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An Analysis of Long Term Rainfall Variability, Trend and Water Availability In Mulunguzi River Catchment Area, Zomba, Malawi.

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ABSTRACT

This paper presents a non-parametric statistical analysis of the annual rainfall time series (1953-1997) in the Mulunguzi River Catchment area. Strongly cyclic rainfall pattern following the El Nino and Southern Oscillation (ENSO) Cycles was detected. Significant departures from the mean rainfall and a general downward trend were also detected. Two change points in the rainfall series were identified: at 1964/65 and 1979/80. The pattern of rainfall variation and downward trend is further echoed by the mean annual river discharge for the same period. Further analysis of catchment water availability through the total annual volume of river discharge recorded just before the Mulunguzi reservoir also detected a declining trend. The projected water availability, if married to the projected water consumption trend in the Municipality of Zomba suggests a water stress point in the Municipality at 2017. The approach does not consider environmental flow requirements, evaporation loses, reservoir losses, seepage, reserves, dead storage and downstream users, which if taken into account would result in the projected stress point year occurring earlier than 2017. It is hence recommended that all water resources planning activities in the catchment should consider variations and trends in rainfall and its dependent variables which in the long run may be indicating climate change.

Key words: Climate variability, climate change, river discharge, base flow, water availability.

1 INTRODUCTION

Global water resources, essentially products of climate, are highly sensitive to climate variability and change. Rainfall is a critical hydro climate indicator whose manner of variation and trend may influence the degree of the response of water resources quantity indicators to climate variation and change, through its dependent hydrologic variables like river discharge Mimikou *et al* (2000) and Kates *et al* (1985). The rainfall variation signal may however not be that loud if analysed at global level or large spatial scale but is more pronounced at lower level spatial scales like catchments. Burn, Mohomed & Elnur (2002) and Kiely (1999) took the catchment approach to detect and analyse some temporal change in various hydrological variables.

In Malawi, significant departures from the normal rainfall regime over the years have also been noted. Just like the rest of Southern Africa, there is clearly a strong correlation with the El Nino and Southern Oscillation and La Nina phenomena (Government of Malawi, 1997). However, not much has been done to determine whether the trend of the rainfall regime is downward (decreasing) or upward and the response of water resources quantity indicators like river flow and base flow. This maybe an important planning tool especially in catchments supplying water to major urban areas.

This study was aimed at finding out the rainfall trend and if there has been a change in the rainfall regime of the Mulunguzi River catchment by analysing the long-term annual rainfall series of the catchment area. Further, the response of the Mulunguzi river flow, one of the critical water resources quantity indicators, was also investigated. The study finally attempted to trace for a possible water stress point in the Municipality of Zomba based on the present rainfall and river flow trends and water consumption projections. Water stress can be defined as a situation where the per capita consumption of water is restricted due to inadequate water availability.

The study area is entirely on Zomba Mountain up to the river gauging station before the Mulunguzi reservoir. This is to the west of the Municipality of Zomba as shown in Fig. 1 and is located at an average altitude of 1800 m. The main rain bearing system in the area is the Inter-tropical Convergence Zone (ITCZ) with a mean annual rainfall of over 2000 mm with occasional cyclonic rainfall activities. The major land use activity is pine forest plantation. This catchment area was chosen owing to its importance as the only source of raw water for the Municipality of Zomba. Hence this analysis of the trends in the historical data would lay the foundation in all water resources planning activities in the area.

2 METHODOLOGY

2.1 Data Requirements

Annual Rainfall (mm/annum), mean annual river discharge (m^3/s) were analysed. The longest possible available record for both series was from 1953/54 to 1997/98 hydrological years (1^{st} November to 31^{st} October). The rainfall data for Zomba Plateau Station was sourced from the Malawi National Meteorological Services at Chileka Airport in Blantyre and Chancellor College Meteorological Station in Zomba. A uniform annual rainfall for the catchment was assumed since the area is approximately at the same height (Linacre, 1992), (Lancaster, 1980).The Mulunguzi River discharge data was obtained from the Ministry of Water Development, Surface Water Resources Section.

In addition, Zomba Municipality water consumption figures were analysed and projected using data from the 1998 Zomba Water Supply project Environmetal Audit report, which was done during the construction of the new Mulunguzi Dam. The report had raw water demand projections for the municipality for 1984, 1995, 2005 and 2015. To project the annual trends for raw water demand, exponential and linear interpolation and projection methods of the following forms respectively were used (van der Zaag, 2002):

$$W_t = W_0 e^{rt}$$
$$W_t = W_0(1+r)^t$$

Where

W_t is the water demand in m^3 at time t
W_0 is the annual water demand in m^3 at time $t=0$
r is the projected growth rate of water consumption in % per year
t is the time in years.

2.2 Data Analysis

Inter-annual variability was determined by normalising the rainfall and river discharge series as follows (Landsea & Gray, 1992):

$$(p-\overline{p})/\sigma$$

Where
p is the time series variable (rainfall and river discharge)
$\overline{p}$ is the mean of the time series
σ is the standard deviation

Long-term annual variation of each of the time series were determined by the coefficient of variation (C_v) and the coefficient of skew ness (C_s) given respectively by (Chow, 1964):

$$C_v = s/\overline{X}$$

Where $\overline{X}$ is the mean of the observed variable with a standard deviation s.

$$C_s = a/s^3$$

Where a is given as:

$$a = N(N-1)(N-2)\sum_{1}^{N}\left(X_i-\overline{X}\right)^3$$

With N graphic the number of data values and X_i is the i^{th} observation with mean $\overline{X}$.

2.3 Trend and Change Point Detection

To filter out noises in the time series so that a clear long term-trend could be detected, a 10-year moving average Low Pass Filter was applied to each of the time series which, according to Kiely (1999)is given as follows:

$$MA_t = \frac{1}{2L}\left(\frac{1}{2}X_{t-L} + \sum_{j=-(L-1)}^{L-1} X_{t+j} + \frac{1}{2}X_{t+L}\right)$$

Where X_t is the variable at year t starting from 1953/54, $L=5$ for a 10-year moving average and j varies from $-(L-1)$ to $(L-1)$. This was done in order to smooth out and remove the effect of cycles for the annual time series (Kiely, 1999).

2.4 Change-point Detection: Mann-Whitney-Pettitt and Mann-Whitney-Wilcoxon Tests

To determine whether there are any significant change point years in all the time series, the non-parametric statistical Mann-Whitney-Pettitt Test was used (Kiely, 1999).This method again used the annual time series as follows:

Length of time series $(T : x_1, \ldots x_T)$ is considered as two samples: $(x_1, \ldots, x_t)$ and $(x_{t+1}, \ldots, x_T)$. The indices $V_{t,T}$ and $U_{t,T}$ are given as follows:

$$V_{t,T} = \sum_{j=1}^{T} \text{Sign}(X_t - X_j)$$

Where

$$\begin{aligned} \text{Sign}(x) &= \ \ 1, \text{for } x > 0, \\ \text{Sign}(x) &= \ \ 0, \text{for } x = 0, \\ \text{Sign}(x) &= -1, \text{for } x < 0. \end{aligned}$$

Then

$$U_{t,T} = U_{t-1,T} + V_{t,T}$$

for $t = 2, T$ and

$$U_{1,T} = V1, T$$

According to Kiely (1999),using the above procedure, the most significant change point is found where the absolute value of $(U_{t,T})$ is a maximum:

$$K_t = \max |U_{t,T}|$$

The approximate significance probability for a change point is then given by the following exponential probability function:

$$P_t = 1 - e\left(-6U_{t,T}^2/(T^3 + T^2)\right)$$

The Mann-Whitney-Wilcoxon Test (Kiely, 1999)was used to test if the mean of the two samples (i.e. from $[x_1, \ldots, x_t]$ where t is the suspected change point year(s) and $[x_{t+1}, \ldots, x_T]$ are equal. This hypothesis is invalid if:

$$Z_c > |u_1 - \alpha/2|$$

Where $u_1 - \alpha/2$ is defined as the '$1-\alpha/2$ quartile' of the standard normal distribution with a significance level of $\alpha = 0.05$ (Kiely, 1999),since the rainfall is a random variable in this case. The index Z_c is called the Z score and is calculated as follows:

$$Z_c = (w - n(T+1)/2) \Big/ \sqrt{n(T-n)(T+1)/12}$$

The variable w, according to Pettitt (1979) in Kiely (1999) is computed by dividing the rainfall time series into two new series with the elements: $[x_1, \ldots, x_m]$ and $[y_1, \ldots, y_{n-m}]$, where each of the two series should contain at least eight elements. The variable w is the sum of the ranks $(r(x_i))$ of the elements of the first series $[x_1, \ldots, x_m]$ defined by rearranging the elements of both series in ascending order.

$$w = \sum_{i=1}^{m} r(x_i) \qquad (1)$$

Changes in the mean value of a sequence of observations ordered in time were also detected using the cumulative sum technique (Kiely, 1999), which is given as follows:

$$S_m = \sum_{i=1}^{m} (X_i - K) \qquad (2)$$

Where K is the average of the observed time series.

The Hypotheses of no change in the mean value is rejected if max $(|S_m|)$ becomes too large. Where no outliers in the series exist, equations (1) and (2) are supposed to approximately fit if plotted on the same chart. This procedure was used to determine change points (if any) in the rainfall series of the area.

3 RESULTS AND DISCUSSIONS

3.1 Rainfall variability and Trends

The study found significant departures from the mean annual rainfall. The annual rainfall coefficient of variation (C_v) for the 44-year period is 0.30. This coefficient of variation however is relatively low and is a feature of most catchment areas that receive heavy rainfall due to local orographic influences (Sefe, 1988).This is however an expected result because Zomba plateau is a high relief area that receives high rainfall, although the departures cannot be ignored. Fig. 2 shows the annual rainfall variability pattern in the catchment area.

Fig.2 clearly shows alternating wetter and drier years mainly following the El Nino and Southern Oscillation (ENSO) and La Nina cycles. According to Government of Malawi (1997), major ENSO years in Malawi, characterised by below normal rainfall, were 1981 to 1984, 1987, 1991 to 1995 and 1997. La Nina years with above normal rainfall occur in from 1961/62 to 1964/65 and again in the mid 1970's, a result which agrees with Kidd (1983) in his studies on Lake Malawi basin.

These results seem to agree with those found by Gommes et al (1996) for the whole Southern Africa region for the period from 1959 to 1993 as shown in fig. 3. Richard *et al* (2001) and McCarthy *et al* (2001) further agrees that the period from 1991 to 1994 was the worst draught period of the century in Southern Africa where some countries had as much as 80 % deficits in the normal rainfall.

The cyclic nature of rainfall variation trend line in Fig. 2 however fails to detect the rainfall trend direction. Fig. 4 shows the annual rainfall for the period 1953/54 to 1997/98 A declining rainfall trend is suggested. The rainfall, however, seem to pick up in the mid-1970s but starts to decline again late in the 1970-1980 decade. Fig. 5 shows rainfall change point years that were identified during this period: at 1964/65 with a significance probability of 0.85 and another one at 1979/80 with a significance probability of 0.83 as shown in Fig. 5.

Table 1 summarises the pre and post-change point year average annual rainfall. In this study, the pre change period was defined as the series in the period before the suspected change point while the post change period is the period after the change (including the change point year itself). The table seems to suggest that the rainfall was indeed decreasing during the period.

Table 1: Average annual rainfall (mm/year) for pre and post change years, Mulunguzi River catchment

Pre-change	Ann. fall	Post-Change	Ann. fall	% Rel. change
1953-1998	2210	-	-	-
1953-1964	2556	1965-1998	2097	−22.4
1953-1964	2556	1965-1980	2207	−16.3
1953-1979	2350	1980-1998	2044	−15

From Table 1, a decreasing rainfall trend can be suggested. All the pre-change point averages are larger than the post change point averages except the 1953-1980 mean which is larger than both the post 1980 and the post 1964 but pre-1980 mean.

The pre-1964 mean is 22.4% greater than the post-1964. Moreover, the pre-1964 average is 16.3% greater than the post 1964 but pre-1979 annual average. The pre-1979 average is 15% greater than the post 1979 average. The post 1964 average is 8% greater than the post 1979 average.

The preceding discussion of the results confirms that significant changes in the rainfall regime of the Mulunguzi River Catchment indeed occurred around 1964/65 and 1979/80. Both change points suggest a generally decreasing rainfall trend towards 1998. The post-1965 but pre-1979 period may, however, indicate an increasing rainfall trend as suggested by the variability pattern. A look at the behaviour of the river discharge time series is now in order.

3.2 Mean Annual River Discharge Variability and Trend

Catchments normally exhibit their response to rainfall variations through river discharge. The mean annual flow of the river from 1953 to 1998 is 0.504 m^3/s. The coefficient of variation of the annual mean flow was 0.38. This coefficient is relatively low just like that of the rainfall series and is typical of areas which receive high rainfall. The mean annual flow series for the period are shown in Fig.6.

From Fig.6, the flow suggests a pattern similar to that of rainfall. The wetter years identified in the mid-1970s in the rainfall series are clearly shown. This suggests a strong correlation between the rainfall and the river flow series.

Fig.7 shows the detected change point years of the flow series with two maximum peaks. The first significant change point occurs around 1964/65 with a probability of 0.881 and the second change point occurs around 1979/80 with a larger significance probability of 0.997 both again coinciding with those of the rainfall series. Table.2 sumarises the pre-change point and post change point mean annual flows and the % change.

Table 2: Mean annual flow (m^3/s) for pre- and post change points

Pre-change	Ann. flow	Post-Change	Ann. flow	% Rel. change
1953-1998	0.504	-	-	-
1953-1964	0.610	1965-1998	0.463	−24.2
1953-1964	0.610	1965-1980	0.551	−8.7
1953-1979	0.581	1980-1998	0.374	−35.5

The mean annual flow for the entire period was 0.504 m^3/s. The pre-1965 mean annual flow was 0.610 m^3/s while the post-1965 mean annual flow was 0.463 m^3/s, representing a 24.2 % decrease from the pre-1965 period. The pre-1980 mean flow was 0.581 m^3/s and the post 1980 means was 0.374 m^3/s representing a 35.53 % decrease from the pre-1980 period. The post 1965 but pre-1980 annual mean was 0.551 m^3/s, 8.7 % less than the pre-1965 mean. It is worth noting however that the post 1980 period relative reduction in river discharge might have been strongly affected by the 1992-1994 El Nino event, which was more of a shock to the river discharge regime.

3.3 Water resources availability for integrated planning in the catchment

The recorded annual volumetric amount of river discharge shown in Fig. 8 can theoretically be taken as the potential that the catchment would be able to supply to various water using activities in the catchment area in a particular year. A decreasing trend just like that of the rainfall and river discharge series is shown. The water availability trend line polynomial was used together with projected water consumption figures to find out the possibility of water stress in the municipality of Zomba and the results are shown in Fig. 9.

If the present water availability and consumption trends prevail, then water stress is likely to occur at around 2017. It is worth pointing out however that these projections do not consider other water using activities like environmental flow requirements, the amount that has to be released downstream of Mulunguzi Dam to maintain the ecological integrity of the river and evaporation losses. If these and others are taken into consideration, then the water stress point year may come earlier than the projection suggests.

Based on the results, although the picture is not clear at this stage as to what is causing the decline in the hydrological variables analysed, the declining trends in all the series may not be by coincidence. Climate change cannot be ruled out. It is hence recommended that alternative sources of water for the municipality of Zomba must be explored as part of water resources planning in the area. The introduction of Water demand management measures may also assist people in getting used to the situation in the eventuality of water stress.

4 CONCLUSIONS

Long-term rainfall variability and trend in the Mulunguzi River catchment area suggests a 15% decline between 1953/54 and 1997/98 with two significant change point years at 1964/65 and 1979/80. The trend during the same period is echoed by the total river discharge which showed a 24.2% reduction and the annual volume of water generated in the catchment area. This suggests a strong correlation between the water resources quantity indicators.

If the detected trend and change in the rainfall and river discharge are married to the present and future trends in water availability and consumption, water stress in the Municipality of Zomba is likely to occur at around 2017, considering exponential population growth rates. This projection excludes environmental water requirements and other use which if included would mean the occurrence of water stress before 2017. Alternative water sources in addition to water demand management strategies must be explored.

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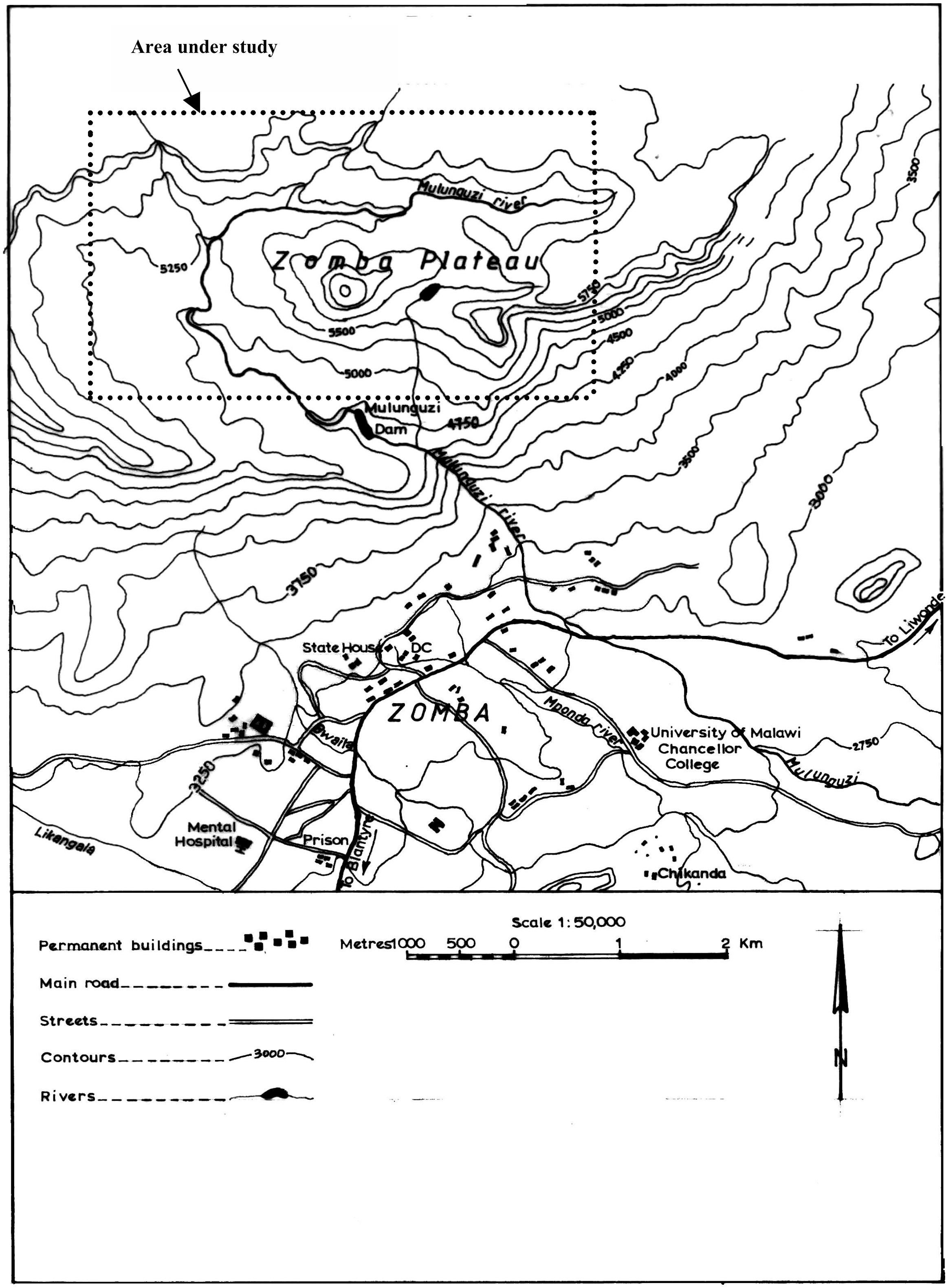

Figure 1: Map of Zomba Showing Mulunguzi River Catchment (Government of Malawi, 1986)

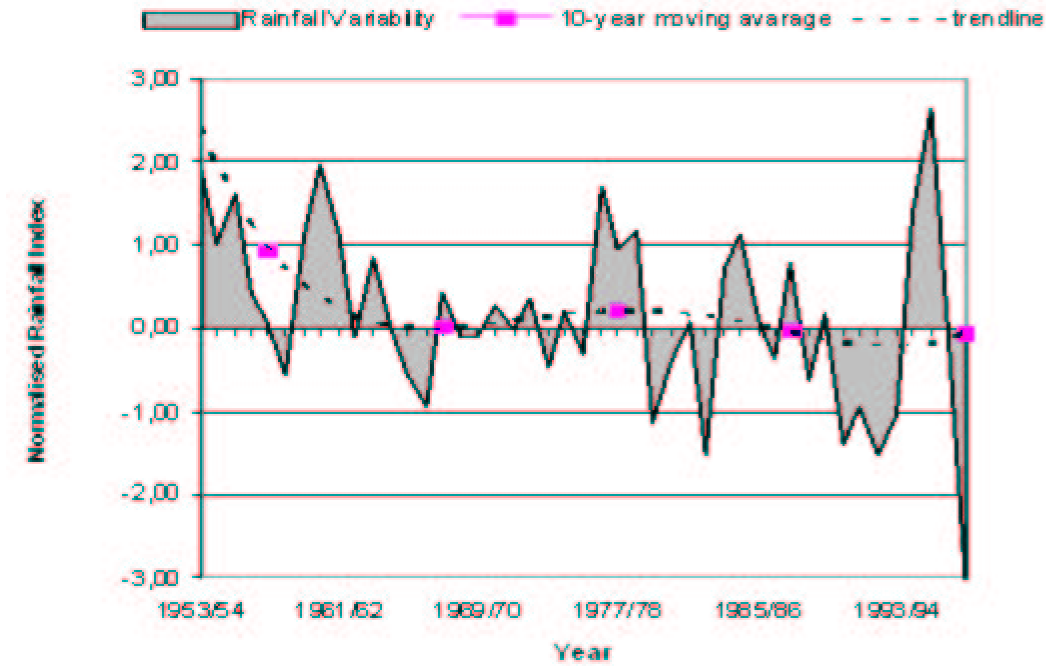

Figure 2: Normalised inter annual rainfall variability in Mulunguzi River Catchment

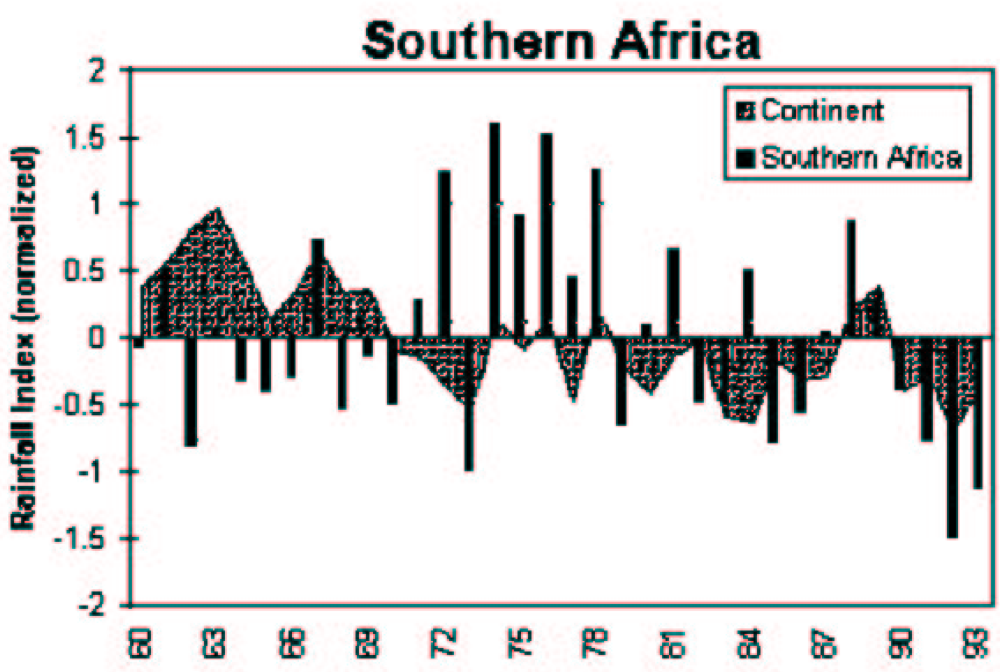

Figure 3: Normalised Rainfall Variability for Southern Africa (Gommes and Petrassi 1996)

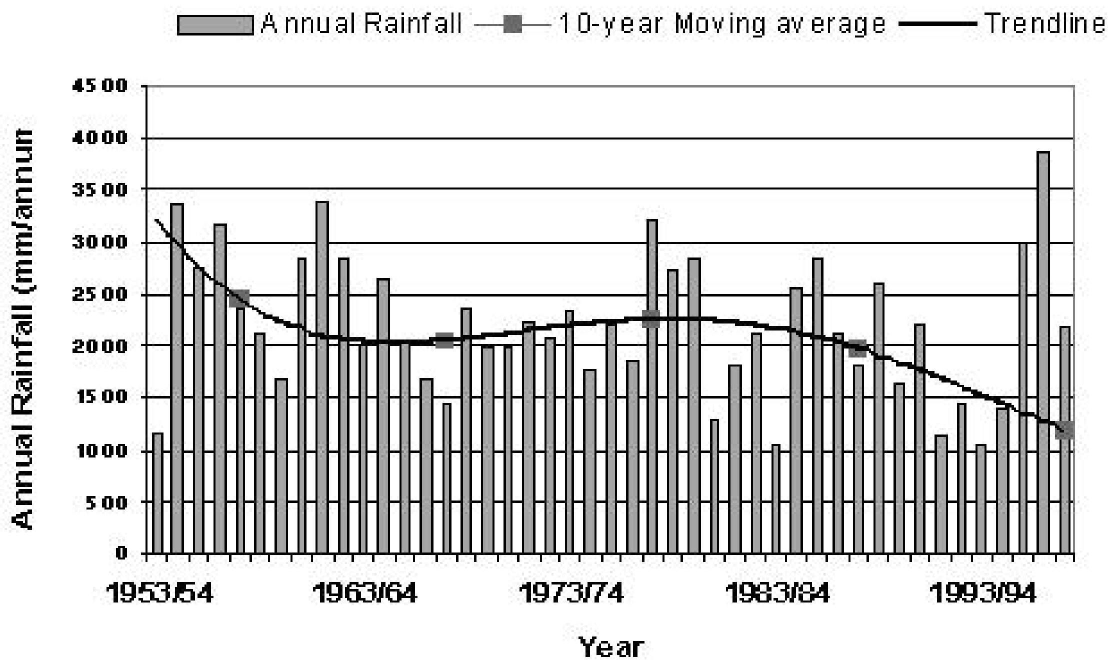

Figure 4: Annual rainfall and 10 year moving average, Mulunguzi river catchment

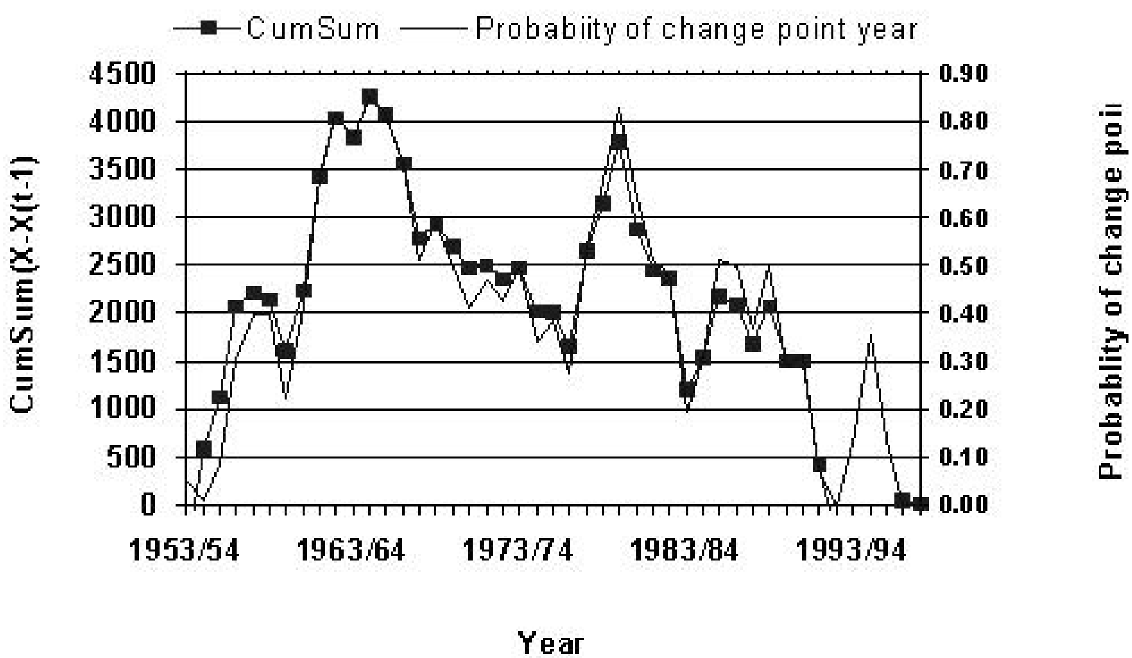

Figure 5: Probability of Rainfall Change Point and Cumsum, Mulunguzi river catchment

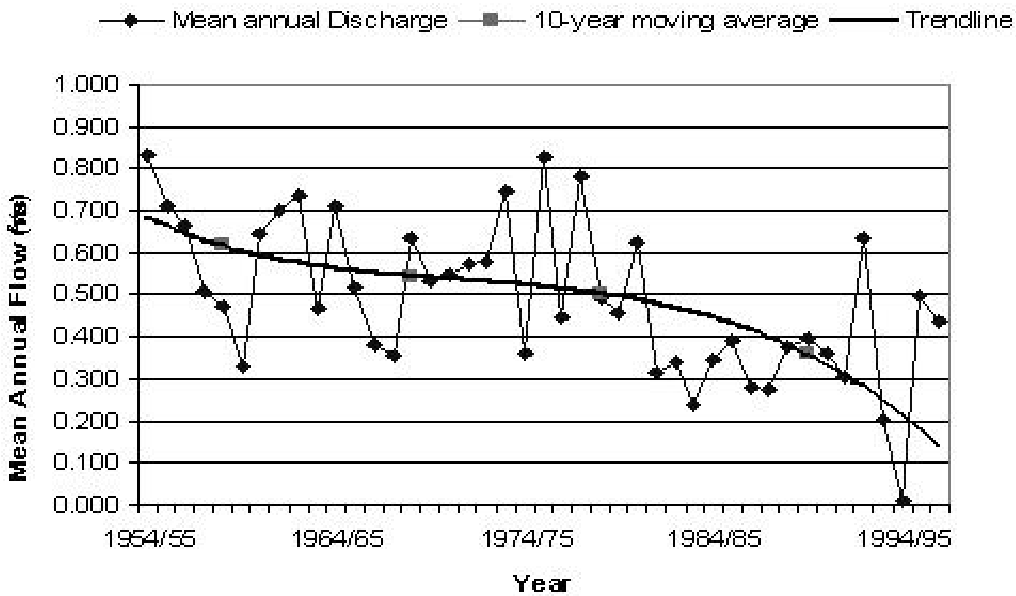

Figure 6: Mean Annual flow and 10 year moving average and trend, Mulunguzi river catchment

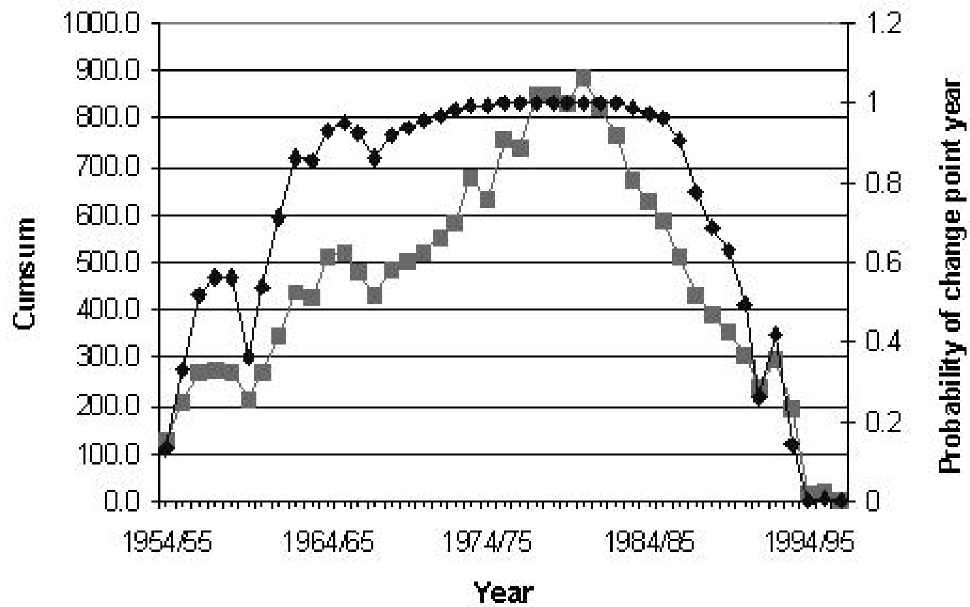

Figure 7: River Flow Change Point Years, Mulunguzi river catchment

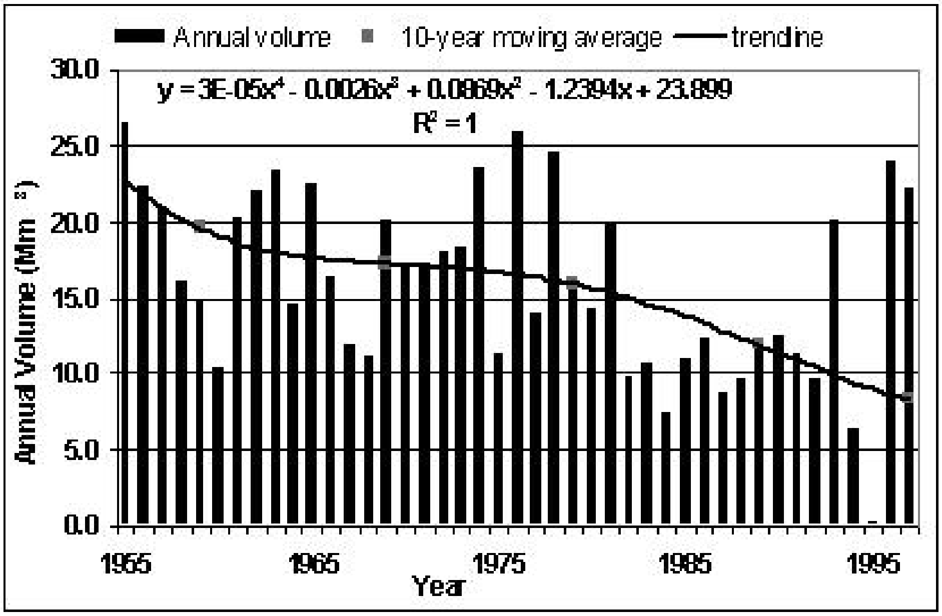

Figure 8: Annual discharge volume and moving average, Mulunguzi River catchment

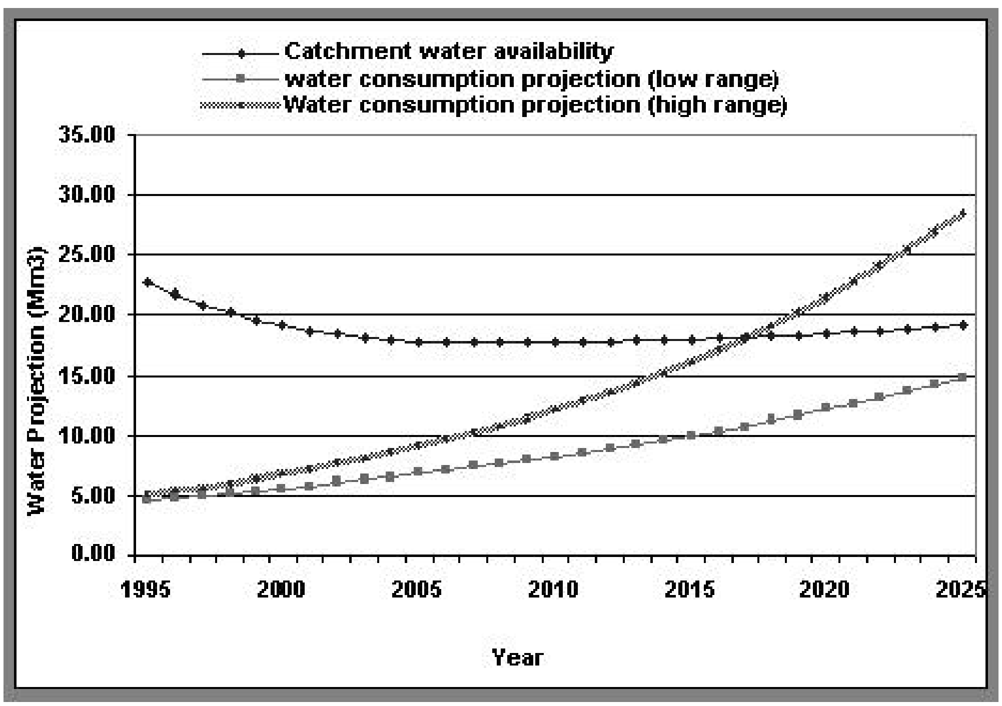

Figure 9: Projected water consumption in the Municipality of Zomba and Water Availability