitoring droughts (29). Meteorological drought was evaluated based on the Percent Normal of Index in Kermanshah Township, Iran, while PNP at a weekly scale was employed to study the spatio-temporal variation of meteorological drought and for drought propagation research over the Mekong River Basin (30, 31).

Soil Moisture Deficit Index (SMDI) was employed to characterise the agricultural drought (32) and computed using weekly soil moisture data based on the equation furnished below.

Soil water deficit $SD_{i,j}$ (%) =

$$\frac{SW_{i,j} - MSW_j}{MSW_j - \text{Min}(SW_j)} \times 100, \text{ if } SW_{i,j} < MSW_j \qquad \text{(Eqn. 5)}$$

Soil water deficit $SD_{i,j}$ (%) =

$$\frac{SW_{i,j} - MSW_j}{\text{Max}(SW_j) - MSW_j} \times 100, \text{ if } SW_{i,j} \geq MSW_j \qquad \text{(Eqn. 6)}$$

$$SMDI_1 = \frac{SD_1}{50} \qquad \text{(Eqn. 7)}$$

$$SMDI_j = 0.5 \times SMDI_{j-1} + \frac{SD_1}{50} \qquad \text{(Eqn. 8)}$$

Where, SD = Soil water deficit (%); SW_{ij} = Average weekly soil moisture (mm); MSW_j, $MaxSW_j$, $MinSW_j$ = Median, maximum, minimum weekly soil moisture (mm), respectively. Agricultural drought severity classification is furnished in Table 1.

Transition time from meteorological drought to agricultural drought was worked out by the Maximum Pearson Correlation Coefficient (MPCC) method. Drought propagation at weekly and monthly time scales was carried out using MPCC by (31) and (14), respectively. In the present study, Pearson correlation analysis was carried out between PNP (with 18-week lag time from 27^{th} to 44^{th} week for the first sorghum growing season and from 35^{th} to 52^{nd} week for the second sorghum growing season) and SMDI (week 1). The response time for agricultural drought to meteorological drought was identified based on lag time (week), which had the highest correlation coefficient. This indicates the rainfall deficits that were accumulated in the preceding 'n' weeks led to soil moisture deficit (33).

Table 1. Drought severity classification based on meteorological and agricultural drought indices

Drought index	Range (%)	Drought severity
Percent normal of precipitation	≤ 40	Extremely dry
	41 - 55	Severely dry
	56 - 80	Moderately dry
Soil moisture deficit index	0 to -2	Moderate drought
	-2 to - 4	Severe drought

Results and Discussion

Spatial changes in average rainfall during crop growing seasons

Average seasonal rainfall over major sorghum cultivating districts in Tamil Nadu showed distinct spatial variation. During the first season (majorly coincides with southwest monsoon season) the lowest rainfall (< 300 mm) was noticed in Thoothukudi and Ramanathapuram districts while the highest rainfall of 1230 mm was observed in certain areas in Coimbatore district followed by Salem (777 mm), Dindigul (636 mm), Theni (605 mm) and Vellore districts (600 mm) (Fig. 2a). Similar kind of spatial difference was noticed that western part of Tamil Nadu, particularly districts bordering Western Ghats receives higher rainfall than the eastern coastal part of the state during southwest monsoon period (34). Generally, districts like Thoothukudi and Ramanathapuram, located eastern coastal parts of Tamil Nadu, receive less rainfall compared to the western part during the first season. This can be attributed to rainfall activity mainly due to moist air currents from the southwest direction and this impact reduces towards the eastern coastal region (35). The areas receiving high rainfall during the first season are mainly due to their proximity to the Western Ghats (in case of Coimbatore, Dindigul, Theni districts) and Eastern Ghats (in case of Salem, Vellore districts) and owing to higher altitude (34).

During the second season, the highest average seasonal rainfall was noticed in Ramanathapuram (670 mm) and Dindigul (662 mm) districts while the lowest was observed in Namakkal (359 mm) and Coimbatore (366 mm) districts (Fig. 2b). Rainfall receipt during this season is influenced by air currents from the northeast direction and most often cyclonic activities over the Bay of Bengal decide whether the above or below normal seasonal rainfall (36). Therefore, eastern coastal districts receive higher rainfall when compared to interior districts and the western part of the state during the second season. It was also confirmed that a decreasing pattern of rainfall was observed from west to the eastern part of the state during the southwest monsoon season and vice versa during the northeast monsoon season (19).

Occurrence of different categories of meteorological and agricultural drought

Different categories of drought based on the PNP at a weekly scale indicated that all the districts experienced extremely dry conditions (weekly rainfall <40 % of normal) more frequently than severe (weekly rainfall 41-55 % of normal) and moderate dry (weekly rainfall 56-80 % of normal) conditions during both the sorghum growing seasons. In general, higher fluctuation is common in the occurrence of drought intensity and frequency when we use rainfall data at a weekly interval than at a monthly scale and annual scale. This agreed that the frequency and severity level of meteorological drought were higher at the weekly scale than at the monthly scale (33).

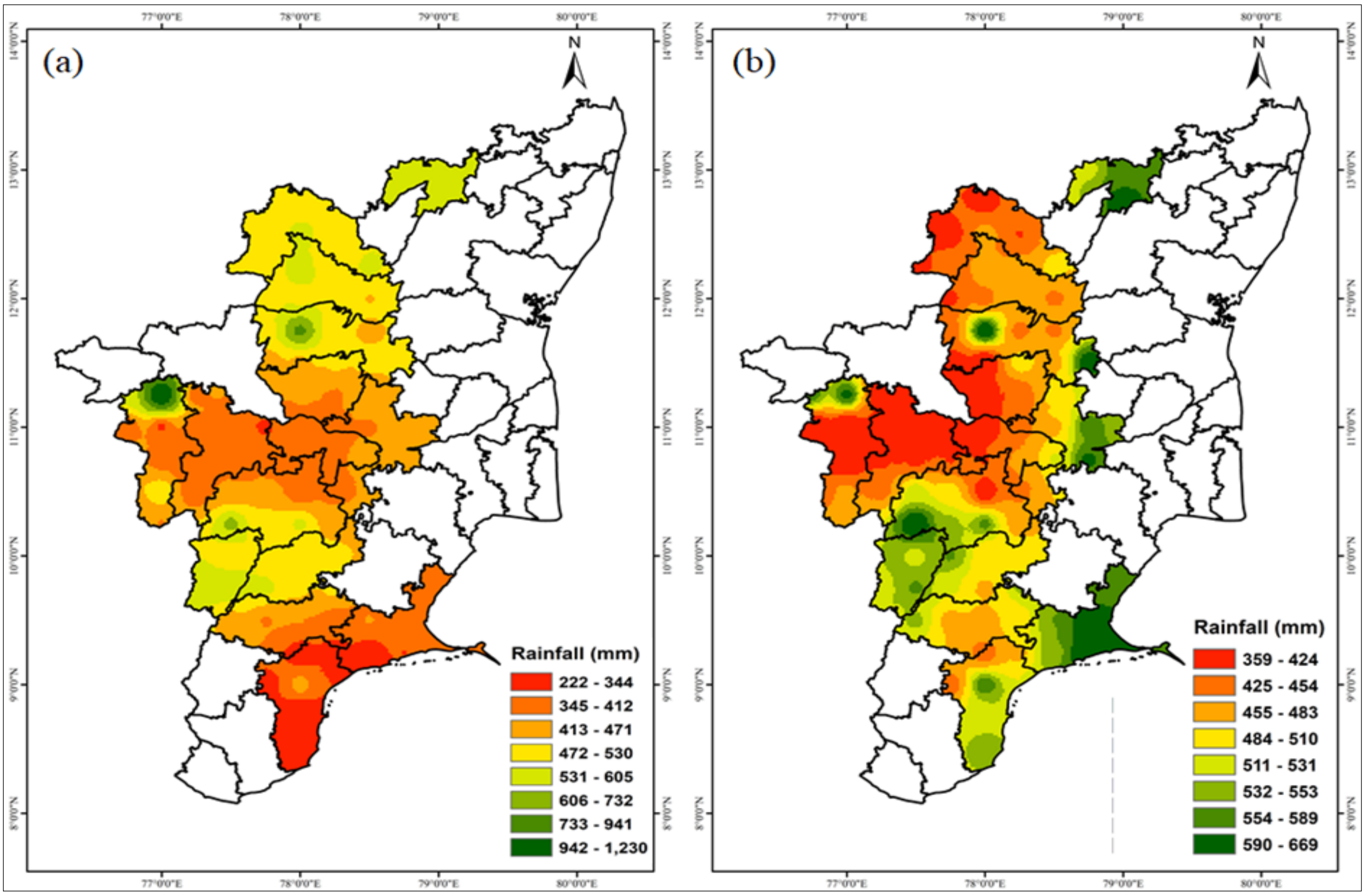


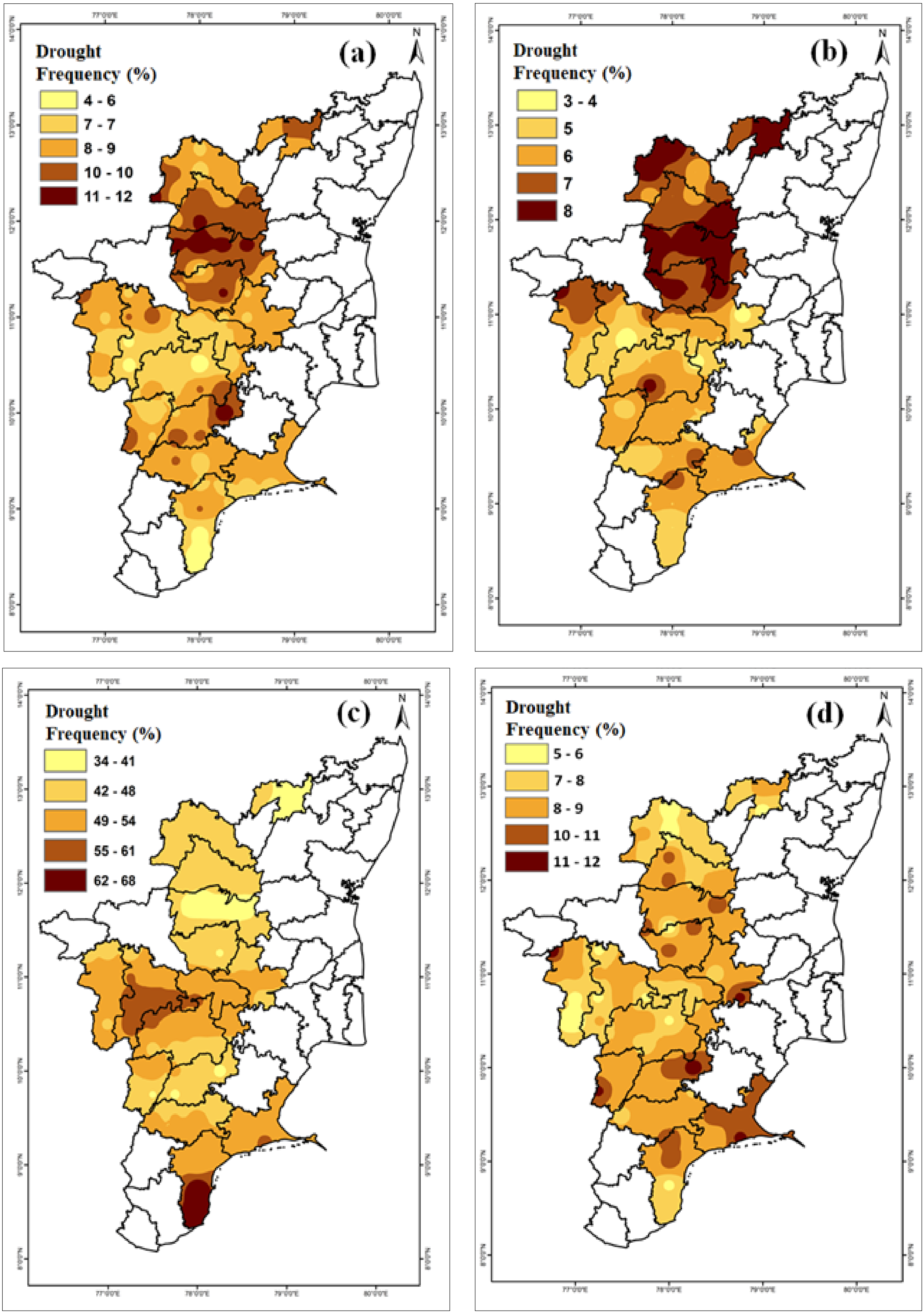
Fig. 2. Average rainfall (a) first and (b) second sorghum growing seasons.

During the first sorghum growing season, the frequency of occurrence of moderate and severe dry conditions was 4-12 % and 3-8 %, respectively, across the study districts (Fig. 3a-3b). At the same time, the highest number of extremely dry condition (≥ 9 weeks out of 18 weeks in the season) had prevailed over most areas of Tiruppur, Thoothukudi, Coimbatore, Dindigul, Ramanathapuram, Tiruchirappalli and Karur districts and some parts of Theni district indicating vulnerability to drought condition (Fig. 3c). These findings are corroborating with previous studies that western and southern parts of Tamil Nadu experience long dry spells during the southwest monsoon period (34). While the lowest occurrence of extremely dry conditions was noticed in some pockets of Salem, Madurai, Vellore, Namakkal and Theni districts, where wetter conditions were noticed (37-38). While the lowest occurrence of extremely dry conditions was noticed in some pockets of Salem, Madurai, Vellore, Namakkal and Theni. During the second season, moderate and severe dry conditions were noticed at lower levels, *i.e.* 5-9 and 3-7 %, respectively (Fig. 3d-3e). On the other hand, most parts of Tiruppur, Coimbatore, Krishnagiri, Dindigul and Thoothukudi districts showed a higher % frequency of extremely drought conditions (≥ 50 %) compared to other districts, indicating these areas are exposed to a higher level of drought severity, which could impact agricultural production (Fig. 3f) (19).

Overall, the percentage frequency of extremely dry conditions varied from 34 to 68 during the first crop growing season and 40 to 55 % during the second crop growing season in different districts during the study period. Investigation on the frequency of different categories of meteorological drought based on monthly Standardised Precipitation Index (SPI) over southern districts of Tamil Nadu also revealed that Ramanathapuram, Virudhunagar, Thoothukudi and Theni districts showed higher frequencies of extreme and severe drought during the southwest monsoon than the northeast monsoon season (20, 39). Based on rainfall deviation, it was found that drought frequencies were higher in Theni, Tiruppur and Karur districts than in other districts (18).

In the case of agricultural drought, the highest frequency (50 %) of moderate agricultural drought was observed in certain areas of Ramanathapuram and Thoothukudi districts while the lowest was noticed in Salem, Coimbatore, Dindigul and Krishnagiri districts (Fig. 4a). Previous research found that erratic rainfall and higher evapotranspiration demand led to moderate agricultural drought over eastern coastal parts of the state (40). Frequency of severe category of drought was high in some areas of Theni district (16-19 % out of 18 weeks) located in south-western part of the state and some parts of Salem, Dharmapuri, Krishnagiri located in north-western part of the state (15-17 % out of 18 weeks) during the first season (Fig. 4b). The per cent occurrence of severe agricultural drought was the lowest (1-5 %) in high-altitude areas of Coimbatore and Dindigul districts and some pockets in Thoothukudi district. This could be owing to orographic rainfall and better soil moisture storage capacity in these high-altitude regions (41).

During the second season, around 32-41 % of the sorghum growing period undergo moderate soil moisture stress over the entire study area with the highest in certain pockets of Coimbatore and Thoothukudi districts (Fig. 4c). Certain pockets of Coimbatore, Tiruppur, Theni and Madurai districts experienced severe agricultural drought in 3 out of 17 weeks and parts of Dindigul and Coimbatore districts experienced only one week (Fig. 4d). This shows that moderate agricultural drought occurred more frequently than the severe category during both sorghum growing seasons. This kind of moderate soil moisture deficit was also observed in dryland areas of Tamil Nadu affects the crop yield (42).


Drought
Frequency (%)
(a)
N
4 - 6
7 - 7
8 - 9
10 - 10
11 - 12
Drought
Frequency (%)
(b)
N
3 - 4
5
6
7
8
Drought
Frequency (%)
(c)
N
34 - 41
42 - 48
49 - 54
55 - 61
62 - 68
Drought
Frequency (%)
(d)
N
5 - 6
7 - 8
8 - 9
10 - 11
11 - 12

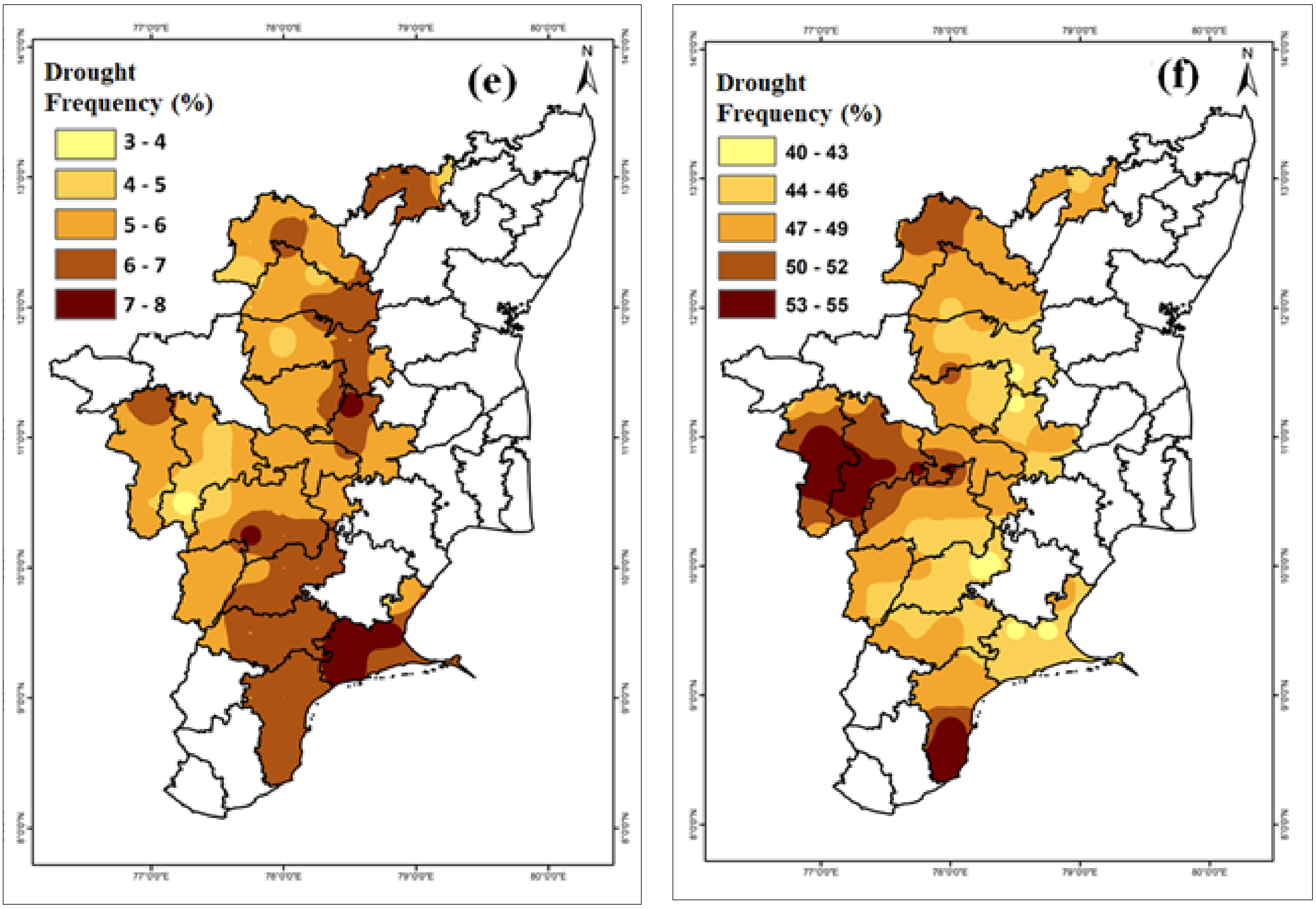
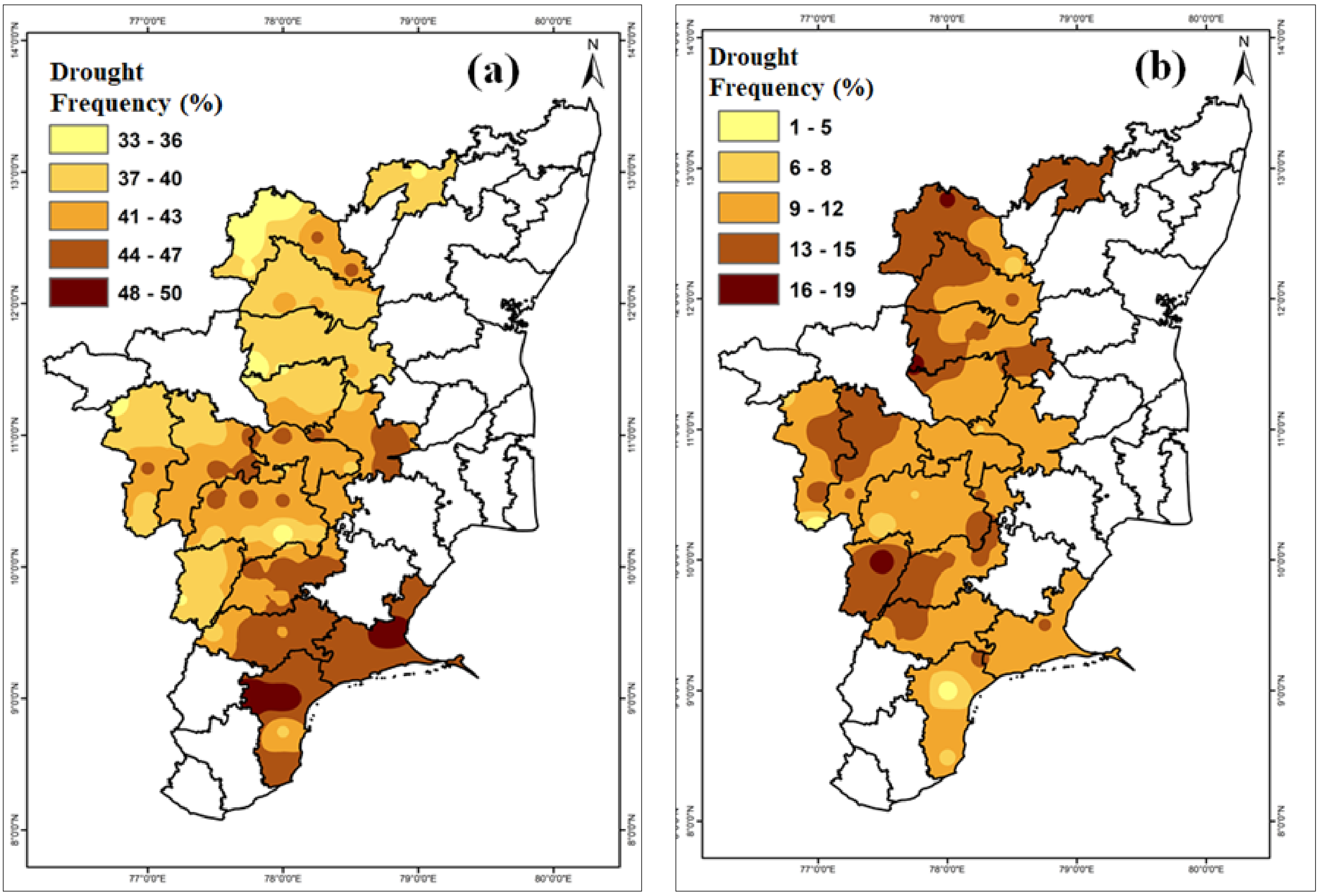


Fig. 3. Percentage frequency of occurrence of moderate, severe and extreme dry conditions over the study area during (a, b, c) first and (d, e, f) second sorghum growing seasons.



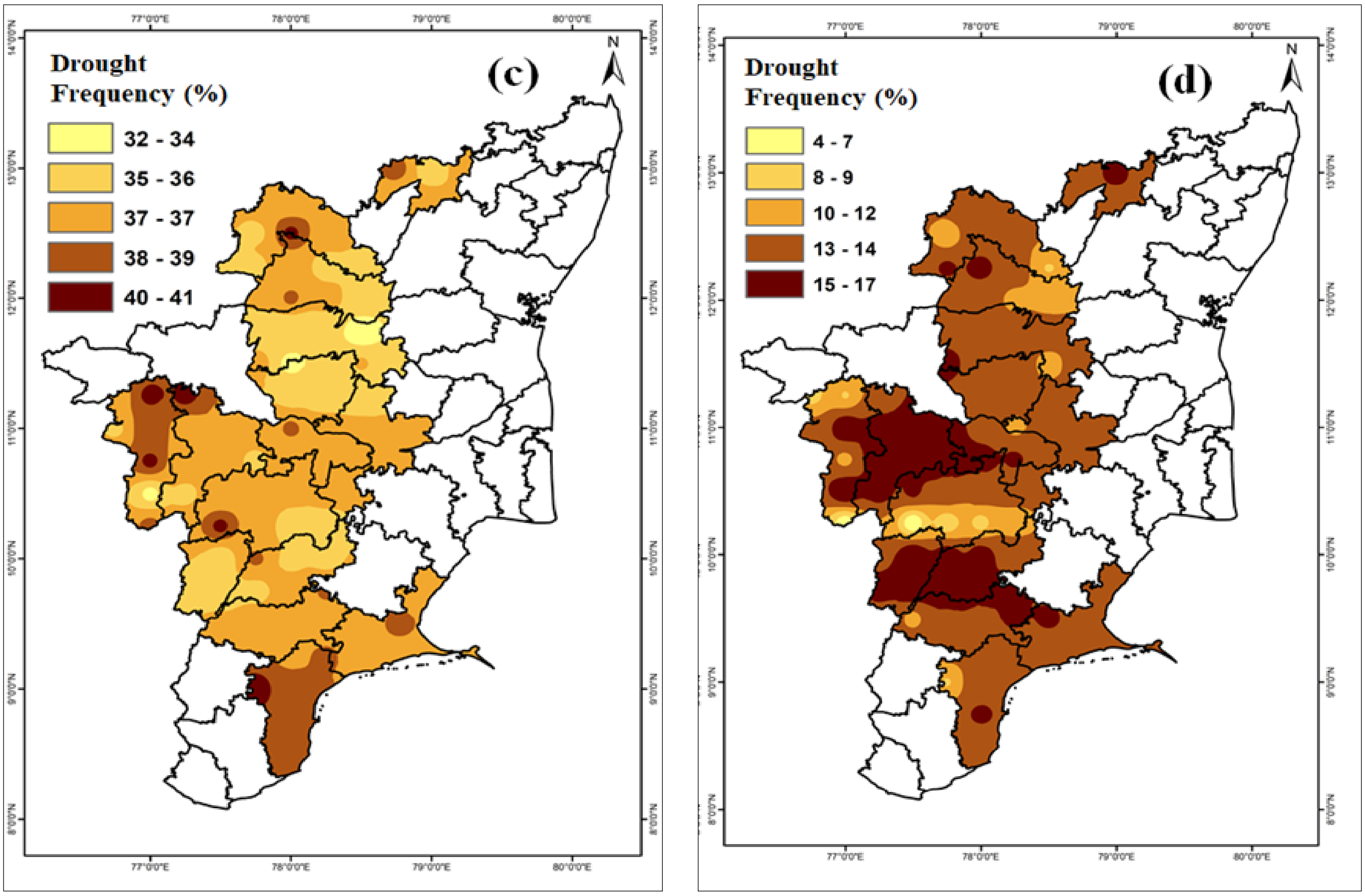


Fig. 4. Percentage frequency of moderate and severe agricultural drought over the study area during the first (a, b) and second (c, d) sorghum growing season.

Propagation time between meteorological drought and agricultural drought

Growth, development and final yield of crops were directly influenced by the level of soil moisture stress in the root zone rather than rainfall, even though rainfall is the source for soil moisture under rainfed conditions. It was found that soil moisture in the crop root zone is the appropriate indicator to know crop status in semi-arid dryland areas (42). Nonetheless, prolonged meteorological drought quickly devours the soil moisture reserve and paves the way to agricultural drought (6). The drought response time computed through MPCC over different sorghum growing districts is furnished in Table 2. Almost the same pattern of spatial difference was noticed in the maximum correlation coefficient and drought propagation time across the study locations during the two sorghum growing seasons. No substantial seasonal variation in correlation between meteorological and agricultural drought was also observed in the previous studies, although the strength of linkage between these droughts may vary with soil and rainfall (43). Analysis showed that the drought propagation period ranged from one week to 17-18 weeks with the lowest maximum correlation coefficient was observed in some parts of Thoothukudi (r=0. 16) followed by Dindigul (r=0. 19) district while the highest was in Krishnagiri district (r=0. 47-0. 50) (Fig. 5). MPCC between SPI and standardised soil moisture index at monthly scale for different agro-climatic regions of the Ganga River Basin was ranged from 0. 23 to 0. 72 (12).

Table 2. Propagation time and the number of grid points in which it occurred over the study area

Propagation time (weeks)	Season 1	Season 2
	No. of points (%)	No. of points (%)
3	1 (1)	1 (1)
4	22 (26)	22 (26)
5	20 (24)	20 (24)
6	1 (1)	1 (1)
7	2 (2)	2 (2)
8	1(1)	1(1)
9	3 (4)	3 (4)
10	3 (4)	3 (4)
11	6 (7)	6 (7)
12	1 (1)	1 (1)
13	0 (0)	0 (0)
14	0 (0)	0 (0)
15	0 (0)	0 (0)
16	3 (4)	3 (4)
17	5 (6)	21 (25)
18	16 (19)	-

The lag time between meteorological and agricultural drought was 4-5 weeks in almost 50 % of the study area (42 points out of 84 points), at which the maximum correlation was obtained. These points are located mainly in western (Coimbatore, Karur and Tiruppur districts), southern (Dindigul, Madurai, Ramanathapuram, Theni, Thoothukudi and Virudhunagar districts) and central (Tiruchirappalli district) parts of the state. Lower soil moisture storage and shallow crop roots lead to a quick transition of meteorological to agricultural drought over semi-arid areas (6). At the same time, around 21 points located in north-western (Dharmapuri, Krishnagiri, Salem and Namakkal districts) and north-eastern part (Vellore district) of the state showed the highest (17-18 weeks) transition time (Table 2). Such variations in drought response time were also reported in Central Asia, Korea and China based on climate, soil and vegetation patterns (15, 43, 44). Under Indian conditions, the drought propagation time from meteorological to agricultural drought varied from one month in the Eastern Himalayan Region to 11 months in the western dry region of the Ganga River basin (12).

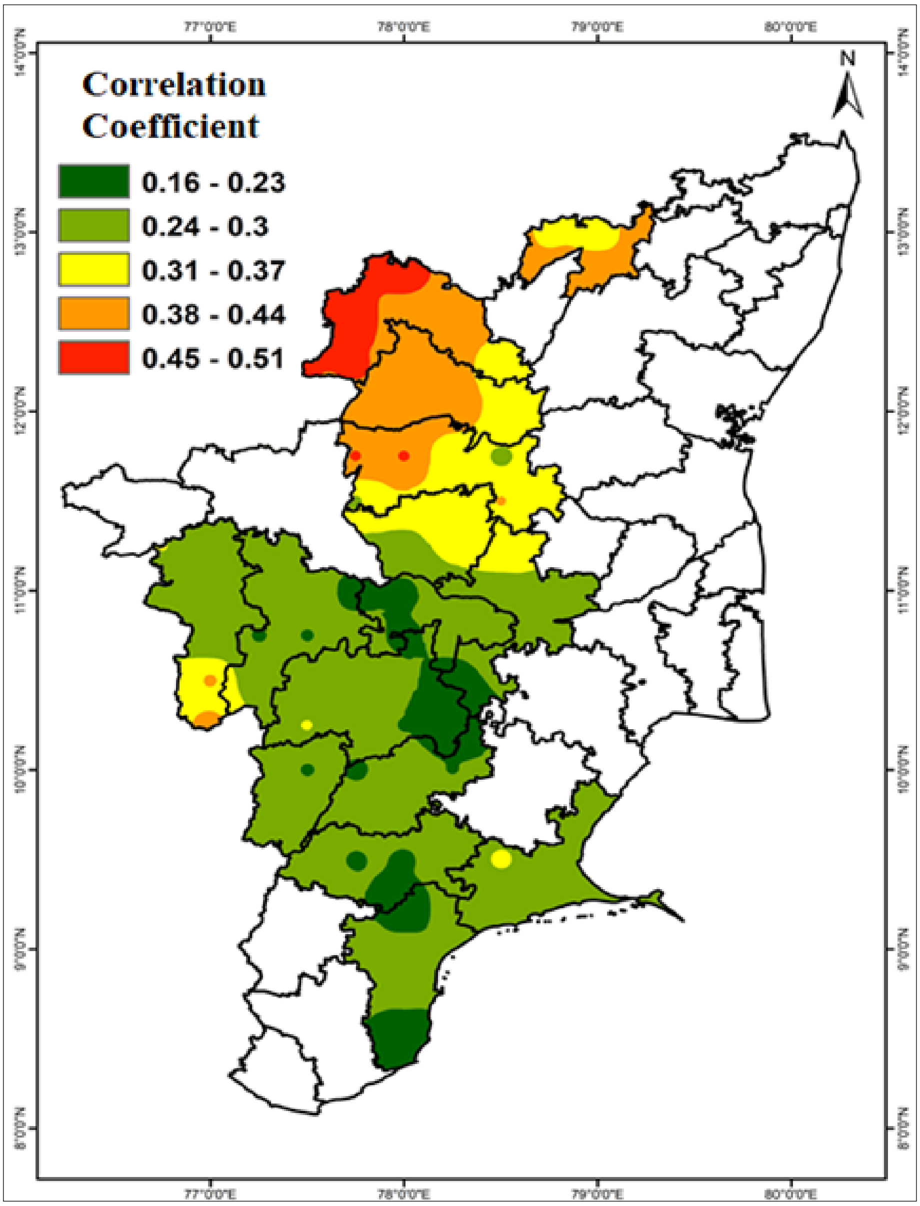


Fig. 5. Spatial variation in maximum correlation coefficient.

Seasonal rainfall and the percent occurrence of meteorological drought could provide possible reasons for short and long propagation times. Low rainfall (222-636 mm) during the first season and a higher frequency of extreme meteorological drought conditions (7-12 weeks out of 18 weeks) over the areas with short propagation time might have led to the quick translation of meteorological drought to agricultural drought. While high rainfall during the first season (402-777 mm) and a lesser frequency of extreme meteorological drought (6-8 weeks out of 18 weeks) had not allowed the soil moisture to deplete faster and thus the propagation period extended around 17-18 weeks. In addition to this, the rooting depth of the crop is influenced by soil texture as fine-textured soil may not allow the root to penetrate deeper depth while coarse-textured soil eases the root penetration to deeper layers. This is also the probable reason why crop roots that penetrated deeper layers could extract soil moisture, specifically during periods of soil moisture stress than a crop with shallow roots. It was found in earlier studies that higher crop yield and reduced drought effect were observed in coarse-textured soils than in fine-textured soils under arid and semi-arid conditions (45). The soil texture in the areas with short propagation period is majorly fine-textured black and brown soil and owing to this, crop roots could not penetrate to deeper layers to absorb soil moisture. Because of this, in these areas, the meteorological drought converted to agricultural drought at a faster rate. It was found that crop yield was higher in coarse-textured soils than in fine-textured soils in arid and semi-arid regions (45).

Seasonal rainfall and frequency of occurrence of extreme drought conditions during the second season were not varied in areas with short and long propagation times. It is understood that the rainfall amount and frequency of extreme drought during the first season were crucial for soil moisture reserve available at the start of the second season. These two factors significantly influence the progression of drought across the seasons (46-47). Further, the second crop growing season (northeast monsoon season) experienced a lower number of drought events and received higher rainfall than the first crop growing season (southwest monsoon season) over the study region (20-21). The leftover soil moisture reserve available at the end of the first season might act as a cushion towards rainfall deficits, which in turn affects the drought propagation period between meteorological and agricultural drought (48).

Conclusion

This investigation aimed to provide insights into spatial variations in meteorological and agricultural drought frequency and the response time between these two drought types during the two sorghum growing seasons across major sorghum growing areas of Tamil Nadu state. The results showed that the frequency of extreme meteorological drought was for 7-12 weeks out of an 18-week crop period during the first season over the western, southern and central parts of the state, while the north-western and north-eastern districts experienced only a 6-8 week period. The propagation time from meteorological to agricultural droughts did not differ significantly between the two seasons. A shorter drought transition time of 4-5 weeks was observed in the districts of Coimbatore, Karur, Tiruppur, Dindigul, Madurai, Ramanathapuram, Theni, Thoothukudi, Virudhunagar and Tiruchirappalli, while it was longer (17-18 weeks) in Krishnagiri, Dharmapuri, Salem, Namakkal and Vellore districts. Therefore, it is imperative to develop strategies for the areas with shorter propagation times, demanding a quick response to minimise the impact of the agricultural drought. This is more vital as climate projection models predicted a significant increase in drought frequency and severity in the ensuing year.

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Authors' contributions

NM conceptualised the study, performed scientific data analysis, wrote the original draft and carried out the final editing. VG provided overall guidance and monitored the progress of the research work. SKB contributed to manuscript editing and evaluation. NKS assisted in editing and validation of the manuscript. BK guided the data analysis process and supported manuscript editing. RR provided guidance in data analysis and interpretation. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: The Authors do not have any conflicts of interest to declare.

Ethical issues: None

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