

Full Length Research Paper

Wet and dry spell analysis for decision making in agricultural water management in the eastern part of Ethiopia, West Haraghe

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The objective this study was to analyze the dry and wet spell of the main and small rainy season in the eastern part of Ethiopia, West Haraghe. Markov Chain model was employed to investigate the extent and characteristics of the dry and wet spell in the study sites. Accordingly, the results exhibited that the chance of having wet decades is relatively higher (greater than 50% of probability of occurrences) during last of June to the start of October for all the study locations (Hirna, Asebe Teferi and Meios). The probability of having wet after wet is also fairly enough that farmers can take significant agricultural operations, like planting during the start of the season, second decade of June. The probability of having wet during belg is however very low (usually less than 40%). But the soil moisture from the season could help farmers start plough earlier so that farmers can have the full advantage of the main rainy season, without wasting moisture for other activities.

Key words: dry, probability, Markov chain, probability, spell.

INTRODUCTION

Precipitation modeling is very important for planning and management of water resources and has many practical applications in engineering and agriculture. The majority of hydrological methods for precipitation modeling try to represent the generating mechanism of the physical process. They are basically mathematical description of the nature of precipitation and of the structure of the sample time sequence. 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 decade, if rain occurs this decade known as conditional probability of a wet decade preceded by a wet decade (P_{WW}), and the probability of rain next decade being wet, if this decade is dry known as conditional probability of a wet week preceded by a dry decade (P_{WD}). Analogously,

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initial and conditional probability for a dry decade 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).

Studies on earth's global climate show an increasing trend on average air temperature. Consequently, the vegetation period is expected to become shorter and even more irregular distribution of rainfall is expected. It has been noted that the long dry spells incur heavy costs to the affected communities. In humid countries the success or failure of the crops, particularly under rainy conditions is highly related with the distribution 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 in agriculture but also other sectors such as fisheries, health, electricity etc. Long dry spells may physically weaken the people which could cause mental degradation due to the lowering of their status. The fish productivity from fresh water is likely to be stricken by longer dry spells. Longer dry spells also interrupt generating electricity using hydroelectric power (Jayawardene, 2005). Therefore, the effects of dry spells in various sectors as described above ultimately have a direct impact on the economy of a country.

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 an average of 30 mm per decade (ten days sum) 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 as Markov chain model of first order was considered as dry and vice versa for a decade with precipitation value of above the threshold level. 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.

The information on the length of dry spells could be used for deciding a particular crop or variety in a given location, and for breeding varieties of various maturity durations. Information on dry spell lengths could be used in decision making with respect to supplementary irrigation and field operations in agriculture. Prior knowledge of dry spell studies can be applied to generate synthetic sequences of rainfall and to the estimation of the irrigation water demand. Crops are more likely to do well with uniformly spread 'light' rains than with a few 'heavy' rains interrupted by dry periods. The timing of breaks in rainfall (dry spells) relative to the cropping calendar rather than total seasonal rainfall is fundamental to crop viability. The longest period of several long dry spells is of crucial importance in planning agricultural

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 behavior 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.

The objective this paper is therefore to explain the characteristics and extent of the dry and wet spells in the eastern part of Ethiopia, West Haraghe.

MATERIALS AND METHODS

In Ethiopia, there are three distinct seasons, namely, bega, belg and kiremt. The definition is presented as in the following;

a) Bega: This is generally the dry season that covers the period from October to January. However, there is occasionally untimely rain over various parts of the country. During this season, most part of the country predominantly falls under the influence of dry and cool northeasterly winds. These dry air masses originate either from the Saharan anticyclone and /or from the ridge of high pressure extending into Ethiopia from Arabian land and from the large high surface pressure over central Asia and, Siberia (NMSA, 1996; Gonfa, 1996).

b) Belg: Belg is small rainy season that covers the period from mid-February to mid-May. However, the rainfall is highly characterized by inter annual and inter seasonal variation. Major systems during the Belg season are the following:-development of thermal low over South Sudan, generation and propagation of disturbances over the Mediterranean Sea, sometimes coupled with easterly waves, development of high pressure over the Arabian Sea, Some of the interaction between mid-latitude depressions and tropical systems accompanied by troughs and the subtropical jet and occasional development of the Red Sea convergence zone (RSCZ) (NMSA, 1996; Gonfa, 1996).

c) Kiremt: Kiremt is the main rainy season that covers the period from June to September. Major rain producing systems during Kiremt season includes; Northward migration of ITCZ, development and persistence of the Arabian and South Sudan thermal low along 20°N latitude, development of quasi-permanent high pressure systems over south Atlantic and south Indian Oceans, development of tropical easterly jet and the generation of low level Somali jet that enhance low level south westerly flow (Tadesse, 1994; NMSA, 1996; Segale and Lamb, 2005).

The analysis of dry and wet spell analysis was carried for the two rainy seasons, belg and kiremt. As Reddy (1990) has already stated that a 3 mm rainfall depth per day is the minimum threshold valued for crops to satisfy their crop water requirement. Accordingly, in this study, a 30 mm per decade of precipitation

Table 1. Standard meteorological decade.

Dekade no	Month	Date
1		1-10
2	January	11-20
3		21-30
4		1-10
5	February	11-20
6		21-30
7		1-10
8	March	11-20
9		21-30
10		1-10
11	April	11-20
12		21-30
13		1-10
14	May	11-20
19		1-10
20		11-20
21	July	21-30
22		1-10
23		11-20
24	August	21-30
25		1-10
26		11-20
27	September	21-30
28		1-10
29		11-20
30	October	21-30
31		1-10
32		11-20
	November	

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 zone (Reddy et al., 2008)

In a crop growing season, decisions have to be taken based on the probability of receiving certain amount of rainfall during a given decade. Therefore, Markov chain model was used to evaluate the dry and wet spell distributions on dekadal basis using dekadal rainfall.

The different formulations of Markov chain model which were used in the assessment of distribution of dry and wet spells are presented in the following series of equations.

Description of the study area

The study area is located in West Haraghe zones, Oromiya Regional State, eastern part of Ethiopia, about 405 km east of Addis Ababa. The Harerghe highlands lying in the eastern part of the country are generally known for their rugged topography, mountainous landscapes which govern the variations in regional geomorphology, soil sequences, ecological zones, quantity and quality of plant and animal life (Tamire, 1981). The climatic

conditions of the study area exist in all agro-ecological zones. The majority is covered by kola, woyena dega and Dega according to its altitudinal range from sea level.

The climate in West Hararghe is warm and temperate, there is significant rainfall. Even in the driest month there is a lot of rain. This location is classified as Cfb by Köppen and Geiger. The averages temperature of the zone is 17.1°C. On an average about 1026 mm of precipitation falls annually in its zone. It has a latitude and longitude of 9°05'N and 40°52'E and an altitude of 1826 meters above sea level.

Standard dekades

The standard dekades are organized as in the Table 1.

Initial probabilities

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

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

Conditional probabilities

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

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

$$P_{WD} = 1 - P_{DD}$$

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

Where: F_D is the number of dry dekads

F_W is number of wet dekads

F_{DD} -is number of dry dekad followed by another dry one

F_{WW} -is number of wet dekads followed by other wet dekads

P_D -is the probability of a dekad being dry

P_W -is the probability of a dekad being wet

P_{WW} -is the probability of wet dekad preceded by another wet dekad

P_{DD} -is the probability of a dry dekad preceded by another dry one

P_{WD} -is the probability of a wet dekad preceded by another dry dekad

P_{DW} -is the probability of a dry dekad preceded by a wet one.

RESULTS AND DISCUSSION

Main rain season

The results of initial and conditional probabilities of dry and wet dekads during *Kiremt* season at *Hirna* area are presented in Table 2. These results revealed that the probability of having a wet of greater than 50% occurred during 19th to 25th dekads while probability occurrence of a dry dekad (P_D) with more than 50% probability of occurrences observed to be between 16th to 18th dekad. Conditional probability of wet dekad preceded by a wet dekad [P_{WW}] at *Hirna* is observed to be greater than 50% (50-86%) except for dekads 16 and 18, 28, 29, which had 33, 10, 0 and 20% in their respective orders.

Similarly, only four dekades were observe to have more

Table 2. Dry-wet spell probability distribution of *Kiremt* based on the Markov Chain model *Hirna* station.

Dekade no.	P-W	P-D	P-WW	P-DD	P-WD	P-DW
16	35	65	33	59	41	67
17	19	81	75	81	19	25
18	38	62	10	38	62	90
19	69	31	72	25	75	28
20	77	23	70	17	83	30
21	85	15	86	25	75	14
22	85	15	86	0	100	14
23	85	15	77	0	100	23
24	85	15	82	0	100	18
25	88	12	83	0	100	17
26	77	23	75	33	67	25
27	31	69	50	39	61	50
28	12	88	0	83	17	100
29	19	81	20	67	33	80

Table 3. Dry-wet spell probability distribution of *Kiremt* based on the Markov Chain *Asebe Teferi* station (1985-2014).

Dekade no.	P-W	P-D	P-WW	P-DD	P-WD	P-DW
16	3.00	97.00	00.00	93.00	7.00	100.00
17	13.00	87.00	00.00	73.00	27.00	100.00
18	37.00	63.00	18.20	47.00	53.00	81.80
19	53.00	47.00	31.00	29.00	71.00	69.00
20	57.00	43.00	53.00	38.00	62.00	47.00
21	80.00	20.00	75.00	33.00	67.00	25.00
22	63.00	37.00	58.00	27.00	73.00	42.00
23	63.00	37.00	74.00	55.00	45.00	26.00
24	87.00	13.00	88.00	25.00	75.00	12.00
25	60.00	40.00	56.00	42.00	58.00	44.00
26	63.00	37.00	58.00	27.00	73.00	42.00
27	50.00	50.00	53.00	60.00	40.00	47.00
28	20.00	80.00	17.00	79.00	21.00	83.00
29	13.00	87.00	00.00	81.00	19.00	100.00
30	10.00	90.00	00.00	93.00	7.00	100.00

that 50% probability of occurrences of dry decades preceded by dry decades (dekade 16, 17, 28 and 29). Moreover, the probability of occurrence of dry dekade preceded by wet dekade or vice versa (P_{WD} or P_{DW}) was found to be in the range of (17-100%) and (14-100%) respectively for the same location.

The analysis of the results for Asebe Teferi showed that dekade 24 is the wettest while the driest is dekade 16 (Table 3). The period between dekade 20 and 27 had the highest probability of wet dekade after wet implying the chance of having good soil moisture for panning agricultural operations during those period. In other words, decision making with respect to planting of crops

is fairly less risky for farmers. On the other hand, the decades beyond dekade 27 should carefully be monitored as the plant may suffer from low soil moisture.

At Meiso, the period between dekade 20 and 24 had the highest chance of wet and wet after wet during the main growing season (Table 4). Planning for sowing crops on dekade 20 can be a good decision but during the decades of October plants could suffer from low soil moisture as the plant may require more water as it develops. Therefore, some soil and water conservation techniques should be exercised during the wettest periods (dekade 20-24) to conserve soil moisture so that it can serve in the later days of the growing season.

Table 4. Dry-wet spell probability distribution of *kiremt* based on the Markov Chain model *Meiso* station (1991-2008).

Dekade no.	PW	P-D	P-WW	P-DD	P-WD	P-DW
16	17	83	0	73	27	100
17	6	94	0	88	12	100
18	17	83	0	73	27	100
19	61	39	55	29	71	45
20	50	50	44	60	40	56
21	78	22	71	25	75	29
22	72	28	54	20	80	46
23	56	44	60	34	66	40
24	61	39	55	43	57	45
25	50	50	33	33	67	67
26	44	56	62	40	60	38
27	28	72	0	62	38	100
28	22	78	50	79	21	50
29	17	83	67	87	13	33

Table 5. Dry-wet spell probability distribution of *Belg* based on the Markov Chain model *Hirna*.area (1985-2010).

Dekade no.	P-W	P-D	P-WW	P-DD	P-WD	P-DW
7	23	77	0	75	25	100
8	38	62	55	69	31	45
9	38	62	40	73	27	60
10	58	42	67	36	64	33
11	62	38	44	30	70	56
12	50	50	46	70	30	54
13	54	46	43	42	58	57
14	46	54	36	57	43	64
15	31	69	25	72	28	75

In general, in the main rainy season, agricultural operations (e.g. planting) enjoy favorable soil moisture conditions during the decades between 20 to 27 for all the study areas. In the dekases where the chance of having wet after wet could create an opportunity to conserve water so that it could be used in the latter days of the crop development stages when the demand of water is relatively high. In this respect, *in situ* water harvesting can be an option to build soil moisture reserve.

Small rainy season (*Belg*)

The Makov chain analysis of the probability of dry and wet spell of belg season at Hirna exhibited that the driest decade is decade 7(23% of wet occurrences) and decade 11 had the highest probability of getting wet (62%) (Table 5). The highest probability of having wet decade after wet

was obtained at decade 10, 67% of occurrences. Correspondingly, the start of the season had the highest probability of occurrences of dry decade, during the decades 7-9. Similarly, during the same period, dry decade after dry is highly probable, ranging from 69 to 75%.

At Asebe Teferi, the highest probability of occurrences of wet decade was observed during decade 8-11 and at decade 13, ranged from 47 to 50% while all decades had more than 50% probability of occurrences for dryness (Table 6). The probability of occurrences of dry decade after dry is still very high for most of the decades at this same area and planning important agricultural operations except plowing could be some how difficult.

The probability getting wet decade during belg at Meiso is relatively low as compared to Hirna and *Aseb Teferi* (Table 7). There were only two decades (8 and 10) that had 50% probability of having wet decade, the rest experienced lower than 40% of occurrences. On the

Table 6. Dry-wet spell probability distribution of *Belg* based on the Markov Chain Model *Asebe Teferi* area (1985-2014).

Dekade no.	P-W	P-D	P-WW	P-DD	P-wD	P-DW
7	17.00	83.00	20.00	80.00	20.00	80.00
8	50.00	50.00	47.00	43.00	60.00	53.00
9	47.00	53.00	43.00	56.00	44.00	57.00
10	50.00	50.00	33.00	40.00	60.00	67.00
11	50.00	50.00	40.00	40.00	60.00	60.00
12	40.00	60.00	33.00	56.00	44.00	67.00
13	50.00	50.00	46.00	40.00	60.00	54.00
14	43.00	57.00	46.00	65.00	35.00	54.00
15	37.00	63.00	27.00	63.00	37.00	73.00

Table 7. Dry-wet spell probability distribution of *Belg* based on the Markov Chain model *Meiso* station.

Dekade no.	P-W	P-D	PWW	PDD	PWD	PDW
7	22	78	25	71	29	75
8	50	50	60	44	63	40
9	22	78	25	64	36	75
10	39	61	43	55	45	57
11	50	50	56	56	44	44
12	22	78	0	64	36	100
13	33	67	17	58	42	83
14	28	72	20	62	38	80
15	17	83	33	73	27	67

other hand, the occurrence of dryness is relatively higher than 50% during this same season, reaching as high as 13%. The implication is that there shall by no means planning for major agricultural operations in the study area for Belg.

Conclusions

Decision making in agricultural operation requires rigorous analysis of precipitation data. The results presented in this study exhibited that the chance of having wet dekades is relatively higher during last of June to the start of October for all the study locations. The probability of having wet after wet is also fairly enough that farmers can take significant agricultural operations, like planting. In order to take the full advantage of the main growing season, farmers should be ready to use the soil moisture from the small rainy season to plough their lands so that they can directly plant their crops right after the start of the main rainy season. On the other hand, the dates at the end of the growing season should be regularly monitored as the chance of having wet period is comparatively low. For long maturing crops, the dryness of October can have impact on the yield as demand for water would be higher

and thus some soil and water (*in-situ water harvesting*) conservation practices can help to build the soil moisture reserve of their land so that crops would not suffer from low soil moisture.

Conflict of Interests

The authors have not declared any conflict of interests.

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