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On the occurrence of wet and dry spells in Bihar

A. CHOWDHURY
Meteorological Office, Pune
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ABSTRACT. Probability concept has been adopted to demonstrate the importance of dry and wet spells for planning weather sensitive agricultural operations. Daily rainfall data from 1 June to 31 October for the period 1936 to 1969 for six stations in Bihar have been analysed. Each month has been divided into three, 10 or 11 day periods as the case may be. Basic and transitional probabilities of a dry or wet day, depending upon the state of weather on the previous day(s) have been determined and discussed.

1. Introduction

The pre-sowing preparation of fields, transplanting nursery palms, application of fertilizers, etc are a few of weather senstive operations which require specific rainfall conditions for their most successful and economic completion. Short range weather forecasting has not yet reached a stage of practical possibility, and so, recourse has to be taken for minimising the risk of the weather hazard by making use of climatological analysis of past weather data. The method of presenting climatological information for annual or short periods, such as, months is in the form of arithmetic means, which though useful may sometimes give misleading results. Since occurrence of a given amount of rain is beset with uncertainty, the probability analysis, do have distinct advantages over the study of arithmetic means.

In this papers Markov chain technique has been adopted to estimate the probabilty of dry and wet spells.

2. Past studies

A number of studies on wet and dry spells have been conducted in India during past few years. Rainfall days at Delhi have been studied by Sarma 1952. Gupta (1966) studied these spells for a few selected stations of Rajasthan. Recently, Chowdhury *et al.* (1979) examined dry spells over Maharashtra and concluded that the core of the drought area is situated over Ahmednagar district.

Gabriel and Neumann (1962) showed that Markov chain model could be used to describe precipitation patterns. Gaskey (1963) pointed out the seasonal variation in transitional probabilities. Feyerherm and Bark (1965) justified the use of a second order Markov chain model in dry spell analysis and found no substantial evidence for the use of third or higher order in preference to a second order chain. Robertson (1976) used Markov chain for estimating probabilities at Ule Jempol (Malaysia) and demonstrated its practical application.

3. Data used

In this study, six stations in Bihar (*viz.*, Gaya, Purnea, Motihari, Darbhanga, Muzaffarpur and Chapra) for which continuous data are available have been chosen. Daily rainfall data from 1 June to 31 October from 1936 to 1969 are used. Each month is divided into 3 periods (*i.e.*, 1-10, 11-20 and 21-30 or 31) and probabilities of dry and wet spells are worked out.

4. Definitions

A day is defined as wet (dry) if the rainfall on that day is greater than or equal to (less than) 2.5 mm. A wet (or dry) spell is a sequence of consecutive wet (dry) days. $F(W)$ and $F(D)$ are frequencies of wet or dry days in a given period, respectively. $F(W/D)$ is the frequency of wet days given that previous day was dry. $F(W/W)$, $F(D/W)$ and $F(D/D)$

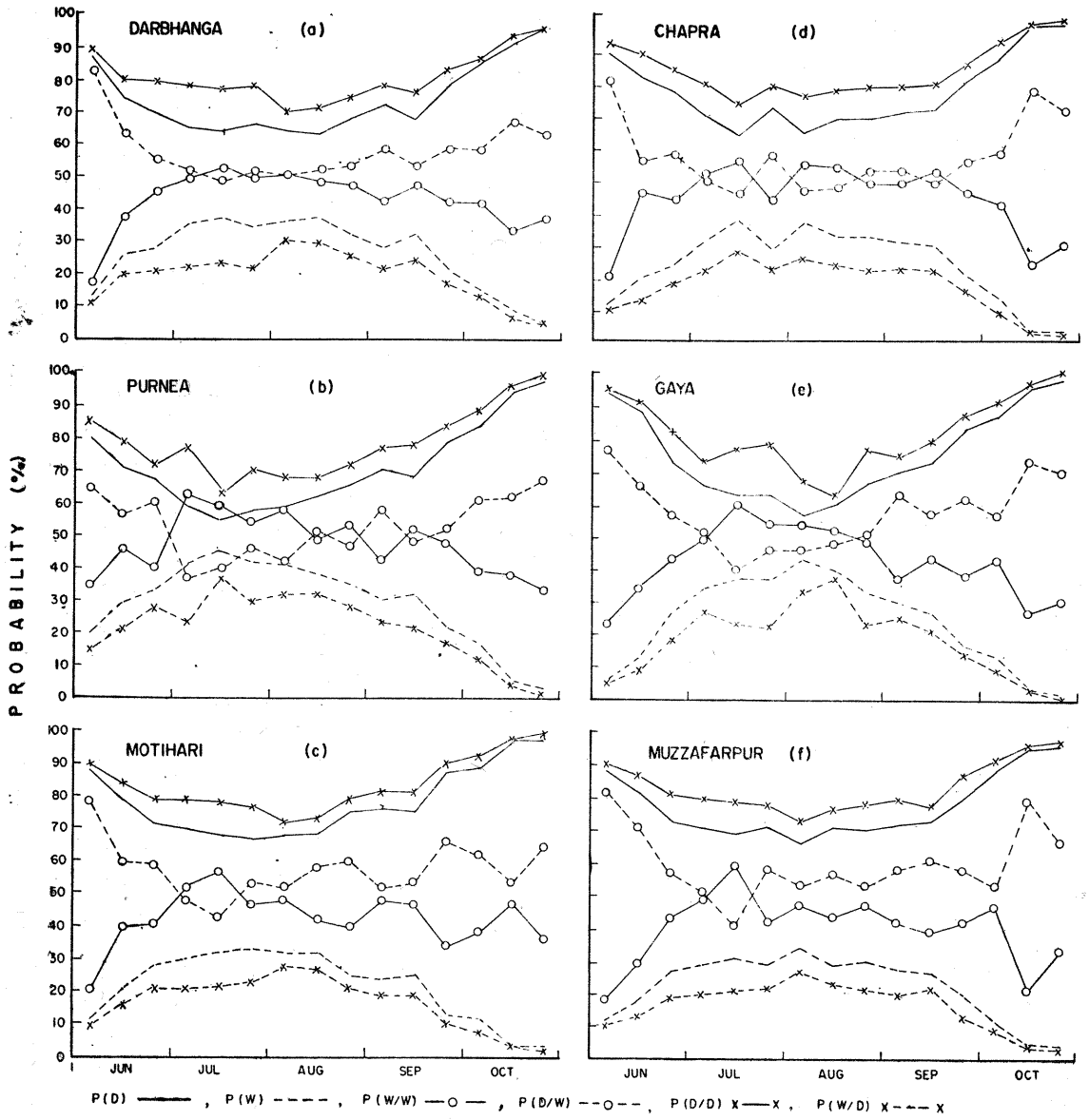

Fig. 1. (a-f). The initial probability of wet/dry and the conditional probabilities of these days determined by the state of preceding day

have similar meaning. $P(W/D)$ is the probability of a wet day given that previous day was dry. $P(W/W)$, $P(D/W)$ and $P(D/D)$ are the transitional probabilities and have similar definitions.

From the above it follows that :

$$P(W) = F(W) / F(W)+F(D) \quad (1)$$

$$P(D) = 1-P(W) \quad (2)$$

$$P(D/D) = F(D/D)/F(D/D)+F(W/D) \quad (3)$$

$$P(W/D) = 1-P(D/D) \quad (4)$$

$$P(W/W) = F(W/W)/F(W/W)+F(D/W) \quad (5)$$

$$P(D/W) = 1-P(W/W) \quad (6)$$

5. Discussion and interpretation

Initial and transitional probabilities have been computed and illustrated in Figs. 1 (a-f) and are discussed below :

5.1. *Number of wet and dry days*

For all stations the probabilities of dry days $P(D)$ is greater than that of wet day $P(W)$ for all periods. In nearly all cases, $P(D)$ exceeds 55 per cent. It is more than 90 per cent in the later half of October, perhaps as result of monsoon withdrawal. Probability of wet days is, com-

TABLE 1

Transitional probabilities of weather on t^{th} day from those of two preceding days

Period	P (*DWD*)	P (*WWD*)	P (*DWW*)	P (*DDD*)	P (*WWW*)	P (*DDW*)	P (*WDD*)	P (*WDW*)
				(a) Darbhanga				
1-10 Jun	8	2	2	69	0	10	9	1
11-20 Jun	9	7	6	47	4	13	12	3
21-30 Jun	8	7	7	45	6	12	12	3
1-10 Jul	7	7	9	39	8	14	11	4
11-20 Jul	7	8	9	38	10	14	11	4
21-31 Jul	7	7	8	40	8	13	11	4
1-10 Aug	10	9	9	31	9	13	13	4
11-20 Aug	9	9	9	32	9	14	13	5
21-31 Aug	9	8	8	37	7	13	13	5
1-10 Sep	9	7	7	44	5	13	12	4
11-20 Sep	9	8	8	39	7	13	12	4
21-30 Sep	8	6	4	54	4	11	11	2
1-10 Oct	6	5	4	64	3	7	10	1
11-20 Oct	4	2	2	79	1	6	6	0
21-31 Oct	3	2	1	86	1	3	5	0
				(b) Purnea				
1-10 Jun	8	4	5	58	2	11	10	2
11-20 Jun	8	7	7	45	6	14	12	3
21-30 Jun	11	7	8	35	5	14	13	5
1-10 Jul	5	9	9	35	16	12	10	3
11-20 Jul	8	12	11	22	16	11	13	7
21-31 Jul	8	9	10	28	12	13	12	6
1-10 Aug	8	11	10	27	14	12	13	6
11-20 Aug	10	10	9	29	9	13	13	6
21-31 Aug	9	10	9	34	10	13	13	5
1-10 Sep	9	7	7	41	5	13	12	4
11-20 Sep	7	8	8	41	9	12	12	3
21-30 Sep	7	6	5	54	5	9	11	2
1-10 Oct	6	4	4	64	3	9	9	1
11-20 Oct	2	1	1	87	1	3	4	0
21-31 Oct	1	0	1	95	0	2	1	0
				(c) Motiharl				
1-10 Jun	7	2	2	71	0	9	8	1
11-20 Jun	7	5	5	56	3	11	11	2
21-30 Jun	9	6	7	45	5	13	12	3
1-10 Jul	7	8	7	44	8	11	12	3
11-20 Jul	6	9	8	41	10	11	12	3
21-31 Jul	8	7	8	40	7	13	12	4
1-10 Aug	10	9	8	35	7	12	14	5
11-20 Aug	11	8	8	36	6	13	13	5
21-31 Aug	9	6	6	47	4	12	12	3
1-10 Sep	7	7	6	50	5	10	12	2
11-20 Sep	7	7	6	49	5	11	11	3
21-30 Sep	6	3	3	70	1	8	8	1
1-10 Oct	4	3	3	74	2	7	6	1
11-20 Oct	7	6	1	91	1	1	3	0
21-31 Oct	7	4	1	93	0	2	2	0

TABLE 1—*Contd.*

Period	*P* (*DWD*)	*P* (*WWD*)	*P* (*DWW*)	*P* (*DDD*)	*P* (*WWW*)	*P* (*DDW*)	*P* (*WDD*)	*P* (*WDW*)
(d) Chapra								
1-10 Jun	6	1	2	73	0	9	7	1
11-20 Jun	5	4	5	63	4	9	9	1
21-30 Jun	7	6	6	53	4	11	11	2
1-10 Jul	7	7	8	43	8	12	11	3
11-20 Jul	8	9	9	33	11	12	12	4
21-31 Jul	9	7	7	44	5	12	12	3
1-10 Aug	7	9	9	36	10	12	12	4
11-20 Aug	7	8	9	40	9	11	12	3
21-31 Aug	8	7	8	41	7	13	12	4
1-10 Sep	8	7	7	43	7	12	12	3
11-20 Sep	7	8	7	44	8	11	12	3
21-30 Sep	7	5	5	58	4	9	10	2
1-10 Oct	4	3	3	74	2	7	6	1
11-20 Oct	2	1	0	91	0	2	3	0
21-31 Oct	1	1	1	93	0	2	2	0
(e) Gaya								
1-10 Jun	4	1	1	84	0	4	4	0
11-20 Jun	5	3	3	72	1	8	7	1
21-30 Jun	7	6	7	49	5	13	11	3
1-10 Jul	9	9	8	35	8	13	13	5
11-20 Jul	6	9	9	37	13	11	11	3
21-31 Jul	6	7	9	38	11	13	11	4
1-10 Aug	9	10	10	25	13	13	13	7
11-20 Aug	11	11	10	24	11	12	14	7
21-31 Aug	8	7	8	40	8	13	12	4
1-10 Sep	11	7	7	39	4	14	13	5
11-20 Sep	9	7	7	45	5	12	12	3
21-30 Sep	7	4	4	63	3	9	9	1
1-10 Oct	4	3	3	72	2	7	7	1
11-20 Oct	2	1	1	90	0	3	3	0
21-31 Oct	0	0	0	98	0	1	0	0
(f) Muzaffarpur								
1-10 Jun	7	1	2	71	0	9	8	1
11-20 Jun	7	3	4	62	1	11	9	2
21-30 Jun	8	6	7	48	5	12	11	3
1-10 Jul	7	7	7	45	7	12	11	3
11-20 Jul	6	9	7	43	11	19	11	3
21-31 Jul	9	7	7	43	5	13	12	4
1-10 Aug	9	8	8	35	7	13	13	5
11-20 Aug	9	7	7	42	5	13	13	4
21-31 Aug	8	7	7	43	7	12	12	3
1-10 Sep	8	6	7	46	5	13	11	3
11-20 Sep	10	6	6	44	4	13	13	4
21-30 Sep	6	4	5	61	3	10	9	1
1-10 Oct	4	4	3	73	3	6	7	1
11-20 Oct	3	1	1	87	0	4	4	0
21-31 Oct	2	1	1	90	0	3	3	0

paratively less. The number of dry or wet days is obtained by multiplying the probability by 10 for all periods except 21-31 of July, August and October, when it is multiplied by 11. The largest number of wet days expected would be 3.4 and 4.6 in 1-10 August at Muzaffarpur and Gaya respectively, 3.7 between 21-31 July at Darbhanga and 3.5 between 21-31 July at Motihari, 4.6 between 21-31 July at Purnea, and 3.8 between 11-20 July at Chapra.

5.2. *Large wet/dry spells*

In any period the larger the values of transitional probabilities $P(W/W)$ and $P(D/D)$, the greater will be the probability of a long continuous wet or dry spell. These probabilities have also been shown in Fig. 1(a-f). As expected, largest spells of wet days should occur either in July or in early August, because during this period the monsoon activity is at its peak.

Largest wet spells at all the stations are experienced during 11-20 July. Occasions of a wet day preceded by a wet day are 6.3 at Purnea, 6.1 at Gaya, 5.9 at Muzaffarpur, 5.7 at Motihari, 5.5 at Chapra and 5.2 at Darbhanga.

Monsoon withdraws from Bihar around second week of October. Consequently, largest dry spells should be expected during this month particularly between 21-31 October, when out of 11 days at least on 10 occasions if a day is dry on the previous day, it is dry as well on the succeeding day. In terms of frequencies these are 11.0 at Gaya, 10.9 at Purnea, 10.8 at Chapra and Motihari, 10.7 at Muzaffarpur and 10.5 at Darbhanga.

5.3. *Persistence in rainfall occurrence*

To find out persistence in rainfall occurrence, probability of two consecutive wet days, *i.e.*, $P(W/W)$, starting with a rainy day (*i.e*, $P(W)_{-1} = 1{\cdot}0$) is determined.

The theoretical probability of

$$P(W/W) = P(W)_{-1} \times P(W)$$

$$= 1 \times P(W) = P(W) \qquad (7)$$

The theoretical value of $P(W/W)$ or $P(W)$ is then compared with observed $P(W/W)$. If theoretical probability is less than observed probability, it can be deduced that given previous day being wet *i.e.*, $[P(W)_{-1} = 1{\cdot}0]$, the probability that the following day will be wet is greater than would be expected, if the two events were random, *i.e.*, there is some persistence in rainfall. (Robertson 1976).

From Fig. 1 it is evident that observed probability is much larger than the theoretical one. It, therefore, appears that strong persistence in rainfall do exist during southwest monsoon.

5.4. *Persistence in dry days*

By the same analogy a comparison of $P(D/D)$ with $P(D)$ would enable to determine persistence in dry days. Form Fig. 1 it is seen that these two probabilities are nearly equal although the former is slightly greater than the latter in most of the cases. As such, it can be said that the persistence present in the occurrence of dry spell is rather a weak.

Thus during monsoon season, the weather can at times be persistently dry, it appears that severe drought is highly improbable over Bihar.

6. The second order Markov chain

6.1. *Effect of weather of preceding two days on the state of the day*

Let *WtWD* represent an occasion when the *t*th day is wet, (*t*-1)th day is also wet and (t-2)th day is dry. For sake of brevity this is denoted as *WWD*. Similar definition hold good for *WWW, WDW, DWD, DWW, DDD* and *WDD*.

The probability of *t* th day being wet, on the condition that (*t*-1)th day is also wet and (*t*-2)th day is dry, *i.e.*, P(WWD), can be computed from the basic probability. $P(D)$ and the transitional probabilities $P(W/W)$ and $P(W/D)$ and is given by :

$$P(WWD) = P(D) \times P(W/D) \times P(W/W) \qquad (8)$$

The other probabilities like $P(WDW)$, etc can be similarly obtained. These probabilities have been given in Table I and discussed below :

The probability of wet day in between two dry days, *i.e.*, $P(DWD)$ rarely exceeds 10 per cent. Low values generally occur during October month. The probability of two wet days succeeding a dry day, *i.e.*, $P(WWD)$ are, in general less than $P(DWD)$. The values are practically less than 5 per cent in the beginning of the monsoon as well as in the October month. Only at Purnea and Gaya, probability does attain large values in the range of 10-11 per cent.

The probability of three consecutive dry days, *i.e.*, $P(DDD)$ assumes high values for all stations in the beginning of June itself when it exceeds 70 per cent, Purnea being exception where the value is about 60 per cent. In the subsequent period there is a gradual fall in the probability. At Darbhanga the lowest value of about 30 per

cent is observed during 1-20 August. The lowest value of about 35 per cent is observed during 1-20 August at Motihari and during 1-10 August at Muzaffarpur while at Chapra the value of this magnitude is attained during 11-20 July. Values less than 30 per cent are observed only at Purnea (11 July to 20 August) and at Gaya (1-20 August), the lowest being 22 per cent during 11-20 July at Purnea and 24 per cent during 11-20 August at Gaya. The probability of $P(DDD)$ subsequently increases rapidly and assumes greater than 75 per cent from 11 October for all stations, the values being 90 per cent or more during 21-31 October.

The probability of three consecutive wet days $P(WWW)$ is zero as shown below :

Period	*Stations*
1-10 Jun	Darbhanga
21-31 Oct	Purnea
1-10 Jun & 21-31 Oct	Motihari
1-10 Jun & 11-31 Oct	Chapra, Gaya & Muzaffarpur

The highest probability of 10-11 per cent is seen at Motihari, Muzaffarpur and Darbhanga during 11-20 July while at Chapra, this is reached during two periods, *viz.*, 11-20 July and 1-10 August. At Purnea and Gaya in most parts of July and August the values are slightly high, particularly at Purnea in July when it exceeds 15 per cent.

The probability of a wet day followed by two consecutive dry days is 10-14 per cent during the monsoon months. Only towards the end of September and October months, the values fall below 10 per cent. The spell of a dry day between two wet days, *i.e.*, WDW, appears to be rather uncommon. Largest values are between 6-7 per cent at Purnea from 11 July to 20 August and at Gaya between 1-20 August. At other places in all the periods and at these two stations in the remaining periods, the values are less than 5 per cent. In fact, after 11 October, the probability is invariably zero, suggesting that a dry day between two wet days after 11 October may rarely occur.

7. Conclusions

The study revealed that (*i*) the probability of a dry day far exceeds that of a wet day even in the rainiest months of July and August. Only 3 to 4 rainy days can be expected in any 10 day periods in these months, (*ii*) Strong persistence in rainfall is observed contributing to frequent floods but severe droughts appear to be improbable over Bihar, (*iii*) High probability of a dry day is observed particularly in early June and October, irrespective of the conditions of previous two days; correspondingly, the probability of a third day being wet is generally small.

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