TRENDS OF RAINFALL AND MAIZE PRODUCTIVITY IN MALAWI

T.A. Kimaro[a] * and H. Sibande[a]

[a] *Water Resources Engineering Department, University of Dar es Salaam,*
P.O Box 35131, Dar es Salaam, Tanzania
e-mail: kimaro@wrep.udsm.ac.tz

ABSTRACT

Daily rainfall data between 1966 and 2005 across all Agricultural Development Areas (ADDs) in Malawi was investigated to determine changes in selected rainfall characteristics and their impact on Maize productivity. Rainfall indices analyzed included rainfall amounts (annual and seasonal), onset, cessation, dry spells and length of rainy season. Man Kendal's trend test was applied to the time series of these indices to detect any trends in the time series. Water Requirement Satisfaction Index (WRSI) for maize crop was used to study the spatial-temporal variation of maize productivity and thus its linkage to rainfall. Definition of onset and cessation adopted from the Department of Meteorological Service (DMS) Malawi was used in demarcating seasons to extract seasonal rainfall amount, length and other parameters. The results of the study indicate that with the exception of Karonga ADD located at the Northern tip of the country there were no significant trends in all variables related to crop productivity including onset, cessation, rainfall amount and dry spells. The spatial and temporal variability of maize production in Malawi was captured quite well by the WRSI. The relationship between long-term average WRSI and maize yield (tonnes/ha) for different stations in Malawi had a correlation coefficient of 0.82 while the relationship of countrywide average WRSI and maize yield had a correlation coefficient of 0.75. Areas with low long term average WRSI like Shire valley also showed low productivity while those with higher WRSI like Mzimba and Salima ADD had a good yield. On average Malawi has sufficient rainfall to sustain rain-fed maize crop as most of the time (67%) rain-fall is enough to give an average yield. It was also found out that Malawi experience droughts and hence food shortages when WRSI value is close to or below 60%.

Key words: *Malawi, WRSI, Maize, rainfall, Trend analysis, onset, cessation.*

1.0 INTRODUCTION

Floods and droughts are the most frequent disasters in Malawi. The country experienced significant droughts in 1978/79, 1981/82 and the worst in 1991/92 (Mkanda et al., 1995). ∅ygard (2005) also reported a drought in the country in 2005. The drought of 1991/92 growing season caused a 67% reduction in maize production while in 2001 floods which occurred in 13 (out of 27) districts in the country contributed to about 32% drop in maize output. According to ∅ygard (2005), maize yield in 2005 fell by 30% of the previous year's poor harvest due to early termination of the 2004/05 rainy season. It is believed that intermittent droughts are likely to become more frequent and severe in the future. The resulting food shortages from these weather related disasters has necessitated the Government and donors to import maize for free distribution or subsidized sale. For example the Government spent about US$80 million on maize imports in 2002/03 while WFP alone spent more than US$250 million on food aid for the country in a period of just 25 years (by 2003). It is evident from these reports that extreme rainfall events and early cessation of rains (and possibly other rainfall pattern variations not mentioned here) have serious effects on maize productivity. Different types of crops have different crop water requirements and also different growing periods (FAO, 2006). An understanding of the variations or trend of the rainfall pattern on the part of the farmer will enable them decide whether to maintain growing the maize crop or to switch to other crops which would be suitable in a particular area under the prevailing weather conditions. The farmer may also adjust the time of planting maize depending on how the rainfall pattern has changed. The objective of this study was to determine the variability of rainfall in Malawi and its impact on maize production. Specifically the study looked into changes in characteristics of rainfall which have impact on maize production including onset of the rain season, cession of the season, length of the season, amount of rainfall and WRSI. On the other hand production data is investigated to see how such changes are reflected on maize production.

2.0 DESCRIPTION OF THE STUDY AREA

Malawi is situated in south-eastern Africa between latitudes 9° 22' and 17° 7' south of Equator and between longitudes 32° 40' and 35° 55' east of Greenwich (Mkanda et al., 1995). It is surrounded by Tanzania to the north, Zambia to the west and Mozambique to the east, (see Figure 1). The country is about 900 km in length (north to south) and about 200 km across (east to west) at its widest section. It has a territorial area of 118,483 km^2 of which 24,208 km^2 is covered by water, mainly Lake Nyasa/Malawi, which is the third largest lake in Africa (Mkanda et al., 1995). The country's land elevation rises from 37 m.a.s.l., in the Lower Shire Valley located in the Great Rift Valley, to 3050 m.a.s.l on the peak of Mount Mulanje, which is the highest in Central Africa. The mean surface elevation of Lake Malawi is 474 m.a.s.l. and deepest point is 230 metres below sea level (Mkanda et al., 1995) i.e. 704 metres deep.

Malawi's climate is subtropical with a generally hot rainy season, which normally runs from November to April. Annual rainfall ranges from about 600 to 3,000 mm, being generally greatest at higher elevations, and least in the Lower Shire Valley (Mkanda et al., 1995). The rains can start as early as October, especially in the southern part of the country and can end as late as May, in the northern part of the country.

Malawi's economy is heavily dependent on agriculture as the country has few exploitable mineral resources. Agriculture accounts for about 80% of all exports and 38.6% of GDP. The sector engages over 80% of the labour force and nearly 90% of the population is involved in subsistence farming. The sector also contributes 63.7% of the total income for the rural population and 65% of the manufacturing industry raw materials (CIA, 2006).

Main food crops for the country's 12 million population are maize, rice and cassava. Maize, the main staple food occupies about 60% of cultivated land and accounts for 70% of calorie consumption (∅ygard, 2005). Malawi also grows tobacco, tea and sugar which are the main export crops in that order of importance.

The country is divided into eight agricultural production zones known as Agricultural Development Divisions (ADD). The ADDs are Karonga, Mzuzu, Kasungu, Salima, Lilongwe, Machinga, Blantyre and Shire Valley as shown in Figure 2.

3.0 METHODOLOGY

3.1 Data Collection

Two types of data were collected for the study. These were climatic data (rainfall and evaporation) and maize production data. Rainfall and evaporation data were supplied by the Department of Meteorological Services (DMS) Malawi while data on maize production was obtained from the Ministry of Agriculture Malawi.

Daily rainfall data records for a period of 40 years from 1966/67 to 2005/06 were collected from 8 rainfall stations across the country, one from each of the eight Agricultural Development Divisions (ADDs). The main criteria for selection of these stations were(i) each ADD to be represented by at least one station, thereby covering the entire country, (ii) station to be located roughly at the centre of the respective ADDs and (iii) availability of long records with minimal, if any, number of gaps. Table 1 shows the names and location of the selected stations.

Daily evaporation data was collected from eight stations, the same stations from which rainfall data was collected (Table 1). However, data collected or available were for varying periods of record, ranging from 20 to 30 years. Criteria for selection of the stations are the same as that for selection of rainfall stations.

Maize production data collected was annual rain-fed maize production and area of rain-fed maize cultivation for each ADD in Malawi for the period 1983/84 to 2005/06 (23 years).

3.2 Extractions of rainfall indices for analysis

The main methodology used to determine changes in the rainfall series is the trend analysis. Trend testing was conducted for time series of annual rainfall, onset, cessation, maximum daily rainfall, dry spells and seasonal rainfall. These indices were derived from annual daily rainfall series as follows.

The annual rainfall was defined as the total sum of daily rainfall from 1st November of the current year to 31st October of the following year. The seasonal rainfall was calculated as the total sum of daily rainfall from November to April which is the rainfall season in Malawi (Mkanda et al., 1995).
The onset of the rains was determined according to the definition used by the Department of Meteorological Services (DMS). In defining onset DMS takes into consideration the time for the establishment of the main rain bearing systems, namely Inter Tropical Convergence Zone (ITCZ) and Congo Air mass. ITCZ climatologically gets established over Malawi in November. Prior to November, rainfall is mainly through thermal storms – discontinuous in distribution over time and space. So for practical purposes, DMS considers that onset does not occur until 1st November. DMS defines onset of rainfall as occurrence of at least 40

mm of rainfall accumulated within 10 days after 1st November and not to be followed by a dry spell of 10 or more consecutive days within one month. The end of rainfall season is determined when accumulated rainfall does not exceed 25mm in 15 days after 15th March. In other words the rain season is not expected to end before March. Following these definitions the length of rain season in each year was then calculated as the number of days between the onset and cessation. The average onset and cessation dates extracted from rainfall records are presented in Table 2.

A dry spell is defined as a period with no rainfall during a season. According to the DMS a non raining day is day when rainfall does not exceed 4mm. The longest dry spell per season (longest period of consecutive non rainy days in the season) was extracted for further analysis.

3.3 Analysis of changes

Methodology used to detect changes in the time series was trend testing. Mann Kendal test (MK test) is a non parametric test and there is not need of prior assumption of the underlying distribution of data. The test is especially suited for non normally distributed data, data with outliers and trends can be linear or non linear (Molnar et al., 2001). Mann-Kendal test statistics (T) is defined as in Kwarteng et al., 2008 as;

$$T = \sum_{i<j} sgn(xi - xj) \text{ where } sgn(x) = \begin{Bmatrix} 1 & if\ x > o \\ 0 & if\ x = 0 \\ -1 & if\ x < 0 \end{Bmatrix}. \quad \ldots\ldots (1)$$

Under the null hypothesis that there is no trend T is distributed as Normal random variable with mean zero and variance assuming no ties with (x_1, x_2, ...x_n) (Hirsch et al., 1992). The tests were carried at 5% significance level.

3.4 Estimation of crop Water Requirement

It was necessary to determine the crop water requirement (for maize) in each ADD in order to calculate the water requirements satisfaction index (WRSI), in other words, to find out for each season whether there was water shortage or not for the growth of the maize crop. The basic formula used to calculate maize crop water requirement is:

$$ET_{crop} = K_c ET_o \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where ET_{crop} is water requirement of maize (mm/month), K_c is the crop factor (or coefficient) determined according to stage of growth (FAO, 2006) and ET_0 is reference crop evapotranspiration (mm/season). ET_o data was obtained from DMS and the ET_{crop} was then calculated using equation 2 above. A weighted average crop coefficient for maize of 0.824 was adopted.

3.5 Estimation of effective Rainfall and Water Requirement Satisfaction Index (WRSI)

Effective rainfall in a growing season is required for calculation of water requirement satisfaction index. The maize growing season was defined as a period of 125 days from the onset of rainfall (FAO, 2006). This period consists of roughly four months. The period was divided into four months and rainfall for each month was then computed by adding daily rainfall during the month, within the period from the 'start or onset of the rains' to the 125th day. Effective rainfall for each month was then calculated using the following two formulas (after Van der Zaag, 2003):

$$P_{eff} = 0.8 * P - 25 \qquad P > 75\, mm/month \cdots\cdots\cdots (3)$$

$$P_{eff} = 0.6 * P - 10 \qquad P < 75\, mm/month \cdots (4)$$

Where P_{eff} is effective rainfall and P is gross rainfall

The total effective rainfall for each season was computed by adding the four monthly effective rainfall amounts.

Water resources satisfaction index was calculated according to Martin et al., (2000) as shown in equation 5 below.

$$WRSI_{season} = 100(1 - \sum_{planting}^{harvest} \frac{ET_m - ET_a}{ET_m}) \ldots\ldots\ldots (5)$$

Where ET_m is the maximum evapotranspiration and E_{ta} is the actual evapotranspiration.

ET_m is estimated as ET_{crop} and ET_a=P_{eff} if P_{eff} < ET_m, otherwise ET_a = ET_m the value of WRSI was calculated for each season and a time series of WRSI for each station was compiled for further analysis.

4.0 RESULTS AND DISCUSSION

4.1 CHANGES IN RAINFALL

Basic statistics of the rainfall stations studied including the indices used for analysis in this study are presented in Table 1 and the results of trend testing are presented in Table 2. Generally the results shows a relatively stationary rainfall all over Malawi where trend testing for almost all stations and for different characteristics of rainfall including annual rainfall, seasonal rainfall, annual maximum rainfall, season length, onset and cessation did not show any significant trends. There are however few exceptions where results deviated from this general trend.

It was found out that large part of Malawi exhibit unimodal rainfall except the northern tip of the country (Karonga station) where a slightly bimodal behaviour was detected. The bi-modal pattern with two distinct peaks in November and March resembles similar characteristics in neighbouring Tanzania where the bimodal and intermediate types of season are widespread (Gommes and Houssiau, 1982). It also happened that Karonga was the only station where a significant negative trend in annual rainfall was detected. The finding is consistent with results reported by Ochieng, 1998 who also detected negative trends for rainfall in south-western Tanzania a few kilometres from Karonga. The striking difference in rainfall pattern between Karonga and the rest of the country indicate also the influence of Lake Nyasa on the local climate further south.

Seasonal rainfall in Karonga was also found to be decreasing. This was however expected as most of the annual rainfall occurs in the rainfall season November to April. Trend testing for individual months did not show any significant change in all stations even in Karonga where negative trends at seasonal and annual scales were detected. This underlies the importance of averaging period (time resolution) when conducting change detection in climatic series. As in this case the changes in individual months are not significant but when summed up over a season they become evident.

The analysis of annual maximum rainfall showed an increasing trend in Kasungu. This station however has a relatively low maximum rainfall as compared to other stations. The average maximum rainfall for this station is 70.4 mm as compared to Salima station with 112.4mm. It was further noted that stations located close to the lake including Salima had high maximum rainfall which indicate the influence of the lake to the local climate.

The analysis of onset and cessation was intended to detect if there are any shifts in the seasons which could easily affect farmers used to certain timing and duration of the seasons. Out of 8 stations tested in Malawi there was no evidence for changes in onset, cessation and length of season or dry spells except for a few cases. In Karonga increasing trend in onset and decreasing trend in cessation were noted. This change also resulted in a significant change of the length of a season. The standard deviation of the onset dates varied between 13 and 30 days the higher value indicating a relatively un reliable onset date. The longest rainy season was detected in Karonga where it extends for 137 days. Although this seems as an advantage over other areas it was later found out that water requirement satisfaction index (WRSI) for maize in this area is not so high in this station as compared to other stations. Further more the maize yield of 1.23 tonnes/ha in Karonga was below the National Maximum yield of 1.468 in Kasungu. Results of analysis further revealed that in Karonga, the number of dry days had a tendency to increase which means though the season is long a number of dry spells in between cause water shortage and affects productivity. It was also found out that number of dry days and the length of longest dry spells were increasing in Chitedze and Kasungu respectively.

It is also worth noting here that the longest rain season was found in Karonga towards the northern part of the country which is close to Tanzania where Gommes and Housia (1982) had found out earlier that the length of rain season is as long as 200 days. This confirms that northern Malawi could be in slightly different climatic region with distinct behaviour from the south.

The results of the study indicate that in all stations except Karonga the length of season was shorter than 125 days which is the length of growing season for maize. This partly explains the very low yield of maize between 0.9 and 1.46 tonnes per hectare in most years the yield was below 0.8 tonnes per hectare.

4.2 Water Requirement satisfaction and maize Yield

The average rain-fed maize production in Malawi from the data gathered in this study is 1.165 tonnes/ha. This is about 15% of the optimal production of 8-10 tonnes/hectare (Rockström, 2003). This yield rate is generally classified as poor (Martin et al., 2000). The higher yield was found in Kasungu ADD (1.468) and the lowest in Shire Valley ADD (0.949).

There were no significant trends in maize yield for the period of study in all the ADDs with the exception of Blantyre ADD, where a positive trend was detected. This trend is however very unlikely to be related to weather as there is no evidence from analysis which show favourable climatic conditions for the area. Most probably the increasing production per hectare is a result of adoption of modern technology and methods of farming by farmers in this area who are close to the city and within reach of services and markets. Blantyre ADD is one of the most densely populated areas (258 persons/km^2 FAO, 2003) and the need for higher return per unit of land is a natural consequence. On average areas with high water requirement satisfaction index also have high maize yield as shown in Figure 3.

Table 3 gives the calculated water requirements satisfaction index (WRSI) for each maize growing season (year) for which evaporation data was available in all the evaporation stations used in the study. From Figure 3 a good relationship between rainfall and maize yield in Malawi may be seen. Low yield is clearly related to low water requirement satisfaction index. The lowest production per hectare (0.949) found in shire valley ADD is clearly explained by low average water requirement satisfaction index (59.95%). The results indicate the suitability of this index in explaining the impact of rainfall on productivity of rain-fed agriculture.

The temporal variation of seasonal rainfall and its impact on maize yield is described using example of Shire Valley data for maize production and rainfall data from Ngabu station. Figure 4 depicts this relation and it may be seen from the plot that years with good rainfall also tend to have high yield and vice versa a fact which agrees with what is portrayed in Figure 3. The plot reveals clearly years when production was severely affected by drought e.g. 1991/92 (also reported by Mkanda et al., 1995) and 2004/05 (reported by Øygard, 2005). A country wide picture of impacts of rainfall on maize yield is presented in Figure 5 which shows temporal variation of maize crop WRSI. The plot presents the average WRSI for the country derived from 8 stations representing the 8 ADDs. Judged from this data Malawi can not be considered as having water induced poor maize production. In most of the years the water limited crop performance is above average (years above the solid line with diamond shaped markers).

The graph also shows years with good performance namely 1973, 1977, 1984 and1988. The years 1972, 1981, 1991, 1993 and 1994 had relatively low WRSI. Mkanda et al., (1995) mentions the years 1972, 1981 and 1991 as years with significant drought and classifies 1991 as the most severe case. Their findings are in agreement with what is presented in Figure 5 even in classification of 1991 as severe case but they differ from present study by not recognising 1993 and 1994 as severe cases. The average country yield graph superimposed on the WRSI graph Figure 5 indicate that 1993 was exceptionally dry year comparable to 1991 but 1994 seems to be a normal year. Possible explanation for this discrepancy is shortage of data for estimation of WRSI in 1994. The WRSI value in 1994 was calculated from fewer stations than in previous years and could be biased. The comparison of the results of the present study and previous findings indicate that Malawi suffers food shortages when WRSI is close to or below 60%. It is particularly interesting to note that a mediocre performance of maize in 1991 was correctly recognised as severe drought in Malawi and the temporal pattern of yield follows quite closely the WRSI pattern(correlation coefficient =0.74 for data between 1982 and 1993).

5.0 CONCLUSION AND RECOMMENDATIONS

The results of this study suggest that there is no significant change in rainfall characteristics that may be linked to poor maize production in Malawi in the last 40 years. All rainfall characteristics including onset and cessation, rainfall amount and dry spells were fairly constant fluctuating randomly without significant trends in all 8 agricultural development divisions. The only exception to this is the northern part of the country, Karonga ADD where trends in annual and seasonal rainfall amount as well as the length of dry spell showed significant changes over the last 40 years. This part of country has a slightly different climate as compared to the rest of the country. The rainfall pattern in Karonga follow similar pattern to station across the border in Tanzania and results of trend testing yielded similar results as those reported by Gommes and Houssiau (1982) for stations in Tanzania.

Water requirement satisfaction index (WRSI) used for studying impact of rainfall on maize productivity has proved to be a very useful tool in explaining the spatial-temporal variability of production of rain-fed maize crop. A fairly good correlation of 0.82 between WRSI and maize productivity was found in Malawi. The spatial variability of maize yield in Malawi has been captured very well by WRSI. The temporal variability of productivity is also well correlated to WRSI (correlation coefficient 0.75). It was found out that Malawi suffers from poor crop performance and hence food shortages when the WRSI is close to or below 60%.

On average Malawi has enough rainfall to sustain rain-fed agriculture as indicated by above average WRSI in most of years (67%). The poor performance in rain-fed maize production may be related to other factors including soil and plant conditions. Particularly Mzimba and Salima have excellent conditions for growing rain-fed maize crop as indicated by a high average WRSI. On the other hand the conditions in shire valley with average WRSI of 59.95 are not so favourable for rain-fed maize growing.

6. REFERENCES

CIA, 2006, *The World Factbook – Wikipedia, the Free Encyclpedia*, www.cia.gov/cia/publications/factbook/index.html Available online on 17th November, 2006 (Google search)

FAO, (2006): Water and Soil Requirements www.fao.org/docrep/L13160E/u3160e04.htm , Available online on 17th January, 2007

Food Security and Nutrition Experts (undated): Food and Nutrition Security Policy. www.odi.org.uk/Food-Security-Forum/seminars/docs/284,1,FOOD AND NUTRITION SECURITY POLICY, Available online on 17th November, 2006 (Google search)

Gommes, R., and Houssiau, M., (1982): "Rainfall Variability, Types of Growing Seasons and Cereal Yields in Tanzania", **Proceedings of the Technical Conference on Climate – Africa – Arusha, United Republic of Tanzania 25-30, January, 1982**, pp 312 – 324, World Climate Programme, WMO-No. 596, WMO Secretariat, Geneva, Switzerland.

Hirsch, R. M., Helsel, D. R., Cohn, T. A., and Gilroy, E. J., (1992): "Statistical Analysis of Hydrological Data", **Handbook of Hydrology**, Maidment, D. R., pp 17.1 – 17.55, McGraw-Hill, Inc, New York

Andy Y. Kwarteng, Atsu S. Dorvlo, Ganiga T., and Vijaya Kumar, (2008), Analysis of a 27-year rainfall data (1970-2003) in the Sultanate of Oman., International Journal of Climatology, Wiley Interscience (www.interscience.wiley.com)DOI:10.1002/joc.1727

Mkanda, F. X., (1995): Malawi: *Greenhouse Gas Inventory and Assessment Climate Change Vulnerability*, Department of National Parks and Wildlife. www.gcrio.org/CSP/IR/IRmalawi.html, Available online on 5th December, 2006

Martin, R.V., Washington, R., and Downing, T.E., (2000). Seasonal maize forecasting for South Africa and Zimbabwe derived from an agroclimatological Model. Journal of applied Meteorology. Vol. 39 pp 1473-1479.

Molnar P., and Ramirez J. A., (2001), "Recent Trends in Precipitation and Stream Flow in the Rio Puerco Basin", **Journal of Climate**, Volume 14, pp 2317-2328, Water Resources, Hydrologic and Environmental Sciences Division, Department of Civil Engineering, Colorado State University, Fort Collins, Colorado.

Ochieng', O. D. A., (1998): Analysis of the Spatial and Temporal Variability of Rainfall in Tanzania, MSc (WRE) Dissertation, University of Dar es Salaam, Dar es Salaam

Øygard, R., (2005), Malawi's Persistent Food Crisis**,** Norwegian University of Life Sciences. www.aae.wisc.edu/seminars/papers/2005%20Fall%20papers/DevEcon/oygard.12.08.pdf, Available online on 19th December, 2006 (Google search)

van der Zaag, P., and Rockström, J., (2003): "Agricultural Water Demand", **Principles of Integrated Water Resources Management,** manuscript for Master's Degree Programme in IWRM, Course Module IWRM 0.1, pp 8.1 – 8.40, WaterNet, Harare

Figure 1: Map of Malawi showing location of the country
(**Source** : www.infoplease.com/atlas/country/malawi.html)

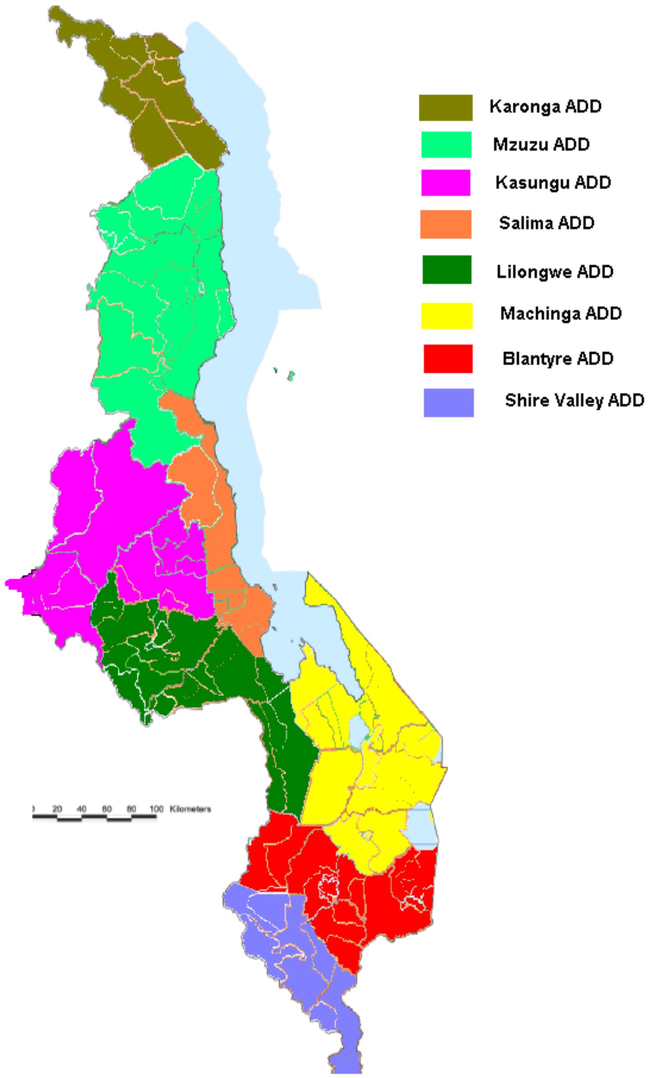

Figure 2: Map of Malawi showing ADDs
(**Source:** http://www.ifpri.cgiar.org/pubs/cp/malawiatlas/malawiatlas_08.pdf)

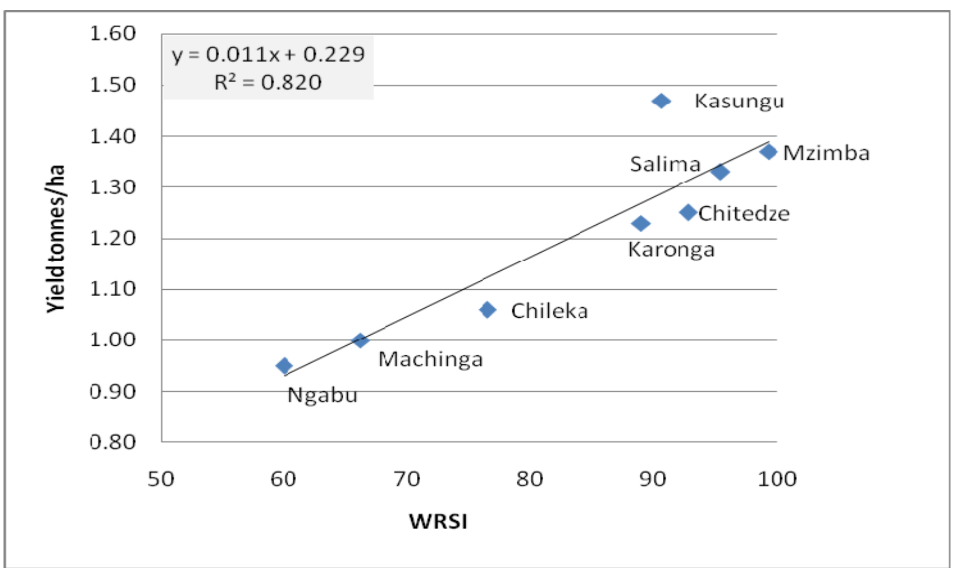

Figure 3: Relationship between Yield and WRSI for rain-fed maize crop in Malawi.

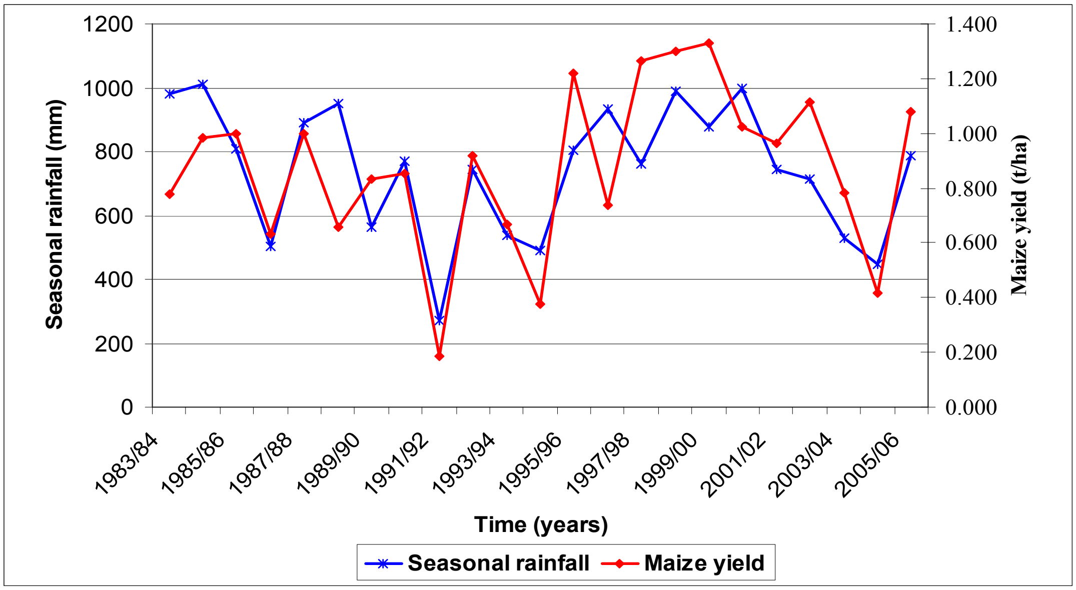

Figure 4: Relationship between seasonal rainfall and maize yield in Shire Valley ADD

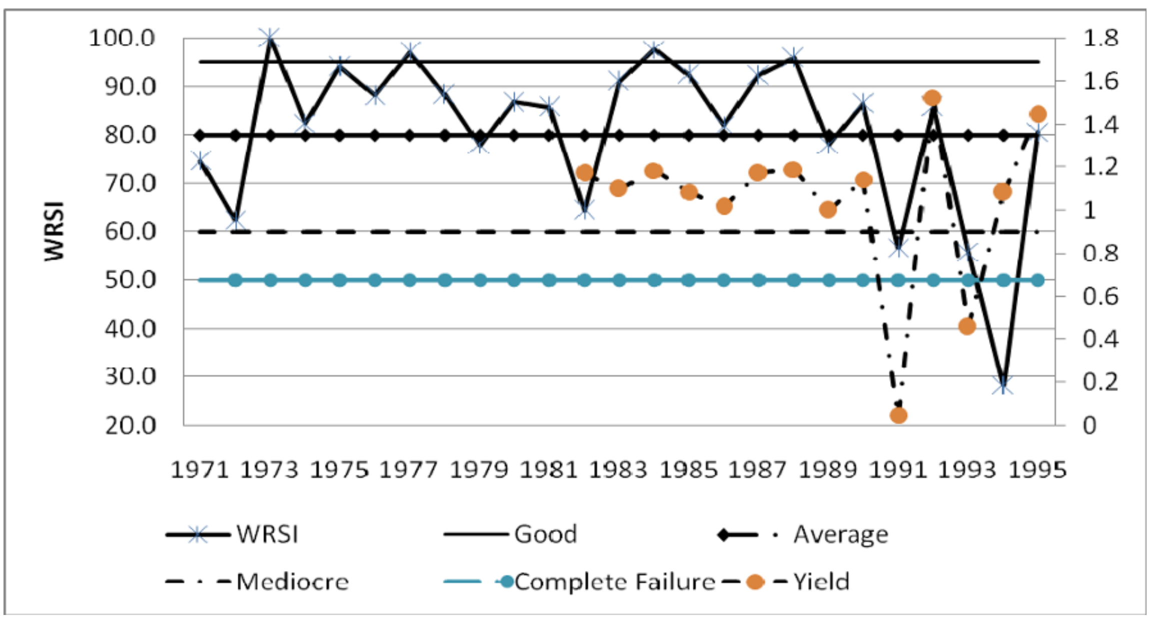

Figure 5: Temporal variation of country average WRSI for Malawi the straight lines indicates limits defining different classes of performance as stated in the legend.

Table 1: List of selected rainfall stations and their location

WMO ID	NAME	LATITUDE	LONGITUDE	ELEVATION (masl)	ADD
9334003	Karonga Airport	-9.954	33.911	529	Karonga
11334000	Mzimba Aerodrome	-11.900	33.600	1349	Mzuzu
13331011	Kasungu Met	-13.020	33.470	1058	Kasungu
13334006	Chitedze	-13.967	33.633	1149	Lilongwe
13344000	Salima Airport	-13.744	34.593	512	Salima
14351000	Mangochi Met	-14.467	35.250	482	Machinga
15344002	Chileka Airport	-15.667	34.967	767	Blantyre
16342010	Ngabu Met	-16.500	34.950	102	Shire Valley

Table 2: Onset and cessation of rains and length of rainy season

Station	Expected Onset Date	Onset Standard Deviation (days)	Expected Cessation Date	Cessation Standard Deviation (days)	Average Length of Season (days)	Coefficient of Variation (%)
Karonga WMO ID 9334003	9 Dec	17	24 Apr	11	137	16.1
Mzimba WMO ID 11334000	3 Dec	15	5 Apr	13	123	17.1
Kasungu WMO ID 13331011	9 Dec	19	28 Mar	14	111	19.8
Salima WMO ID 13344000	8 Dec	16	4 Apr	14	119	16.8
Chitedze WMO ID 13334006	2 Dec	13	30 Mar	13	119	14.3
Mangochi WMO ID 14351000	14 Dec	21	29 Mar	13	106	23.6
Chileka WMO ID 15344002	22 Nov	18	26 Mar	15	124	20.2
Ngabu WMO ID 16342010	6 Dec	29	26 Mar	27	111	27.9

Table 3: Water requirements satisfaction index in all stations under study

Year	Water Requirement Satisfaction Index (%)							
	Karonga	Mzimba	Kasungu	Salima	Chitedze	Mangochi	Chileka	Ngabu
1971/72	-	-	49	-	100	-	-	-
1872/73	-	-	63	-	62	-	-	-
1973/74	-	-	100	-	100	-	-	-
1974/75	100	100	100	97	100	65	61	37
1975/76	100	100	100	100	100	100	85	67
1976/77	100	100	78	100	100	59	100	68
1977/78	100	100	100	100	100	100	100	76
1978/79	100	100	55	100	100	100	90	61
1979/80	100	100	100	100	86	60	65	13
1980/81	100	100	100	100	100	50	100	44
1981/82	66	100	100	77	100	74	80	89
1982/83	80	100	96	100	76	6	44	14
1983/84	100	100	100	72	97	100	59	100
1984/85	100	100	100	100	100	100	81	100
1985/86	80	100	100	100	100	77	96	86
1986/87	100	100	100	100	100	48	71	37
1987/88	89	100	100	100	100	59	100	90
1988/89	67	100	100	100	100	100	100	100
1989/90	53	100	100	100	94	58	72	48
1990/91	84	94	100	100	73	75	95	71
1991/92	100	93	52	91	54	28	31	5
1992/93	88	100	100	100	100	69	58	71
1993/94	72	100	-	72	-	7	42	42
1994/95	-	-	-	-	-	21	32	32
1995/96	-	-	-	-	-	77	97	68
1996/97	-	-	-	-	-	100	100	-
Percentage of time crop water requirement satisfied	55.0	90.0	72.7	75.0	68.2	30.4	26.1	13.6
Percentage of time water stress experienced	45.0	10.0	27.3	25.0	31.8	69.6	73.9	86.4

Note: Mzimba station is in Mzuzu ADD, Mangochi in Machinga ADD, Chileka in Blantyre ADD and Ngabu in Shire Valley ADD. The other stations' names are the same as the names of the ADDs in which they are located.