Effect of Climate Change on Rainfed Maize Production

-Assessment of Maize Production vs. a Changing Rainfall Pattern in Malawi-

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Abstract. Maize, a staple food crop in Malawi in sub-Saharan region has been grown under rainfed conditions for many years but many factors affect its production. Changing rainfall pattern has been a main factor which is believed to have come about due to the changing climate in recent years. A case study of over 60 years of rainfall data in Malawi's central region was analyzed where rainfall data over time was compared with maize production yields. Other non-climatic factors were also studied to explain their impact on production. Both observed monthly and daily rainfall data were used. Thiessen polygon method was used to calculate daily areal rainfall from the available 4 gauging stations. Since the gauging network was not adequate a regression analysis of the areal rainfall against the recorded time series from the stations was carried out. A regression equation created from the station with highest correlation was used to predict the daily rainfall data which was analyzed in detail to identify daily pattern changes. It was found that rainfall distribution characteristics have changed over time becoming more unpredictable and, hence, reducing production. In general, everytime there was an erratic rainfall pattern, maize production was affected. The paper recommends building more sustainable irrigation systems so that agricultural production can be under control during droughts. It also recommends removing policy that depends on rainfed food production and economic activities to control the problems associated with the changing rainfall pattern.

Keywords: Maize; Rainfed agriculture; Rainfall pattern; Climate change; Malawi

1 Introduction

Malawi faces food insecurity problems despite having a lot of water resources in sub-Saharan region (Shela, 2000). Recently, particularly in 2005, it faced a serious food shortage with an estimated 4.85 million people (nearly 50% of the population) in need of emergency food support (NSO, 2006; FAO, 2005). Watson (2001) suggested that nearly 800 million people in the world are malnourished and food production has to double in the next 35 years to sustain future needs. To keep pace with future food needs, the advances have to be achieved in the face of climate change, the recent consensus being that it will affect lives of many people in many ways (IPCC, 2001).

Maize is the main food crop in Malawi; however, the changing rainfall pattern has had an effect on maize production both in Malawi and the sub-Saharan region at large. Out of the sub-Saharan countries of Southern African Development Corporation (SADC), Malawi receives on average a reasonable annual amount of precipitation to adequately sustain crop production. Its annual maximum rainfall is as high as 3000 mm and lowest averages ranges between 635 mm and 889 mm. Almost all rainfall in Malawi come in summer with very insignificant levels in winter. In Malawi, the changing climate seems to affect rainfall pat-

tern both spatially and temporally and that has significantly impacted both the maize production trends and levels.

Malawi is a sub-Saharan country in Southern Africa located between latitudes 9°22'S and 17°03'S and longitudes 33°40'E and 35°55'E with surface area of 118,480 km². It is bordered by Tanzania on the north and northeast, by Mozambique on the south and southwest, and by Zambia in the west (Figure 1). Lake Malawi, Africa's third largest lake, takes up 20% of its land mass and is mostly in the central and northern parts of the country. There are smaller lakes of Chilwa and Malombe in the south. Malawi's rainfall has a unimodal distribution, generally, with the rainfall season starting from November and ending in April (Figure 2). The Inter-Tropical Convergence Zone (ITCZ), the Congo Air Boundary (CABS), and the winter Asian monsoon which contribute to precipitation from November to April affect Malawi's precipitation. Tropical cyclones and depressions originating in the Mozambique Channel or entering from the southwest Indian Ocean also affect precipitation. Recently, El Niño/Southern Oscillation (ENSO) phenomenon has been recognized as a major factor in determining precipitation patterns in Malawi. ENSO affects the ITCZ and CABS, the main rain-bearing mechanism; On the other hand, La Niña brings more rainfall, which normally results in floods (Jo-Ansie, 1998; Kundel, 2007; Clay, E. et.al. 2004).

Malawi's food production is mainly from rainfed agriculture. The principal food production period is dependent on the rainy season and the main crop produced is maize (*Zea mays*) produced by about 97% of all farming households (NSO, 2005a.b.and c). The changing weather pattern in the world climatic regions has not left the sub-Saharan

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Figure 1: Map of Malawi showing the Lilongwe River catchment area

Figure 2: Typical Malawi seasonal calendar and critical events (adapted from FEWS, 2008)

region unaffected. Rainfall distribution is no longer uniform and predictable as it used to be in the past.

The reliance on rain to produce maize for the national consumption has also posed a great challenge. The main producers are smallholder farmers whose land holding size averages 0.3 ha. Although there are some irrigation systems in the country, these schemes are mainly dedicated to tea, coffee, sugarcane and rice production. The irrigation systems available to the majority of maize-producing smallholder farmers are so rudimentary that they have little or no capacity to prevent impacts of erratic rainfall and dry spells during the main cropping season. The paradox, however, being that when rains fail, there is less maize production and creates economic problems in the national economy despite maize not being categorized as an economic crop.

2 Objectives

This paper analyzes rainfall time series of more than half a century ago in comparison with the most recent data to assess the extent to which the change of the rainfall trends has affected the maize production in Malawi. It also takes stock of some strategic policy interventions that Malawi has taken to strategically prevent the maize shortage problems. A wider view is also discussed where other non-climatic factors influence maize production in Malawi. This is discussed to draw a sense of understanding between shortage problems and the non-climatic factors. It is also aimed at understanding how Malawi has mitigated shortages at policy (government) and implementation (farmer) level to draw lessons for possible future action. The discussion also helps to show how food crises in sub-Saharan countries could be dealt with as global warming continues to influence climatic change patterns.

3 Methodology

This research focused on the Lilongwe River catchment area which is located in the south-west of the central region of Malawi (Figure 1). Rainfall data was compiled from various rain gauge stations in the catchment through the Meteorological Department during the research period in 2006. The central region, like the other parts of the country, has good geographical features which includes good climate and rich soils for agricultural production and

contributes a major share of national maize yield. The total national annual maize production figures from 1961 to 2007 were available from the Government of Malawi (GoM), and Food and Agricultural Organization (FAO) (2008). A wide range of literature and bulletins that included ones from government, NGOs, and International Aid Agencies were also studied to assess how production varied with the rainfall trends.

Monthly rainfall data was available from 1949 to 2005 from 13 stations. However, daily rainfall figures were available only from 4 stations, i.e. Kamuzu International Airport - KIA (also known as Lilongwe International Airport - LIA), Chitedze Research Station, Dedza District centre and Salima District centre from 1961. Rainfall data on daily time step was also available from the Department of Meteorology. Out of the 13 stations, only 9 stations were operational during the time of the study. Despite the existence of 9 operational stations in and around the catchment which reported long data on a monthly time-step, only 6, i.e. KIA, Chitedze Research Station, Dedza District, Salima District, Mchinji District and Kasungu District stations had a long record of daily rainfall available for this research. Kasungu and Mchinji Stations are outside the Lilongwe Catchment, therefore they were not considered for this study.

A study period from 1961 to 2005 was chosen for this research. Rainfall comparison, on daily time-step, was carried out for the period 1961-1966 (representing early period) and 2000-2005 (representing later period). The daily rainfall was computed to an areal rainfall using the Thiessen polygon method. Monthly observed rainfall data and daily simulated areal rainfall data were assessed using both the visual description and the statistical analyses of the temporal variability of the rainfall to determine pattern behavior and significant difference of the data series between the earlier years and the later years of the study period. The monthly rainfall descriptive comparison done between 1949-1959 and 1995-2005 periods provided a longer comparison on actual recorded rainfall variation on a monthly time-step.

National annual maize production from 1961 to 2005 was also assessed. Monthly maize (crop) yield estimates (usually conducted by Ministry of Agriculture and Food Security) were not available for this research. As such, the entire annual production since 1961 was considered in wholesome. Since there was no data specifically from the Lilongwe catchment on the maize yield, it was assumed that maize production in Lilongwe catchment has a positive correlation to that of the national yield. The conclusions drawn from the rainfall comparison during the study period were contrasted to the maize production trend. This was done taking into account other non-climatic factors that determine national adequacy of maize e.g. population and area of cultivation to determine the years which were designated as famine years. Malawi Government policies over the time of the study were also reviewed since maize is largely a staple food which attracts government intervention in its production and trade. A statistical analysis was also conducted on the maize yield data between the

early years (1961-1966) and the later years (2000-2005) of the study period.

A further assessment of the changing pattern of the rainfall on a daily basis during both periods was also carried out by assessing the dry spells. The duration of dry spells and their length of occurrence during rainy seasons of the two study periods were counted and analyzed. The assessment of dry spell trend was necessary to determine if there has been any change in their occurrence since maize crop is sensitive to and critically affected by their duration and length of occurrence during specific plant physiological growth periods. A statistical analysis was also conducted on the dry spell data from the two periods to assess their significant differences.

The size of the catchment (8,877 km²) was too large to be represented by 4 rain-gauge stations. The areal rainfall calculated from the observed data of the stations was too sparse to represent well enough the rainfall over the area. In absence of data, but with the nudge to obtain a rainfall time series that is closely representative of the catchment, the calculated areal rainfall was correlated to each of the four stations' rainfall to determine which station correlated strongest with the areal rainfall. A data series with the highest correlation factor, R^2 was determined from which a regression equation was formulated. The regression equation from this data set was in turn used to simulate another set of time series which was used in the daily assessments of daily rainfall trend for the Lilongwe Catchment.

3.1 Rainfall data screening

The reliability of the rainfall data was checked by following a Double Mass Curve analysis method (Gupta, 1989). Accumulated sum of the data from each of the four gauging stations (KIA, Chitedze, Dedza and Salima) were plotted against the accumulated mean of the rest of the stations. A straight line was obtained from each plot which indicated that the data has no spurious trends and therefore is consistent and can be used for further analyses.

3.2 Areal rainfall calculation

In order to calculate the areal rainfall over the Lilongwe catchment area, a Thiessen polygon procedure was followed. This method was chosen amongst many methods for its advantage of being more accurate, objective and having a computational procedure that is simple once areas of polygons are known. The catchment area was subdivided into polygonal sub-areas using gauging stations as centers (Figure 3). The entire map was further crisscrossed with 13 sub-polygons that were subdivided into triangles with known perpendicular heights. The total area of the triangles in each polygon was calculated to estimate the polygon area (i.e. sub-area a). The areas of the 4 polygons were then added to estimate the size of the catchment (A). The mean areal rainfall was calculated as

$$P_n = \sum_{i=1}^n \frac{Ra}{A} \quad (1)$$

Figure 3: Thiessen polygon map showing the sub-catchment polygons for the weighted areal rainfall calculation

where P_n = mean daily areal rainfall, R = rainfall measurements at each rain gauge station, A = total area of catchment, and a = polygon area corresponding to rain gauge station. The estimated area representing the Lilongwe River catchment stretching up to the confluence in Salima is 4,940 km². (Linthipe River sub-catchment accounts for 3,936 km² area).

3.3 Rainfall correlation

As commented by Yoo *et al.* (2007), the estimation error for a catchment areal rainfall can be much smaller if there is a significant inter-station correlation among gauges. As the rain gauge density increases in a basin, the possibility of having higher inter-station correlations increases, which therefore rapidly decreases the error involved in the areal average rainfall rate. The regression analysis between the areal rainfall calculated from the observed daily rainfall and each of the individual rainfall time series at the 4 major rainfall observation stations from 1961 to 2005 showed the strongest correlation with Chitedze Research Station time series (Table 1). A regression equation was formulated and used to simulate a more meaningful areal rainfall time series over the catchment. The simulated areal rainfall was calculated as

$$Y = 0.65966X + 0.94828 \quad (2)$$

where Y = the simulated areal rainfall in mm/day, and X = the observed rainfall (mm/day) from Chitedze Research Station.

This procedure has a benefit of reducing the error of estimation in the event of lack of a more representative gauging network in a catchment. The simulated rainfall was plotted on a daily time-step for a further detailed analysis of how the rainfall distribution changed over the period of daily rainfall observation over the catchment area.

Table 1: Regression statistics results between areal rainfall and observed rainfall at the 4 stations

Statistical parameter	Chitedze	Dedza	Salima	KIA/LIA
Observations	16191	16191	16191	16191
Multiple R	0.855293	0.666268	0.55865	0.757709
R ²	0.731526	0.443913	0.31209	0.574122
Adjusted R ²	0.731509	0.443879	0.312048	0.574096
Standard error	3.241787	4.665571	5.189184	4.082966
Coefficients	0.948285	1.185638	1.570336	1.143216
Intercept	0.659666	0.533479	0.288561	0.605466

Table 2: Statistical analysis of the monthly and annual rainfalls between the two periods

Statistic	Monthly rainfall later period	Monthly rainfall early period	Annual rainfall later period	Annual rainfall early period
Mean	103	88	763	753
Variance	4,884	4,515	6,237	14,14
Observations	37	43	5	5
Pooled Variance	4,686		10,192	
Hypothesized Mean	0		0	
df	78		8	
t Stat	1.02		0.16	
P(T<=t) one-tail	0.1564		0.4385	
t Critical one-tail	1.67		1.86	
P(T<=t) two-tail	0.3128		0.8770	
t Critical two-tail	1.99		2.31	

3.4 Statistical analysis

T-test statistical analyses were carried out on rainfall, dry spell and maize production parameters for the two studied periods. Table 2 lists the result from the analysis of observed monthly and annual averaged data. The calculated t-test statistic for both observed monthly rainfall (t-stat = 1.02 being < t-critical two-tail = 1.99 for degrees of freedom, df. = 78) and annual averaged rainfall (t-stat = 0.16 is < t-critical two-tail = 2.31 at df = 8) shows no significant differences.

Similar analyses done on annual monthly averaged observed rainfall, monthly averaged simulated rainfall and daily averaged simulated rainfall are listed in Table 3. The annual monthly averaged observed rainfall (t-Stat = 0.01 is < t-critical two-tail = 2.07 at df = 22), giving no significant differences between the means of the two data sets. Monthly averaged simulated rainfall also provided (t-stat = 0.04 is < t-critical two-tail = 2.12 at df = 16) with no significant differences. The daily simulated rainfall data which yielded (t-stat = 0.14 is < t-critical = 1.96 at df = 510) no significant differences too.

Number of dry spells and the annual maize yields for both periods were also subjected to a t-statistical test analysis and the results are shown in Tables 4 and 5 respectively. In Table 4, dry spells that were at least less than 10 mm rainfall and lasted more than 10 days had shown (t-stat = 2.76 is > t-critical = 2.31 at df = 8) significant differences between the two periods. The dry spells that got at most 0-1 mm rainfall in at least 6-10 days (t-stat = 0.98 is < t-critical

Table 3: Statistical analysis of the monthly averaged observed, simulated and daily averaged simulated rainfalls between the two periods

Statistic	Monthly averaged observed rainfall		Monthly averaged simulated rainfall		Daily averaged simulated rainfall	
	Later period	Early period	Later period	Early period	Later period	Early period
Mean	77.84	77.46	84.80	83.65	2.98	2.94
Variance	9384.01	9637.31	5256.24	3922.50	11.78	8.67
Observations	12	12	9	9	256	256
Pooled Variance	9510.66		4589.37		10.22	
Hypothesized Mean Difference	0		0		0	
df	22		16		510	
t Stat	0.01		0.04		0.14	
P(T<=t) one-tail	0.50		0.49		0.44	
t Critical one-tail	1.72		1.75		1.65	
P(T<=t) two-tail	0.99		0.97		0.89	
t Critical two-tail	2.07		2.12		1.96	

Table 4: Statistical analysis of the dry-spells between the two periods

Statistic	< 10 mm lasted > 10 days		Total number		(0-1 mm) within 6-10 days	
	Later period	Early period	Later period	Early period	Later period	Early period
Mean	13	8	32	26	9	8
Variance	13	9	21	19	8	2
Observations	5	5	5	5	5	5
Pooled Variance	11		20		5	
Hypothesized Mean Difference	0		0		0	
df	8		8		8	
t Stat	2.76		2.21		0.98	
P(T<=t) one-tail	0.01		0.03		0.18	
t Critical one-tail	1.86		1.86		1.86	
P(T<=t) two-tail	0.02		0.06		0.36	
t Critical two-tail	2.31		2.31		2.31	

= 2.31 at df = 8) showed no significant differences. As for the total number of dry spells that occurred (t-stat = 2.21 is < t-critical = 2.31 at df = 8) also showed no significant difference at t-critical two-tail but was significant at a t-critical one-tail = 1.86, giving the impression that the mean for the total number of dry spells for the earlier period was greater than the one for the later period (test for t-stat one-tail analysis). In Table 5, the total maize production for the two periods (t-stat = 5.02 is > t-critical two tail = 2.23 at df = 10) give a significant difference. All the analyses were carried out at 95% confidence level using excel-spread sheet software and the hypothesis assumed no difference in variances of the data for the two periods (null hypothesis; $H_0=0$, no differences in means).

4 Results

Temporal graphical plots of the actual recorded rainfall from each of the four gauging stations were made. Rainfall trend observed in the early part of the past half century

Table 5: Statistical analysis of the total maize production between the two periods

Statistic	later period	earlier period
Mean	1,764,729	856,333
Variance	190,345,620,082	6,241,866,667
Observations	6	6
Pooled Variance	98,293,743,374	
Hypothesized Mean Difference	0	
df	10	
t Stat	5.02	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.81	
P(T<=t) two-tail	0.00	
t Critical two-tail	2.23

KIA

KIA

Chitedze

Chitedze

Dedza

Dedza

Salima

Chitedze

Figure 4: Daily observed rainfall in 1962-1963 at KIA, Chitedze, Dedza and Salima

indicates a fairly uniform trend during the planting season (rainy summer season) as represented by the 1962-1963 rainfall pattern shown in Figure 4. The distribution appears to vary in the later part of the half century as evidenced in the represented 2002-2003 rainfall in Figure 5 from the same gauging stations. The onset of the rainy season which enables early season maize planting had been in November but there has been a shift which shows that rainfalls are now most adequate in mid December. However, the monthly observed rainfall in both periods show that during the observed years, the gauging stations received almost

same total monthly average rains by November that normally would support an early maize planting (Figures 6a and 6b). Averaged monthly observed rainfall also seems to support the observation (Figure 7a).

The simulated areal rainfall pattern between the two periods is shown in Figures 8a and 8b. As seen from the plots, the daily areal rainfall trend shows a shift in the onset of the rainy season, i.e. 4 of the 5 years in the early period had rains consistently commencing in October/November unlike during the later period where only 1 of the 5 years had rains that begun in November, and the rest of the rainy

Figure 6a: Monthly rainfall from 1949-1950 to 1958-1959

Figure 6b: Monthly rainfall from 1995-1996 to 2002-2005

Figure 7a: Observed average monthly rainfall comparison for the two periods

Figure 7b: Simulated average monthly rainfall comparison for the two periods

seasons erratically begun at variable dates in December and January. This shift and inconsistency of the rainy season commencement dates yields unpredictability, rendering planning and maize agronomy decision making difficult at all levels of the farming community with possible negative consequences on the yields.

The rainfall seasons in the early period, during most of the years generally ended with gradual decreasing rainfall rates in April/May, which is usually good for maize maturity, drying and avoid rotting and wastage, as the rainy season smoothens out (Figure 8a). In the later period, the rains generally ended erratically and mostly unpredictably (Figure 8b). The most pronounced characteristic being where the end of rainy season was preceded with large storms: e.g. during the 2001-2002, 2002-2003, 2003-2004 and 2004-2005 seasons. Many, such intensities are a precursor for flash floods and landslides, and Malawi has experienced many such cases during the later period. These, likewise, make harvesting difficult, causing losses due to inundation and rotting in the process. A comparison of the rainfalls, regardless of whether it is observed or simulated, however, shows no significant different changes between the two periods, also as supported by the t-statistic analysis (Figures 7a and 7b: Tables 2 and 3).

In general, the rainy seasons had fewer and shorter periods of dry spells during the earlier period (Figure 8a and Table 6a), but the later period, experienced frequent and longer dry spells (Figure 8b and Table 6b). A count of the number of dry provide evidence that there were more dry

spells in the later period of study than the earlier period, in all categories of dry spell lengths, as supported by their averages (Tables 4, 6a and 6b). The analyses of the dry spells that received less than 10 mm of rainfall and lasted more than 10 days were more significant in the later period than they were in the earlier period (Table 4). Water stress created on a maize plant during such dry spell lengths would easily diminish the maximum allowable depletion (MAD) and draw the crop closer to its permanent wilting point thereby affecting its yield (Panda *et al.* 2003; Singh and Singh, 1995). A one-tail, t-Test statistic analysis of means done on the total number of dry spells for the two periods also indicate a more significant difference in the later period than in the earlier period, although there was no significance when conducted in a two-tail t-Test (Table 4). There was no significant difference for the dry spells that lasted 6-10 days and received 0-1 mm of rainfall between the periods (Table 4) and as expected, these would not have as much a critical stress level on the crop so as to affect yields.

The most critical period of maize growth, during which water stress affects yield, is between 2 weeks before and 2-3 weeks after silking (Singh and Singh, 1995). Dry spells longer >15 days in the early period mostly occurred at the very end of the rainy season, mostly long after the crop has passed its grain filling (aka silking) physiological phase. In contrast, the 2000-2005 period had dry spells mostly occurring at the beginning of the rainy season, i.e. soon after planting, or at the middle of the growing season. For

Figure 8a: Predicted daily areal rainfall for periods (1961-1962 to 1964-1965)

instance: in 2001-2002 season, there was a one month dry spell from 20th November to 13th December which occurred 18 days after first rains; in 2002-2003 season, there was a dry spell (>15 days) occurring 15 days after planting;

Figure 8b: Predicted daily areal rainfall for periods (2000-2001 to 2004-2005)

in 2003-2004 season, 70 days after planting there was a one month long dry spell; and lastly 2004-2005 season experienced the shortest rainy season in the study period. In this season (2004-2005), the effective cropping season general-

Table 6a: Total number of dry spells in between 1961 and 1966 rainy seasons.

Rainy season year	Depth (mm/day)	Number of dry spells in specific duration (days)			Total annual dry spells
		6-10 days	11-15 days	>15 days	
1961-1962	0-1	6	3	1	29
	2-10	18	1	0	
1962-1963	0-1	8	3	1	28
	2-10	12	4	0	
1963-1964	0-1	10	6	0	29
	2-10	9	3	1	
1964-1965	0-1	8	0	0	19
	2-10	7	1	3	
1965-1966	0-1	8	5	3	24
	2-10	5	1	2	
Average	0-10	18	5	2	26

Figure 9: Average national maize yield from 1960 to 1995

ly started on 24th November and ended on 28th February (representing about a 90-day rainy season - the shortest on record). In addition, this season experienced some of the worst dry spells both at the beginning and the end, effectively shortening the cropping season. Such erratic rainfall seasonality meant that the dry spells occurred at critical times when the physiological maize growth and maturation is usually dependant on adequate soil moisture for a satisfactory grain yield production. This meant that prevalence of rainfall failure at such times affected the crop negatively.

5 Discussion

Many researchers widely believe that in the 20th century there have been changes in cultivation intensity which have accelerated the depletion of much of the country's natural fertility (Smale and Heisey, 1997). Although the declining soil fertility is one of the major constraints on maize production, this study suggests that evidence of changing temporal rainfall pattern has also occurred during same period which might have also affected national maize yield as many reports suggests (IMF, 2003; FEWS NET, 2001, 2002, 2003, 2006, and 2008). Every year that food insecurity has been declared as a national problem in Malawi by the authorities, rainfall has been erratic causing droughts, dry spells besides flooding during critical grain filling stages (Menon, 2008). In the past 3 decades, the country

Table 6b: Total number of dry spells in between 2000 and 2005 rainy seasons.

Rainy season year	Depth (mm/day)	Number of dry spell in specific duration (days)			Total annual dry spells
		6-10 days	11-15 days	>15 days	
2000-2001	0-1	11	5	0	40
	2-10	13	4	7	
2001-2002	0-1	12	4	2	31
	2-10	9	3	1	
2002-2003	0-1	8	1	1	30
	2-10	12	4	4	
2003-2004	0-1	11	4	3	29
	2-10	5	4	2	
2004-2005	0-1	5	5	2	30
	2-10	7	7	4	
Average	0-10	19	8	5	32

has experienced variability and unpredictability in seasonal rainfall. Droughts in 1978-1979, 1981-1982, 1991-1992 (the worst), 1992-1993, 1996-1997, 2001-2002 and 2004-2005 growing seasons were significant and caused crop failures and low yields (Mkanda, 2006; GoM, 2005; Clay, 2003). According to IMF (2003), the recent droughts in 2001-2002 and 2004-2005 are just but some recent evidence where famine got triggered mainly by failure of the rain-bearing systems during the critical periods of the planting season, a view supported by this study.

During the early study period, the total maize production was above national requirement, registering bumper yields throughout the 5 years with an average of 40% above national requirement. However, in the later period, the yields had been lower than the national requirement with an average of 13% below national requirement (Tables 7 and 8). A statistical comparison of the yield between the two periods indicates a significant difference, with the earlier period having produced a significantly greater amount of maize than the later period (Table 5). This seems to come about due to prevalence of significant critical dry spells observed in the later period than the earlier (as had been discussed in Section 4). According to records, from 1961 through 1991, maize output had increased by 1.8% per annum, representing a total of 55%. The production of maize per unit area had an incremental trend too (Figure 9). Government documents suggest that about 75% of the estimated increase in total production resulted from the expansion in maize area but does not indicate the precise role climatic conditions played in contributing to this increase. The per capita maize production, however, declined over the past half century as production lagged behind an exponential annual population growth rate of over 3.0% (Smale and Heisey, 1997) as shown in Figures 10 and 11. Overall, yields appear to have increased at rate of 0.4% per year. However, the increments registered in the later period are not significant in comparison to the earlier period as observed in the analysis of the yields for the two periods (Table 5).

The Government of Malawi established many policy frameworks, several institutions and policy interventions over the years to mitigate maize grain shortage. In 1971,

Figure 10: Total maize yield (tons) vs. per capita yield between 1961 and 2007 period.
(calculated from FAOSTAT 2008 and NSO 2005,2006)

Agricultural Development and Marketing Corporation (ADMARC) was established as a national state-run farm agency to buy grain including maize during harvest times and resale during lean periods. Although, widely criticized as overbearing, sells assure supplies of hybrid seeds and fertilizer and guarantees prices for whatever is grown. National Food Reserve Agency (NFRA), also known as Strategic Grain Reserve (SGR) established in 1999 by government, International Monetary Fund (IMF)(2003) and World Bank (WB)(2001), that stockpiles maize in silos for national redistribution when need arises is another institution that mitigates a national maize grain shortage. When rains fail and famine occurs, these two institutions help to prevent grain shortages.

It could have been more complete if a state-run company in similar capacity was coordinating irrigation activities so that grain production and food security issues are placed at the lowest level i.e. in the hands of the farmers themselves. The annual rainfall quantities have not changed much over the period of study. It is the frequent occurrence of the critical dry spells that have mostly increased in the last period of study which seem to affect maize production. The shifting of the onset of the growing season, which has consequently shifted the planting dates, may also have had an impact due to occurrence of pests which are associated with erratic rainfall trends and late planting.

Various water schemes have remained on the drawing board and planning phase for a long period in Malawi. Less than 1% of Malawi is irrigated and that land mainly belongs to commercial farms that grow tea, sugar and tobacco for export (FAO, 2005; GoM, 2005). According to a 2004-2005 Integrated Household Survey (IHS) report, modern methods of irrigation in most households are almost nonexistent (GoM, 2005). There has been low priority in irrigated agricultural production despite the increased publicity the sector has been given over the past 15 years. There seems to be reluctance on government to initiate efforts that would ensure that rainfalls into the catchments of Malawi are looked at as a recharge into the many water resources (wetlands, rivers, dams and lakes), to be utilized for a supplemental irrigation activity during eventualities

Figure 11: Population trend since 1900

Table 7: Comparison between estimated requirement and average maize production for 1961-1966 seasons

Period	Production (Metric tons)	requirement (Metric tons)	% above/below requirement
1961-1962	815,000	561,709	45%
1962-1963	850,000	580,150	47%
1963-1964	726,000	599,196	21%
1964-1965	907,000	618,867	47%
1965-1966	890,000	639,184	39%
Average	837,600	599,821	40%

Table 8: Comparison between estimated requirement and average maize production for 2000-2005 seasons

Period	Production (Metric tons)	Requirement (Metric tons)	% above/below requirement
2000-2001	1,713,064	1,750,000	-2%
2001-2002	1,556,975	1,800,000	-14%
2002-2003	1,983,440	1,950,000	2%
2003-2004	1,733,125	1,950,000	-11%
2004-2005	1,225,234	2,000,000	-39%
Average	1,642,368	1,890,000	-13%

of critical dry spell. With the right infrastructure and proper institutions in place, erratic rainfall trends could easily be mitigated and maize grain shortages would be avoided.

Although recent droughts caused crop failures and low yields and Government increasingly realized the importance of irrigation as a means of ensuring food security at both household and national level, there is still no tangible action on the ground that ensures that maize crop does not get affected by bad rains. The significance of Malawi Poverty Reduction Strategy Paper (MPRSP) to recognize irrigation development in Malawi as a matter of priority in its poverty reduction strategic plans (GoM 2002) needs to be translated into sustainable water schemes that ensure a steady supply of water to the maize fields at the time of bad weather.

The status of irrigation has been recently raised to a ministry level where a 23-point irrigation development strategy plan for poverty alleviation has been drafted. The new strategy gives highest priority to the development of irrigation and water resources in the country and strengthens the new created ministry with sufficient funds and staff to undertake studies on pumping sites, boreholes and dam development (Phiri, 2006; GoM, 2005). These are significant steps towards ensuring a reliable hedge to water resources supply.

It is also important to recognize that currently there are no functional catchment based water resources institutions that would assist with ensuring water distribution equity to users. Such institutions are essential when planning any intra-rainy season water resource rescue plan to farmers whose crops may be at risk from bad rainfall. The existing Department of Irrigation (DoI) under the Ministry of Irrigation and Water Development (MIWD) lacks the capacity to implement a meaningful schematic irrigation network amongst smallholder farmers. Such networks would adequately buffer water shortages during dry spells or produce maize from the many old schemes that exist in the country. As a matter of fact, there are plenty waters in Malawi that flow unused to the ocean through idle land even in dry season when rainfed cropping is in recess.

Maize is a highly politicized crop in Malawi owing to its nature as a main food crop. As such, government interferes either directly or indirectly in its production and trade at all levels. However, the private sector also responds sharply whenever there is a maize shortage like in 2005 (Figure 12).

Figure 12: Informal maize trade import trends from 2005-2006 to 2007-2008 seasons

In the past 20 years, under pressure from the IMF, WB and other donor institutions, Malawi liberalized its agricultural economy and dismantled the state-run agricultural system. The government's clumsy implementation of this change has led to a failure of the emergent market to deliver a more efficient and bountiful harvest. The government has also sold off state food reserves at times from the SGR, leaving nothing for emergencies. There seems to be no government institution or department that has tried to bring about a policy that directly deals with rainfall changing pattern with an aim of helping maize farmers tackle the dry spell problem.

There have been special government programs like Malawi Universal Starter Pack Program initiated in 1998-1999 which was later changed to Targeted Inputs Program (TIP) in 2001; but discontinued in 2005 when donors got disillusioned by the sustainability of the program which provided free hybrid maize seed and fertilizers to farmers. Later in 2005, the Fertilizer Subsidy Program was introduced on the back drop of overwhelming pressure from the countries' donor community, including the WB and IMF, to adhere to free market policies and cut back or eliminate fertilizer subsidies. The program was praised for the wonders it has produced in turning the country from a maize beggar to an exporter within one season of introduction (Table 9). It is a fact that these policy measures only targeted input (fertilizer and seed) side of maize production. It was, however, viewed strongly that the subsidies worked well in achieving bumper yields because of good rains in the years 2005-2007, as this study seems to reveal.

The strategy of strengthening food security policy by improving the transparency of maize operations by ADMARC, which operates the SGR on behalf of the NFRA is essential. It is also believed that price distortions by government through ADMARC depresses maize prices thus creating disincentives for producers and contributing to the shortages especially in drought years. In this food security strategy, there is no direct action in terms of dealing with the rainfall inability to support production. National subsidies on both maize production and external purchases are a cost to the national budget and reducing them is essential to ensuring that the national economy is not distorted during famine. For instance, the budget was derailed in fiscal year 2000-2001, in part, because the government bailed out the NFRA by repaying its commercial loans. In addition, budgetary support amounting to 1.5 percent of GDP was pro-

Table 9: Comparison between estimated and average maize production from 2002-2003 agricultural season

Period	Production (Metric tons)	% above/below average
2002-2003	1,983,440	-10%
2003-2004	1,733,125	-21%
2004-2005	1,225,234	-44%
2005-2006	2,576,716	18%
2006-2007	3,444,655	57%
2007-2008	3,282,624	50%

vided to ADMARC during 2000-2001. The rainfall in that year was not reliable either. A strong investment in water resources in general and irrigation infrastructure in particular can adequately surmount the pressures of buying maize externally when there is a drought.

The food crises, however, also point to weaknesses in Malawi's agricultural policies. One problem is Malawi's overreliance on rainfed maize production. Maize is not drought resistant and to maintain yields it requires fertilizer as it exhausts soil nutrients quickly and fresh hybrid seeds each year. The diversification into other food crops appears to be one of the achievements in the revised agricultural policy although most dietary needs of Malawians are still dominated by maize. Growing crop varieties which suit the current changing climatic pattern is one of the main strategic mitigation measures that can curb the adverse effects of the erratic rainfall.

6 Conclusion

The temporal distribution of rainfall in Malawi observed in the past half century has changed significantly. This change has affected crop production regime in general and maize cropping in particular. Annual rainfall pattern for the past years has shown a change in the dates of the beginning of the rainy season. The peak rainfall period which usually came in December has shifted to January/February. The rains which usually had a fairly uniform distribution throughout the rainy season, increasing gradually to the peak in December and then decreasing at gradual rates until end of season in April have now become so erratic that there is usually an abrupt increase of rain in January/February and the entire rainy season is mostly punctuated by longer than normal dry spells. Crop production period in the rainy season has become shorter in recent periods but the average annual rainfall total has generally remained the same. Worse enough are the flash runoff due to high intensity rainfalls, causing flooding thereby further worsening the maize production. This change which is believed to arise from the effects of climate change has affected maize production to an extent that maize imports became the order of national budgetary requirements. The GoM is a member of the United Nations Conventions on Climate Change, combating desertification and on Biological Diversity, with the objective of mitigating the adverse effects of climate change on water availability, agriculture and food security, economic development, fisheries, and people's livelihoods. It is also currently engaged in construction of small dams; mapping of flood and drought areas; introduction of rain harvesting techniques and public awareness campaigns in water conservation measures; rehabilitation of flooded areas; forecasting and early warning systems; construction of dikes and canals to redirect/divert overflows in vulnerable areas as mitigative measures. The pace of implementation, however, is very slow.

This study established that there is still a great reliance on rainfed agriculture in both food and economic production activities. The availability of a significant water resources development potential (that includes irrigation development) can create a more predictable agricultural pro-

duction regime. Such a development can eliminate the climatic uncertainties in maize production processes, but there seems to be reluctance by government to initiate forcefully such projects.

The following non-climatic factors also contributed greatly to maize production problems in Malawi; non-sustainable agricultural practices, poorly supported structural changes in agriculture; institutional weaknesses in the agriculture and water sectors that include deteriorating statistics; de-industrialization with the reintegration of republic of South Africa (RSA) into the SADC regional economy; political instability and problems of governance; the short-term behavior of aid donors, contributing to volatility of public finances; and the effects of HIV/AIDS on human resources.

There also seems to be a tendency of the existing irrigation schemes to maximize production in the rainy (wet) season instead of the winter (dry) season when production is very unreliable and unpredictable and crucially requires water. This, despite existence of many water resources, does not exploit a full potential because rainy season dry spells only need supplemental irrigation while dry season maize production requires a full irrigation supply. Absence of dams for irrigation (to capture rainwater and redistribute during dry spells) in most parts of the country has also aggravated the situation of lack of water for irrigated agriculture. There is hardly any inter-basin water transfer techniques explored to see if the low flow streams could benefit from the high stream flows of adjacent basins to enable farmers in dry catchments have access to sufficient water for maize production.

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