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Research Article

Dry spell length analysis for crop production using Markov-Chain model in Eastern Hararghe, Ethiopia

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Abstract: The information on the length of dry spells could be used for deciding a particular crop or variety, supplementary irrigation water demand and for others agricultural activities. The study was conducted in three districts: Babile, Haramaya and Kersa, eastern Hararghe, Ethiopia. The aim of the study was to analyze dry spell lengths and its implications on crop production in eastern Hararghe, so as to minimize unexpected damage due to long dry spells and to have effective and efficient planning for farming communities.Thirty years of rainfall data for each district were collected form National Meteorological Agency of Ethiopia. Data quality control has been done prior to analysis. Markov-Chain model were employed to analyze the collected data. The result of the study revealed that dry spells were highly hitting Babile district comparing to the other two districts. The probability of dry spell lengths of 5 and 7 days in Babile district was found to be about 99 and 80%, respectively.Whereas, in Haramaya district, the probability of dry spell length of 5 days was found to be 80% during 181(Days of the Year) DOY, then it falls to below 50 % by 221DOY. Moreover, the probability of the occurrences of dry spells of 10, 15, and 20 days were below 5% in Haramaya district during the main rainy season. The study also investigated that in Kersa district, the probability of occurrences of the dry spell lengths of 5, 7, 10, 15, and 20 days were estimated to fall below 30%, showing that the area was better in crop production as compared to the rest districts. The annual rainfalls in all the districts were decreasing as per the trend line and variable in all the districts: Babile, Haramaya and Kersa districts, having the CV values of, 41, 34 and 31%, respectively.Information regarding dry spell length analysis has to be well understoodat grass root levels to ensure food security via lifesaving irrigation schemes or any other options.

Keywords: *crop production, dry spells, Ethiopia, Markov-chain model*

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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. Drought is a common agenda that takes place nearly every year in many areas of the world, particularly, in developing countries. 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). Findings on earth's global climate indicate an increasing trend of average air temperature. As a result, the vegetation period is expected to become shorter and shorter with irregular distribution of rainfall (IPCC, 2008). It has been noted that the long dry spells incur heavy costs to the affected societies. In tropics and subtropics, the success or failure of the crops is highly related with the occurrences of dry spells. For achieving maximum benefits from dry land agriculture the knowledge of distribution of dry spells within a year is useful. Dry spells affect not only crop production it could also stricken other sectors like fisheries, health, electricity etc. whichin turn cause a crisis to the economy of a given country (Jayawardene, 2005). 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), breeding varieties of various maturity durations, 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 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). A number of studies have been conducted in Ethiopia on climate characterization such as number of rainy days, length of growing period, onset and offset of seasonal and annual rainfall. Few of them highlighted the heavy losses in major crop production in the country due to prolonged dry spells and the importance of studying the temporal and spatial variability of dry spells (Seleshi and Zanke, 2004; Seleshi and Camberlin, 2006; Hadgu, et al., 2013). However, nothing has been done so far in eastern Hararghe in regarding with either climate characterization or dry spell analysis. Dry spell lengthscould be determined using Markov-chain model (Barron, 2004).The Markov chain probability model for the analysis of wet spells and dry spells was first introduced by Gabriel and Neumann (1957) using 27 years (1923 -1950) of rainfall data from November to April at Tel Aviv in Israel considering the threshold of 0.1 mm (Gabriel and Neumann, 1957). The results were validated using chi square tests. Since then the Markov process models have been used extensively by many authors throughout the world.

Therefore, this study aims to analyze dry spell lengths and its implications on crop production in eastern Hararghe, so as to minimize unexpected damage due to long dry spells and to have effective and efficient planning for farming communities.

Materials and Methods

Description of the study area

The study was conducted in Babile, Haramaya, and Kersa districts of Eastern Hararghe Zone, Ethiopia (Table 1).

Table 1. Study site information

Station name	Latitude (^{0})	Longitude (^{0})	Altitude (m)	Geographic classification	Average temperature (^{0}C)	Data available
Babile	9.21	42.33	1518	Lowland	26.50	1980-2013
Haramaya	9.16	41.97	1980	Highland	18.11	1980-2013
Kersa	9.32	41.92	2200	Highland	18.07	1980-2013

Data collection and Quality Control

A baseline of thirty four years of daily rainfall data for each districts were collected from National Meteorological Agency of Ethiopia (NMA). Then prior to any analysis the data were subjected for its quality using the cumulative deviation test (Sahin and Kerem, 2010), common in detecting for climatologically time series data (Sahin and Kerem, 2010; Kang and Yusof, 2012).

Research approach

A Markov-chain model is useful for analyzing random events whose likelihood depends on what happened last (Gabriel and Neumann, 1957). Time series dry spells depends on what happened in the past, and Markov process models can be used to study properties of dry spells. A stochastic process, whose state at time t is Y_T (t > 0), such that the value of Y_s(s<t) does not depend on the values of Y_u (u<s) then the process is said to be Markov process (Medhi, 2009).
That is,

$$P\left(Y_{t+h} = {}^{y}\!/_{Y_{t1} = y_1, Y_{t2} = y_2 \ldots\ldots Y_{tn} = y_n}\right) = P(Y_{t+h} = {}^{y}\!/_{Y_{tn} = y_n})$$

It indicates that the probability of its having state Y at time t+h, conditioned on having the particular state Y_{t+h}at time t, is equal to the conditional probability of its having that same state Y but conditioned on its value for all previous times before t. This captures the idea that its future state is independent of its past states, but depends only on the immediate past. In dry spell analysis as a day is classified either 'wet state' or 'dry state' depending on the rainfall amount of a day, Markov process can be applied. The order one (order 1) process assumes that the present state (wet or dry) depends only on the condition of the previous state being wet or dry. The transition matrix of the Markov model of order 1 for two state (D=0 for the dry state and W=0 for the wet state) is given by:

$$\begin{bmatrix} & D & W \\ D & P_{00} & P_{01} \\ W & P_{01} & P_{11} \end{bmatrix}$$

Where P_{ij}= probability of the present day state i (i=0 or 1) given that previous state is j (j=0 or 1). Thus, using Geometric distribution the probability of a dry spell lasting exactly n days will be given by the following formula;

$$P_n = P_{00}^{n-1}P_{01} = P_{00}^{n-1}(1 - P_{00})$$

Where p_{00} is the probability of a dry day occurring after a dry day$P_{01}$is the probability of a wet day occurring after a dry day.

In this study, probabilities of a dry spell greater than a particular length based on the condition of the previous days (that is, the probabilities of dry spell followed by dry season and that of followed by wet season) were computed. The probabilities of the dry spell lengths exceeding 5, 7, 10, 15 and 20 days were computed using Markov model of order two under the assumption of binomial error structure (Abeysekera et al.,1983). For the study, rainfall data from 1980-2013of all districts: Babile, Haramaya and Kersa collected were used.

Results and Discussion

The results of the study revealed that dry spell lengths of the considered days: (sp5) 5 days, (sp7) 7 days, (sp10) 10 days, (sp15) 15 days and (sp20) 20 days varies from place to place over the study areas of Babile, Haramaya and Kersa districts.In line with this, the impacts caused due to the dry spell lengths also varies. The challenges of dry spell were so much over Babile district as compared to other two districts. Even during the main rainy season of Ethiopia: June, July, August and September (JJAS), the probability of dry spell length of 5 days was about 99%. The probability of dry spell length of a week was also more than 80%. On the other hand, the probability of dry spell length of 20 days was below 20% (Figure 1).

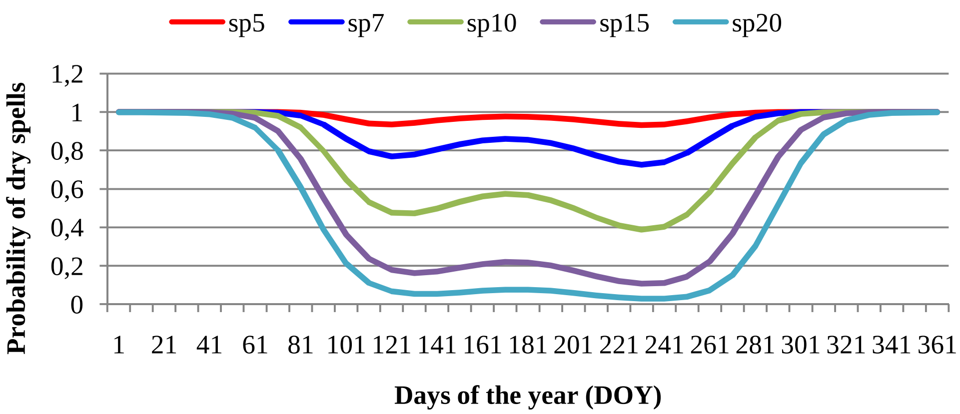

Figure 1.Markov-Chain model output of dry spells for Babile district

According to Barron (2004), Markov model is capable to analyze the agricultural dry spell lengths and respective risks. He reported that the probabilities of agricultural dry spell exceeding 10 days in East Africa varied from 20% to 70% or more depending on onset of rainy season. In general, this implies that growing crops in the district was under high probability of risks, given the harsh climatic condition, very high rainfall variability, CV value of 41% (Table 2). The study also depicts that the annual rainfall in the districts was decreasing from time to time as per the trend line indicates (Figure 2). Poverty driven by drought was hitting the farming communities in this area and food aids were given almost every year over the past three decades.

Table 2. Simple descriptive statistics of rainfall feature over the period 1980-2013

Station name	**Mean**	**Minimum**	**Maximum**	**SD**	**CV**
Babile	404	174	819	164	41
Haramaya	712	309	1200	245	34
Kersa	760	462	1363	247	31

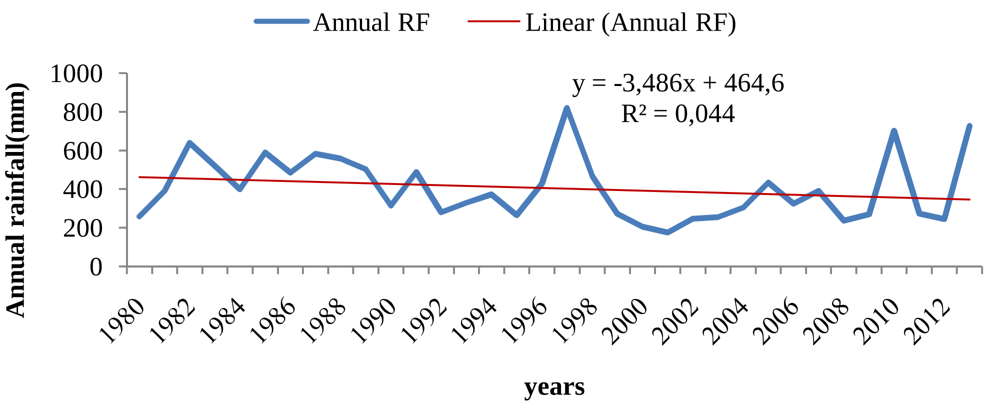

Figure 2. Annual rainfall distribution of Babile for the period 1980-2013

On the other hand, in Haramaya district the probability of dry spell length of 5 days was found to be 80% during 181DOY (1st decade of June), then it declined to below 50 % by 221DOY (3rd decade of July) (Figure 3). Beginning from 2021 DOY, the probability that the area faced dry spell length of 5 days had been increased up to 100% by 301DOY (3rd decade of September). It has been also clarified that in Haramaya district, the probability of dry spell lengths of 7 days or a week has been reached about 20% in July. However, the probability of the occurrences of 10 days, 15 days, and 20 days were fall below 5% during the main rainy season of the area, JJAS. This is the critical time for planting crops. Thus, the crops in the area might be influenced due to the high occurrences of the dry spell lengths of 5 days than any other dry spell lengths occurrences.

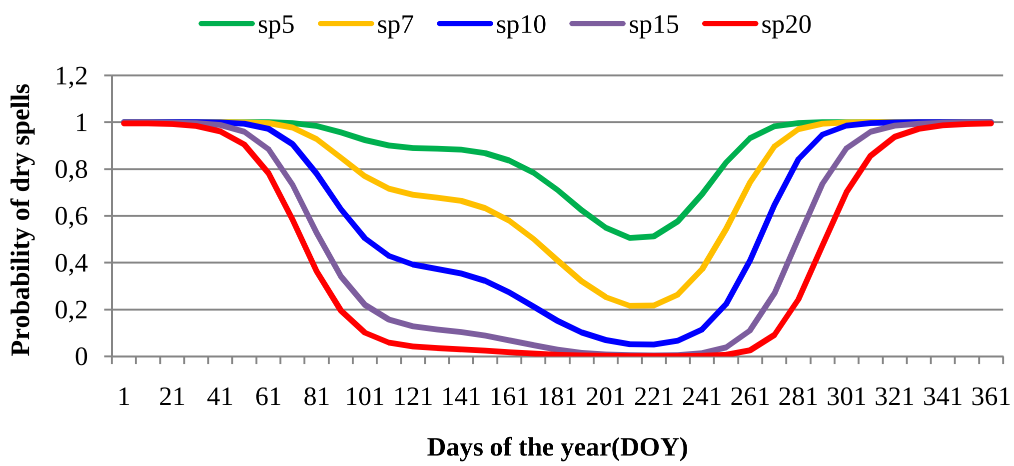

Figure 3. Markov-Chain model output of dry spells for Haramaya district

Major crops of the area like maize (*Zea mays*) and Sorghum (*Sorghum bicolor)* were impacted due to this problem. This is what has been well recognized in the area over the last thirty years (as per the informal interview with the local farming communities which has not been incorporated in to this work). The annual rainfall condition over the district was tends to decrease over the period of 1980- 2013, as shown by the trend line in Figure 4. The area had also faced high annual rainfall variability, showing the CV of 34% (Table 2).

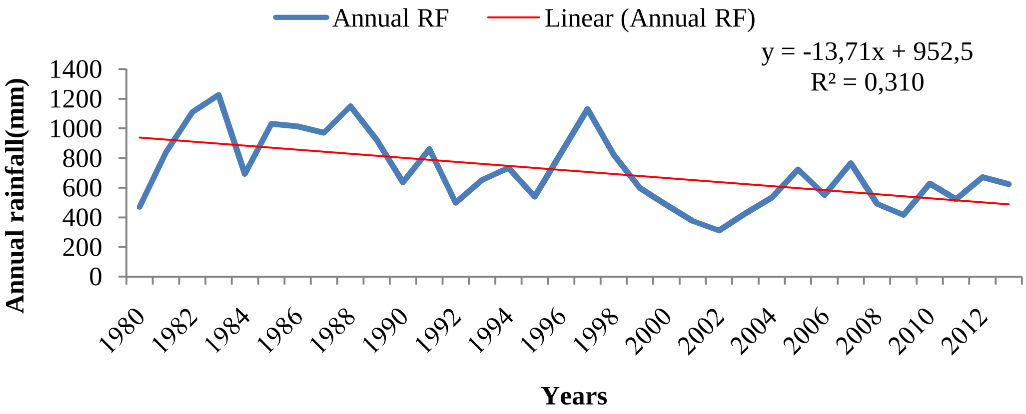

Figure 4. Annual rainfall distribution of Haramaya district for the period 1980-2013

Furthermore, the study depicted that the impacts caused due long dry spells in Kersa district was not as difficult as the other two districts. The dry spell lengths for all the considered dry spell days in this particular study were estimated to fall below 30% in Kersa district, during the main rainy season of the area, JJAS (Figure 5). The implication for this was that the agricultural crop production in the area was better as compared to the other two districts. Thus, farmers in this area were producing goodcrops, though the rainfall was decreasing (Figure 6) and variable (Table 2) over the last three decades. Sorecha et al. (2017) reported that the rainfall over Kersa district showed a decreasing trend by -10.61 mm/yr, although not statistically significant.

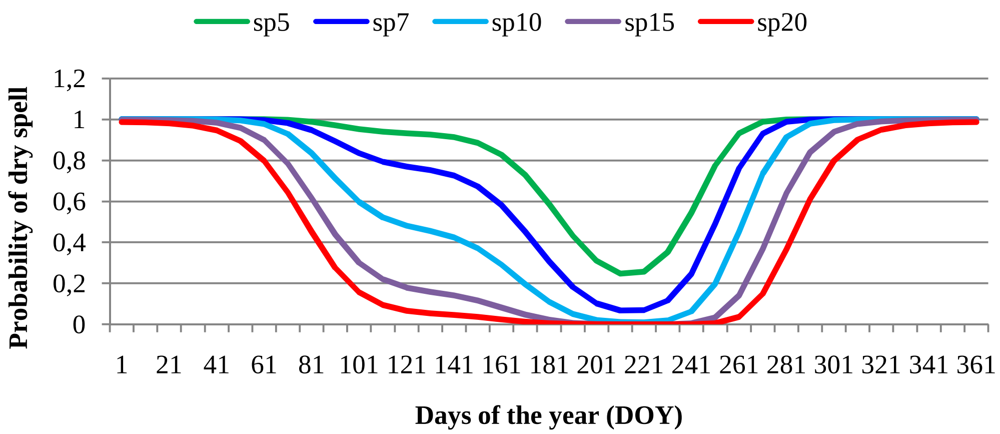

Figure 5.Markov-Chain model output of dry spells for Kersa district

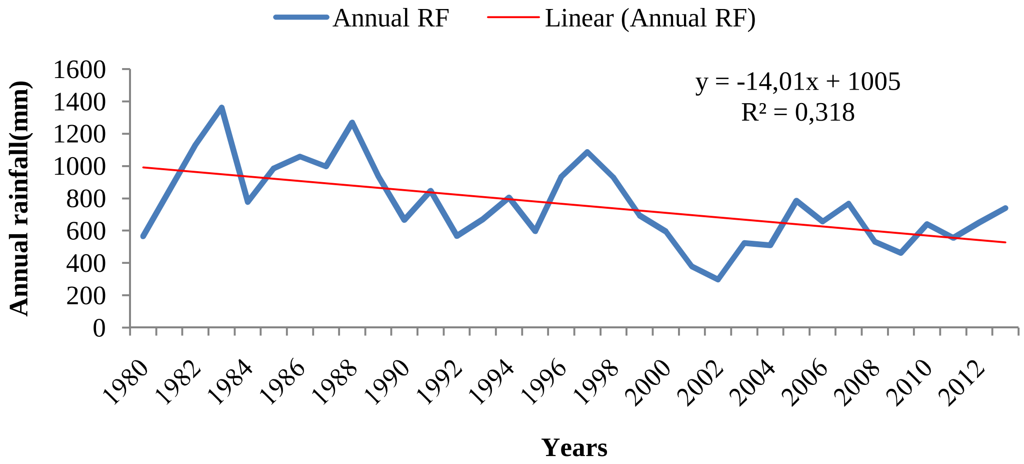

Figure 6. Annual rainfall distribution of Kersa district for the period 1980-2013

Conclusion

The study attempt to analyze the dry spell lengths over three districts and pointed out that dry spell lengths of the considered days: 5 days, 7 days, 10 days, 15 days and 20 days varies from place to place over the study areas of Babile, Haramaya and Kersa districts. In line with this, the impacts caused due to the dry spell lengths also varies. The dry spell lengths of 5 days and a week or 7 days were well notified over the considered stations, except in Kersa district where the dry spell lengths fall below 30 %. Dry spellswere hitting Babile district more comparing to the other two districts. The probability of dry spell length of 5 days and 7 days in Babile werefound to be about 99 and 80%, respectively. The study also depicts that the annual rainfall in all districtswere decreasing as per the trend line and variable as per the CV values for respective stations. Therefore, such baseline information regarding the dry spell length analysis has to be well understood by the farming communities to enable them to get ready against the challenges associated with dry spells in the upcoming periods, so as to ensure food security and climate resilient economy.

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