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Crop Planning using Rainfall Variability and Probability Analysis for Madurai District of Tamil Nadu

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ABSTRACT

Background: Agriculture is the most sensitive sector to climate variability. In rain-fed ecosystems, rainfall is the single most essential component in crop planning. Crop planning using rainfall variability and probability analysis helps to improve the productivity.

Methods: A study was taken for crop planning in Madurai district by analyzing the rainfall variability and probability analysis using 40 years (1982-2021) of weekly, monthly, seasonal and annual rainfall data.

Result: The mean annual rainfall in Madurai district was 925.5 mm was spread over 74 rainy days with 24.7 per cent of coefficient of variation thereby the rainfall is dependable over years with decreasing trend. The probability analysis showed that receiving 20 mm rainfall per week was for 12 weeks (32 to 45th week) except 35 and 37th week which is helpful for sowing and planting. On the other hand, highest mean monthly rainfall was received in October (176 mm) followed by September (137.4 mm). Seasonal analysis resulted that Southwest monsoon had high rainfall quantity with mean value of 397.7 mm. Rice is the major crop cultivated in this region should be replaced by maize, green gram, black gram, cowpea, sorghum, ragi and minor millets which can withstand drought conditions with less crop duration.

Key words: Crop planning, Initial and conditional probability, Rainfall, Trend analysis, Variability analysis.

INTRODUCTION

Rice is the staple food of India and it is grown on 2.2 M ha in Tamilnadu. The state's average crop productivity is about 2.8 tonnes/ha and the biggest limiting factor that impacts crop productivity is rainfall. The amount, timing and spatial variability of rainfall occurrence determines the agricultural practices of the region. Also the onset, distribution and cessation of rainfall vary throughout the year which is affecting the agricultural operations (Pradhan *et al.,* 2020). Rainfall fluctuation has significant effects on the economies of all nations, including India (Yadav *et al.,* 2014). Although the change in rainfall is difficult to quantify due to cloud formation and the unpredictable nature of rain, long-term rainfall analysis could be used to improve agricultural planning in rainfed areas (Rao *et al.,* 2010). Crop planning by using annual and seasonal rainfall variability and its probability analysis in Tamilnadu (Chattopadhyay and Ganesan, 1995). To achieve maximum agricultural productivity and minimizing the risk, it is critical to quantify rainfall variability at local levels (Vairavan *et al.,* 2002). To understand the implications of rainfall variability in agricultural planning and management, rainfall records must be interpreted in relation to local agricultural practices to develop optimal cropping strategies in the area (Agarwal, 2000). Weekly rainfall analysis helps in better crop planning in Madurai and Bhavanisagar in Tamilnadu suggested by Subbulakshmi *et al., (*2005).

Madurai district is located in the southern zone of Tamilnadu which is a rain-shadow region. Out of seven agro climatic zones of Tamilnadu, Southern zone occupies 24 percent of dry land area (Kannaiyan *et al.,* 2001). The uneven spatial and temporal distribution of rainfall affects the agricultural productivity in this region. In this context, the Markov chain model has been used to study the probabilities of rainfall occurrence (Gaberial and Newmam, 1962). Hence the analysis of occurrence of initial wet spell and dry spell as well as the conditional probability of wet spells may be utilized for minimizing risk factors due to weather conditions in crop production. Gupta *et al.* (1975) suggested that the rainfall at 50% probability is the medium limit for taking risks. In this paper, an attempt has been made to analyze the rainfall variability on a weekly, monthly, seasonal and annual basis to suggest crop planning in this region.

MATERIALS AND METHODS

The daily rainfall data of Madurai district comprising of 11 raingauge stations for 40 years (1982-2021) had been collected from PWD, Periyar Vaigai Basin Division, Madurai. The latitude and longitude of raingauge stations were

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depicted in Table 1 and it was 101 m elevation above sea level. The daily data were converted into weekly, monthly, seasonal, annual and decadal data for analysis as per the India Meteorological Department (IMD) guidelines. The converted data was used to analyse the variability of rainfall which helps to understand the rainfall behaviour of a particular location with respect to agriculture. The coefficient of variation (CV) is expressed as percentage and is used to determine the dependability of rainfall. The higher dependability has decreased the rainfall variability in a location. The rainfall dependability classification is depicted in Table 2 reported by Veeraputhiran *et al.,* 2003. The initial and conditional probabilities were estimated using the Markov Chain Analysis method of receiving 10 mm, 20 mm and 50 mm of rainfall in a given week. Markov chain analysis is a universal method employed for rainfall analysis which helps to obtain specific information for crop planning and for carrying out agricultural operations (Sivakumar, 1992). Gupta *et al.,* (1975) suggested that 50 per cent probability is medium limit for taking risk. The weekly probability estimation results for initial and conditional probability of a wet week is given by the formula

$$P\,(W) = \frac{F\,(W)}{F\,(W) + F\,(D)} \times 100$$

$$P(W_2/W_1) = \frac{F(W_2W_1)}{F(W_1)}$$

Where;

P(W)= Probability of week being wet(%).

F(W) and F(D)= Frequency of wet and dry weeks in a data set.

$P(W_2/W_1)$= Probability of second week being wet followed by preceding week wet and

$F(W_2W_1)$= Frequency of wet week preceded by wet week.

Rainy day is receiving more than 2.5 mm of rainfall in a day is used for calculation and heavy rainfall events are also estimated.

RESULTS AND DISCUSSION

Annual and seasonal rainfall

The mean annual rainfall of Madurai district was 925.5 mm with the highest and lowest values of 1449.2 mm and 370.6 mm which was spread over 75 rainy days with a standard deviation of 228.8 mm and coefficient of variation as 24.7 per cent. The annual rainfall analysis indicated that the rainfall was considered to be dependable because of the lower CV than the threshold level (level 25%). The trend analysis reflects that the annual rainfall over the past 40 years had been in a decreasing trend (y= -7.0521x+1065.5). The five years moving average of annual rainfall showed a cyclic pattern with an increasing and decreasing trend and after the year 2011, it was dipped below the long period average (Fig 1). The seasonal rainfall analysis of this region in terms of winter (January-February), summer (March- May), southwest monsoon (June-September) and northeast monsoon (October-December) indicated that except winter (121.8%), all other seasons had CV value lower than the threshold level of 50 per cent and the rainfall was much dependable in summer as 42.1 per cent, Southwest monsoon (SWM) as 36.1 per cent and Northeast monsoon (NEM) as 39.5 per cent. The mean rainfall of winter, summer, SWM and NEM were 13.9 mm, 145.1 mm, 397.7 mm and 368.8mm respectively (Table 3). Most of the rainfall received during Southwest Monsoon period was highly used to grow samba rice crop in this region.

Monthly and weekly rainfall

The mean monthly rainfall was higher in October (176 mm) with the CV of 38.7 per cent followed 137.4 mm of rainfall with 44.8 per cent of CV in the month of September. The lowest mean monthly value was observed in January (6.6 mm) with CV of 107.2 per cent. The maximum amount of rainfall was received during August month as 344.1 mm and the higher minimum rainfall was received during October month with 15.1 mm The coefficient of variation was lower than the threshold level (<100%) between the months from April to December which clearly showed that the rainfall during these months were highly dependable (Table 4). Decadal monthly analysis of SWM (4 decades *i.e.*, 1982-1991, 1992-2001, 2002-2011 and 2012-2021) showed that the rainfall received during 2012-2021 had increased in trend in August (4.24 per cent) and September (21.06 per cent) which highly coincides with the crop growing season of Madurai district (Fig 2).

Table 1: Raingauge stations in Madurai district with geographical location.

Location	Latitude	Longitude
Chittampatti	9°59′50″N	78°16′36″E
Edayapatti	9°46′30″N	78°16′15″E
Kallandiri	10°2′10″N	78°12′10″E
Kuppanampatti	9°57′10″N	77°50′59″E
Madurai	9°56′26″N	78°7′58″E
Melur	10°1′44″N	78°20′4″E
Mettupatti	10°2′48″N	78°6′56″E
Pullipati	10°5′10″N	78°17′30″E
Sathiyar dam	10°4′16″N	78°6′42″E
Thaniyamangalam	10°1′23″N	78°23′39″E
Virahanur regulator	9°53′44″N	78°12′40″E

Table 2: Rainfall dependability and Non-dependability classification for variation (%).

Period	Threshold level of CV (%)	Non dependability of CV (%)
Daily rainfall	<250	>250
Weekly rainfall	<150	>150
Monthly rainfall	<100	>100
Seasonal rainfall	<50	>50
Yearly rainfall	<25	>25

Table 3: Variation in seasonal rainfall at madurai (1982-2021).

Season	Mean rainfall (mm)	Standard deviation	Coefficient of variation (%)	Maximum (mm)	Minimum (mm)
Annual	925.5	228.8	24.7	1449.2	370.6
Winter	13.9	16.9	121.8	82.0	0.0
Summer	145.1	61.1	42.1	330.1	46.6
SWM	397.7	143.5	36.1	754.3	45.1
NEM	368.8	145.8	39.5	712.9	40.4

Table 4: Mean rainfall (mm), maximum and minimum rainfall (mm) along with standard deviation and coefficient of variation (%) in Madurai (1982-2021).

Month	Mean rainfall (mm)	Standard deviation	Coefficient of variation (%)	Maximum (mm)	Minimum (mm)
January	6.6	7.1	107.2	30.4	0
February	7.3	15.7	215.9	82.0	0
March	19.3	33.9	175.8	188.8	0
April	41.4	31.1	75.2	129.2	4.0
May	84.4	42.9	50.9	192.4	0
June	47.0	24.4	52.0	108.4	0
July	93.3	49.5	53.0	192.7	0
August	120.1	72.0	60.0	344.1	0
September	137.4	61.5	44.8	286.9	0
October	176.0	68.1	38.7	304.5	15.1
November	134.9	91.0	67.4	336.0	0
December	57.8	53.7	92.9	239.3	0

The mean weekly rainfall was higher during 44th standard week (29 Oct-04 Nov) which received 44.9 mm of rainfall with the CV of 89.8 per cent. The stable rainfall period was found between 15 to 48th standard week (April 9 to December 2) with the corresponding CV of less than 150 per cent except 46th standard week (November 12-18) which had a CV of 171.5 per cent (Fig 3). Thus, the total average growing period at Madurai district was for 33 weeks. This showed that the successful crop production can be done during these weeks with an assured moisture regime.

Weekly rainfall probabilities

The occurrence of hard pans at shallow depth is the most prevailing soil physical constraint in this region. The agricultural crops are denied of the full benefits of soil fertility and nutrient use due to this constraint. The sub-soil hard pans are characterized by high bulk density which in turn lowers infiltration, water storage capacity, available water and movement of air and nutrients, with related adverse effects on the yield of crops (Rai and Singh, 2009). This problem was predominantly occuring in Madurai particularly under rainfed farming. To mitigate this, atleast 10mm of rainfall was required for cultural practices like land preparation and sowing. The probability of getting 10mm or more rainfall exceeded 50 per cent for 24 weeks between 18 to 48th week except 19, 23-26, 46-47th week. For successful crop production the normal requirement of rainfall was considered as 20 mm/week and 50 mm/week in particular for rice crops. The probability of receiving 20 mm rainfall per week with more than 50 per cent were between 32 to 45th week (for 12 weeks) respectively, except in 35th and 37th week when probability was 47.5 and 45 per cent only. The probability of 30 mm rainfall per week with more than 50 per cent was received during 39 to 45th week (6 weeks). When the probability was fixed as 50 mm of rainfall, it did not achieve more than 50 per cent in any of the week (Table 5). After the onset of monsoon, 32nd standard week (6-12 August) can be considered for final land preparation and sowing of *kharif* crops. Maize can be sown in between 18 to 20th standard week with low risk, as rainfall of 10 mm or more exceeds 50 per cent probability. The conditional probability of getting 10 mm rainfall with above 50 per cent was received during 18-45th week and it was essential for cultural operations like ploughing, land preparation, weeding, *etc*. For successful crop production, 20 mm of rainfall was necessary. In this region, 20 mm of rainfall was occurred during 32-45th week (6 Aug-11 Nov). The samba rice was predominantly sown during August month in this region. The probability of getting 50 mm of rainfall with above 50 per cent during 24th week (June 11-17) is used for recharging the ground water.

Rainy day

The mean annual rainy day for Madurai from 1982-2021 was 74 days with a maximum of 114 rainy days received during the year 2000 and a minimum of 36 days received during 2009. The trend analysis showed that there was a decreasing trend in annual mean rainy days with a linear equation of Y= -0.3939X + 862.83 with the R^2 value of 0.0584 (Fig 4). The mean monthly rainy day analysis results that October month was having a maximum number of rainy days of 13 followed by September with 11 rainy days (Fig 5). The farmers in this region are mostly taking sowing of Paddy crop during August month which coincides with high rainfall month and rainy days which is helpful for the vegetative growth of the crop. During November month, the crop was harvested on time which does not affected by rainfall and the post-harvest process is not delayed so storage and transportation of produce is made easy. The seasonal rainy days analysis showed that South West Monsoon is predominant with 34 mean rainy days in this region followed by North East Monsoon with 25 rainy days. The results from the decadal seasonal rainy day analysis showed that the last two decades had a decreasing number of rainy days. The 2012-2021 decadal analysis results that South West Monsoon and North East Monsoon was having 26 and 20 rainy days with 76 and 57 per cent deviation from normal (Fig 6).

Heavy rainfall events

The annual heavy rainfall events analysis resulted that South West Monsoon having 12 rainy days with 10-25 mm of rainfall received during the period (June to September) followed by North East Monsoon with 10 rainy days (October to December). The rainfall of 25-50 mm during SWM and NEM was received within 2 and 3 rainy days (Table 6). When heavy rainfall occurs, large portion of water lost as surface runoff during the monsoon period (Pandey *et al.,* 2002). In

Table 5: Initial and conditional probability (%) of receiving weekly 10, 20 and 50 mm of rainfall in Madurai.

Std wk	Mean (mm)	Coefficient of variation (%)	Initial probability (%)			Conditional probability (%)		
			10 mm	20 mm	50 mm	10 mm	20 mm	50 mm
15	10.4	136.9	38	20	3	33	25	0
16	10.3	137.1	35	20	3	43	25	0
17	10.0	102.7	40	13	0	38	20	0
18	22.8	101.2	65	45	8	69	61	0
19	16.3	126.7	43	33	8	41	38	0
20	16.9	92.1	60	38	3	54	40	0
21	16.5	103.4	58	28	5	57	27	0
22	18.1	88.6	53	40	3	62	38	0
23	14.4	112.6	48	28	5	37	27	0
24	10.5	132.2	45	13	5	61	40	50
25	6.9	145.9	25	13	0	30	0	0
26	9.1	129.5	38	10	3	13	0	0
27	17.6	106.6	58	38	8	57	33	0
28	21.5	92.4	65	43	10	65	47	25
29	22.6	101.9	70	45	10	82	44	0
30	21.2	105.6	65	33	15	65	46	17
31	25.6	115.3	50	45	28	50	44	27
32	25.3	96.8	68	55	15	67	55	33
33	27.9	91.6	63	55	23	68	55	0
34	28.4	90.2	63	58	13	68	65	0
35	26.0	88.8	68	48	18	67	53	29
36	24.8	98.6	65	53	15	62	52	17
37	27.7	100.1	68	45	18	70	44	0
38	32.8	85.1	75	65	23	77	69	22
39	38.9	75.5	85	75	25	82	67	20
40	36.2	85.0	75	65	28	70	65	45
41	37.6	91.3	78	63	30	81	64	25
42	39.4	74.9	83	70	33	85	75	31
43	42.2	98.1	75	65	33	73	62	31
44	44.9	89.8	68	60	43	67	58	29
45	40.4	109.5	70	60	30	64	71	42
46	25.7	171.5	45	35	15	44	29	17
47	22.9	147.9	48	33	18	42	31	29
48	20.1	139.6	50	43	8	40	29	0

the event of heavy rainfall, a substantial portion of the water is lost due to deep percolation and run-off. When the next rainstorm comes, if the soil is already moist, it will simply be unable to hold any more water. As a result, the rainwater will percolate below the root zone and finally reach the groundwater (Kumar *et al.,* 2018). IMD and State Agricultural Universities are providing weather based agro advisories to farmers to avoid operations like weeding, fertilizer and pesticide application during that heavy rainfall period. Farmers can make proper drainage facilities to the crop field to mitigate water stagnation. Check bunds, infiltration tanks and water harvesting structures such as farm ponds must be built to store the excess water during monsoon period and utilized for summer season to maintain ground water recharge in the face of a declining ground water table (Sagar *et al.,* 2022). Weather based Crop Insurance helps the farmers mitigate the hardships against the financial loss owing to the anticipated crop loss resulting from adverse weather conditions relating to rainfall, temperature, wind, humidity (Clarke *et al.,* 2016).

Table 6: Heavy rainfall events with no. of rainy days in Madurai.

Season	Rainfall (mm)	Rainy days count
Southwest monsoon	10-25	12
	25-50	2
	50-75	0
Northeast monsoon	10-25	10
	25-50	3
	50-75	0
Summer	10-25	4
	25-50	0
	50-75	0
Winter	10-25	0
	25-50	0
	50-75	0

Crop planning

Rice is the predominant single crop grown by farmers in this region. On the other hand, some farmers grow sugarcane and banana as a wetland crop, which is highly

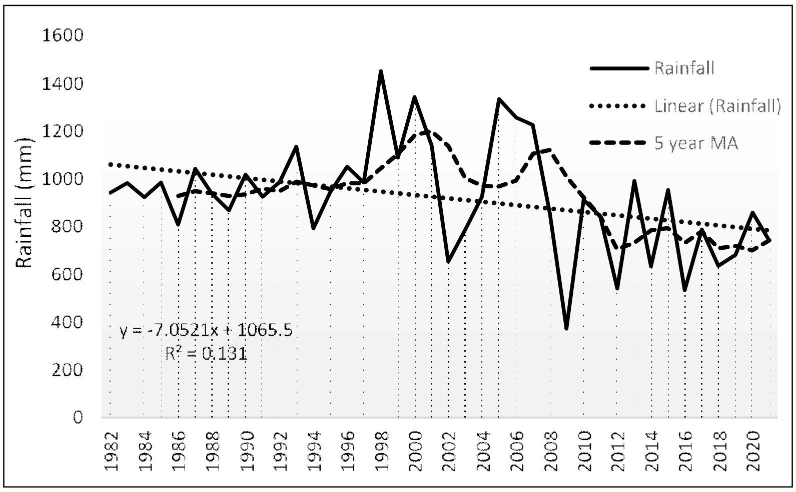

Fig 1: Trend in annual rainfall (mm) along with 5 year moving average in Madurai.

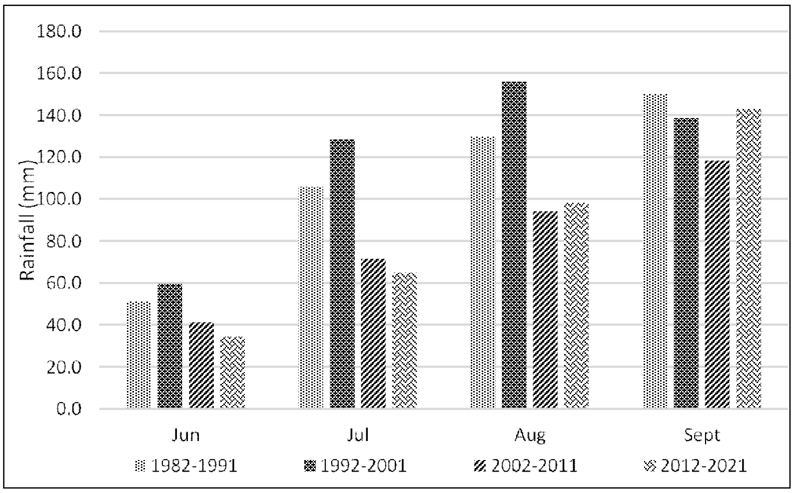

Fig 2: Decadal variation in South West Monsoon (June- Sept) in Madurai.

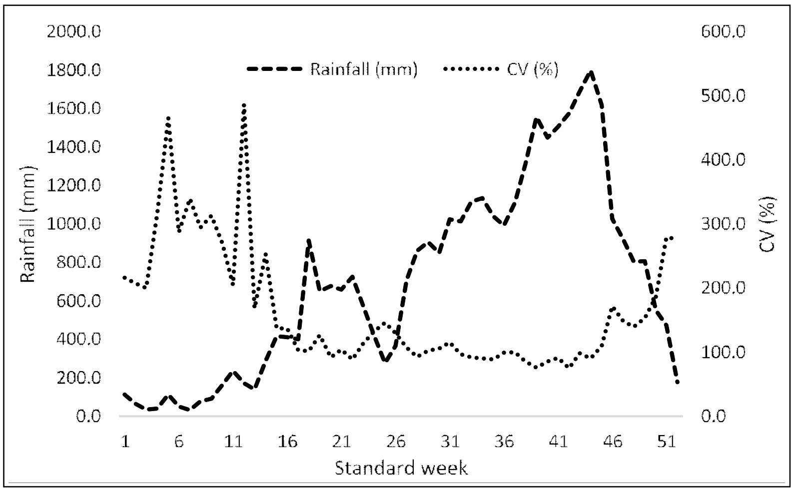

Fig 3: Variation in Weekly rainfall (mm) and Coefficient of Variation (%).

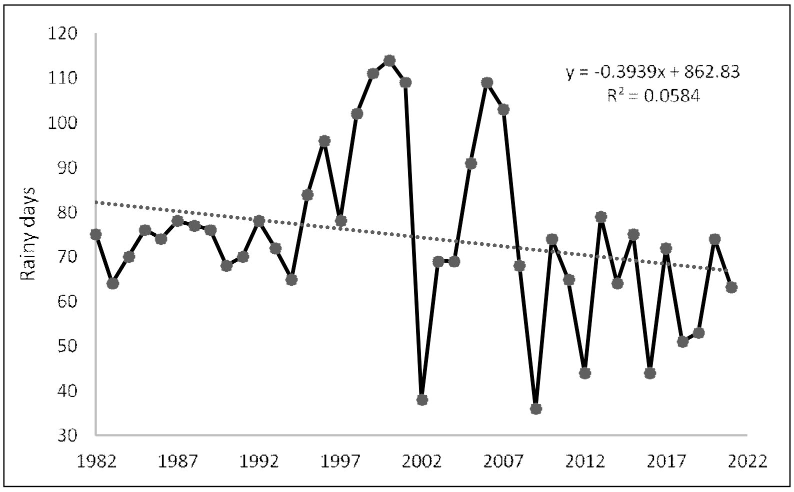

Fig 4: Mean annual rainy day from 1982-2022 in Madura.

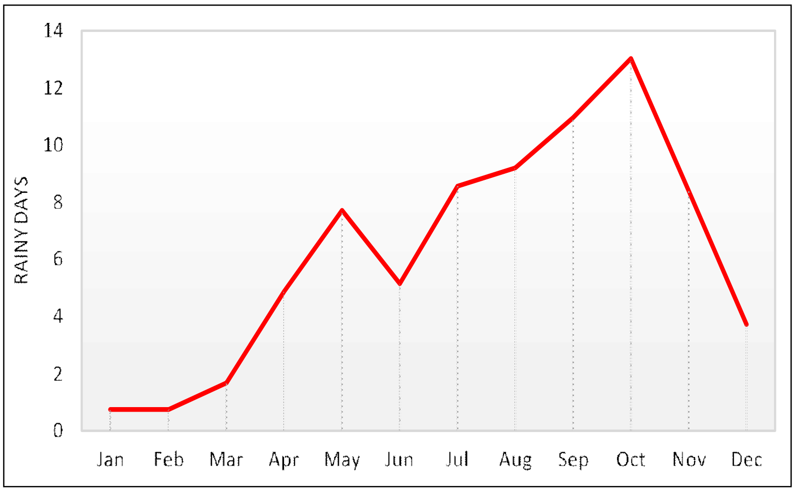

Fig 5: Mean monthly rainy day in Madurai district.

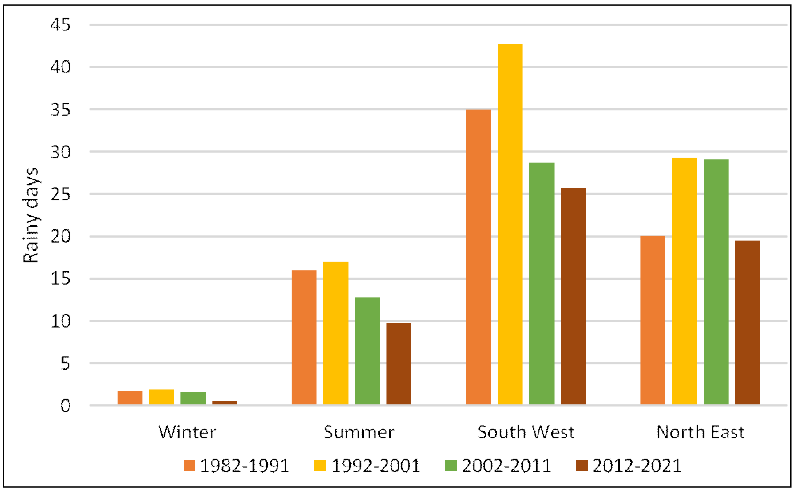

Fig 6: Decadal seasonal rainy day variation in Madurai district.

water demanding should be replaced by low water requiring crops like maize, cumbu, sorghum, pulses, ragi and other minor millets. Sowing of maize, cowpea, groundnut and black gram during second fortnight of June can utilize the monsoon rain (Bhargava *et al.,* 2010). The traditional method followed by farmers is sowing of crop soon after receiving first rainfall may affect the crop germination and initial growth due to moisture availability constraints right after sowing. In order to mitigate the monsoon anomalous, the existing cropping pattern should be modified. Altering the double crop of rice to single crop area and soon after the harvest of rice crop, farmers can grow green gram, blackgram, horsegram, cowpea, maize and minor millets such as finger millet, foxtail millet, proso millet and others are drought resistant and may be grown with little soil moisture suitable for weather prevailed in this region.

The predominant soil type in this region is clay loam which is having high water holding capacity and good aeration suitable to grow crops like groundnut and pulses which can penetrate their roots deep in the soil. Intercropping/mixed cropping of maize with cowpea/ green gram/ black gram should be followed in this region. As agronomic methods, paddy can be transplanted with 3-4 seedlings per hill to enhance plant population from 50 to 60 hills per m^2. For enhanced germination and optimum plant stand, pruning and thinning of overage paddy seedlings may be beneficial. Under dry spells or conditions with little rainfall, mulching with straw or grass cover may also be done to preserve soil moisture for improved production. In order to boost the productivity of the land and attain sustainability, growing green manures would benefit from the rainfall that was obtained throughout the summer. Hence the onset of monsoon starts from June month but the crop growing season starts from August in this region hence there should be a change in cropping pattern/cropping system including the variety.

The trend of rainfall is decreasing over the years, so advancements in crop production should be employed for the betterment of crop yield. Based on the amount and distribution of seasonal and monthly rainfall, it is clear that water stress during cropping season is a regular scenario in PVC area (Sathyamoorthy *et al.,* 2018). There is a need to review the cropping patterns, crop selection, cultivars and management practices to reduce risks in food production in this region. Since all agriculture is based on rainfall patterns, it is advisable to grow crop that do not require more than 13 or 14 weeks of crop duration (Kumari *et al.,* 2014).

CONCLUSION

Agriculture is the most climate sensitive sector which is directly affected by deviations in temperature and rainfall. The major cropping period in this region is observed from August to November for single crop and June to January for double crop of rice which coincides with the Southwest and Northeast monsoon period. Within the cropping period, dry spells may occur which can affect the crop growing period and maturity stages by shortening the length of growing period. From the analysis, farmers can grow short duration crops like pulses, sorghum, maize and millets during summer which can produce good amount of yield using less water and can withstand drought conditions. As a result, in the face of significant climate variability, crops like maize, pulses and millets production and consumption need to be encouraged.

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