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Original Research Article

A Markov Chain Approach for Wet and Dry Spell and Probability Analysis

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A B S T R A C T

Sequence of dry and wet periods along with onset and withdrawal of rainy season is necessary for successful agricultural crop planning and soil and water conservation measures. In the present study, Markov chain probability model to calculate the chances of occurrences of dry and wet spells was applied for Mayurbhanj using 20 years (1997 to 2016) weekly rainfall. The rainfall characteristics were analyzed on annual, seasonal, monthly and weekly basis. The average annual rainfall of Mayurbhanj was found to be 1790.8 mm and coefficient of variation (CV) was 11.8 % which is less than threshold limit that indicates that the rainfall is highly dependable. Monsoon starts on the 24th standard meteorological week (SMW) (11 – 17th June) and remains active up to 43rd SMW 22-28th October) with a total length of 20 weeks (140 days). Initial, conditional and consecutive dry and wet week probabilities showed that chances of occurrence of a week getting wet is high during from 24th week onwards upto 40th week. Chances of occurrence of wet week of more than 50% at the beginning of Kharif season indicates that summer ploughing and initial seed bed preparations shall be taken up in the 20th – 22nd SMW (14th May - 3rd June) and sowing operations can be taken up since 23rd SMW (4th – 10th June). Lower values of CV showed that variability of rainfall during this period is very less which enables the growing of rainfed crops. During the rabi season, from 46th week to 50th week there is chance of occurrence of wet week is about 30%. During this crop season the CV is more than threshold limit of 50 percent. This indicates less dependability of rainfall during this period. Hence, agricultural operations like planting/sowing can be undertaken successfully during this period with assured irrigation

Keywords

Markov chain model, Wet and dry week, Weekly rainfall, Coefficient of variation, Onset and withdrawal of rainy season

Introduction

In a predominantly agricultural system, natural rainfall is the main source of water for agricultural sector. Absence of rainfall or minimal rainfall results in drought. As a result, the vegetation period is expected to become shorter and shorter with irregular distribution of rainfall (IPCC, 2008). Dry spell is a period where the weather has been dry, for an abnormally long time, shorter than and not as severe as a drought (Wilhite and Glantz, 1985). The success or failure of the crops is highly related with the occurrences of dry spells. The information on the length of dry spells could be used for deciding a particular crop or variety, supplementary irrigation water demand (Mathlouthi and Lebdi, 2008; Admasu *et al.*, 2014), breeding varieties of various maturity

durations and field operations in agriculture in a specific location (Sivakumar, 1992; Taley and Dalvi, 1991; Sharma, 1996). Crop growth performs well with uniformly spread 'light' rains than with a few 'heavy' rains interrupted by dry periods. In cropping calendar of plants, the timing of breaks in rainfall (dry spells) is critical to crop viability than total seasonal rainfall (Usman and Reason, 2004). Moreover, Simane and Struick (1993) reported that the amount of rainfall and its distribution in a given season is critical for crop production. Uneven distribution of rainfall could lead crops to different degrees of dry spells without significant reductions in total rainfall (Barron *et al.,* 2003; Manikandan *et al.,* 2017). Dry and wet spell analysis assists in estimating the probability of intra-seasonal drought and management practices can be adjusted accordingly (Kumar and Rao, 2005).

The purpose of estimating probability with respect to a given amount of rain fall is extremely useful for agricultural planning. In a growing season decisions have to made based on the probability of receiving certain amount of rainfall during a given decade. The probability of rain during next week, if rain occurs this week known as conditional probability of a wet week preceded by a wet week (PWW), and the probability of rain next week being wet, if this week is dry known as conditional probability of a wet week preceded by a dry week (PWD). Analogously initial and conditional probability for a dry week can be defined (Srinivasa *et al.,* 2008). These initial and conditional probability would help in determining the relative chance of occurrence of a given amount of rain fall and the chance of any threshold amount of rain fall depends on the purpose for which the different probability may be computed (Virmani, 1976).

Reddy (1990) stated that 3mm rainfall depth per day is the minimum threshold value for crops to satisfy their crop water requirement during a growing season. In his study Reddy (1990) described wet spell duration as a sequence of wet decades preceded and followed by the dry decades and correspondingly the dry spell duration is the sequence of dry decades followed and preceded by the wet ones. Prior knowledge of dry spell studies can be applied to generate synthetic sequences of rainfall and to the estimation of the irrigation water demand. The longest period of several long dry spells is of crucial importance in planning agricultural Sifer *et al.,* (1993) activities and managing the associated water supply systems (Sharma, 1996). Since drying (the dry period) in one year is not necessarily the same as in another year, thus knowledge of behaviour of these patterns has become increasingly important to understand. For assessing the dry and wet spell distribution, a number of probability models have been developed in many studies to describe the pattern of rainfall distributions (Manning, 1950; Feyerherm and Bark, 1967; Kulandaivelu, 1984; Phien and Ajirajah, 1984; Topalogu, 2002). Aneja and Srivastava (1986, 1999) came up with two-state (with two parameters) and three-state (with five independent parameters) Markov chain models to study the pattern of occurrence of rainfall. Purohit *et al.,* (2008) used two-state Markov chain model to find the probabilities of occurrence of dry and wet weeks. The probability analysis of dry and wet spell distribution is believed to help in support of planning agricultural water management, particularly during the rainy season. Therefore, this study aims to analyze dry spell lengths and its implications on crop production in Mayurbhanj district of Odisha, so as to minimize unexpected damage due to long dry spells and to have effective and efficient planning for farming communities

Materials and Methods

Daily rainfall data was recorded for Mayurbhanj district for a period of 47 years (1997 – 2016) was processed and converted into weekly rainfall. Assessment of dry and wet spell has been carried out using weekly rainfall data based on Markov chain probability model. A week is considered as a dry week when rainfall is less than 20 mm in a week and when rainfall is more than 20 mm it is a wet week (Pandharinath, 1991). Markov chain probability model has been found suitable to describe the long-term frequency behaviour of wet or dry spells. Markov chain probability model assumes that the probability of rainfall occurring on any week depends on whether the previous week was wet or dry. Rainfall amount is involved only in the definition of occurrence or non-occurrence of rain. In the first order Markov chain the probability of an event that would occur on any single day depends only on the conditions during the preceding day and is independent of events of further preceding days. The model calculates the initial probabilities of getting a dry spell / wet spell in a given standard meteorological week. The calculation of conditional probabilities provides the information on the dry spell followed by dry spell or wet spell *vice-versa*. The calculation of initial and conditional probabilities are given below;

Initial rainfall probability (%)

Initial rainfall probability of getting less than 20 mm rainfall of week Wx

$$P_D = \frac{F_D}{N}$$

$$P_W = \frac{F_W}{N}$$

Conditional rainfall probability (%)

Conditional rainfall probability (%) of getting less than 20 mm rainfall during next week also when there was rainfall of > 20 mm during this week (x)

$$P_{DD} = \frac{F_{DD}}{F_D}$$

$$P_{WW} = \frac{F_{WW}}{F_W}$$

$$P_{DW} = 1 - P_{WW}$$

Consecutive dry and wet week probabilities

Probability of 2 consecutive dry weeks starting with the week

$2D = P_{DW1}P_{DDW2}$
$2W = P_{wW1}P_{WWW2}$
$3D = P_{DW1}P_{DDW2}\ P_{DDW3}$
$3W = P_{WW1}P_{WWW2}\ P_{WWW3}$

Where,

P_D - Probability of the week being dry

P_W - Probability of the week being wet

N - Number of years of data

F_D - Number of dry weeks

F_W - Number of wet weeks
N - Number of years of data

P_{DD} - Probability (conditional) of a dry week preceded by a dry week

P_{WW} - Probability (conditional) of a wet week preceded by a wet week

P_{WD} - Probability (conditional) of a wet week preceded by a dry week

P_{DW} - Probability (conditional) of a dry week preceded by a wet week

F_{DD} - Number of dry weeks preceded by another dry week

F_{WW} - Number of wet weeks preceded by another wet week

2D - Probability of 2 consecutive dry weeks starting with the week 2W - Probability of 2 consecutive wet weeks starting with the week 3D - Probability of 3 consecutive dry weeks starting with the week 3W - Probability of 3 consecutive wet weeks starting with the week

P_{Dw1} - Probability of the week being dry (first week)

P_{DDw2} - Probability of the second week being dry, given the preceding week dry

P_{DDw3} - Probability of the third week being dry, given the preceding week dry

P_{Ww1} - Probability of the week being wet (first week)

P_{WWw2} - Probability of the second week being wet, given the preceding week wet

P_{WWw3} - Probability of the third week being wet, given the preceding week wet

Onset and withdrawal of rainy season

Forward and backward accumulation methods were used for computation of onset and withdrawal of rainy season from weekly rainfall data. In this method weekly rainfall was summed by forward accumulation (20+21+…+ 52 weeks) until a certain amount of rainfall was accumulated. Seventy five millimetres of rainfall accumulation has been considered as the onset time for the growing season of dry seeded crops and land preparation (Babu and Lakshminarayana, 1997; Panigrahi and Panda, 2002). The withdrawal of rainy season was determined by backward accumulation of rainfall (48+47+46+…+30 weeks) data. Twenty millimetres of rainfall accumulation was chosen for the end of rainy season, which is sufficient for ploughing of fields after harvesting the crops (Babu and Lakshminarayana, 1997).

Probabilities of onset and withdrawal of rainy season

The percent probability (P) of each rank was calculated by arranging them in ascending order and by selecting highest rank allotted for particular week. The following Weibull's formula has been used for calculating percent probability:

$$P = \frac{m}{N+1}$$

Where, m is the rank number and N is the number of years of data used.

Results and Discussion

Rainfall characteristics

The mean annual rainfall at Mayurbhanj (Figure 1) was found to be 1600.2 mm and it varied from 1460.9 (lowest in 2016) to 2174.4 mm (highest in 1999) with standard deviation (SD) of 208.74 mm. The average annual rainy days was 100 which were between 74 days (2016) and 119 days (1997). It was also observed that over the study period, 20 years (90%) received rainfall above annual average. Analysis of

seasonal rainfall showed that the rainfall contributed to the annual rainfall during the winter (Jan-Feb), summer (March-May), southwest (Jun-Sep) and northeast monsoon (Oct-Dec) were 8, 14, 70 and 8 per cent respectively.

The highest mean monthly rainfall (Figure 2) was received during July (429.93) followed by August (360.07 mm), June (302.04mm), September (283.29 mm) and May (181.55 mm). The minimum rainfall of 7.95 mm was received in the month of December, it was followed by January (15.89 mm). The average monthly rainy days was 8 and only five months experienced more than the average rainy days. The maximum rainy days were in the month of July (20 days) followed by August (19 days), June (16 days) and the minimum rainy days were in the month of January followed by February.

The weekly mean rainfall, rainy days and coefficient of variation were also computed and tabulated (Table 1). The maximum weekly rainfall was recorded in the 28th week (114.47 mm) followed by 30th week (103.52 mm). Twenty one weeks (40per cent) received a rainfall less than the average weekly rainfall of 35 mm. The maximum number of weekly rainy days (more than 2 days per week) was recorded from 18th to 40th week.

The coefficient of variation (CV) in percentage is an indicative of dependability of rainfall. The threshold levels for CV for any interpretation are < 25, < 50, < 100 and < 150 per cent for annual, seasonal, monthly and weekly rainfall respectively (Manorama *et al.*, 2007). If the CV is within the threshold limit of variability, it is considered that the rainfall is highly dependable and *vice-versa.* At Mayurbhanj CV of annual rainfall was found to be 11.8% which is lower than threshold limit, so it indicates that the mean annual rainfall amount is highly dependable.

The CV of winter, summer, southwest and northeast monsoon was found to be 117.5, 63.6, 27.4 and 127.2 per cent respectively. The CV of seasonal rainfall was found to be lower than the threshold limits which indicates rainfall is much dependable around mean seasonal rainfall.

The monthly rainfall CV varied from 19 % in August to 125.3 % in January. The CV of March to October was well within the threshold limits (< 100%) which shows dependable rainfall around the mean monthly rainfall at Mayurbhanj station.

Onset and withdrawal of rainy season

The data on onset, withdrawal and duration of the rainy season (difference between onset and withdrawal time) and its variability in Mayurbhanj are presented in Table 2. Weekly rainfall data of 20 years (1997 – 2016) indicated that the monsoon starts effectively from 24th standard meteorological week (SMW) (11 – 17th June) and remains active up to 43rd SMW (22-28th October). Therefore, mean length of rainy season was found to be 20 weeks (140 days) which include rainfall of both south west and north east monsoon.

The earliest and delayed week of onset of rainy season was 20th SMW (14-20th May) and 29th SMW (16-22nd July) respectively. Similarly the earliest and delayed week of termination of rainy season was 41st SMW (8 – 14th October) and 45th SMW (5-11th November) respectively. The longest (subtraction of earliest rainy season and delayed withdrawal of rainy week) and shortest length of rainy season was 30 and 16 weeks respectively.

The probabilities of onset and withdrawal of rainy season was calculated by Weibull's formula and results are presented in Table 3. The results reveal that there is a 75 % chance that the onset of rainy season and termination of rainy season will occur during 23rd and 45th SMW respectively.

Initial, conditional probabilities and consecutive dry and wet week probabilities of rainfall at Mayurbhanj

Initial, conditional probabilities and consecutive dry and wet week probabilities calculated for Mayurbhanj are presented in Table 4 for all the 52 standard meteorological weeks. The results in relevance with rainy season starts from the first week of June and ends during the last week of October (20th SMW – 45th SMW) only are discussed.

From the Table, initial probabilities showed that chances of occurrence of a week getting dry is high during early part of the season and the probability decreases with the progress of rainy season from 34th week onwards. Subsequently chance of occurrence of a week getting wet is high upto 45th week due to heavy downpour during north east monsoon.

Parallel patterns are followed for conditional probabilities and consecutive dry and wet week probabilities. The chances of occurrence of dry week preceded by another dry week (P_{DD}) are less during monsoon periods particularly from 38 to 44th SMW. The chances of occurrence of wet week preceded by another wet week (P_{WW}) are high during rainy season. Chances of occurrence of wet week preceded by another dry week (P_{WD}) are very limited whereas chances of occurrence of dry week preceded by another wet week (P_{DW}) are very high throughout the year.

Results of analysis of consecutive dry and wet week during rainy season showed that the chances of occurrence of 2 or 3 consecutive dry weeks starting with the week (2D and 3D) are high throughout the year except rainy season. But the chances of occurrence of 2 or 3 consecutive wet weeks starting with the week (2W and 3W) are high during rainy season.

Planning of agricultural crops-applications

Proper planning of agricultural crops and water management requires the knowledge of chances of occurrence of wet and dry spells during the monsoon period and co-efficient of variation (CV) of rainfall. Some of the applications towards agricultural planning are presented below.

Threshold limit of 20 mm per week at more than 50% of initial probability during the rainy season is adequate for crop activities like land preparation and the conditional probability of occurrence of rainfall at 20mm per week above 50% is the right week for sowing/planting. The estimation of co-efficient of variation (CV) of rainfall is more suited for agricultural purposes. The higher the CV, the lesser the dependability of rainfall and *vice-versa*. The threshold limit for CV for weekly rainfall should be less than 150% (Senthilvelen *et al.*, 2012).

During the *kharif* season under rainfed condition, crops cultivated are Paddy, maize, greengram, blackgram, Arhar, cowpea, groundnut, castor and sesame. Land preparation and sowing/planting is done in the month of May/June/July which falls in the 20th – 30th SMW. Summer ploughing and initial seed bed preparations shall be taken up by utilizing pre-monsoon rain during 18th – 22nd standard week (30th April - 3rd June). Average weekly rainfall received

during this period ranges from 25 to 60 mm and chances of occurrence of wet week are more than 30%. The sowing operations can be taken up since 23rd SMW (4th – 10th June). Also the mean onset of rainy season is found to be 24th SMW (11th – 17th June). Average weekly rainfall received from 23rd to 36th week (03rd – 09th Sep) ranges from 75 to 115 mm.

During the *kharif* season, the co-efficient of variation of rainfall ranges from 19% to 39%. The CV is less than threshold limit of 50 percent at the beginning of *kharif* season. This indicates higher dependability of rainfall during this period. Hence, agricultural operations like planting/sowing can be undertaken successfully during this period.

Major crops cultivated during *rabi* season are chickpea, greengram, blackgram, cowpea etc. The planting/sowing *rabi* crop starts in the month of November. From 46th week to 50th week average rainfall ranges are between 2 to 4 mm. During this period chances of occurrence of wet week are more than 30% and consecutive wet weeks are average. The CV of rainfall during the sowing period of *rabi* crop varies from 83% to 175%. During this crop season the CV is more than threshold limit of 50 percent. This indicates less dependability of rainfall during this period. Hence, agricultural operations like planting/sowing can be undertaken successfully during this period with assured irrigation.

Delay in the start of rainy season delays the time of sowing/planting under rainfed conditions. In the case of two to four weeks delay in start of monsoon, groundnut + blackgram/greengram/cowpea or six week delay, Maize + blackgram/greengram/ cowpea may be taken up. Due to delay in start of monsoon and high chances of occurrence of dry weeks increases the chances of poor germination of seeds and severe moisture stress. Further delay in sowing due to start of monsoon or low rainfall during monsoon may cause very low productivity and crop failure.

Since the mean length of rainy season is observed to be 20 weeks (140 days), during *kharif* and *rabi*, short duration crops of Maize, chickpea, greengram, horse gram, cowpea, groundnut, and sesame and other low water required crops which have high return value can be taken up.

Another advantage of growing short duration cereals, pulses and oilseeds in first fortnight of June is that these can be harvested by the end of September (39th SMW) and short duration *rabi* crops can be sown during 40th to 43rd SMW (1st Oct – 28th October). Since, winter rainfall is uncertain and erratic than south west and north east monsoon, growing of high value *rabi* crops without supplementary irrigation would be highly risky.

This study found out the chances of occurrences of dry and wet weeks for appropriate crop planning and water management. A mean of 140 rainy days with a commencement of rainfall from 24th SMW and 43th week as termination of rainy season will occur. Land preparation and sowing could be taken up between 23 and 26 weeks for main rainy season crop cultivation. Supplementary irrigation and moisture conservation practice need to be practiced during 38th week to 40th week for short duration crops and supplementary irrigation and moisture conservation could be extended if the crop is long duration. Harvesting runoff water and construction of soil erosion measures need to be practices during 28th to 33 week for better water management.

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