Rainfall Occurrences, Precipitation Deficit and Surplus Analysis for Rainfall Water Harvesting and Management in the Central highlands of Ethiopia, the Case of Bishoftu District, Oromia Region

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This research is finance by the Ethiopian Institute of Agricultural Research

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

Rainfall is the dominant source of water for agriculture through out Ethiopia in general and the central highlands of Ethiopian in particular. Recent studies reported that the rianfed agriculture is still contributing more than more than 50% to GDP and about 60% to foreign exchange earnings and provides livelihood to more than 85% of the population (Goodswill *etal.*, 2007). But the rainfall variability, unreliable occurrences in sufficient amount and delay in onset dates are reducing the crop yields with reasonable amount almost in all parts of the country.

Contrary to those facts, large amount of increase in crop yields is expected to come from the rainfed agriculture to fill the food demands of the world as whole and the country in particular. This is because there are limited land resources to bring in to medium and large scale irrigation projects and also the investment required for the same is too big (WDR, 2007. Thus improving the rainfall water management for sustainable crop production remains the question to address and the priority to be taken to least maintain the optimum level of crop yields.

Some studies conducted in sub-Saharan Africa indicated that there is a potential opportunity for increasing crop yields in the region. An assessment made by Baron (2004) showed that the cereal crop yields could reach as high as 3.5 t ha^{-1} against the existing yield 1 t ha^{-1} yield estimated by Rockstrom (2003). This wide gap suggests that there is an enormous opportunity to raise crop yield from rainfed agriculture. This is entirely linked to focusing attention on maximizing yield per unit of water. But this requires of adapting to the prevailing climate variability and rainfall occurrences. Appropriate quantification methods of the historic climatic data have been very helpful for planning in crop production and thereby improving the desired achievements, increasing the yield per unit water (Mersha, 2005).

Analysis of Rainfall probability occurrences is becoming an important work especially in water resources sector and risk associated rainfed agriculture (Sayang et.al., 2008). Integration of the rainfall occurrences with the crop water requirement is observed to be more practical and sound for many of crop rainfall water management activities. Different researchers and organizations defined some threshold values of rainfall or water amount for the crop to grow and perform well in a growing season. Accordingly FAO (1978, 1998) developed simple soil water balance model that relates the minimum threshold value of rainfall with potentail evapotranspiration. In this model, the rainfall amount in a certain growing season should at least be equal half of the potential evapotranspirtation of the place the crop is to grow. This is from the plant physiological point of view in that the

plant is seriously affected if the amount of water given to it is less than this threshold values (Mersha, 2005). Reddy (1990) also defined that a 3 mm is the minimum daily rainfall or water mount that an ideal crop requires for its crop water requirement.
Therefore the present study critical examined the rainfall occurrences at different probability levels and also identified the precipitation deficits and surplus of an agricultural important district of the central highlands of Ethiopia, bishoftu based on the FAO(1978) and the Reddy(1990) models so that the result will help in decision making of agricultural activities in the study area.

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2. Methods and Data

The study district is found at 45 km south east of Addis Ababa, Ethiopia. The area receives an annual mean rainfall of around 789 mm with medium seasonal variability and bimodal pattern. The "*blegr*" rain, which is quite small to support crop production, usually occurs during the periods from the second week of March to second or third week of May. The long rainy season extends from the second week of June to the last week of September. The area is intensively cultivated for crop production. The major crop types grown in the watershed are wheat and indigenous Ethiopian crop, "teff.

A weather record of thirty three years (1975-2007) was obtained from the Debre Zeit Agricultural Research Centre's weather archive and was organized at decadal time unit for appropriate analysis. 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

(Messay, 2006). In other words, whole year will have 36 decades starting from the month of January which will have the first three decades (decade number 1, 2 and 3) and it follows the same pattern where the last three decades of a given year will be for December (decade number 34, 35 and 36 respectively..
The Weibul frequency formula was employed to obtain the rainfall occurrences at 95, 80, 60, 50 and 25 % probability levels.

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

Where,
P is the percent probability,
M is the rank at which the different probability levels of rainfall occurrences for each decade when organised in descending order
n is the number of observations
The reference evapotranpspiration was obtained from the Crop wat version 4.3 that employed the Penman-Month equation as in the equation given below.

$$ET_O = \frac{0.408\Delta[Rn - G] + \gamma\left(\frac{900}{T + 273}\right)U_2[e_s - e_a]}{\Delta + \gamma[1 + 0.34U_2]}$$

Where
ETo reference evapotranspiration [mm day-1],
Rn net radiation at the crop surface [MJ m-2 day-1],
G soil heat flux density [MJ m-2 day-1],
T mean daily air temperature at 2 m height [°C],
u2 wind speed at 2 m height [m s-1],
es saturation vapour pressure [kPa],
ea actual vapour pressure [kPa],
es - ea saturation vapour pressure deficit [kPa],
Slope of vapour pressure curve [kPa °C-1],
psychrometric constant [kPa °C-1].
The rainfall occurrences at the specified probably levels have been compared with the threshold level of the reference evapotranspiration, 0.5*ETo to identify the precipitation deficit, optimum and surplus points during the two growing seasons, the shorter(belg) and the main rainy season(kiremt) for the district. In general a descriptive statistics is used to explain the rainfall and reference evapotrapnspiration distribution in the district.
Rainfall distribution is behaving less temporally erratic during the main rainy season (kiremt) while the shorter one, belg is observed to have the highest variability in all the decades of this particular season (table 1 and 2).
As one can clearly see from the tables, the minimum coefficient of variation during the decades of the shorter rainy season is observed to be above only 88 %(decade 11th), the rest have more than 100% variability. The higher coefficient of variation implies that patterns could not be easily understood and consequently decisions pertaining to crop planting and related activities can only be made with difficulties and with high risk (Yemenu, 2009) during this particular season.
But the statistical analysis of the threshold reference evapotranspiration values showed low variability with a standard deviation ranging from 1.17 to 4.16 mm per decade for average values of 19.77 and 21.33 mm respectively during the decades of the main growing season. The same analysis for the shorter season(belg) resulted that the minimum and maximum standard deviation values are 2.41 and 6.63 mm per decade for average values of 22.9 and 26.72 mm in their respective orders(table 3 and 4).
The results in the above tables indicate that the limiting factor for crop growth in the district is more of rainfall variability and occurrences` of the sufficient amount than any other weather element. Hence, planning of agricultural activities should give considerable attention to this weather element for successfully attaining the optimum level of crop yields.
From the analysis of the rainfall probability of occurrences it is observed that the main rainy season is having well above the threshold limit (minimum of 30mm in a decade) for most of the decades of the season at higher probability levels (e.g. 80%). Surprisingly enough, the shorter rainy season, belg showed no occurrences of the threshold limit even at the medium probability levels (50%), it had only fewer occurrences at the lower one, 25% probability level. In other words, rainfall above the threshold limit can be expected in four out of five

consecutive years for most the decades of the main growing season while the shorter one had fewer occurrences of these even in one out of the four consecutive years(table 5 and 6).

Similarly, as illustrated in figures 1 and 2 below; the ratio between precipitation amount of 50 and 80% probability levels and the average of threshold reference evapotranspiration(0.5*ETo) showed that the main rainy season is still enjoying rainfall amount much higher than the threshold limit for most of the its decades while in belg, let alone at the higher probabilities, the rainfall amount remained much below the threshold of the crop water requirement at 50% probability of occurrences for all the decades(figure:3). But some precautions should also be done during decade 21 of the main rainy season as it carries the highest possibility of run of because of surplus precipitation. The ratio between the precipitation and the threshold ETo is nearly fourfold in this particular decade. As result there could also be high risks of waterloging conditions which could affect the crops because of poor aeration and in addition, there might be damages due to erosion in the down steams of areas of the district. This is parallel to the results obtained from elsewhere in the world that when precipitation values are in excess of the potential evapotranspiration, especially for regions having poor infiltration capacity of soils, there is danger of flood and accelerated erosion (Mutsaers, 1997).

In general, moisture from rainfall is critical during the shorter rainy season and thus it can never help to harvest the major crops grown in the district (wheat, chickpea and the indigenous crop 'tef') as it does not satisfy the crop water requirements of those crops (Yemenu, 2009 and Sihin and Yemenu, 2009). But, the moisture during this period could be used to facilitate land preparation activities for early planting in the main rainy season (Mersha, 2005) and this subsequently saves time and moisture that could have been used from the main cropping season. As a result, planting could be carried out earlier during the start of the main season and the probable loss of moisture for the land preparation activity during ***Kiremt*** could be minimized.

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Table:1 Rainfall behaviour during the main rainy season(Kirmet) (1975-2007)

	Parameters				
Decade no	Minimum(mm)	Maximum(mm)	Average(mm)	SD(mm)	CV(%)
16	0	113	20.15	24.23	120.24
17	0	125	28.88	26.11	90.42
18	2.8	118	43.24	24.50	56.65
19	3.9	124	59.70	32.02	53.64
20	17.3	114	58.63	24.67	42.07
21	12	168	74.00	31.90	43.11
22	0	122	62.33	30.40	48.78
23	0	122	62.33	30.40	48.78
24	0	125	56.42	29.28	51.89
25	7.3	82	37.83	20.03	52.94
26	0	97	33.61	24.23	72.10
27	0	94	18.89	19.09	101.06

Table:2 Rainfall behavior during the decades of the shorter rainy season(,belg) (1975-2007)

			Parameters		
Decades	Minimum(mm)	Maximum(mm)	Average(mm)	SD(mm)	CV (%)
7	0	139	13.85	26.97	194.71
8	0	87	17.45	24.19	138.61
9	0	117	25.30	30.59	120.91
10	0	70	21.25	22.29	104.88
11	0	58	16.75	14.79	88.32
12	0	71	17.30	20.00	115.60
13	0	109	22.72	30.20	132.95
14	0	83	13.18	19.64	149.03
15	0	149	19.53	30.08	154.01

Tabel:3.Statistical Behaviour of the threshold value(0.5*ETo) of the reference evapotranspiration in kiremt

		Parameters			
Decade no	Minimum	Maximum	Average	SD	CV
16	19	28	21.60	2.16	10.00
17	19	26	21.13	1.72	8.12
18	18	42	21.13	4.16	19.68
19	17	22	20.13	1.22	6.08
20	16	22	19.77	1.17	5.89
21	15	23	19.76	1.41	7.11
22	15	23	19.47	1.57	8.06
23	15	24	19.53	1.78	9.09
24	15	25	19.63	1.96	9.96
25	16	26	20.03	2.11	10.53
26	17	27	20.27	2.26	11.14
27	18	27	20.70	2.56	12.38

SD -Standard deviation

CV-Coefficient of variation

Tabel:4.Statistical Behavior of the threshold value(0.5*ETo) of the reference evapotranspiration in belg

Parameters					
Decade no	Minimum	Maximum	Average	SD	CV
7	22	34	25.79	2.92	11.32
8	22	34	25.72	2.90	11.28
9	22	58	26.72	6.63	24.82
10	21	33	25.45	2.81	11.04
11	21	29	24.69	2.44	9.87
12	20	33	24.76	2.79	11.25
13	21	33	23.97	2.77	11.56
14	20	32	23.38	2.38	10.19
15	20	31	22.90	2.41	10.53

Tabel:5. Rainfall occurrences at different probability levels during kiremt, the main rainy season(1975-2007)

	Probability levels (%)					
Decades	95	80	60	50	25	5
17	0.87	6.63	17.33	24	42	111.67
18	8.93	22	33.33	40	60	105.33
19	4.1	33	47.67	53	87.5	122.3
20	23.5	35.3	46.4	54.1	75.15	111
21	20	45.67	61.67	73	93	155.33
22	19.33	36.67	46.33	51	91	119.67
23	19.70	36.25	46.75	52.00	90.70	117.5
24	5.87	34.33	46.67	52.00	68.00	123.67
25	7.8	16.0	29.7	38.0	53.0	79.7
26	2	11.67	27.67	33	42	95.33
27	0	2.17	12.67	13.00	29.00	78.33
28	0	0	0.9	2.1	15	95

Tabel:6. Rainfall occurrences at different probability levels during belg, the shorter rainy season(1975-2007)

	Probability levels (%)					
Decades	95	80	60	50	25	5
7	0	0	0	1.5	25	73
8	0	0	1	4	30	73
9	0	1.23	9.36	17	41	74.66
10	0	1.20	6.1	18	38.5	67.67
11	0	2.37	10	13	27	53.67
12	0	0	6.67	9	27	71
13	0	0	9.5	14	27	99
14	0	0	1.7	2.9	21	72.33
15	0	0	3.53	9.4	24.5	127

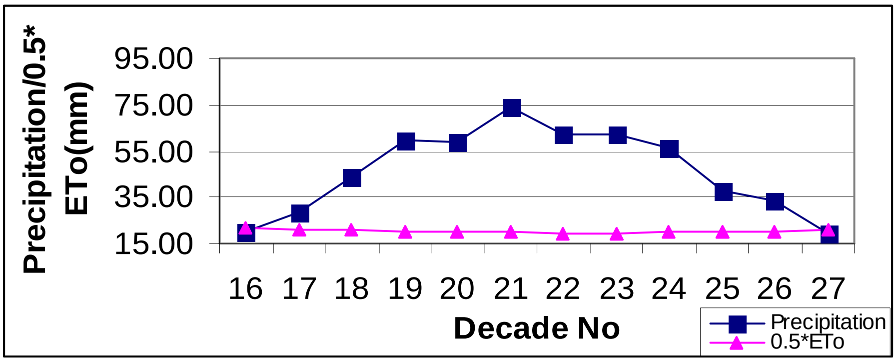

Figure 1. Comparison of precipitation at 50% probability of occurrences and average 0.5*ETo(Kiremt)

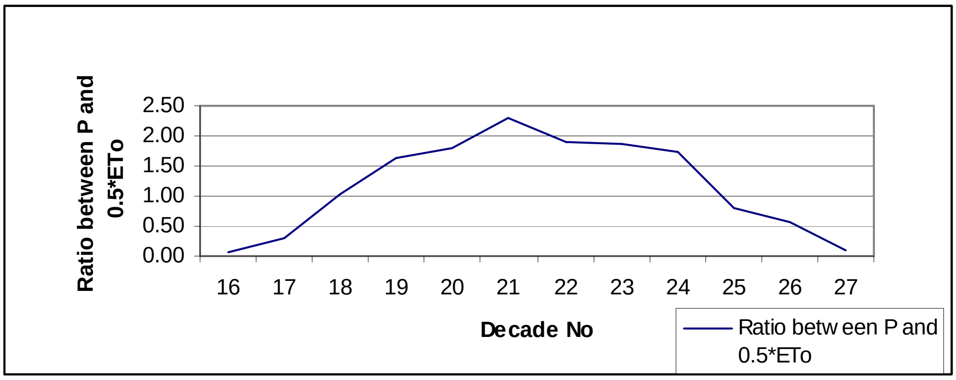

Figure 2. The ration between precipitation at 80% probability level and 0.5*ETo(Kiremt)