

Dry and Wet Spell Analysis of the Two Rainy Seasons for Decision Support in Agricultural Water Management for Crop production in the Central Highlands of Ethiopia

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Abstract

Rainfall remains the crucial component of the weather elements for improving agricultural yield in Ethiopia. Rainfall occurrence analysis is extremely helpful in planning of water resources and agricultural development. A study was conducted to asses the potential of sufficient rainfall occurrences and precipitation surplus and deficits in the central highland of Ethiopia for a selected district based on thirty three years of weather record data. The FAO(1978) and Reddy (1990) models were employed to set the threshold limits and the Weilbul frequency formula was used to calculate the probability of occurrences during the two growing seasons, belg(shorter) and kiremt (main). The results showed that the probability of occurrences of the sufficient amount of rainfall during the decades of main rainy season is promisingly stable while belg is observed to suffer from fewer occurrences of the sufficient amount even at the lower probability levels (25% probability of occurrences). Thus rainfall water harvesting during the main rainy season (Kiremt) is promising either for double cropping practices or other domestic uses.

Key words: Frequency, Weibull, belg, kiremt

1. Introduction

Rain-fed agricultural is always dependent on the prevailing climate and weather variability phenomenon. The most important limiting weather element in agricultural sector is precipitation. Extreme climatic conditions and high inter-annual or seasonal variability of this weather element could adversely affect productivity [6] because rainfall governs the crop yields and determines the choice of the crops that can be grown. One of the reasons for low crop production in semi arid areas is marginal and erratic rainfall exacerbated by high run off and evapotranspiration losses. The in-field rainwater harvesting techniques has been shown to improve the yield of maize and sun flower on some benchmark ecotypes in South Africa [3]. Rainfall in terms of amount and frequency in a growing season is crucial for panning and management of agricultural practices. It is of some importance in adapting farming systems to supplementary water resources to know how long a wet spell is likely to persist, and what probabilities are experiencing dry spells of various duration at critical times during the growing season.

The analysis of rainfall records for long periods provides information about rainfall pattern and variability [5].Dry and wet spell analysis assists in estimating the probability of intra-seasonal drought and management practices can be adjusted accordingly [4]. A kind of work should not only focus to the semi-arid areas where rainfall is erratic but it is paramount important in the regions where rainfall seems good enough on annual scale while the temporal distribution through a growing season requires attention. Analysis of rainfall probability on this particular time scale can only give a general in formation about the rainfall pattern of a certain location. Therefore there is a need of having specific information for critically planning agricultural operations for the benefit of increasing crop yields.

In this regard, dry and wet spell analysis at decadal time unit (tem day basis) more or less satisfies the required supportive information for decision making in rainfall water resource management and planning in agricultural sectors[1 and 7]. Like wise, in the central highlands of Ethiopia, rainfall persists relatively less erratic on annual scale, but what a limiting factor is the unexpected occurrence of the dry spell during some of the most important crop development stages and high intensity of rainfall in the middle of the season causing runoff and subsequently damaging the crops in the field. Thus understanding of those events is extremely important for reducing the adverse effects through appropriate planning and management of agricultural practices suitable to a certain pattern and characteristics of rainfall regimes in a growing season.

In this paper, an attempt was made to critically analyze the dry and wet spell probabilities for two growing seasons for a selected and agriculturally important district in the central highlands of Ethiopia based on the Markov chain probability model. The rainfall occurrence of dependable value at 80% probability level was also determined and subsequently a comparison analysis with FAO threshold reference evapotranspiration was a done for the selected district.

2. Methods and Data

The bishoftu district is located in the central highland of Ethiopia, 45 Kms South East of the capital, Addis Ababa. The district is agriculturally the most important one in the region. The district has two distinct seasons; the shorter (*belg*) lasts from March to end of May while the main rainy season (*kiremt*) is length of the period between June and September. The analysis of the work was entirely based on the thirty three years of meteorological records (1975-2007) obtained from Debre Zeit Agricultural Research Center's Weather Archive. The standard or meteorological decades (SMDs) are constructed in such a way that each month of a given year was divided in to three decades and subsequently the first two ten days are considered as the first and second decade for each month, respectively. The rest of days in each month again will be summed up to form the last or third decade.

Reddy [8] has already stated that a 3 mm rainfall depth per day is the minimum threshold value for crops to satisfy their crop water requirement. Accordingly, in this study, a 30 mm per decade of precipitation depth was taken as a threshold value for evaluating whether a decade is in a dry or wet spell. A decade with a depth of precipitation below this value was considered as dry and vice-versa for a decade with precipitation value of above the threshold level. The following expressions were used in the Markov chain analysis of dry/wet spells in the district [7]

$$P_D = \frac{F_D}{n} \quad \textbf{(1)}$$

$$P_W = \frac{F_W}{n} \quad \textbf{(2)}$$

$$P_{WW} = \frac{F_{WW}}{F_W} \quad \textbf{(3)}$$

$$P_{DD} = \frac{F_{DD}}{F_D} \quad \textbf{(4)}$$

$$P_{WD} = 1 - P_{DD} \quad \textbf{(5)}$$

$$P_{DW} = 1 - P_{WW} \quad \textbf{(6)}$$

Wet spell duration is defined as sequence of k 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. The distributions of the spells by length or duration are found to be geometric [1] with the probability of wet spell of length *k* given by the following equation:

$$P(W = k) = (1 - P_1)P_1^{K-1} \quad \textbf{(7)}$$

$$P(W > k) = P_1^k \quad \textbf{(8)}$$

Similarly,

Probability of a dry spell of length *m* and greater than *m* were calculated using the following equations respectively.

$$P(D = m) = P_O(1 - P_O)^{m-1} \quad \textbf{(9)}$$

and

$$P(D > m) = (1 - P_O)^m \quad \textbf{(10)}$$

Where,

P_D is the probability of a decade being dry
F_D is the number of dry decades
P_W is the probability of a decade being wet
F_W is the number of wet decades
n is the number of observations

P_{WW} is the probability of wet decade followed by another wet decade
F_{WW} is he number of wet decades followed by other wet decades
P_{DD} is the probability of a dry decade followed by another dry one
F_{DD} is the number of dry decade followed by another dry one
P_{WD} is the probability of a wet decade followed by another dry decade
P_{DW} is the probability of a dry decade followed by a wet one.
P_1 is the probability that a decade is wet give that the previous decade is wet and denoted by P (W/W)
P_0 is the probability that a decade being wet given that the previous is dry and is
A reference evapotranspiration was calculated from meteorological records based on the Pen man-Months equation.
The Weibull frequency or probability formula of the following order was employed to obtain the probability of rainfall of each decade.

$$p = \frac{m}{n + 1} * 100$$

(11)

Where,
P Probability of Occurrences
m is the rank at which the value occurs when arranged in descending order
n is the total number of observation

Results and Discussions

The probability of a decade being wet in the *Kiremt (the main rainy season)* was found to be greater than 40% throughout the meteorological decades with the exception of decade number 16 and 17, which gave a corresponding probability, value of 21% each (Table 1). The probability of getting a wet decade after wet in the study district during the main rainy season was also found to be in the range of 14 – 100% with most of the meteorological decades skewed to the maximum. In general, the *Kiremt* season is having well above the threshold limit for most of the years during the study period.
However, the probability of getting a wet decade during *belg (smaller)* rainy season was limited in the range of 15 to 30 % (Table 2). The same table also showed that high probability of occurrence of dry spells was observed (greater than 70% in all decades), as expected. Further, the probability of getting a dry decade after dry in the study district during the *belg* season was also high (exceeded 65%) throughout the meteorological decades.
Furthermore, a relative high probability of occurrence of more than three consecutive dry decades was also showed up (Table 3) in this particular season as compared to the main season. This result suggests high chance of crop failure in the season and thus the season needs to be out of the major cropping practices, sowing and planting but the moisture could be used for land preparation for early planting in the main rainy season.
Therefore, crop harvesting during the main rainy season is less likely affected by moisture stress. This corresponds to high probability of run off and erosion hazard possibilities during the kiremt season (Reddy, 2008), and the results also indicated that there could be high risks of waterloging conditions which could affect the crops because of poor aeration and on the other hand, there might be damages in the down stream areas due to flooding in those decades that experience wet after wet conditions unless there have been strong soil and water management options in the study district.
The high consecutive wet week probability during 20th-25th decade of the main rainy season on the other hand hints for potential scope of harvesting excess runoff water for future supplemental irrigations and also drives attention towards soil erosion measures to be taken up for soil erosion control. However, one can infer from the presented tables that the belg season is getting below the threshold minimum requirement of rainfall and hence planting during *Belg* season is less likely.
Similarly, as illustrated in figure1 (a and b) below; the ratio between precipitation amount at 80% probability of

occurrences and the average threshold reference evapotranspiration (0.5*ETo) showed that the main rainy season is still enjoying rainfall amount much higher than the minimum for most of the its decades while in *belg,* the rainfall amount remained much below the threshold of the crop water requirement at the same probability level of occurrences for all the decades.

In general, the moisture from the rainfall during the shorter rainy season is extremely below the threshold level to support crop production. This is because rainfall amount below half of the corresponding evapotranspiration does not satisfy the crop water need and subsequently the crops are physiologically affected [1 and 2]. The results also indicated that maximum benefits should be derived from the ample moisture of the main rainy season. Besides this particular season holds some soil erosion and runoff possibilities, especially during decade 21st and thus it requires attention with respects soil and water conservation practices and also design of water harvesting structures.

Conclusions

Decisions in rain-fed agriculture always require detail analysis of the weather component. In the principle of the past gives a clue to the future, probabilistic analysis of the weather records of the past is an important step towards understanding and developing appropriate technologies that support crop growth under varying rainfall regimes. Some of the decisions: land preparation, crop and variety choice, fertilizer application rate, soil/water conservation measures and disease and pest control practices can be supported by the information obtained from the probabilistic analysis of the weather elements. But, for a kind of work is to be practical and applicable, a reasonable reliable data source and collection is crucial. Thus quality weather data handling is always paramount important for working out the analysis more informative for decision making. To sum it up, selection of appropriate technologies in agricultural development should always follow a detailed understanding and analysis of the climate, particularity the rainfall variability and pattern.

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Table 1. Dry/wet spell probability distribution through the *Kiremt* rainy seasons

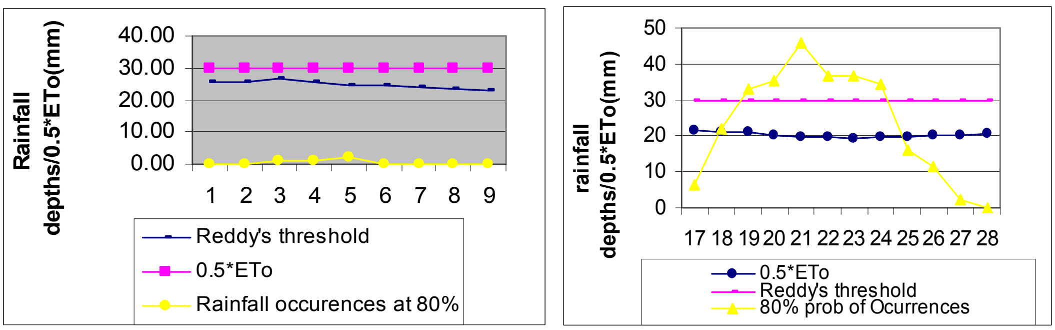
Dekade No	Pw	PD	Pww	PDD	PWD	PDW
16	21	79	14	92	8	86
17	21	79	57	88	12	43
18	42	58	29	89	11	71
19	64	36	52	75	25	48
20	88	12	69	25	75	31
21	88	12	66	0	100	34
22	91	9	87	0	100	13
23	94	6	90	0	100	10
24	94	6	100	0	100	0
25	88	12	100	0	100	0
26	61	39	90	8	92	10
27	52	48	53	56	44	47

Table 2. Dry-wet spell probability distribution of Belg based on the Markov Chain model (1975-2007)

Dekade No	Pw	PD	Pww	PDD	PWD	PDW
9	30	70	30	87	13	70
10	30	70	60	78	22	40
11	30	70	50	74	26	50
12	18	82	33	67	33	67
13	18	82	17	74	26	83
14	21	79	14	81	19	86
15	15	85	20	75	25	80

Table 3. Dry-wet spell duration distribution in the two seasons

	Probability of wet sequences at least				Probability of dry
k	2	3	5	7	spell > 3dek
Bega	0.13	0.048	0.0062	0.00082	0.58
Kiremt	0.43	0.28	0.12	0.01524	0.19



a b

Figure 1.Rainfall Occurrence at 80% probability and corresponding reference evapotranspiration during the growing seasons, *belg* and *kiremt* respectively