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Markov Chain analysis of rainfall of Coimbatore

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सार – वर्षा को सबसे महत्वपूर्ण मौसम प्राचलों में से एक माना जाता है जो बुआई, कीट और रोग प्रबंधन तथा कटाई का समय तय करने में मदद करता है। मार्कोव श्रृंखला विश्लेषण पिछले मानों के आधार पर भविष्य के मानों के अनुमानों से संबंधित है। इस अध्ययन में, मार्कोव श्रृंखला विश्लेषण का उपयोग मासिक वर्षा की भविष्य की संभावना का अनुमान करने और कोयंबटूर जिले में वर्ष 1982 से 2016 (34 वर्ष) तक दैनिक वर्षा डेटा का उपयोग करके वर्षा के प्रतिरूप और वितरण की जाँच करने के लिए किया गया। इस अध्ययन में मुख्य रूप से मार्कोव श्रृंखला प्रक्रिया के आधार पर तमिलनाडु के कोयंबटूर जिले में वर्षा की संभावना का विश्लेषण किया गया। राष्ट्रीय जल विज्ञान और मौसम विज्ञान के आधार पर, प्रति दिन वर्षा की तीव्रता को वर्गीकृत किया गया और 0.1 मिमी से कम वर्षा को उस दिन शून्य वर्षा माना गया, 0.1 मिमी से 10 मिमी के बीच वर्षा को कम वर्षा, 10 मिमी से 20 मिमी वर्षा को मध्यम और 20 मिमी से अधिक वर्षा को भारी वर्षा माना गया। पिछले दिन की वर्षा को देखते हुए किसी विशेष दिन पर वर्षा की प्रतिबंधी संभावना के आधार पर प्रत्येक महीने के लिए संक्रमण संभाव्यता मैट्रिक्स और स्थिर-अवस्था संभाव्यता मैट्रिक्स की गणना करके अगले दिन की वर्षा की स्थिति की अनुमान लगाना है। इस अध्ययन में बताया गया है कि फसल उत्पादन के लिए जल की उपलब्धता सर्दियों के दौरान, मॉनसून पूर्व, दक्षिण-पश्चिमी मॉनसून के आरंभ और उत्तर-पूर्व मॉनसून के अंत में अधिक होती है। कृषि गतिविधियों के लिए अगस्त से नवंबर तक जल की कमी हो सकती है। इस अध्ययन के आधार पर, किसान बेहतर उपज के लिए पहले से ही बेहतर फसल प्रणाली की योजना बना सकते हैं।

ABSTRACT. Rainfall is considered one of the most important weather parameters which helps in deciding the time of sowing, pest and disease management and harvesting. Markov chain analysis deals with predicting future values based on past values. In the present study, Markov Chain analysis was used to predict the future probability of monthly rainfall and examine the pattern and distribution of rainfall using daily rainfall data from the year 1982 to 2016 (34 years) in the Coimbatore district. This study mainly analysed the probability of rainfall in the Coimbatore district of Tamil Nadu based on Markov chain process. Based on the National Center for Hydrology and Meteorology, the intensity of rainfall per day was categorized and a day is considered as no rain if rainfall was less than 0.1 mm, low rain if rainfall was between 0.1 mm to 10 mm, moderate rain if rainfall was between 10 mm to 20 mm and heavy rain if rainfall was above 20 mm. By calculating the transition probability matrices and steady-state probability matrices for each month based on the conditional probability of rain on a particular day given that rain on the previous day which is to predict the state of rainfall on the next day. This study reported that the availability of water for crop production is higher during the winter, pre-monsoon, the onset of the southwest monsoon, and at the end of the northeast monsoon. There may be a scarcity of water from August to November for agricultural activities. Based on this study, farmers can plan for a better cropping system in advance to get a better yield.

Key words – Markov chain analysis, Transition probability matrices, Steady state probability matrices, Rainfall.

1. Introduction

Rainfall plays a major role in the success of crops in dry farming areas and also inrainfed agriculture. Total rainfall and its distribution is an important factor for crop cultivation. Rainfall distribution is mainly based on the onset of monsoon, weekly, or monthly rainfall. In India, there are mainly four seasons, *viz*., Winter (Jan-Feb), Pre Monsoon/Summer (Mar-May), Southwest Monsoon (Jun-Sep) and Northeast Monsoon (Oct-Dec). Among these seasons, the Southwest Monsoon is the most important, as it covers major parts of India and brings the bulk of the total annual rainfall. Whereas, the distribution of rainfall is more important than total rainfall.

Trend analysis was carried out to find the change in rainfall and frequency of rainfall intensity by using daily rainfall data in Coimbatore (Arthi Rani B., 2014). In this study, Markov chain analysis was used to assess the rainfall pattern by using daily rainfall data. Transition matrices were computed by using the conditional probability of rain or no rain on a particular day given that it rained or did not rain on the previous day, as studied by Tettey, Oduro, Adedia and Abaye, (2017). In forecasting daily rainfall occurrences, the first order Markov model is accurate up to 73%, as given byPerera, Sonnadara and Jayewardene, (2002). And also, ahidden Markov Model is used to predict weather by using the Markov chain property (Khiatani and Ghose, 2017). Moody, DuClouy and Mathematics, (2014) used the Markov Chain to indicate how to assess the probability that the mathematical achievement gap between African Americans and White Americans would close during a particular year. A Markov Chain model has been fitted to weekly rainfall data to obtain sequences of dry and wet spells during the monsoon season (Banik, Mandal, Rahman and Society, 2002). And also itis important for crop planningand acts as a bench mark for both crop planning and sustainable agricultural management. Kar, Sahoo, Subudhi and Applications, (2014) used a Markov chain model to derive the probability of dry or wet weeks. And also find forward and backward accumulation of rainwater suitable for crop production, dry and wet spells tend to persist during a rainy season and can be represented using a Markov process (Vidya K. N., 2022). The Markov Chain Probability Model wasalso used to analyze the long-term behaviour of wet or dry weather spells in Coimbatore district in the western zone of Tamil Nadu (Asha Joseph, 2017).

2. Study area

Coimbatore district is in the western part of Tamil Nadu. The district is rich in Fauna because of its proximity to the Western Ghats. The average annual temperature in Coimbatore is 25.4 °C and the annual rainfall is 952 mm (Source: Climate-Data.org).

Coimbatore's climate is a local steppe climate and due to its proximity to thickly forested mountain ranges, it has a pleasant and salubrious climate. Under the KÖppen climate classification, the Coimbatore district has a tropical wet and dry climate, due to the northeast monsoon and a wet season from October to December. More elevated parts of the district gets benefit from the southwest monsoon (June to September) because of the presence of the mountain. The main monsoon runs from October to early November. Here, precipitation is lowest in January and most of the precipitation falls in October.

3. Materials and methods

The present study is based on the daily rainfall data collected from the Agro Climatic Research Centre (11° N 77° E) of the Tamil Nadu Agricultural University of Coimbatore district. The data from around 34 years (1982 to 2016) has been analysed and predicted the future probability of rainfall in the Coimbatore district using Transition probability matrices and Steady State probability matrices through Markov Chain Analysis. Statistical Analysis is carried out by R 3.5.1. Hence these findings are useful for agriculturists in the advancement of agricultural activities.

3.1. *Markov Chain*

A Markov Chain is "a stochastic model describing a sequence of possible events in which the probability of each event depends on the state attained in the previous event" (Gagniuc, 2017). The Markov process, named after Andrey Markov, satisfies the Markov property (considered "memorylessness"). A process fulfills the Markov property if one can predictits future state based on its present state as well asits past state. And the process must be conditional on the present state, its future and past states are independent.

A Markov Chain is a process in either discrete or continuous time with a countable state space. Markov Chain is called Drunkard's walk, a random walk on the number line where, at each step, by +1 or -1 the position may change with equal probability. There are two alternative exits from any position: to the subsequent or preceding integer. The transition probabilities are independent of how the position was reached but simply depend on the present position. However, the theory is applied only when the probability distribution of the next step depends non-trivially on the current state.

According to Tettey *et al.* (2017), the Markov chain model is as follows:

The probability of going from state *a* to state *b* in *n* time steps is given as

$$P^{(n)}_{ab} = \Pr (X_n=b|X_0=a)$$

In the above formula, 'n' represents number of steps, 'a' represents initial state, 'b' represents final state. In words, $P^{(n)}_{ab}$ refers to probability of going from initial state (a) to final state (b) in 'n' number of steps and

Pr (X_n=b|X_0=a) refers to probability of attaining final state (a) in 'n' number of steps given that initial state (a) at 0.

If n = 1, *i.e*., one-step transition then the probability of going from a to b in a single step is as follows,

P_{ab} = Pr (X_1=b|X_0=a)

For a time-homogeneous Markov chain:

$P^{(n)}_{ab}$ = Pr (X_{k+n}=b|X_k=a) and

P_{ab} = Pr (X_{k+1}=b|X_k=a)

3.2. *Markov chain analysis of the rainfall data*

The probability of no rain, low rain, moderate rain, or heavy rain was determined for each month with their transition matrices. Transition matrices can be obtained by the conditional probability of the fact that the rainfall is in the any of the state as given in Table 1 at time t = n if it was in the any of the state as given in Table 1 at time t = 0. To find out the stable future probabilities, steady state matrix was calculated from the transition matrix by multiplying the probability vector with probability transition matrix and we get the same exact probability vector, it is in a steady state.

In this study, Markov Chain analysis is used to studythe rainy days in Coimbatore. The term Markov Chain refers to any system in which there are a certain number of states (four states) and with given probabilities that the system changes from any state to another state.

The four states are as follows:

TABLE 1

Classification of rainfall intensity

State	Rainfall (mm/day)
No Rain	<0.1
Low Rain	0.1 – 10
Moderate Rain	10 – 20
Heavy Rain	>20

3.3. *Transition probability matrix and Steady State probability matrix*

If a Markov Chain consists of k states, then the transition matrix is of order k × k, whose entries record the probability of moving from each state to another state. For this study, the transition matrix is of order 4 × 4 matrix. The rows of the transition matrix correspond to the current state and the columns correspond to the next state. For example, the entry in row 1 and column 2 records the probability of moving from state 1 to state 2. Remember, rows mean "from" and columns mean "to" (Markov Chain: Definition, Applications & Examples).

$$P = \begin{pmatrix} p_{11} & p_{12} & \cdots & p_{1k} \\ \vdots & \vdots & \ddots & \vdots \\ p_{k1} & p_{k2} & \cdots & p_{kk} \end{pmatrix}$$

The rows of the limiting matrix contain the probability that a particular one of the states will approach a limiting value as time goes to infinity. These probabilities are called steady-state probabilities.

$$\lim P^{n} = \begin{pmatrix} p_1 & p_2 & \cdots & p_k \\ \vdots & \vdots & \ddots & \vdots \\ p_1 & p_2 & \cdots & p_k \end{pmatrix}$$

In other words, in the far future, the probabilities won't change much from one transition to the next. If the probability vector is multiplied by the probability transition step matrix and we get the same exact probability vector, it is in a steady state. A State Vectorp^n is a vector that records the probabilities that the system is in any given state at a particular step of the process. The value of p^n approaches a fixed square matrix as n increases.

4. Result and discussion

The Rainfall data collected over 34 years (1982-2016) in the Coimbatore district describes that rainfall was not evenly distributed because of seasonal variation. Rainfall data was analyzed month-wise from January to December and used the stochastic model Markov Chain to predict the probability of rainfall on the next day by Transition matrices. In this study, we assume that No Rain - a, Low Rain - b, Moderate Rain - c, Heavy Rain - d.

For each month, the probability of rainfall on the next day is predicted by using Markov chain is shown in Table 2.

For January, Table 2 clearly shows that if today is no rain then there is a 86% chance of it being no rainagain, 12% chance of it being low rain, 2% chance of it being moderate rain and 1% chance of it being heavy rain on the next day. And if today is low rain then there is a 50% chance of it being no rain, 42% chance of it being low rain again, 6% chance of it being moderate rain and 2% chance of it being heavy rain on next day and so on.

TABLE 2

Markov Chain analysis of daily rainfall data for Coimbatore district

Month		Transition matrix (p)				n	Steady-state matrix			
		a	b	c	d		a	b	c	d
January	a	0.86	0.12	0.02	0.01	17	0.78	0.19	0.03	0.01
	b	0.50	0.42	0.06	0.02					
	c	0.47	0.43	0.10	0.00					
	d	0.55	0.18	0.18	0.09					
February	a	0.83	0.15	0.01	0.01	18	0.73	0.22	0.03	0.02
	b	0.49	0.44	0.05	0.02					
	c	0.41	0.31	0.24	0.03					
	d	0.44	0.22	0.22	0.11					
March	a	0.83	0.15	0.01	0.01	16	0.75	0.22	0.02	0.01
	b	0.55	0.41	0.03	0.01					
	c	0.39	0.50	0.00	0.11					
	d	0.40	0.50	0.10	0.00					
April	a	0.83	0.15	0.02	0.01	15	0.77	0.20	0.02	0.01
	b	0.57	0.35	0.06	0.02					
	c	0.58	0.38	0.04	0.00					
	d	0.62	0.38	0.00	0.00					
May	a	0.79	0.13	0.04	0.04	17	0.68	0.20	0.06	0.06
	b	0.45	0.37	0.09	0.08					
	c	0.45	0.32	0.12	0.11					
	d	0.35	0.34	0.14	0.17					
June	a	0.79	0.15	0.03	0.03	28	0.60	0.25	0.07	0.08
	b	0.36	0.39	0.12	0.13					
	c	0.33	0.40	0.10	0.17					
	d	0.20	0.40	0.18	0.22					
July	a	0.83	0.13	0.02	0.02	21	0.74	0.19	0.04	0.03
	b	0.55	0.35	0.08	0.02					
	c	0.40	0.33	0.15	0.13					
	d	0.24	0.45	0.12	0.18					
August	a	0.93	0.05	0.01	0.01	24	0.89	0.08	0.02	0.01
	b	0.62	0.28	0.07	0.03					
	c	0.41	0.41	0.06	0.12					
	d	0.08	0.69	0.00	0.23					
September	a	0.97	0.02	0.01	0.01	23	0.94	0.03	0.02	0.02
	b	0.55	0.24	0.15	0.06					
	c	0.71	0.18	0.06	0.06					
	d	0.19	0.38	0.31	0.13					
October	a	0.95	0.03	0.01	0.01	23	0.91	0.05	0.02	0.03
	b	0.50	0.23	0.15	0.12					
	c	0.41	0.29	0.12	0.18					
	d	0.56	0.19	0.04	0.22					
November	a	0.91	0.07	0.01	0.01	14	0.87	0.09	0.02	0.02
	b	0.62	0.26	0.06	0.07					
	c	0.68	0.11	0.11	0.11					
	d	0.65	0.22	0.09	0.04					
December	a	0.87	0.08	0.03	0.02	14	0.83	0.11	0.04	0.03
	b	0.66	0.20	0.06	0.08					
	c	0.53	0.24	0.13	0.11					
	d	0.53	0.26	0.12	0.09					

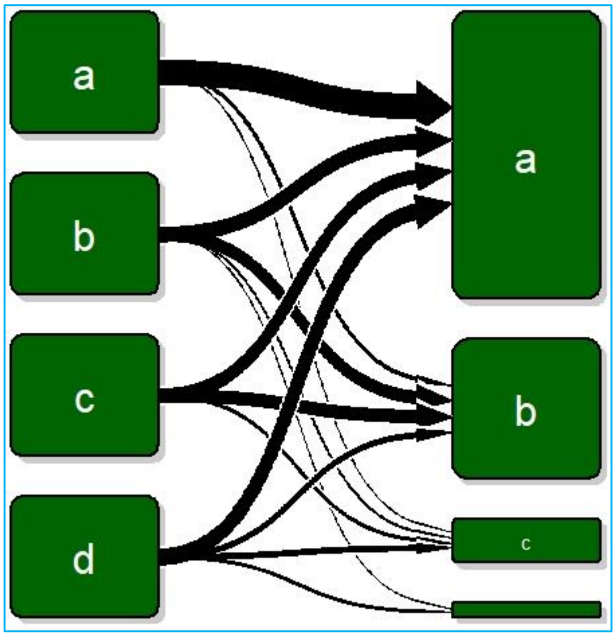

Fig. 1. Transition plot for January month

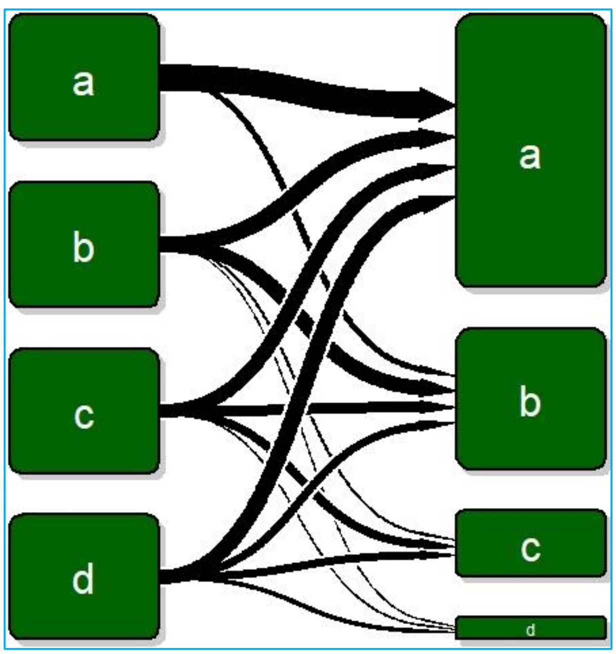

Fig. 2. Transition plot for February month

For February, Table 2 clearly shows that if today is no rain then there is a 83% chance of it being no rain again, 15% chance of it being low rain, 1% chance of it being moderate rain and 1% chance of it being heavy rain on the next day. And if today is low rain then there is a 49% chance of it being no rain, 44% chance of it being low rain again, 5% chance of it being moderate rain and 2% chance of it being heavy rain on the next day and so on. The probability of rainfall for the remaining months was also mentioned in Table 2.

In Table 2, 'n' represents the number of years, January attains a steady state after 17 years with a chance of 78% no rain, 19% low rain, 3% moderate rain and 1% heavy rain. February attains a steady state after 18 years with a chance of 73% no rain, 22% low rain, 3% moderate rain and 2% heavy rain and so on.

From the Table 2, the probability of receiving moderate rain was lower during August to November, with a chance of 2% and also less in March and April. At the same time the probability of receiving low or heavy rain was also lower during August to November compared to other months. The study reported that the availability of water for crop production is higher from December to July. Finally, one can plan the suitable cropping system in advance, which is also useful for famers to get a better yield and income.

5. Conclusion

Seasonal rainfall distribution is very important in day-to-day human life. For agricultural activities, summer rain is useful for land preparation and for summer ploughing. Most of the agricultural activities depend on the southwest monsoon and northeast monsoon. In particular, rainfed and irrigated crops depend on rainfall. The major area under the rainfed crop is green gram and the major area under the irrigated crop is sugarcane in both the *Kharif* and *Rabi* seasons in the Coimbatore district. Sugarcane is a water-intensive crop, so it requires more water to get a better yield. It is raised in two seasons (*i*) Main season - Early (Dec-Jan), Mid (Feb-Mar), Late (April-May), and (*ii*) Special season (Jun-July).

From this study, the probability of receiving rain is higher during the main season as well as in the special season. The study concludes that the availability of water for crop production is higher during the winter, pre-monsoon, the onset of the southwest monsoon, and at the end of the northeast monsoon. There may be a scarcity of water from August to November for agricultural activities. Based on this study, one can plan for a better cropping system in advance and it is also useful for many organizations to plan their activities accordingly.

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