Conditional Probabilities of Excess, Normal and Deficient Southwest and Northeast Monsoon Rainfall of Kerala

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A B S T R A C T

The dominant monsoon spells in Kerala are southwest and northeast monsoons during June to September and October to December, respectively. The crop planning in the state varies in accordance with the pattern of these monsoons and their duration. Hence, it is beneficial to assess the influence of monthly rainfall on the rainfall during southwest monsoon and northeast monsoon seasons in order to help better crop and irrigation management. The method of conditional probability was employed in the present study to determine the critical months in corresponding monsoon seasons. Since the cropping pattern varied spatially across Kerala, the study was concentrated in stations representing the five agroclimatic zones of Kerala viz., Pilicode (northern zone), Vellanikkara (central zone), Vellayani (southern zone), Ambalavayal (high range zone) and Kumarakom (problem area zone). Using the seasonal and monthly rainfall data of 37 years from 1983 to 2019 collected from former stations, the probabilities of excess, normal and deficit rainfall was estimated in terms of quartiles, for each season and month in different stations. An attempt was made to estimate the conditional probabilities to decide whether the seasonal rainfall was excess, normal or deficient when monthly rainfall was excess, normal and deficient, respectively. At Vellayani, the exceedance probability is more than 50 per cent for southwest monsoon when rainfall in June was excess. When July or September has excess rainfall at Kumarakom, the season expects excess rainfall with 60 per cent probability. Similarly, excess rainfall in June or July determines excess rainfall in the season at Vellanikkara. When August or September receives excess rainfall, the probability is more for excess rainfall during southwest monsoon, at Pilicode. Ambalavayal experiences excess rainfall with 80 per cent possibility when July has excess rainfall. Similarly, the effect of rainfall in October and November varies over northeast season. Such information from probability analysis can be manipulated to decide when to take prior measures to anticipate the threat of extreme conditions of rainfall.

Key words: Rainfall, Conditional probabilities, Excess, Normal, Deficient, Monsoon

Kerala is classified into five agroclimatic zones viz., northern zone, central zone, southern zone, high range zone and problem area zone, based on the topography, agronomic environment and rainfall features existing in these regions. Thus, agriculture in a station is essentially correlated with the distribution of rainfall received in the particular zone to which the station belongs. About 80 per cent of annual rainfall in Kerala is contributed by southwest and northeast monsoons [1]. Hence, excess or deficient rainfall events during monsoon seasons would result in reduction in crop yield and economic losses. When prior information on the probability of occurrence of excess, normal and deficit rainfall during the seasons in terms of monthly rainfall is provided, such losses can be anticipated earlier. Probabilities for occurrence of droughts and floods during the period from 1871 to 1984 in major meteorological subdivisions of India [2] and [3] carried out a study on dependence of seasonal rainfall on monthly rainfall across different sub-divisions of India, while [4]. analyzed the rainfall of Pakistan to find the contribution of monthly rainfall to make the seasonal rainfall excess or deficient and found conditional probabilities of seasonal monsoon to be in excess, deficient and normal when the monthly rainfall of July, August and September is considered to be in excess and deficient. In the present study, rainfall data over five agroclimatic zones of Kerala were analyzed to determine the excess, normal and deficient rainfall months, and the conditional probabilities of southwest and northeast monsoons to be excess, normal and deficient.

MATERIALS AND METHODS

Daily rainfall data gathered from Vellayani, Kumarakom, Vellanikkara, Pilicode and Ambalavayal were segregated into seasonal (southwest and northeast monsoon) and monthly (June- November) rainfall data over the period 1983- 2019 from for the present study. Rainfall in December

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was negligible at all stations and hence, was ignored from the analysis. The seasonal and monthly rainfall deviated from normal distribution in all the five stations [5]. Hence, excess, normal and deficient rainfalls were defined for months and seasons considered, at all five stations based on quartiles. If rainfall of a month or season in a year exceeds their third quartile (Q_3), then the particular year is defined as excess rainfall year for that month or season. Similarly, if the monthly or seasonal rainfall is less than first quartile Q_1 in a year, then the year is a deficient year for that month or season. If the year has rainfall greater than or equal to Q_1 and less than or equal to Q_3, it is defined as a normal rainfall year for a month or a season. The probabilities of excess, normal and deficit rainfall in southwest and northeast monsoon seasons and months from June- November were estimated for all the five stations using the formula:

Probability of excess rainfall during SWM or NEM or month
$$= \frac{No.\, of\, years\, with\, SWM\, or\, NEM\, or\, monthly\, rainfall > Q_3}{Total\, no.\, of\, years}$$

Probability of normal rainfall during SWM or NEM or month
$$= \frac{No.\, of\, years\, with\, SWM\, or\, NEM\, or\, monthly\, rainfall\, \geq Q_1\, and\, \leq Q_3}{Total\, no.\, of\, years}$$

Probability of deficient rainfall during SWM or NEM or month
$$= \frac{No.\, of\, years\, with\, WM\, or\, NEM\, or\, monthly\, rainfall\, below\, Q_1}{Total\, no.\, of\, years}$$

To estimate the conditional probabilities, say, for southwest monsoon rainfall to be excess (X) when rainfall during June, July, August or September were excess/ normal/ deficient (Y), probability of the common years with excess rainfall during southwest monsoon and the month, P (X∩Y) is found:
Here, P (X∩Y)

$$= \frac{Number\, of\, common\, years\, with\, excess\, rainfall\, in\, both\, SWM\, and\, month}{Total\, number\, of\, years}$$

Where P(Y) is probability for rainfall in the month to be excess. Now, the conditional probability of southwest monsoon rainfall to be excess when monthly rainfall is excess, is given by:

$$P\,(X/Y) = \frac{P\,(X \cap Y)}{P(Y)}$$

$$= \frac{P(Excess\, SWM\, rainfall\, and\, monthly\, rainfall}{P\,(Monthly\, rainfall\, to\, be\, in\, excess)}$$

The similar procedure is followed to estimate the conditional probabilities for excess/ normal/ deficient southwest and northeast monsoon rainfall when rainfall was excess/ normal/ deficient during June, July, August, September, October and November.

RESULTS AND DISCUSSION

After classifying excess, normal and deficient rainfall in all the five stations for monsoon months (June- December) and seasons (southwest monsoon and northeast monsoon), it was found that in all the above cases, the number of years greater than Q_3, less than Q_1 and between Q_1 and Q_3 were 10, 10 and 17, respectively. Also, total number of years is 37 in all cases [6-7]. But the actual years receiving excess, normal and deficient rainfall and their amounts vary for monthly and seasonal rainfall in the different stations (Table 1-2).

Table 1 Range of excess, normal and deficit rainfall (mm) during SWM months in five stations

Month	Excess	Normal	Deficient
	Vellayani		
	Greater than (mm)	Range (mm)	Less than (mm)
June	326.3	183.2-326.3	183.2
July	232.1	108.7-232.1	108.7
August	189.3	87.2-189.3	87.2
September	223.0	68.9-223.0	68.9
SWM	931.8	610.7-931.8	610.7
	Kumarakom		
June	683.7	456.0-683.7	456.0
July	567.8	397.3-567.8	397.3
August	417.4	220.9-417.4	220.9
September	375.0	191.2-375.0	191.2
SWM	2003.4	1492.6-2003.4	1492.6
	Vellanikkara		
June	565.0	799.6-565.0	799.6
July	477.7	793.2-477.7	793.2
August	320.8	549.7-320.8	549.7
September	158.6	391.6-158.6	391.6
SWM	2385.0	2385.0-1703.0	1703.0
	Pilicode		
June	1117.5	903.8-1117.5	903.8
July	1167.0	721.0-1167.0	721.0
August	739.7	505.6-739.7	505.6
September	368.1	139.9-368.1	139.9
SWM	3245.0	2439.0-3245.0	2439.0
	Ambalavayal		
June	425.9	224.2-425.9	224.2
July	535.2	277.4-535.2	277.4
August	373.8	221.2-373.8	221.2
September	199.4	99.0-199.4	99.0
SWM	1444.0	1012.5-1444.0	1012.5

Table 2 Range of excess, normal and deficit rainfall (mm) during NEM months in five stations

Month	Excess	Normal	Deficient
	Vellayani		
	Greater than (mm)	Range (mm)	Less than (mm)
October	324.5	160.2-324.5	160.2
November	244.3	124.0-244.3	124.0
December	108.2	8.6-108.2	8.6
NEM	685.3	366.2-685.3	366.2
	Kumarakom		
October	407.7	170.8-407.7	170.8
November	199.8	64.2-199.8	64.2
December	60.9	2.0-60.9	2.0
NEM	580.7	297.4-580.7	297.4
	Vellanikkara		
October	194.7	386.7-194.7	386.7
November	22.1	151.2-22.1	151.2
December	24.4	0.0-24.4	0.0
NEM	483.5	303.5-483.5	303.5
	Pilicode		
October	345.2	136.7-345.2	136.7
November	106.8	37.6-106.8	37.6
December	23.6	0.0-23.6	0.0
NEM	425.7	223.1-425.7	223.1
	Ambalavayal		
October	270.6	138.0-270.6	138.0

November	120.6	37.1-120.6	37.1
December	31.6	0.0-31.6	0.0
NEM	397.6	297.4-397.6	297.4

Table 3 Conditional probabilities for southwest monsoon at Vellayani

Monthly rainfall		Probability (%) SWM rainfall		
		Excess	Normal	Deficient
June	Excess	60.00	30.00	10.00
	Normal	17.65	58.82	23.52
	Deficient	10.00	40.00	50.00
July	Excess	50.00	50.00	0.00
	Normal	23.52	35.29	41.18
	Deficient	10.00	60.00	30.00
August	Excess	40.00	60.00	0.00
	Normal	29.41	41.18	29.41
	Deficient	10.00	40.00	50.00
September	Excess	50.00	50.00	0.00
	Normal	17.65	52.94	29.41
	Deficient	20.00	30.00	50.00

Table 4 Conditional probabilities for southwest monsoon at Kumarakom

Monthly rainfall		Probability (%) SWM rainfall		
		Excess	Normal	Deficient
June	Excess	50.00	50.00	0.00
	Normal	29.41	47.06	23.53
	Deficient	20.00	50.00	30.00
July	Excess	60.00	30.00	10.00
	Normal	23.53	64.71	11.76
	Deficient	40.00	30.00	30.00
August	Excess	40.00	60.00	0.00
	Normal	23.53	41.18	35.29
	Deficient	10.00	50.00	40.00
September	Excess	60.00	30.00	10.00
	Normal	17.65	64.71	17.65
	Deficient	10.00	30.00	60.00

Table 5 Conditional probabilities for southwest monsoon at Vellanikkara

Monthly rainfall		Probability (%) SWM rainfall		
		Excess	Normal	Deficient
June	Excess	70.00	30.00	0.00
	Normal	17.65	47.06	35.29
	Deficient	0.00	60.00	40.00
July	Excess	70.00	20.00	10.00
	Normal	17.65	58.82	23.53
	Deficient	0.00	50.00	50.00
August	Excess	50.00	50.00	0.00
	Normal	23.53	47.06	29.41
	Deficient	10.00	40.00	50.00
September	Excess	40.00	50.00	10.00
	Normal	23.53	52.94	23.53
	Deficient	20.00	30.00	50.00

The conditional probabilities of southwest monsoon at Vellayani are given in (Table 3, Fig 1). When excess rainfall was received in the month of June, the probability for excess rainfall during southwest monsoon is 60 per cent at Vellayani. Similarly, there is about 59 per cent probability of southwest monsoon to have normal rainfall, when rainfall is normal in June at Vellayani [8]. Also, there is 50 per cent chance for southwest monsoon to have deficient rainfall, when deficient rainfall was received during June or August or September at Vellayani. (Table 4, Fig 2) give the conditional probabilities

computed for southwest monsoon rainfall to be excess, normal or deficient when monthly rainfall received is excess, normal or deficient at Kumarakom [9]. When the rainfall in July or September was in excess, Kumarakom received excess rainfall in southwest monsoon with 60 per cent probability. When normal rainfall was received in either in July or September, the probability of getting normal rainfall during southwest monsoon was 65 per cent [10-11]. The southwest monsoon season received deficient rainfall with 60 per cent probability, when September had deficient rainfall. The conditional probabilities of southwest monsoon rainfall at Vellanikkara are given in the (Table 5, Fig 3).
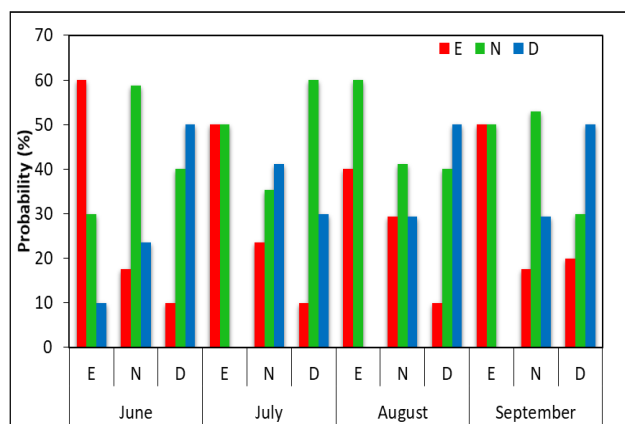

Fig 1 Conditional probabilities of southwest monsoon rainfall when monthly rainfall is excess/ normal/ deficient at Vellayani
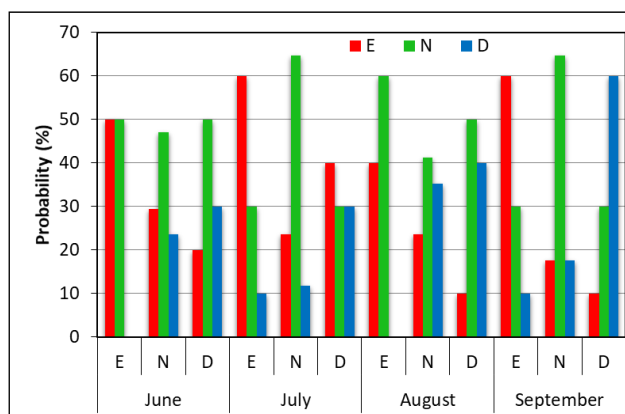

Fig 2 Conditional probabilities of southwest monsoon rainfall when monthly rainfall is excess/ normal/ deficient at Kumarakom
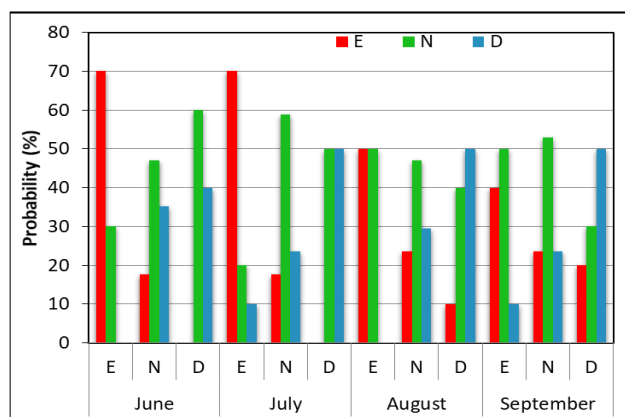

Fig 3 Conditional probabilities of southwest monsoon rainfall when monthly rainfall is excess/ normal/ deficient at Vellanikkara

Table 6 Conditional probabilities for southwest monsoon at Pilicode

Monthly rainfall		Probability (%) SWM rainfall		
		Excess	Normal	Deficient
June	Excess	40.00	40.00	20.00
	Normal	23.53	47.06	29.41
	Deficient	20.00	50.00	30.00
July	Excess	40.00	60.00	0.00
	Normal	35.29	47.06	17.65
	Deficient	0.00	30.00	70.00
August	Excess	70.00	30.00	0.00
	Normal	17.65	41.18	41.18
	Deficient	0.00	70.00	30.00
September	Excess	70.00	20.00	10.00
	Normal	5.88	70.59	23.53
	Deficient	20.00	30.00	50.00

Table 7 Conditional probabilities for southwest monsoon at Ambalavayal

Monthly rainfall		Probability (%) SWM rainfall		
		Excess	Normal	Deficient
June	Excess	50.00	40.00	10.00
	Normal	11.76	70.59	17.65
	Deficient	30.00	10.00	60.00
July	Excess	80.00	20.00	0.00
	Normal	11.76	64.71	23.53
	Deficient	0.00	40.00	60.00
August	Excess	40.00	50.00	10.00
	Normal	23.53	58.82	17.65
	Deficient	20.00	20.00	60.00
September	Excess	50.00	50.00	0.00
	Normal	29.41	47.06	23.53
	Deficient	0.00	40.00	60.00

Table 8 Conditional probabilities for northeast monsoon at Vellayani

Monthly rainfall		Probability (%) SWM rainfall		
		Excess	Normal	Deficient
October	Excess	60.00	40.00	0.00
	Normal	11.76	64.70	23.53
	Deficient	20.00	20.00	60.00
November	Excess	80.00	20.00	0.00
	Normal	11.76	64.71	23.53
	Deficient	0.00	40.00	60.00

Table 9 Conditional probabilities for northeast monsoon at Kumarakom

Monthly rainfall		Probability (%) SWM rainfall		
		Excess	Normal	Deficient
October	Excess	60.00	40.00	0.00
	Normal	23.53	58.82	17.65
	Deficient	0.00	30.00	70.00
November	Excess	70.00	30.00	0.00
	Normal	11.76	58.82	29.41
	Deficient	10.00	40.00	50.00

Vellanikkara received excess rainfall in southwest monsoon with 70 per cent probability when excess rainfall was received in either June or July [12]. The normal rainfall received in July had 59 per cent probability to determine the normal rainfall in southwest monsoon at the station. The deficient rainfall in any of the months of July, August and September could make the southwest monsoon rainfall deficient with 50 per cent probability, at Vellanikkara [13]. Pilicode had a high exceedance probability of 70 per cent for

southwest monsoon, when the rainfall in either August or September was excess (Table 6, Fig 4). Pilicode experienced a high chance of about 71 per cent for receiving normal rainfall in southwest monsoon when the rainfall in September was normal [14]. The deficiency in rainfall in the month of July determined the southwest monsoon rainfall to be deficient with 70 per cent probability, at Pilicode. Ambalavayal expected excess rainfall in southwest monsoon with 80 per cent probability, when excess rainfall occurred in July (Table 7, Fig 5). The southwest monsoon had normal rainfall with nearly 71 per cent probability when normal rainfall was received in June at Ambalavayal. Deficient rainfall in June, July, August and September equally influenced southwest monsoon rainfall to be deficient with 60 per cent probability for, at Ambalavayal [15].
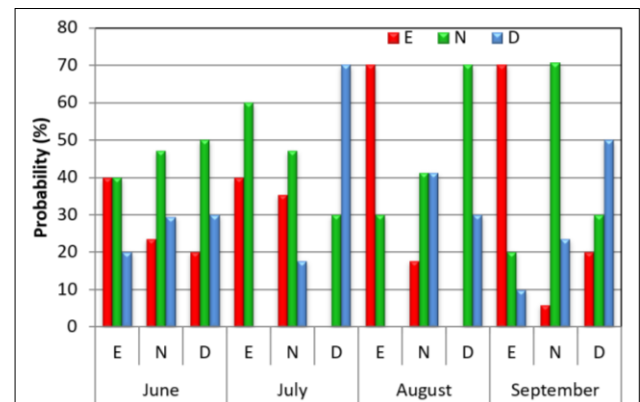

Fig 4 Conditional probabilities of southwest monsoon rainfall when monthly rainfall is excess/ normal/ deficient at Pilicode
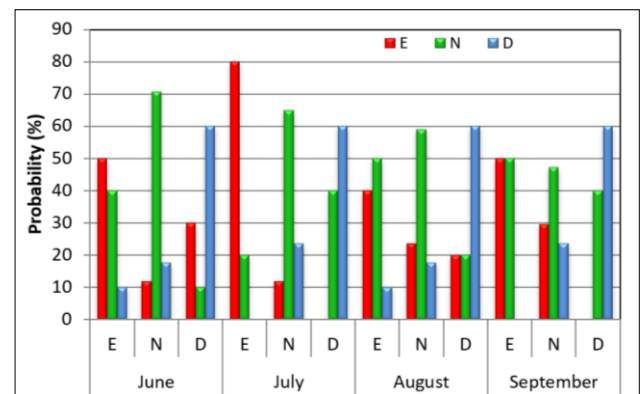

Fig 5 Conditional probabilities of southwest monsoon rainfall when monthly rainfall is excess/ normal/ deficient at Ambalavayal
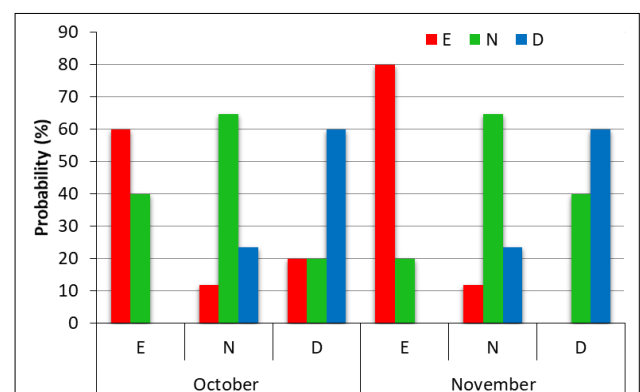

Fig 6 Conditional probabilities of northeast monsoon rainfall when monthly rainfall is excess/ normal/ deficient at Vellayani
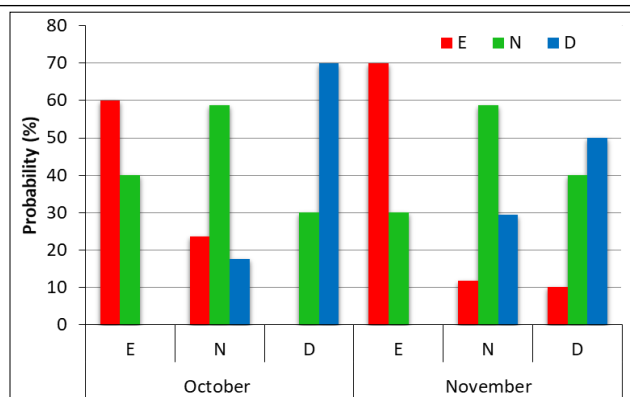
Fig 7 Conditional probabilities of northeast monsoon rainfall when monthly rainfall is excess/ normal/ deficient at Kumarakom
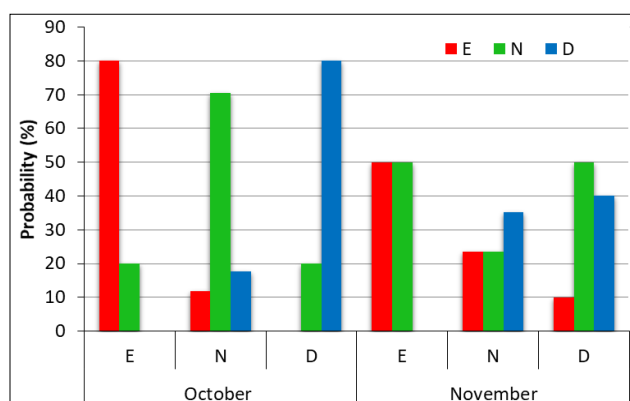

Fig 8 Conditional probabilities of northeast monsoon rainfall when monthly rainfall is excess/ normal/ deficient at Vellanikkara

Table 10 Conditional probabilities for northeast monsoon at Vellanikkara

Monthly rainfall		Probability (%) SWM rainfall		
		Excess	Normal	Deficient
October	Excess	80.00	20.00	0.00
	Normal	11.76	70.59	17.65
	Deficient	0.00	20.00	80.00
November	Excess	50.00	50.00	0.00
	Normal	23.53	23.53	35.29
	Deficient	10.00	50.00	40.00

Table 11 Conditional probabilities for northeast monsoon at Pilicode

Monthly rainfall		Probability (%) SWM rainfall		
		Excess	Normal	Deficient
October	Excess	90.00	10.00	0.00
	Normal	0.00	76.47	23.53
	Deficient	10.00	30.00	60.00
November	Excess	20.00	70.00	10.00
	Normal	41.18	35.29	23.53
	Deficient	10.00	40.00	50.00

When June rainfall was excess there was more than 50 per cent probability for southwest monsoon rainfall to be excess in Kerala [16]. This was in agreement with the results of conditional probabilities for all stations, except for Pilicode. At Vellayani (Table 8), the chance of receiving excess northeast monsoon rainfall was 80 per cent when rainfall in November was excess. The normal rainfall in both the months had about 65 per cent probability to determine normal rainfall in northeast monsoon. The deficient rainfall in October or

November could make northeast monsoon deficient with 60 per cent probability (Fig 6). At Kumarakom (Table 9, Fig 7), the probability was 70 per cent for northeast monsoon to receive excess rainfall when rainfall received in November was excess. The normal rainfall in both October and November had about 60 per cent probability to determine normal rainfall in northeast monsoon. When deficient rainfall was received in October, the northeast monsoon also had deficient rainfall with approximately 70 per cent probability. Vellanikkara possessed greater probability of 80 per cent to receive excess rainfall in northeast monsoon season when rainfall in October was excess (Table 10, Fig 8).

Table 12 Conditional probabilities for northeast monsoon at Ambalavayal

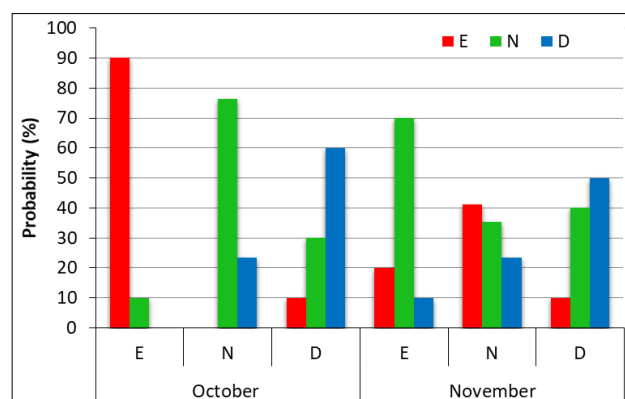| Monthly rainfall		Probability (%) SWM rainfall		
		Excess	Normal	Deficient
October	Excess	70.00	30.00	0.00
	Normal	17.65	64.71	17.65
	Deficient	0.00	30.00	70.00
November	Excess	30.00	60.00	10.00
	Normal	35.29	35.29	29.41
	Deficient	10.00	50.00	40.00

Fig 9 Conditional probabilities of northeast monsoon rainfall when monthly rainfall is excess/ normal/ deficient at Pilicode
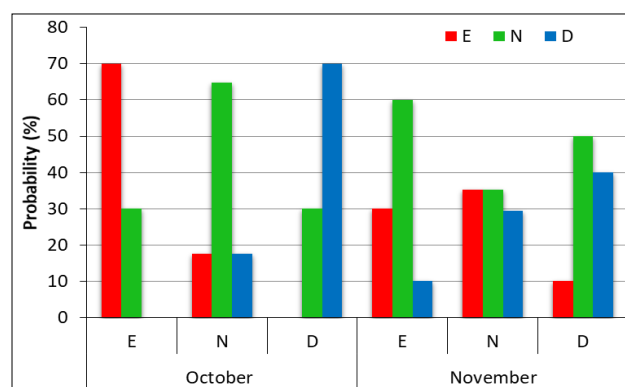

Fig 10 Conditional probabilities of northeast monsoon rainfall when monthly rainfall is excess/ normal/ deficient at Ambalavayal

The normal rainfall in October determined the normal rainfall in northeast monsoon at 70 per cent probability level. The month of October also determined deficiency in rainfall received during northeast monsoon with higher probability (80 per cent). From (Table 11, Fig 9), it is clear that there is a high probability (90 per cent) for northeast monsoon to have excess rainfall at Pilicode when excess rainfall was received in October. When normal rainfall was received in October, there

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was a higher chance (about 75 per cent) for northeast monsoon also to receive normal rainfall. The deficient rainfall in October had relatively higher probability (60 per cent) than November (40 per cent) in deciding deficient rainfall in northeast monsoon [17]. From (Table 12, Fig 10), it could be observed that, Ambalavayal had 70 per cent probability for northeast monsoon to get excess rainfall when excess rainfall occurred in October. When normal rainfall was received in October, there was a higher chance (about 65 per cent) for northeast monsoon also to receive normal rainfall. The month of October also determined deficiency in rainfall received during northeast monsoon at Ambalavayal, with 70 per cent probability [18].

CONCLUSION

The information on the probabilities for excess/normal/deficient rainfall conditions during southwest and northeast monsoon seasons according to the occurrence of excess/normal/deficient rainfall during the months falling under each season helps the planners and farmers in taking timely decision.

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