RELATIONSHIP BETWEEN RELATIVE YIELD AND MAIZE WATER REQUIREMENT IN THE SOUTHERN PROVINCE OF ZAMBIA

BY

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DECLARATION

I declare that this is my original work and has not been presented in any institution for examination.

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ABSTRACT

Adequate water is indispensible for crop growth and rainfall is the most important source of water for crop production in Zambia. Better utilization of water which includes rainfall, surface water and ground water on the strategy to investigate on crop water requirement for maximum yield production of a crop is essential. An attempt of a problem of this kind on maize is employed in this study. Maize growing periods from the years 1998 – 2007 were determined for the Southern Province of Zambia using meteorological data from the meteorological department and phenological data from the ministry of Agriculture (Zambia), dekadal records were used to estimate the evapotraspiration for maize (Eto) and the Maize water requirement for maximum yield (Etm) or crop water requirement (Etc), in this case, maize is considered at the various annual stages and season. The estimates of the potential evapotranspiration were based on the Penn- monteith approach, using crop coefficient (Kc) - (agrometshell computer program), while maximum yield and percentage of yield reduction were estimated using FAO.IDP, No. 33, procedure. Correlation and Regression analysis were also used to discuss the yield response to optimum maize water requirement under the different stages of plant growth.

Simple and Multiple regression analysis have been employed based on the water balance parameters and the trend. Results obtained indicated the water requirement satisfaction index can be used in determining the general view of the expected yield. The major contributors to the observed yield were the water excess and actual evapotranspiration at different stages of growth for the different districts. On validation, the yield estimating model was found to be a good predictor by 51% in Choma, 70% in Kafue and 54% in Livingstone districts.

DEDICATION

I dedicate the success of this project firstly to my dearest caring Mother Mrs. Rachel Simatimbe Thole and My Loving Late Father Mr. Mloyi Sailesi Thole who have been my role models in terms of education matters and also my sources of inspiration all my life time. These two people have been so supportive and encouraging and their word to me has always been “In education, the sky is the limit!”

Secondly to my family especially my husband Masonga Zulu and children Dinah and Taza for being so patient and giving me courage and hope while I was away from them during my two year study.

For this, I say MAY GOD BE WITH YOU ALWAYS.

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I wish to thank the following for their great contributions towards the success of this project, May the good lord bless you in his own special way.

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My thanks to Victor Bupe for his willingness to help me acquire and organise the necessary data needed which made my workability easy, Dr Joseph Kanyanga for his ever encouraging words and Dr Elijah Mukhala who first introduced me to the water balance, this lured me into taking up this study.

Special thanks are due in particular to my supervisor Mr. Peter Kimani Runanu for his able supervision, patience and valuable assistance in the preparation of this project work. Despite his busy schedules, he worked so tirelessly and gave me his full support and encouragement throughout.

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1.0 INTRODUCTION

Weather is one of the most important factors affecting the crop growth and yield. The important meteorological variables which influence the growth, development and yield of the crops are rainfall, solar radiation, temperature (amount and distribution), relative humidity and wind velocity. (Abbate et al. 2004; meeena and Daharma, 2004; Reddy and Reddi, 2003). Since crop yield is the culmination of many temporal plant processes and is affected by various external factors related to soil, weather and technology, parameterization of these factors and investigation of their relationship with yield are essential for crop yield modeling. Agro meteorological maize yield forecasting models were developed for the districts in the southern province of Zambia. This would serve as a forecasting tool which will contribute to improved food security, planning and poverty alleviation management practices in the countries.

For crop forecasting, the impact of climate on crops is always transformed into a certain loss of water, i.e. "evaporation", which depends on the available water and on available energy. In case of cropped surfaces, this continuous loss in the form of vapour is called "evapotranspiration" since water loss is due to the combined evaporation from the soil and the transpiration through plant surfaces.
For crops, it is important to evaluate maximum water loss under certain climatic conditions and under unlimited water availability at the root system level, i.e. the "maximum evapotranspiration" (ETM).

Maize is an important food, feed and cash crop in Zambia but its productivity is greatly reduced by poor rains, floods, soil–water deficits, diseases etc. Delays on the onset of the rainy season reduce the length of the growing period which may result to lower yields. Variety based tolerance to soil types and drought/floods is a cheap and sustainable way of increasing productivity for smallholder farmers who are the predominant producers.

Several crops are grown in Zambia both on commercial and small scale, of these, the staple foods grown are cassava, maize and groundnuts but the established main staple food is Maize of which accounts to about 99.9% of the populations dependence. Since the 1990s, crop production in the country has faced negative impacts of extreme climate events which are believed to be manifestations of long-term climate change. Zambia has experienced some of its worst droughts and floods in the last two decades. Significant rainfall deficits at critical stages of crop growth have frequently led to a serious shortfall in crop production, e.g. the yield during the severe drought of 1991/92 was less than half that of 1990/91. Notable shortfalls in maize yield were also recorded in the seasons 1972/73, 1979/80, 1981/82, 1983/84, 1986/87, 1993/94 and 1994/95, most of which were characterized as seasons with below normal rainfall by the Zambia Meteorological Department. Drought has been the biggest shock to food security in the country during the last two decades (MoA 2000; Muchinda 2001). The impact of extreme climate events has been felt in substantial loss of livestock and fertile soil. In short, changes in the supply of rainfall, whether in the total volume or in its distribution within a season, have enormous consequences for agricultural production in Zambia.

In some years the yield has been only 40% of the long-term average. Major factors contributing to this low yield have been the long dry spells within a season and the shorter rainfall seasons which have been experienced by the country in the past years. Crop production data obtained from the Central Statistical Office (CSO) indicates that the major crop of the Southern, Central and Eastern Provinces is maize which occupies more than 70% of the total area cultivated in these provinces.

2.0 LITERATURE REVIEW

Maize (*Zea mays* L.) also referred to as corn or Indian corn originates from Latin America. Its cultivation is considered to have started by 3000 BC at the latest. It is a cereal plant of the Gramineae family of grasses that today constitutes the most widely distributed food plant in the world.(JAICAF)

The crop is grown in climates ranging from temperate to tropic during the period when mean daily temperatures are above 15°C and frost-free. Adaptability of varieties in different climates varies widely. Successful cultivation markedly depends on the right choice of varieties so that the length of growing period of the crop matches the length of the growing season and the purpose for which the crop is to be grown. Variety selection trials to identify the best suitable varieties for given areas are frequently necessary. (F.A.O. 2009)

In Zambia, the crop was introduced from Latin America way back in the 16th century and since then it's cultivation has spread to wide areas, thus providing a crucial food source for most of the population in the country.

Maize cultivation in Zambia is mostly rain-fed, which necessarily leads to substantial fluctuation in production from one year to the next i.e. any unfavorable weather condition such as drought creates the need to import the maize to fill the deficit.

Maize is an efficient user of water in terms of total dry matter production and among cereals it is potentially the highest yielding grain crop. For maximum production a medium maturity grain crop requires between 500 and 800 mm of water depending on climate (Slatyer, R.O.1967). To this, water losses during conveyance and application must be added. The crop factor (kc) relating water requirements (ETm) to reference evapotranspiration (ETo) for different crop growth stages of grain maize is for the initial stage 0.3-0.5 (15 to 30 days), the development stage 0.7-0.85 (30 to 45 days) the mid-season stage 1.05-1.2 (30 to 45 days), during the late season stage 0.8-0.9 (10 to 30 days), and at harvest 0.55-0.6. (FAO 2009 – crop water information)

Zambian maize is mostly used as food, although it is also used for brewing and animal consumption. As a staple crop, most of the maize is milled and then boiled in hot water until it thickens like dough for eating. This staple food, known as *nsima* in Zambia, is very similar in its preparation to what is called to *tô* in Burkina Faso and ugali in Kenya and Tanzania, both serving as staple food.(Japan association for international collaboration of Agriculture and forestry - (JAICAF)

2.1 DOMAIN OF STUDY REGION

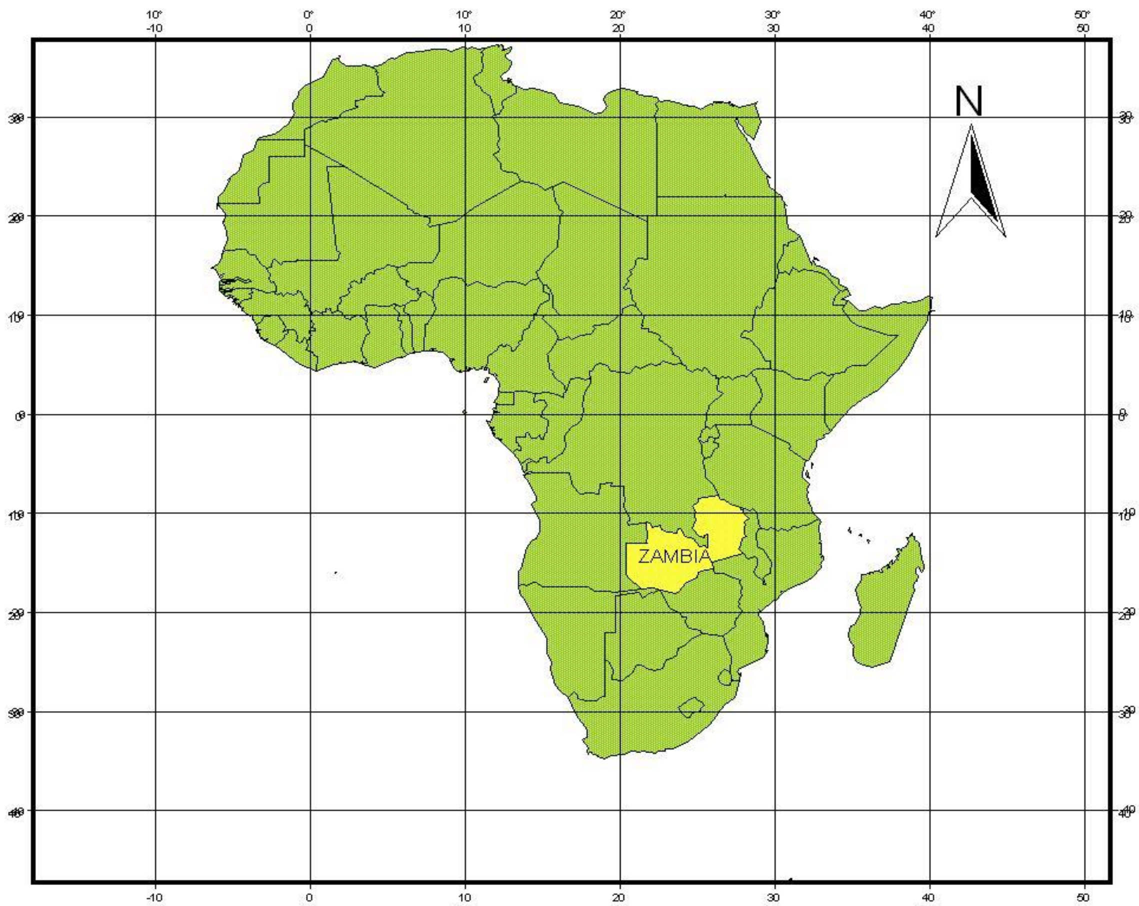


Fig 1.Location of Zambia with respect to Africa (*map created using arc view)*

Zambia is a landlocked country in Southern Africa, and covers an area of about 752 600 km^2 located between latitudes 8º and 18º South and longitudes 22º and 33º East. A large part of Zambia is on the Central African plateau between 1 000 and

1 600 metres above sea level. Although Zambia is tropical, temperatures are moderated by altitude. There are three seasons: the cool dry (April-August), the hot dry (August-November) and the hot wet season (November-April). The average temperatures range from a mean monthly minimum of about 10^{o}C in June and July to a mean monthly maximum of 30^{o}C in October and November. Rainfall varies from 700 mm in the south to 1 500 mm in the north, with most of it concentrated over the period November to March. The population of Zambia is about 11,920million.

2.2 Area of Study

The location of this study is southern province. This is one of Zambia's nine provinces located at latitude 15°30′s and 18^o south and longitude 25°and 28°30′E . This province cuts across two agro ecological zones (region I and region II). The centre of the province, the Southern Plateau, has the largest area of commercial farmland of any Zambian province, and produces most of the maize crop, thereafter named the maize belt of Zambia.

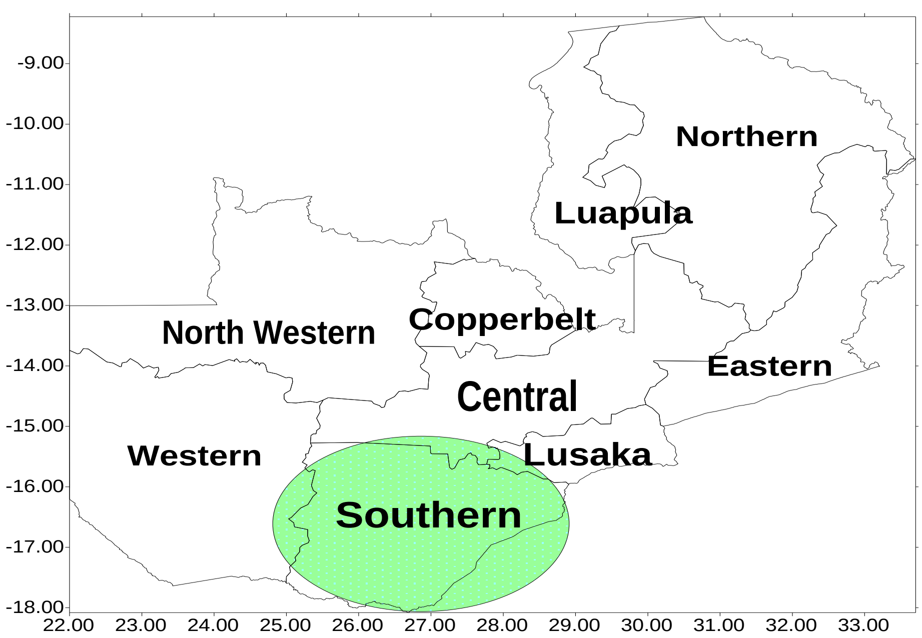


Fig 2**. Location of southern province.** ***(map produced using surfer software).***

1.2.1. Physical Features of the Study Region

Zambia is divided into three agro-ecological zones with rainfall as the dominant distinguishing climatic factor.

These three zones are widely diverse in area, soil type, population density, number of districts and agricultural practices, so to have a representative sample it was considered inappropriate to select the same number of districts from each zone. (Suman Jain).

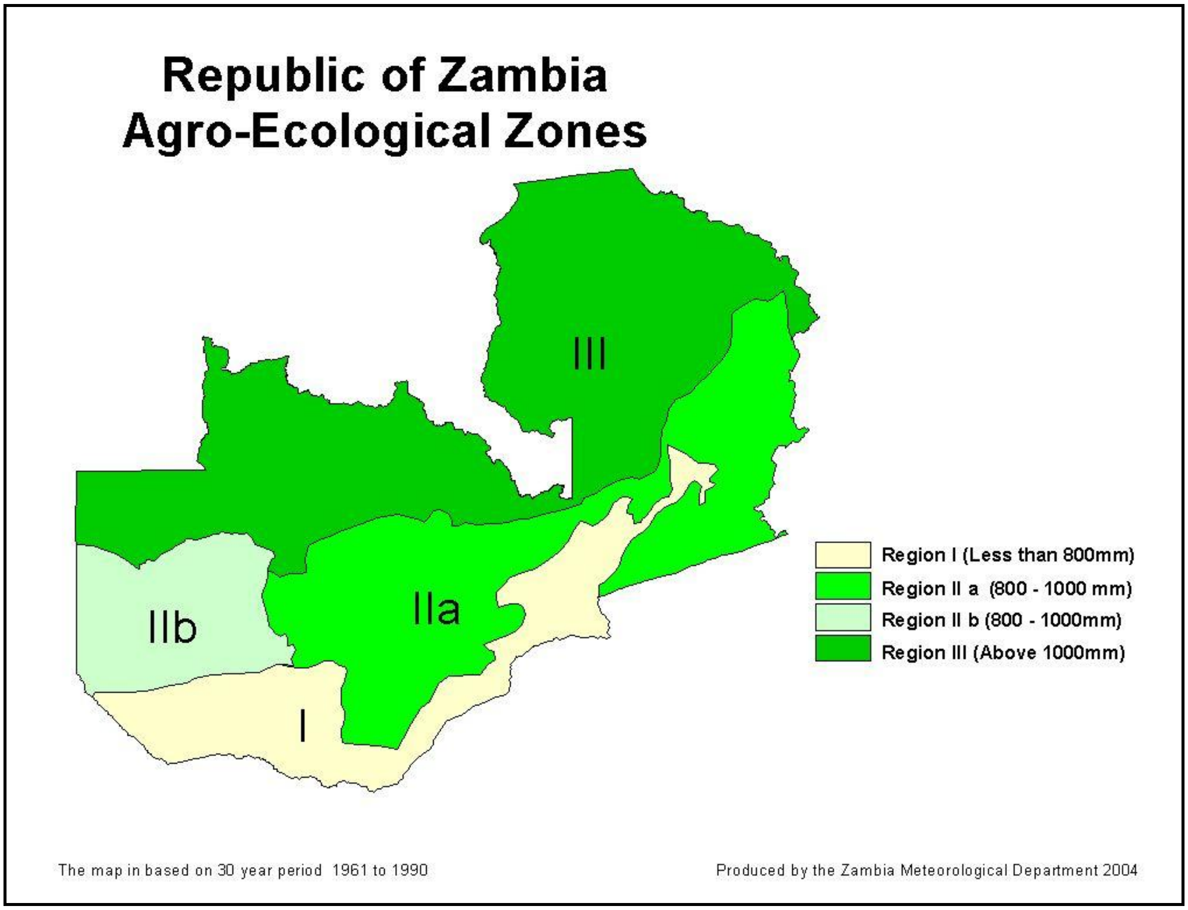


Fig 3. **Agro ecological zones of Zambia**.

Zone I lies in the western and southern part of the country and accounts for about 15% of the land area. It receives less than 800mm of rain annually. It used to be considered the bread basket of the nation but for the last 20 years it has been experiencing low, unpredictable and poorly distributed rainfall. The observed meteorological data suggests that it is currently the driest zone, very prone to drought and has limited potential for crop production.

Zone II covers the central part of the country, extending from the east through to the west. It is the most populous zone with over 4 million inhabitants and has the highest agricultural potential. The soils here are relatively fertile. It receives about 800–1000mm of rainfall annually, which is evenly distributed throughout the crop growing season.

Zone III spans the northern part of the country and has a population of over 3.5 million. It receives over 1000mm of rainfall annually. The high rainfall in this region has resulted in the soils becoming leached. It is suitable for late maturing varieties of crop. About 65% of the region in this zone has yet to be exploited.

2.3. Justification:

Agriculture and food security are the some of major sensitive sectors of the country. For food security, preparedness, planning and poverty alleviation, I decided to take on the study of the southern province of Zambia which is the main producer of this crop and for this it is known as the Maize belt of Zambia. This area is adversely affected with droughty or floody weather conditions almost every rain season as compared to other parts of the country. The economic activities of Zambia rely very much on the performance of the rainy season which has been affected by extreme climate events in recent years.

In order to achieve better crop production and for food security purposes, climatic and crop parameters of a given area and varieties need to be studied with a view to identifying the crop whose climatological requirements especially water requirement which fit those of the area and the crop.

The applications of climate information in agricultural production are of crucial importance. We often emphasize on the importance of well documented onset and cessation dates of seasonal rainfall as well as monitoring of the phenological stages of crops for crop yield assessments in our country. However, it is also important to carry out cost benefit analysis on determination and applications of appropriate planting dates in order to take full advantage of limited soil moisture availability in a shortened crop growing season. The drought tolerant crops can be grown in zones where the prevailing soil moisture is the major climate constraint on yield. The crop varieties that are higher yielding, more drought resistant, earlier maturing, disease and pest tolerant are recommended in these moisture constrained zones for communities' sustained food security and adaptation.

There is also a need to invest in higher yielding crops during a good rainy season by taking advantage of the timely early warning as well as improved awareness seasonal climate consensus forecasts, for example those issued by regional climate outlook fora and Southern African Regional Climate Forecast (SARCOF).

2.4 Objectives

The main objective of this study is to investigate the usefulness of critical crop water requirement for maximum yield of maize varieties for estimating yield and the average (possible) planting dekad (date) on the knowledge of rainfall distribution and onset to avoid crop water stress over the growing season when it needs optimum amounts to maximise yield on small scale and commercial farmers. Little has been done on peak crop water requirements periods in relation to planting dates and the resulting yield relationship on the maize grown in Zambia.

2.4.1. The specific objectives is to

a) To investigate on crop water requirement for maximum yield production of the maize crop.
b) Come up with a possible tool for estimating the final yields of the local maize variety grown in the southern province of Zambia.
c) Investigate the stage where the crop experienced moisture deficits.

2.5 STATIONS USED IN THE STUDY

The figure below indicates the spatial distribution of the meteorological network of observing stations used in the study.

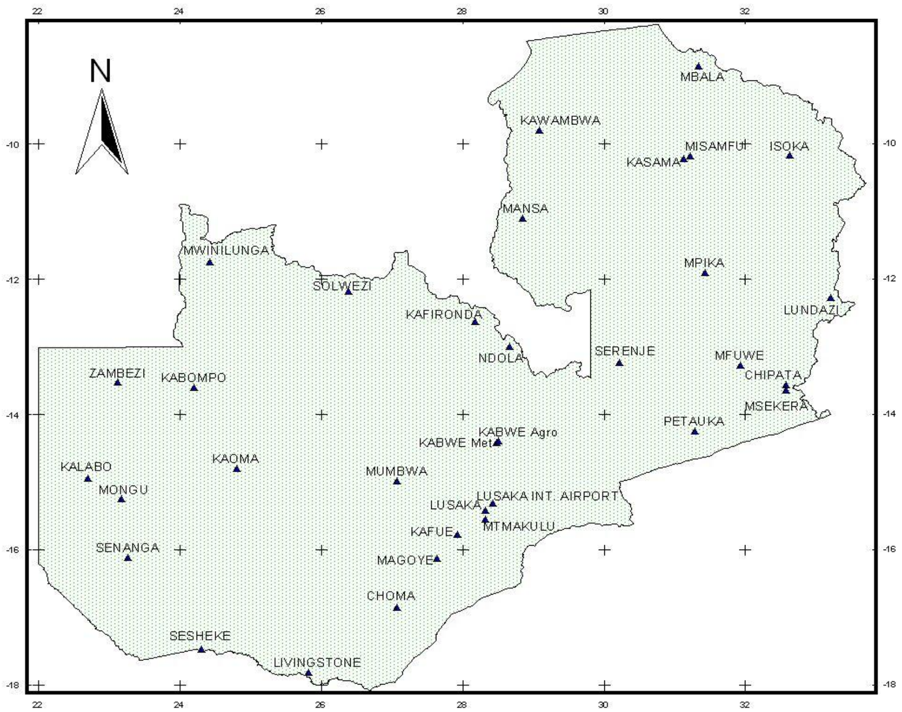


Fig 4. Zambia network of meteorological stations (***map created using arc view***).

Table 1: Longitudes and latitudes of stations used

STATION	LONGITUDE (DEG)	LATITUDES (DEG)	STATION	LONGITUDE (DEG)	LATITUDES (DEG)
CHIPATA	32.58	-13.57	**MANSA**	28.85	-11.10
CHOMA	27.07	-16.85	**MBALA**	31.33	-8.85
ISOKA	32.63	-10.17	**MFUWE**	31.93	-13.27
KABOMPO	24.20	-13.60	**MISAMFU**	31.22	-10.18
KABWE Met	28.48	-14.42	**MONGU**	23.17	-15.25
KABWE Agro	28.50	-14.40	**MPIKA**	31.43	-11.90
KAFIRONDA	28.17	-12.63	**MSEKERA**	32.57	-13.65
KAFUE	27.92	-15.77	**MTMAKULU**	28.32	-15.55
KALABO	22.70	-14.95	**MUMBWA**	27.07	-14.98
KAOMA	24.80	-14.80	**MWINILUNGA**	24.43	-11.75
KASAMA	31.13	-10.22	**NDOLA**	28.66	-13.00
KAWAMBWA	29.08	-9.80	**PETAUKA**	31.28	-14.25
LIVINGSTONE	25.82	-17.82	**SENANGA**	23.27	-16.12
LUNDAZI	33.20	-12.28	**SERENJE**	30.22	-13.23
LUSAKA	28.32	-15.42	**SESHEKE**	24.30	-17.47
LUSAKA INT. AIRPORT	28.43	-15.32	**SOLWEZI**	26.38	-12.18
MAGOYE	27.63	-16.13	**ZAMBEZI**	23.12	-13.53

3.0 METHODOLOGY

3.1 Data acquisition

The dekadal data employed in this study are for the period between 1988 and 2008. These include actual rainfall (ACT) and 30 year dekadal normal rainfall from the Zambia Meteorological department Agrometeorological section, the former is obtained on dekadal basis while the latter is 30year averages from 1961 to 1990. Dekadal normal potential evapotranspiration (penman) for the same period, the crop coefficient (Kc) of maize which is taken as the ratio of the actual evapotranspiration to that of the potential evapotranspiration (AET/PET), the planting dekad which is determined by a threshold of 20mm of rainfall, the cycle length of the maize crop which in this case is 120days for the variety under study (20days at initial stage, 30days at both vegetative and flowering stages and 40 days at grain filling and ripening stage). Soil data (water holding capacity) was obtained from the Food and Agriculture Organization (FAO) database (FAO 2003), from various soil types as classified by the FAO world map. The percentage effective rainfall this is where the rainfall experienced is considered to be 100% effective, the pre-season crop coefficient which is the crop coefficient (kc) related to bare soil and also the historical yield data gotten from the Ministry of Agriculture - Zambia. A standard time interval of 10 days (dekad) has been adopted in all data processing and analysis.

The data was quality controlled before being subjected to analysis in order to ensure continuity in the rainfall records. It is recommended that the missing rainfall data be filled in with the dekadal normal values while the missing yield data for year 2000 was incorporated in the post processing run in order to derive the post processed parameters for that year in order to help predict yield for that year.

3.2 Methods used in the study

The methodology employed in this study is basically based on the water balance calculation scheme. Basically, the water balance is the difference between the effective amounts of rainfall received by the crop and the amounts of water lost by the crop and soil due to evaporation, transpiration and deep infiltration. The amounts of water held by the soil and available to the crop is also taken into account.

The modeling approach is based on a continuous monitoring of the cropping season, which determines a cumulative water balance for each period of 10 days ("dekad") from planting to maturity. The water balance is carried out from the beginning to the end of the crop cycle, the water available - i.e. soil moisture - at the beginning of each dekad being the amount available at the end of the previous one, plus rainfall, minus crop water consumption.

The approach takes into account both rainfall amounts and distribution every ten days, the water available to crops (rainfall and stored soil moisture) is derived from weather data and crop water requirements (Potential Evapotranspiration- ETC).

In this case, the water balance is computed using a bookkeeping approach. The computation is done dekad-by-dekad (DEK), and starts before the planting in order to take into account previous rainfall amounts stored into the soil.

In this section, we discuss the various methods used in this scheme i.e. calculation of water requirement (WR), available water amount (AvW), soil water (SW), deficits or surpluses and finally the water satisfaction Index (WRSI) summarizes, up to a specific growth stage or the end of its development, the degree to which cumulative crop water requirements have been met.

We also discuss the post processing procedure carried out on the water balance parameters the estimation of the relative yield and the validation of the model.

3.2.1 Calculation of water requirement (WR)

WR is calculated from the Penman-Monteith potential evapotranspiration (PET) using the crop coefficient (K_c) to adjust for the growth stage of the crop.

$$WR = PET * K_C \text{ ……………………………………….(1)}$$

3.2.2 Calculation of the available water (AvW).

The available water amount (AvW) is the difference between the crop water requirements and the working rainfall (WRK). Those amounts do not consider water stored by the soil. i.e.

$$AvW = WRK\ (effective) - WR \text{.................. (2)}$$

The working rainfall amount reflects the effective water received by crop, in this case, the rainfall amount received during the dekad is considered to be 100% effective.

3.2.3. Calculation of soil water (SW)

The soil water content is obtained through a simple mass balance equation where the amount of soil water is monitored in a bucket defined by the water holding capacity (WHC) of the soil and the crop root depth.
That is,

$$SW_i = SW_{i-1} + PPT_i - AET_i \text{ ………….......... (3)}$$

Where, SW is soil water, PPT is precipitation, and “i” is the time step index. In this case, the model is run in dekadal (10-day) time step.

Surplus or deficit (S/D) result from the water budget between the soil water storage

(SW), ranging between the field capacity and the permanent wilting point, depending on the root depth, and the soil water holding capacity (WHC).

3.2.4. Calculation of water requirement satisfaction index.

The Water Requirement Satisfaction Index (WRSI) is a crop performance indicator based on the availability of water to the crop during a growing season. It expresses which percentages of the crop's water requirements were actually met. This is done using a computer program, Agrometshell. FAO studies (Doorenbos and Pruitt, 1977) have shown that WRSI can be related to crop production using a linear-yield reduction function specific to a crop. WRSI for a season is determined based on the water supply and demand a crop experiences during a growing season. It is calculated as the ratio of seasonal actual evapotranspiration (AET) to the seasonal crop water requirement (WR).

$$WRSI = \frac{AET}{WR} * 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Actual evapotranspiration (AET) represents the actual amount of water withdrawn from the soil water reservoir ("bucket"), where shortfall from the potential evapotranspiration (PET) is calculated by a function that takes into consideration the amount of soil water in the bucket. (FAO irrigation and drainage paper No.24). It is the amount of water actually used by the crop excluding runoff.

The working rainfall amount reflects the effective water received by the crop, in this case, the rainfall amount received during the dekad is considered to be 100% effective.

3.3 Water Balance Post Processing

It is an important step in the forecasting method to convert the data to comparable units (area averaging), usually administrative areas that are used by planners or decision makers in the field of food security. In this case, down scaling to the area of interest (southern province) was done where 3 districts were selected and used in this study.

Combination of the analysis of these calculated water balance outputs from the 3 stations with historical yield records was carried out using the water balance post processing procedure (WBPP program). This model attempts to simulate the way in which a crop responds to its environment. The outputs from this procedure are value-added parameters at different stages of plant growth that are more closely linked to crop yield than the inputs. i.e., crop soil moisture is more relevant to crop growth than is rainfall as it may run off.

3.4 Correlation Analysis

Correlation analysis were used examines the relationship between pairs of variables namely the dependent variable (Y) and the independent variable (X). The degree of relationships between the pair of variables Y and X is often quantified using correlation coefficient. This simple correlation coefficient "r" may be expressed as:

$$r = \frac{\sum_{i=1}^{N}(X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\left[\sum_{i=1}^{N}(X_i - \overline{X})^2\right]\left[\sum_{i=1}^{N}(Y_i - \overline{Y})^2\right]}} \qquad \text{……………………………………………… (4)}$$

where "r" is the correlation coefficient and X_i and Y_i are i^{th} observations of variables X and Y respectively, while $\overline{X}$ and $\overline{Y}$ are means of the variables with sample sizes N. In this study, X and Y are water balance parameters and yields respectively. The value of "r" lies between -1 and +1. The value of "r" equals +1 when X and Y are perfectly related, while it is zero when there is no relationship between the variables. Negative and positive values of "r" reflect negative (one increases as the other decreases) and positive (both increase and decrease simultaneously) relationships between X and Y.

In this study, correlation between the post processed water balance parameters and actual yields was carried out in order to identify the potential determinants of the yields hence used as the predictors at a later stage.

3.5 Regression Analysis

Explaining the distribution of a spatial phenomenon requires the analysis of relationships between the phenomenon and potential predictors. The analysis of variance (ANOVAs) is one of the commonly used methods for significance tests.

Regression analysis was used to examine the relationship between the study phenomenon and multiple explanatory variables and also to determine the value of the physically meaningful coefficients. In this case, multiple linear regression analysis was done where the Leave-One-Out (LOOs) cross validation technique approach was used to estimate the yield. This is where one year is removed from the data base then the regression with the same (X) predictors and the data of the remaining years is fitted and the error of that year is then defined. ANOVA tables developed were used to extract the X and Y coefficients intercept and random error for regression. The final regression equation used to predict the maize yield was

$$Y = \beta o + \beta 1 X1 + \beta 2 X2 + \ldots \beta n X n + \varepsilon \text{......................(5)}$$

Where Y denotes the dependent variable, Xi=1 to n are predictors; β**o** represents the intercept; β**n** denotes parameter of the variable Xn and ε is the randomly distributed error term.

3.6 Trend analysis.

Trend is the long term behavior of the time series and indicates whether the series is stationary or non stationary (over or under prediction). Both statistical and graphical methods were used to examine the trend in the time series. Polynomial best of fit lines were fitted on these results to examine the trends.

3.7 Model Validation.

In order to evaluate model validity, the model predicted yields were compared with the corresponding actual yields using relative deviation (RD) for the years under study, i.e.

RD% = 1OO (predicted yield – actual yield) /actual yield

4.0. RESULTS AND DISCUSSIONS

This section presents and discusses the results that were obtained from the various methods that were used to address the objectives of this study. These include the analysis of the water requirement satisfaction index, correlation and regression analysis of the indices (parameters) obtained from the water balance post processing procedure, the estimation of yields, analysis of the trends and the validation of the yield estimation model.

4.1. Results from the water balance calculation scheme.

The graphs below indicate the water requirements (WR) of the crop, the actual decadal rainfall (ACT) and the water requirement satisfaction index (WRSI). This index is a crop performance indicator and was used to give a general view of the expected yields. An index of 100% indicates expected good yield while an index of 50% or below indicates total crop failure.

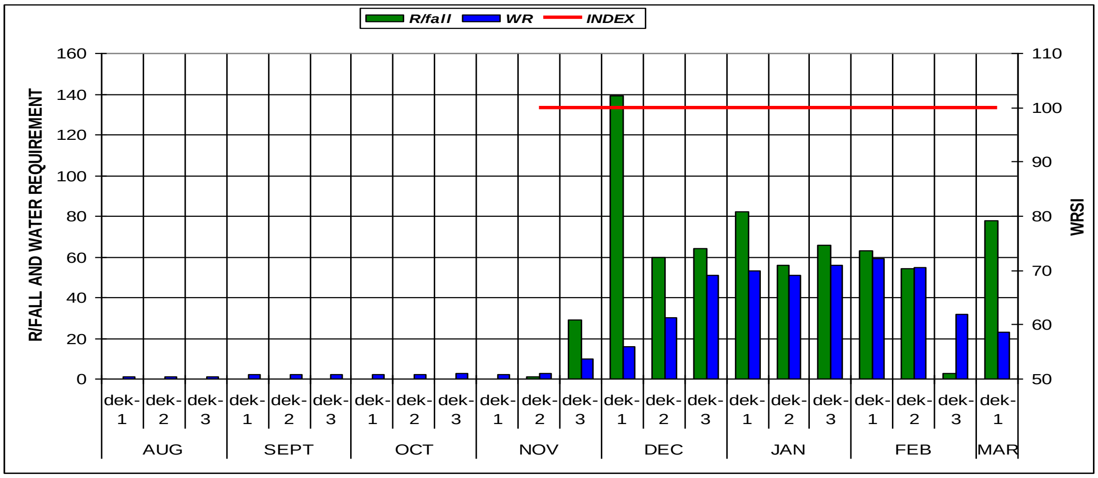


Figure 5: Choma Water Balance for 1998/99 season.

Table 2: Choma Water Balance for 1998/99

STATION	PHASE Period	INITIAL 20Days	VEGETATIVE 30Days	FLOWERING 30Days	RIPENING 40Days	TOTALS (MM)
	ETAt (WR)	11	97	274	55	437
CHOMA	Surplus	0	135	48	25	208
	Deficit	-2	0	0	0	2

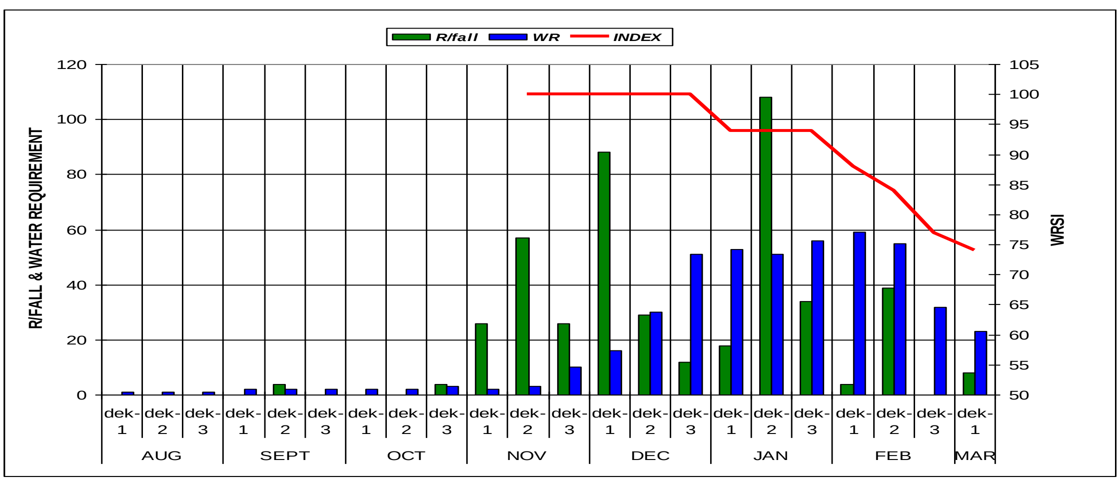


Figure 5a: Choma Water Balance 2001/02 season.

Table 2a: Choma Water Balance 2001/02 season.

STATION	PHASE Period	INITIAL 20Days	VEGETATIVE 30Days	FLOWERING 30days	RIPENING 40dys	TOTALS (MM)
	ETAt (WR)	13	97	206	8	324mm
CHOMA	Surplus	45	72	7	0	124mm
	Deficit	0	0	-68	-47	115mm

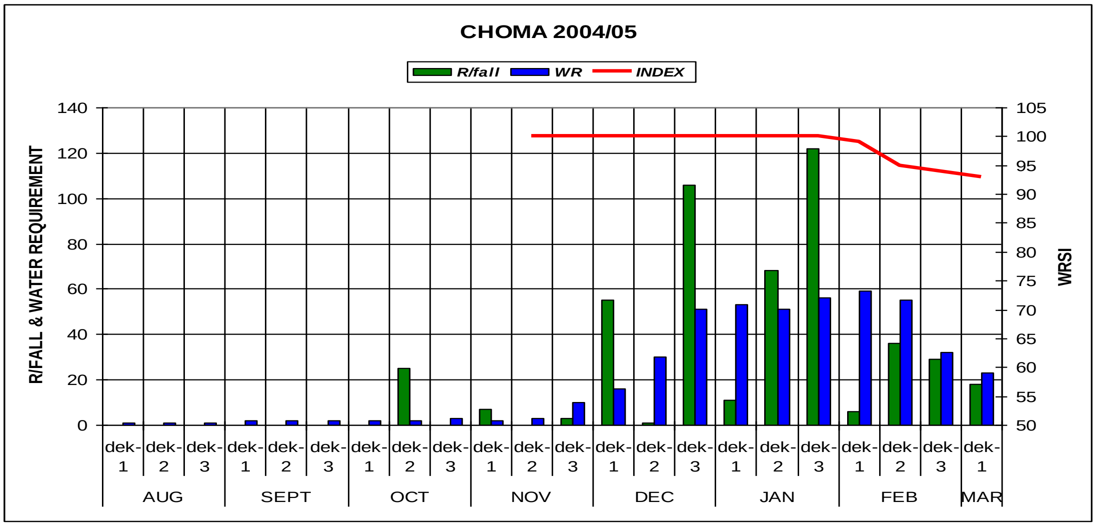


Figure 5b: Choma Water Balance 2004/05season.

Table 2b: Choma Water Balance 2004/05

STATION	PHASE Period	INITIAL 20Days	VEGETATIVE 30Days	FLOWERING 30Days	RIPENING 40Days	TOTALS (MM)
	ETAt (WR)	13	97	252	47	409mm
CHOMA	Surplus	0	30	41	0	71mm
	Deficit	0	0	-22	-8	30mm

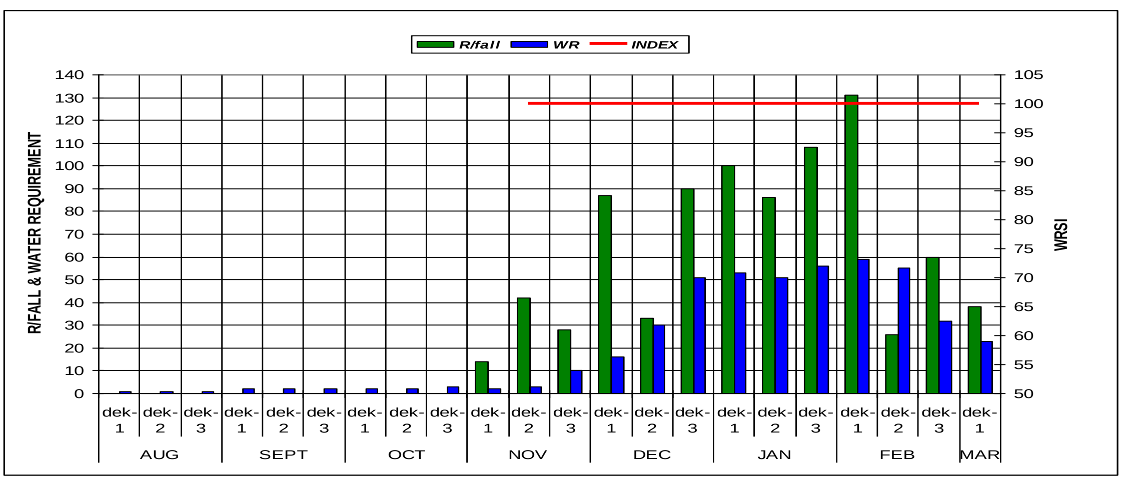


Figure 5c: Choma Water Balance 2005/06 season.

Table 2c: Choma Water Balance 2005/06

STATION	PHASE Period	INITIAL 20Days	VEGETATIVE 30Days	FLOWERING 30Days	RIPENING 40Days	TOTALS (MM)
	ETAt (WR)	13	97	274	55	439mm
CHOMA	Surplus	19	113	206	14	352mm
	Deficit	0	0	0	0	0mm

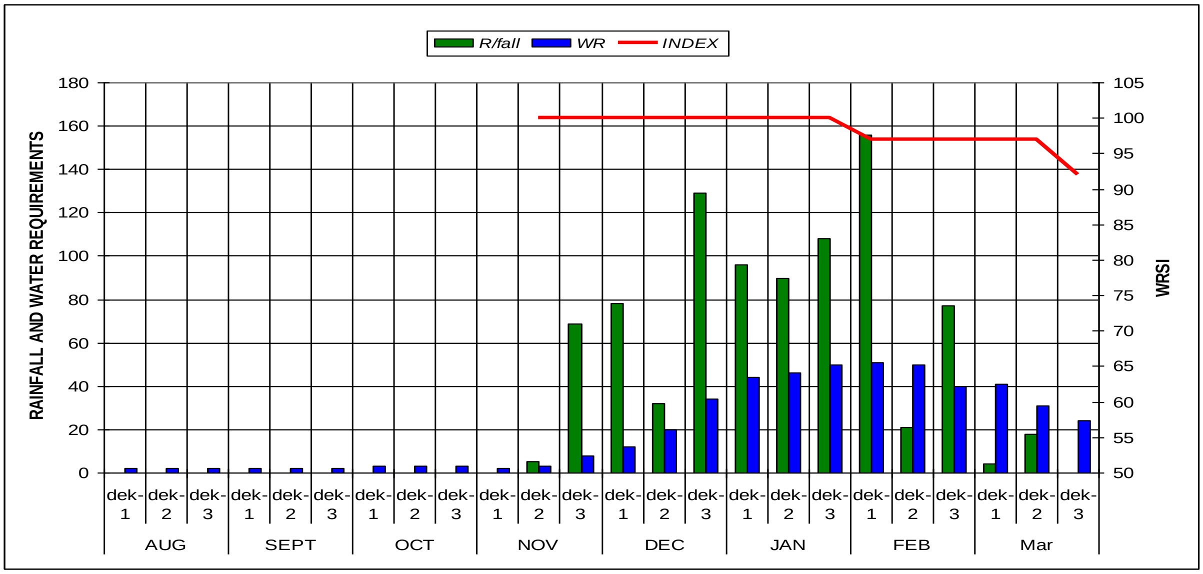


Figure 5d: Kafue Water Balance 1998/99 season.

Table 2d: Kafue Water Balance 1998/99 season.

STATION	PHASE Period	INITIAL 20Days	VEGETATIVE 30Days	FLOWERING 30Days	RIPENING 40Days	TOTALS (MM)
	ETAt (WR)	23	98	237	72	430mm
KAFUE	**Surplus**	79	159	215	0	453mm
	Deficit	0	0	0	-24	24mm

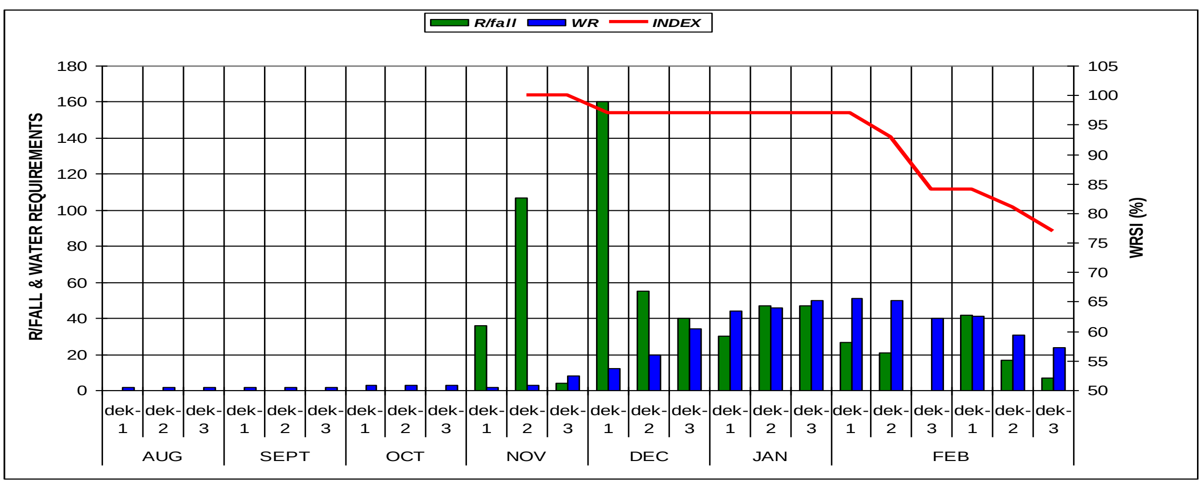


Figure 5e: Kafue Water Balance 2001/02 season.

Table 2e: Kafue Water Balance 2001/02 season.

STATION	PHASE Period	INITIAL 20Days	VEGETATIVE 30Days	FLOWERING 30Days	RIPENING 40Days	TOTALS (MM)
	ETAt (WR)	23	98	178	66	365mm
KAFUE	**Surplus**	232	41	0	0	273mm
	Deficit	0	0	-59	-30	89mm

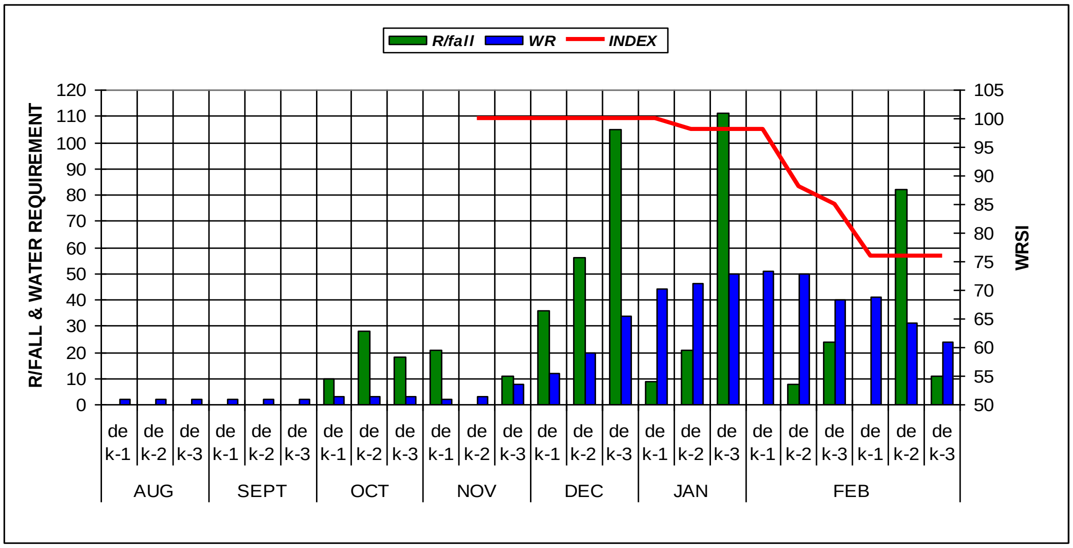


Figure 5f: Kafue Water Balance 2004/05 season.

Table 2f: Kafue Water Balance 2004/05 season.

STATION	PHASE Period	INITIAL 20Days	VEGETATIVE 30Days	FLOWERING 30Days	RIPENING 40Days	TOTALS (MM)
	ETAt (WR)	23	98	168	55	344mm
KAFUE	Surplus	24	107	11	1	143mm
	Deficit	0	0	-69	-41	110mm

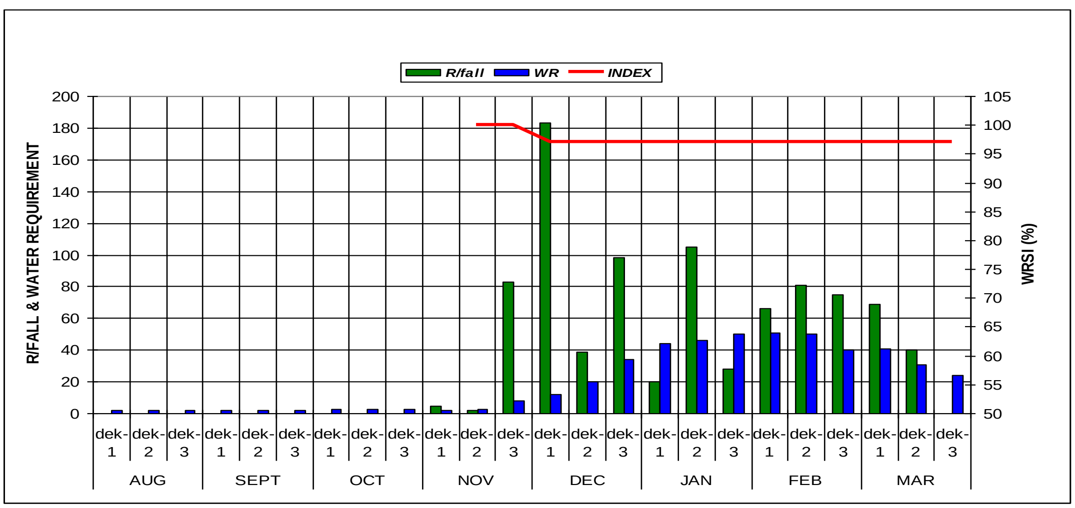


Figure. 5g: Kafue Water Balance 2005/06 season.

Table 2g: Kafue Water Balance 2005/06 season.

STATION	PHASE Period	INITIAL 20Days	VEGETATIVE 30Days	FLOWERING 30Days	RIPENING 40Days	TOTALS (MM)
	ETAt (WR)	23	98	237	96	454mm
KAFUE	Surplus	198	83	94	37	412mm
	Deficit	0	0	0	0	0mm

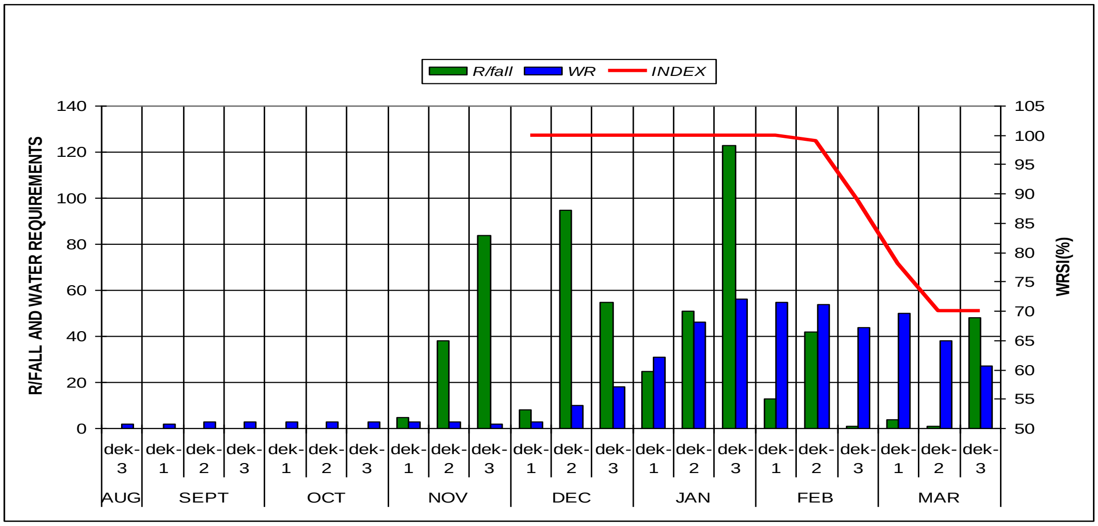


Figure 5h: Livingstone Water Balance 1998/99 season.

Table 2h: Livingstone Water Balance 1998/99 season.

STATION	PHASE Period	INITIAL 20Days	VEGETATIVE 30Days	FLOWERING 30Days	RIPENING 40Days	TOTALS (MM)
	ETAt (WR)	13	95	166	28	302
LIVINSTONE	Surplus	90	37	66	0	198
	Deficit	0	0	-93	-37	130

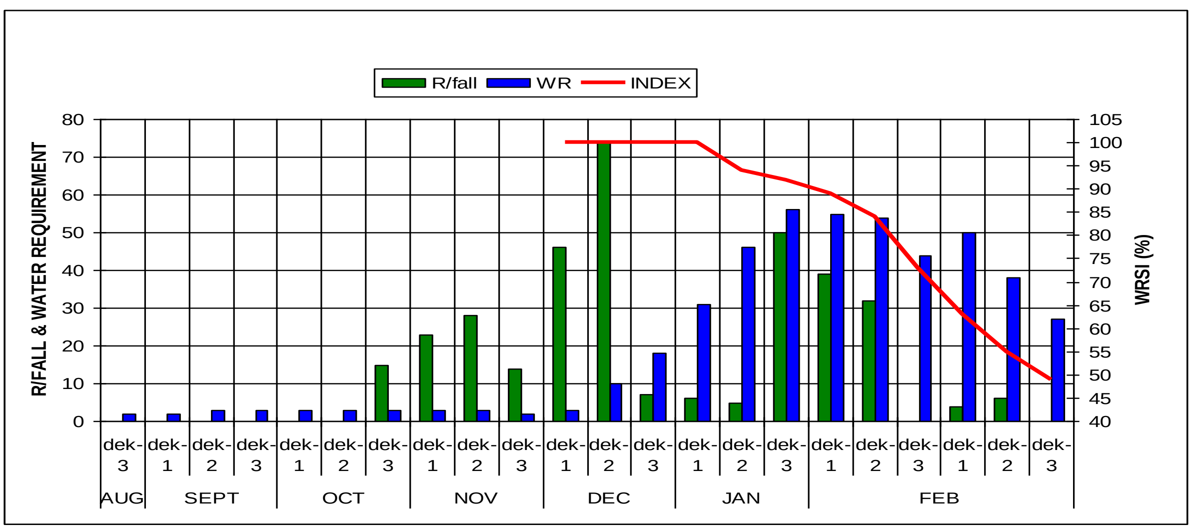


Figure 5i: Livingstone Water Balance 2001/02 season.

Table 2i: Livingstone Water Balance 2001/02 season.

STATION	PHASE Period	INITIAL 20Days	VEGETATIVE 30Days	FLOWERING 30Days	RIPENING 40Days	TOTALS (MM)
	ETAt (WR)	13	68	125	6	212mm
LIVINGSTONE	Surplus	107	0	0	0	107mm
	Deficit	0	-27	-134	-59	220mm

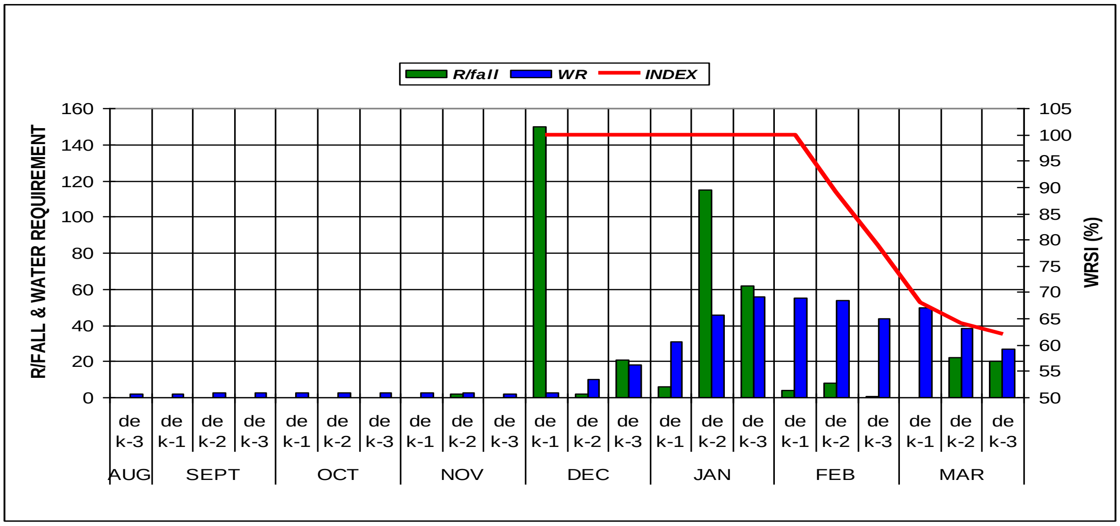


Fig. 5j. Livingstone Water Balance 2004/05 season.

Table 2j: Livingstone Water Balance 2004/05 season.

STATION	PHASE Period	INITIAL 20Days	VEGETATIVE 30Days	FLOWERING 30Days	RIPENING 40Days	TOTALS (MM)
	ETAt (WR)	13	95	119	42	269mm
LIVINGSTONE	Surplus	97	39	6	0	142mm
	Deficit	0	0	-140	-23	163mm

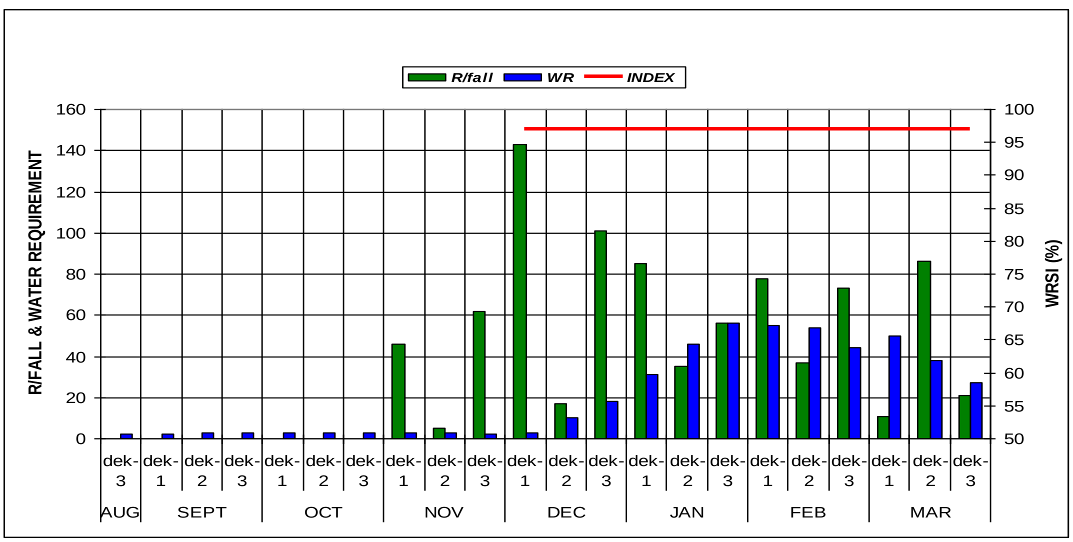


Figure 5k: Livingstone Water Balance 2005/06 season.

Table 2k: Livingstone Water Balance 2005/06 season

STATION	PHASE Period	INITIAL 20Days	VEGETATIVE 30Days	FLOWERING 30Days	RIPENING 40Days	TOTALS (MM)
	ETAt (WR)	13	95	259	65	432mm
LIVINGSTONE	Surplus	147	137	24	9	317mm
	Deficit	0	0	0	0	0mm

From the water requirement satisfaction index alone indicated that for the 3 stations, poor yields were likely to be observed if no other parameters come into play except rain in 2002 and 2005 where we had the index falling below 100 by a substantial margin. Livingstone was likely to have a crop failure due to the index which dropped to 48%. The index also indicated good yields for the year 1999, 2000, 2003, 2004 and 2006 seasons as index was maintained closer to 100% for most of the stations under study.

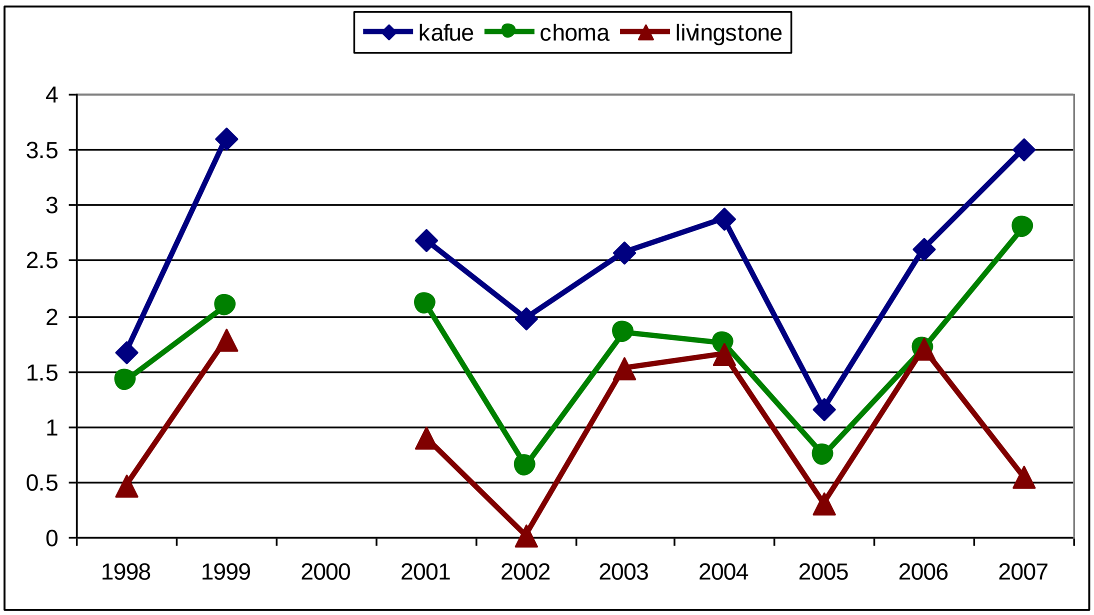


Figure 6: Actual yields

Upon observations of the actual yields 1998/99 and 2005/06 seasons, which were characterized with good yields, the water requirement satisfaction index for the 3 districts showed that the index was maintained at above 80% which was an indicator that the expected yields were to be good for the year 1999 and 2006, however, some lower index was observed in Livingstone where the index fell to 70% although the yield was quite significant.

Observations show that the seasons 2001/02 and 2004/05 which were characterised with lower actual yields, the index fell below 80% in the 3 stations except for Choma where index of 93% in 2004/05 season was observed.

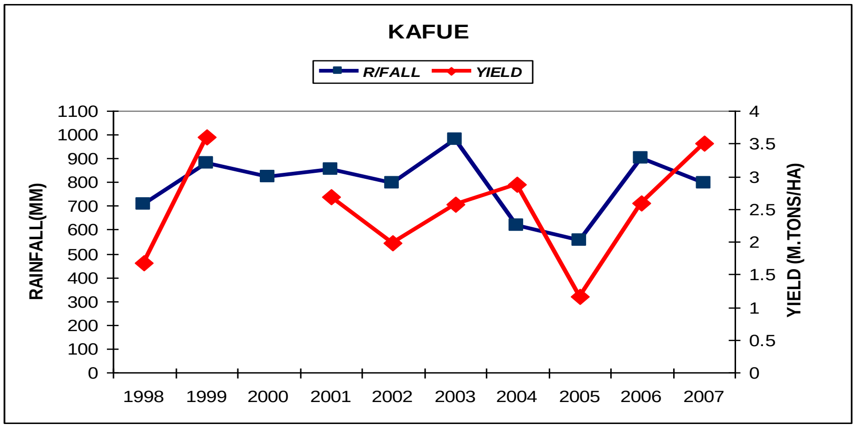


Figure 7: Rainfall and Yield for Kafue district.

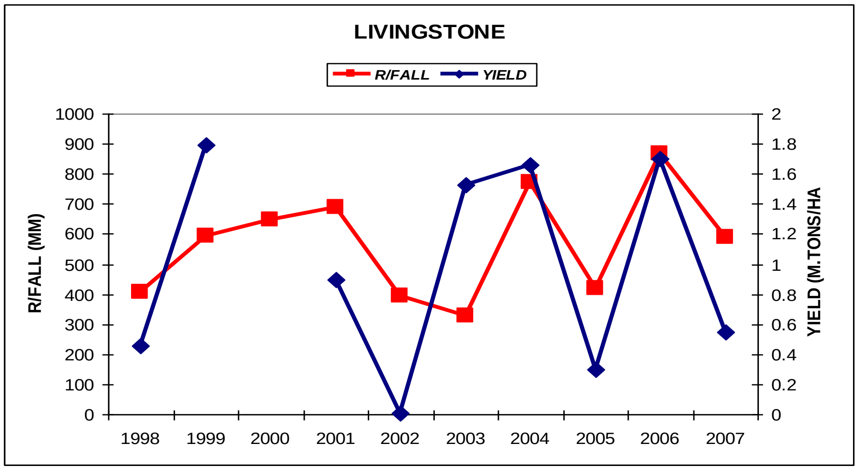


Figure 7a: Rainfall and Yield for Livingstone district.

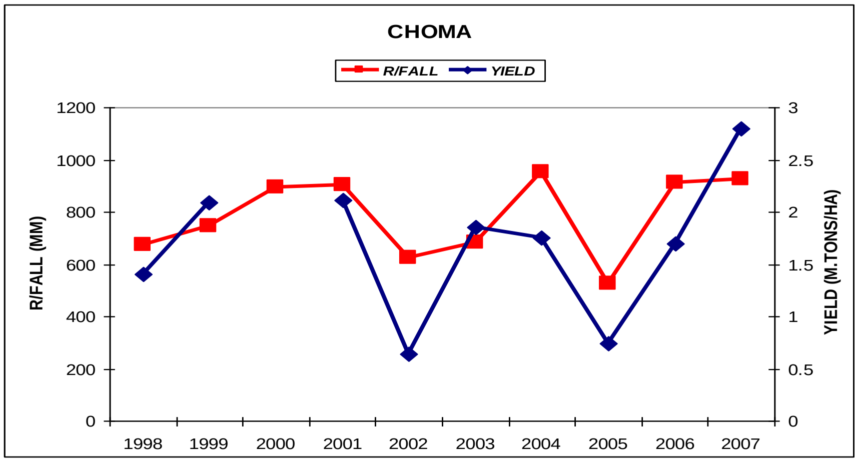


Figure 7b: Rainfall and Yield for Choma district

4.2. Spatial Distribution of the Water Deficits

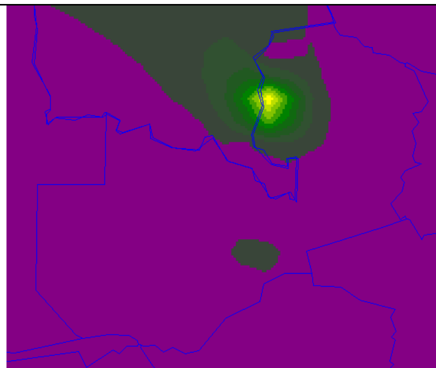
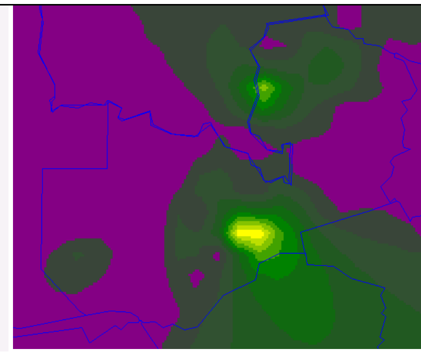
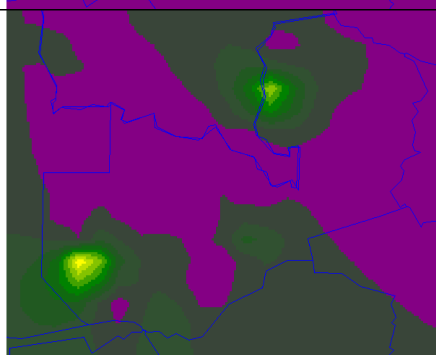
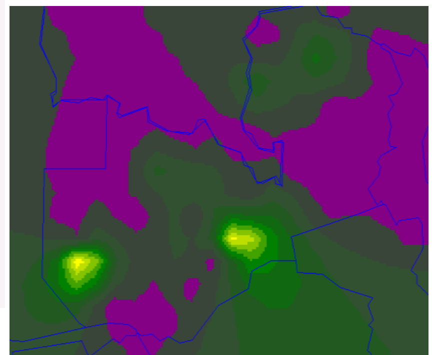
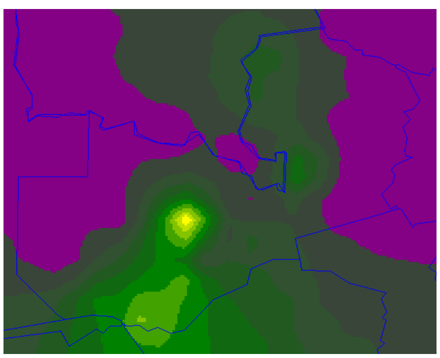
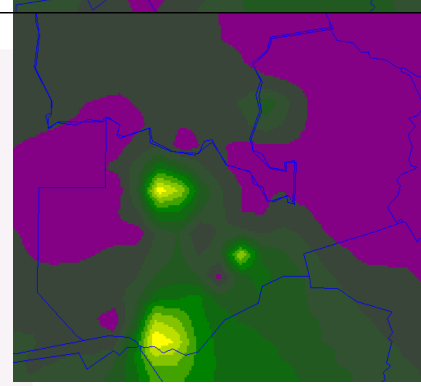
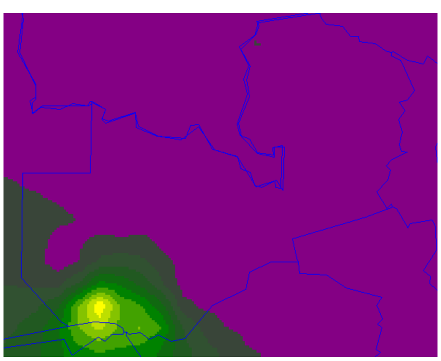
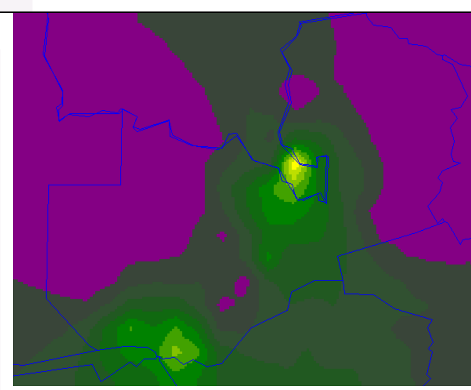
STAGE	2002		2006
Initial		>-32.4 to -29.1 >-29.1 to -25.7 >-25.7 to -22.4 >-22.4 to -19.0 >-19.0 to -15.7 >-15.7 to -12.3 >-12.3 to -9.0 >-9.0 to -5.7 >-5.7 to -2.3 Missing	
Vegetative		>-51 to -45 >-45 to -40 >-40 to -35 >-35 to -30 >-30 to -24 >-24 to -19 >-19 to -14 >-14 to -9 >-9 to -4 Missing	
Flowering		>-122 to -110 >-110 to -97 >-97 to -84 >-84 to -72 >-72 to -59 >-59 to -47 >-47 to -34 >-34 to -21 >-21 to -9 Missing	
Ripening		>-71 to -63 >-63 to -56 >-56 to -49 >-49 to -41 >-41 to -34 >-34 to -27 >-27 to -20 >-20 to -12 >-12 to -5 Missing	

Figure 8: Spatial distribution of the water Deficits.

In years 2000 and 2006, it was observed that the crops experienced more water deficits at the flowering and ripening stages. Missing values indicates that there were no deficits or the deficits were negligible.

4.3. Water Balance Post Processing.

This calculation scheme yielded important parameters indicating the water holding capacity of the soil (WHCa), water surplus at ripening (SWpr), percentage effective rainfall (PcEF), planting dekad (PlDe), cycle length (Cycl) and total water requirement (TWr). Other calculated indices include the Water Satisfaction Index (WSI), Water Excess (WEX), Water Deficit (WDF) and Actual Evapotranspiration (AET) all these at initial (i), vegetative (v), flowering (f) and ripening (r) stages and also the yield for the years under study. Missing actual yield data for the year 2000 was incorporated in the run with -999 in order to allow for the calculation of the water balance parameters and hence results used in the correlation and regression to estimate of the yield for the missing year. However, the results used in the regression were for those years with available actual yield data.

4.4. Correlation Analysis

On basis of examination of the determination coefficients (R^2) of the parameters, the best agrometeorological indices were selected to develop the agrometeorological yield models for the different districts, for Kafue district, the best agrometeorological subset to incorporate in the model was selected i.e. highest value these were water excess at initial stage with a correlation coefficient of 0.1264 and the actual evapotranspiration at initial stage with a correlation coefficient of 0.2949, while for Choma district, the best subsets were the water excess at initial of 0.18403 and the actual evapotranspiration at initial and vegetative stages with correlation coefficients of 0.4132 and 0.1898 respectively.

Yield in Livingstone district was found to be highly correlated to the water excess at initial stage and the total water excess with coefficients of 0.132459 and 0.119469 respectively.

4.5. Regression Analysis

Results of the predicted yields were as shown in the graphs below. An illustration of the statistical summaries on analysis of variance (ANOVA) is shown in the table below.

Table 3: **ANOVA TABLE**

SUMMARY OUTPUT								
Choma 2005								
Regression Statistics								
Multiple R	0.966442							
R Square	0.934011							
Adjusted R Square	0.884519							
Standard Error	0.210761							
Observations	8							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	3	2.514906	0.838302	18.87206	0.007983			
Residual	4	0.177681	0.04442					
Total	7	2.692588						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-3.73626	4.552986	-0.82062	0.457952	-16.3774	8.904854	-16.3774	8.904854
X Variable 1	0.004562	0.001197	3.811003	0.018924	0.001238	0.007885	0.001238	0.007885
X Variable 2	0.542196	0.103401	5.243615	0.006325	0.255108	0.829284	0.255108	0.829284
X Variable 3	-0.03024	0.040272	-0.75081	0.494521	-0.14205	0.081577	-0.14205	0.081577

The table indicates the degrees of freedom were 7 in total for the example given above and the significance F value was very significant in that the level of significance was above 99%.

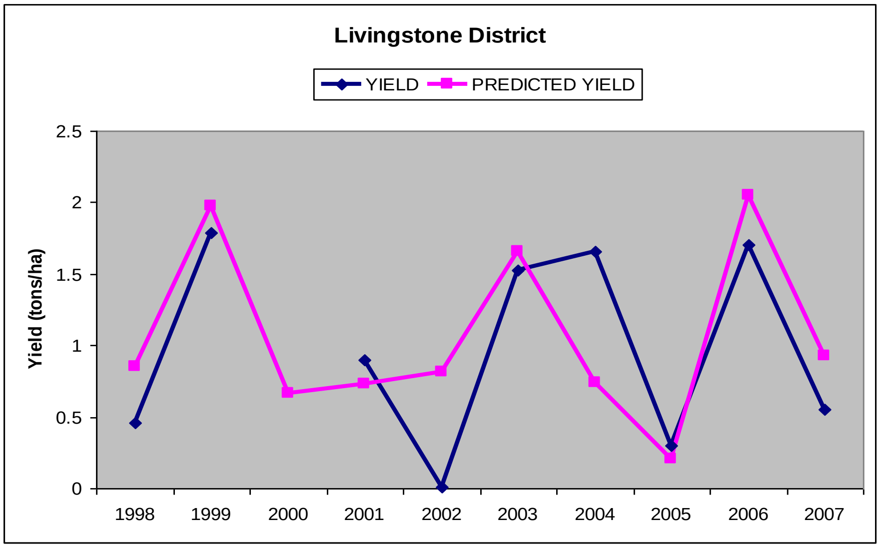


Figure 9: Comparison of the predicted and actual yields for Livingstone district

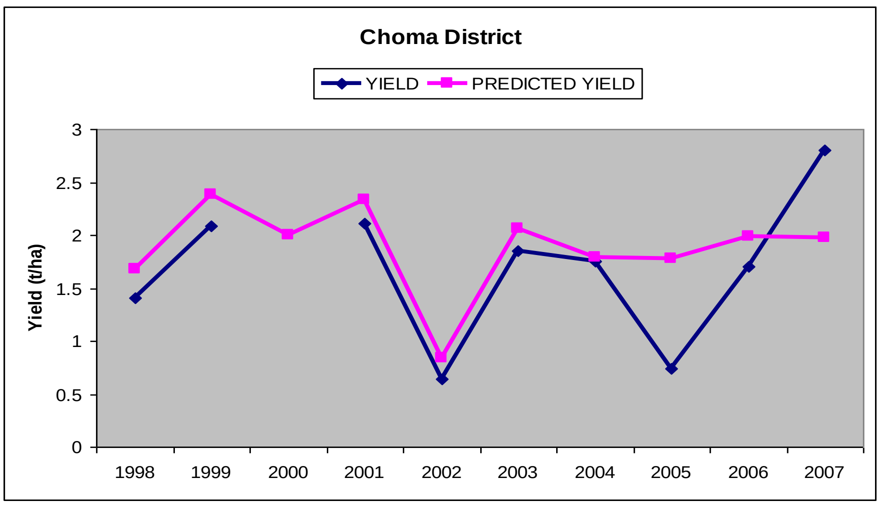


Figure 9a: Comparison of the predicted and actual yields for Choma District

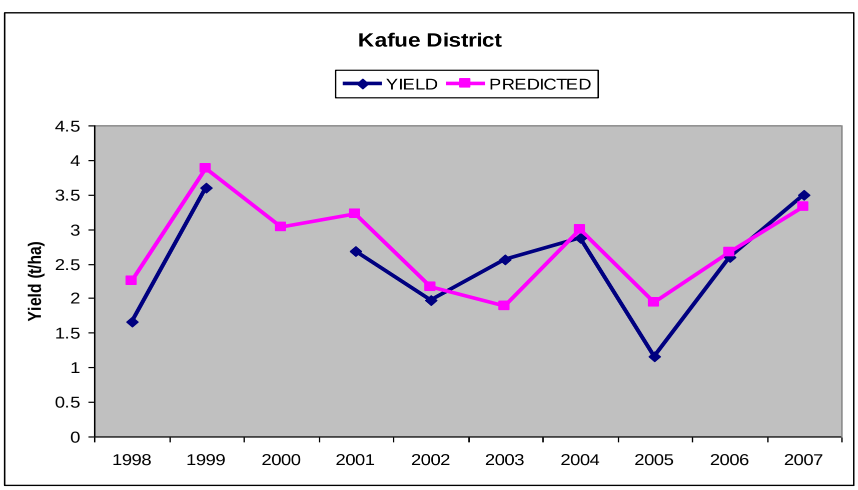


Figure 9b: Comparison of the predicted and actual yields for Kafue District.

4.6. Trend analysis of actual and predicted yields.

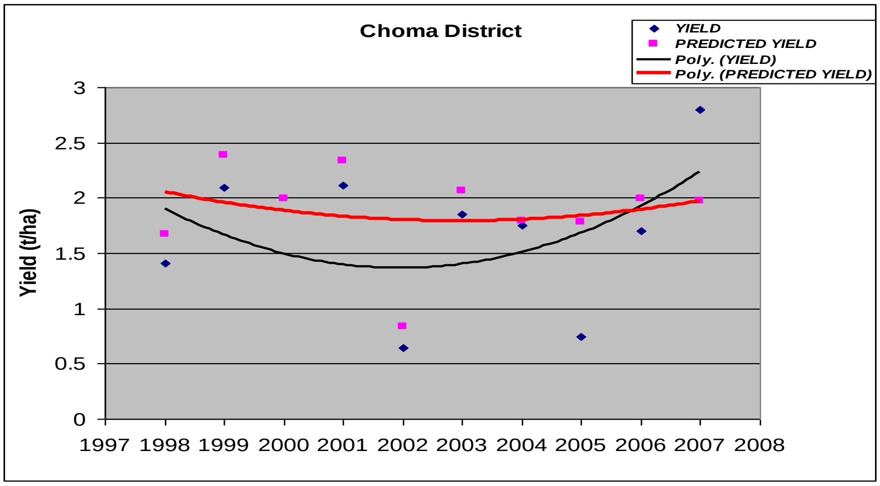


Figure 10: regression model for Choma District.

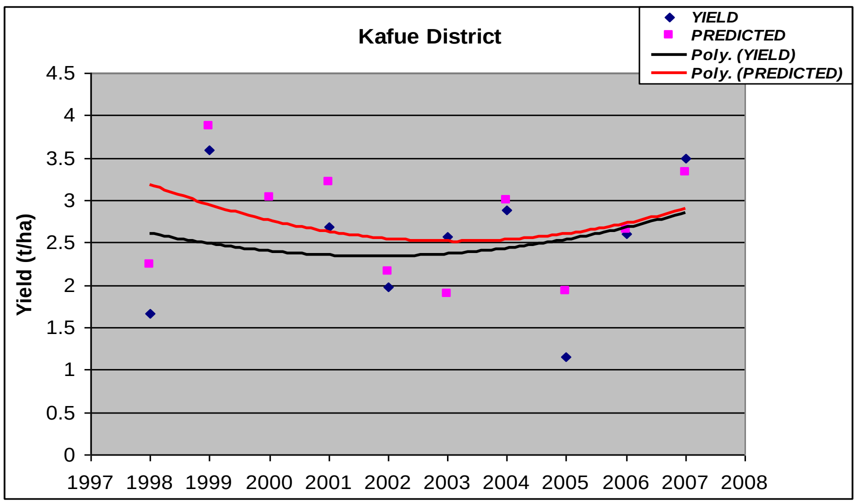


Figure 10a: Regression model for Kafue District.

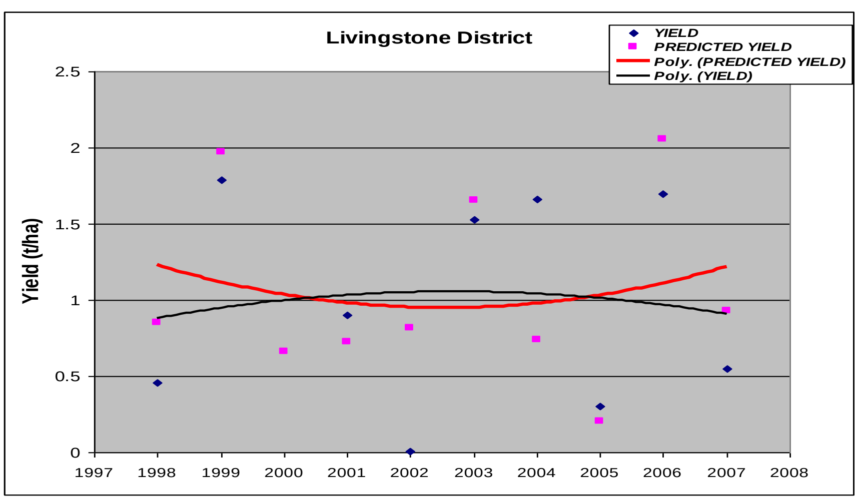


Figure 10b: Regression model for Livingstone district.

Trends showed that for Choma district at the beginning of the study period the model over predicted the yields in the beginning of the study period but towards the end, the model under predicted. For Kafue district, the model was over predicting for the earlier years and later towards the end, the estimates were much closer to the actual yields. For Livingstone district, the polynomial trend lines indicated opposite trends for the actual and the predicted values, however, the model was over predicted for the first and last part of the study period while it under predicted in the middle years under study.

4.7. MODEL VALIDATION.

The predicted maize yields obtained from these models ranged from -55% to 8037.6% deviation. For Livingstone District, the deviation ranged from -55.3% to 8037.%, -41.6 – 100% for Choma district and for Kafue district, they ranged from -26.5% to 66%. The high deviation observed in Livingstone was an indication of a likelihood of crop failure in that district.

On the other hand, the model is assumed valid when the (R^2) regression value is above 50%, hence the model was valid for the three stations used in the study. The figures below illustrate these findings;

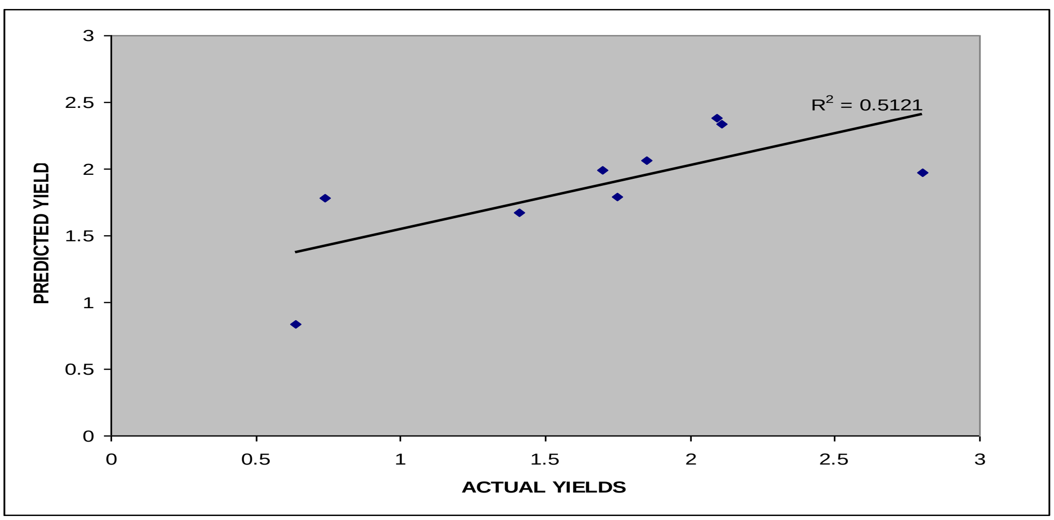


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Figure 11: CHOMA

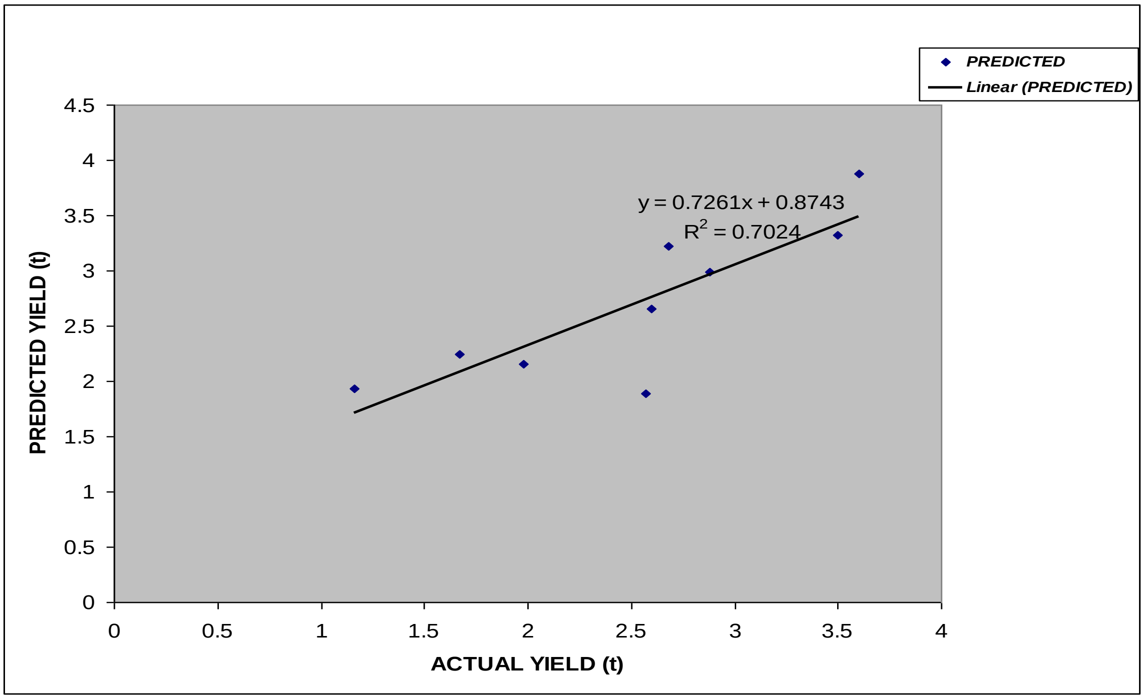

Figure 11a: KAFUE

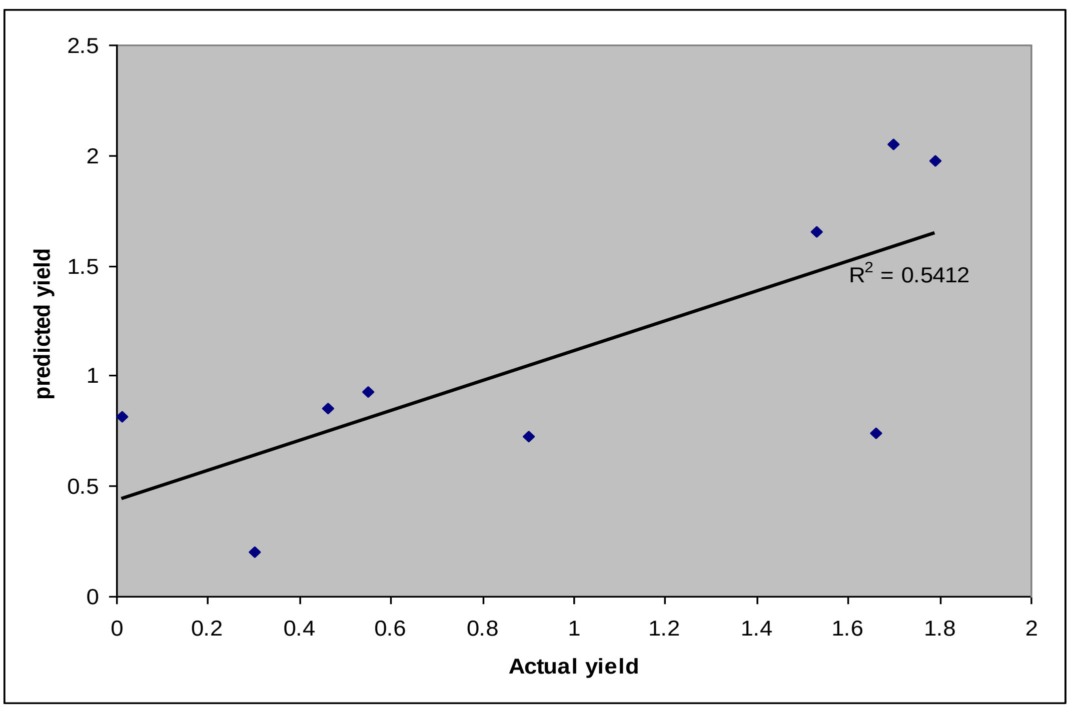

Figure 11b: Livingstone

5.0. SUMMARIES AND CONCLUSIONS

In investigating the crop water requirement for maximum yield production of maize, the water balance calculation indicated that for most stations, the crop water requirement was satisfied except for Livingstone district in the 2001/02 season where the index fell below 50%.

This fall of the index below 50% signifies a crop failure as the water requirements were not met, an index ranging between 50% and 75% signifies the yield would be mediocre while an index above 75% is an indicator of a good harvest. On the other hand, some appreciable yields were expected for the other years under study. This was confirmed with the actual yields obtained for that season; Livingstone had a yield of 0.01 metric tons per hectare. This season was characterized with low rainfall amounts which resulted into some water deficits.

In investigating the stage at which the crop experienced moisture deficits, the water balance calculation indicated that for Livingstone district, the total water deficits amounted to 220mm for the 2001/02 season which is significantly high compared to Choma and Kafue which had deficits of 115mm and 89mm respectively. On analysis of the spatial distribution of the water deficits at different stages of growth, it was found that the maize crop experienced more water deficits at vegetative and flowering stages of their growth.

It has been established that the more the predictors used in the model, the better the prediction of the yield and this tool can be used for estimating the yield of the local maize variety grown in the southern province The potential predictors for Livingstone district were the water excess at initial stage and the total water excess, while for Choma district, predictors were the water excess at initial and the actual evapotranspiration at initial and vegetative stages, for Kafue, the water excess and actual evapotranspiration both at initial stages were the principle components contributing the yield. Upon implementation of the estimating tool, it indicated that the model was over predicting for the stations in the agro ecological zone II for most parts of the period of study while for Livingstone which lies in agro ecological zone 1 the model under predicted, this was attributed to the low rainfall amounts received in that zone compared to the other zones. This low rainfall amounts resulted into higher deficits at different stages of growth. On the other hand, the predicting indices had low correlation coefficients hence the under prediction of the model.

The maize yield prediction is better performed when both meteorological and agrometeorological indices are used in combination rather than when they are used individually in the model.

6.0. RECOMMENDATIONS

Research on the improvement of maize yield prediction and water requirements should continue receiving a very high priority as it contributes much to the food security in the country and the region. Further understanding of other parameters such as satellite information should be incorporated jointly with point data in the investigation of water requirements of the maize yields over the region.

On the other hand, it may be possible to improve the accuracy of the yield when agrometeorological indices integrate with the remotely-sensed based indices due to the high spatial resolution of satellite data.

Regional outlook fora should incorporate yield forecasting based on the knowledge of the onset of the rain and its distribution on regional basis as it is of great importance in improving the food security and hence alleviate poverty in the region.

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