AN EVALUATION OF CLIMATE AND RUNOFF VARIABILITY AND ASSOCIATED LIVELIHOOD RISKS IN THE MZINGWANE CATCHMENT, LIMPOPO BASIN, ZIMBABWE[#]

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ABSTRACT

Climate change occurs over relatively long time scales, although some acceleration in changes can also be seen in data of the last twenty years. The reasons for the current changes in the climatological variables might be anthropogenic (e.g. greenhouse gas emission) or natural (e.g. solar variability etc.), or most likely a combination of both reasons. An increasing body of evidence shows that greenhouse gas emissions are changing our climate significantly. Climate change is projected to substantially reduce available water (as reflected by projected runoff from a catchment) in many of the water-scarce areas of the world

A statistical analysis was carried out of over fifty years of precipitation, temperature and runoff data from several locations in the Mzingwane Catchment – the portion of the Limpopo Basin that falls within Zimbabwe. The trends show declines in precipitation and runoff and increases in maximum and minimum temperatures, across the catchment. The trends observed are comparable to those predicted from some of the global circulation models (GCMs) based on the Intergovernmental Panel on Climate Change Special Report on Emission Scenarios (IPCC (SRES)). Regression analyses show the relationships between climate variability and change and decreasing runoff.

The trends observed have major livelihood implications. Zimbabwe's second largest city, Bulawayo, and some other urban and mining centres, obtain water from the Upper Mzingwane subcatchment, and the long term reliability of this supply is threatened. The majority of the population in the Mzingwane Catchment are smallholder farmers, dependant largely on rainfed agriculture. Reduced and erratic precipitation threatens their future yields. Mitigating the impact of climate change requires a package of strategies including (i) water demand management in the urban centres, (ii) a major investment in soil water conservation strategies for smallholder farmers, (iii) expansion of recycling by large water users, and (iv) development of alternative livelihood strategies.

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INTRODUCTION

Climate Change and Variability

Climate change occurs over long time scales, although some acceleration in changes can also be seen in data of the last twenty years. The reasons for the current changes in the climatological variables might be anthropogenic – principally from greenhouse gas emissions (1) or natural – caused by periodic changes in distribution of incoming solar radiation resulting from variations in the earth's orbital geometry that is the tilt, precision of equinoxes and eccentricity (2) – or most likely a combination of both reasons. An increasing body of evidence shows that greenhouse gas emissions are changing our climate significantly:

- The global average surface temperature has increased over the 20th century by about 0.6 °C
- Temperatures have risen during the past four decades in the lowest 8 km of the atmosphere
- Snow cover and ice extent have decreased
- Global average sea level rose between 0.1 and 0.2 m during the 20th century
- The effect of anthropogenic greenhouse gases is detected, despite uncertainties in sulphate aerosol forcing and response (3).

Studies of the climate of Africa have indicated variability at annual and sub-decadal time steps. The annual cycle is found to be the dominant mode. At the sub-decadal time scale, years of high annual precipitation correspond with La Niña and low annual precipitation corresponds with El Niño (45), although there are regional variations.

At the multi-decadal time step, the effect of climate change in sub-Saharan Africa can be seen in warming by around 0.7°C over most of the continent during the last 100 years and a decrease in rainfall over large portions of the Sahel in the same period, with all but one year since 1970 recording rainfall below the 100 year annual average (5).

Global climate change is being modelled in two stages: (i) estimation of possible future levels of greenhouse gas and aerosol emissions, such as the Intergovernmental Panel on Climate Change Special Report on Emission Scenarios (IPCC SRES scenarios) (1); (ii) development of climate models incorporating the effects of the emission scenarios – at the global level these are often general circulation models (6). General circulation models developed with the IPCC SRES scenarios suggest increased temperatures from 0.2°C per decade (low scenario) to more than 0.5°C per decade (high scenario). The scenarios predict greatest increases in temperature in the Sahel and in central southern Africa (5). Rainfall in southeastern Africa is expected to decline with the annual rainfall expected to between 10 % and 40 % below the 1961-1990 averages by 2099 (7,40).

Climate change is projected to substantially reduce available water (as reflected by projected runoff) in many of the water-scarce areas of the world (3). Modelling runoff from rainfall and evaporation levels predicted from general circulation models using the IPCC SRES scenarios has shown that by 2020 the effect of climate change on mean annual runoff will be greater than that of climate variability in 66 % of the world, and in around 90 % of the world by 2080 (8). By the 2050s, in the eastern part of southern Africa, runoff is expected to decline by between 10 % and 40 % compared to 1961-1990 averages (8,9,40).

Widely ranging livelihood impacts have been predicted on the basis of these changes (10). It is clear that the significantly reduced precipitation and runoff over the next fifty years is likely to produce corresponding food shortages (11, 5; 12, 13). There will also likely be decreases in availability of water for domestic purposes and in hydroelectric power generation. Water intensive industries such as thermal power generation and mining are also likely to be impacted. Vector- and water-borne diseases may increase, especially in areas with inadequate health infrastructure (5). Risks to livestock production will also increase, perhaps beyond the capacity of farmers to adapt (22).

In this paper, an attempt is made to determine trends in rainfall, temperature and precipitation in the water-scarce Mzingwane Catchment in Zimbabwe, in order to characterise some of the possible livelihood risks.

Study Area

The Mzingwane Catchment is the water management area of portion of the Limpopo Basin within Zimbabwe, and comprises the sub-basins of the left bank tributaries of the Limpopo from the Shashe to the Mwenezi (see Fig. 1). The Mzingwane Catchment contributes around 9 % of the runoff of the Limpopo River (14).
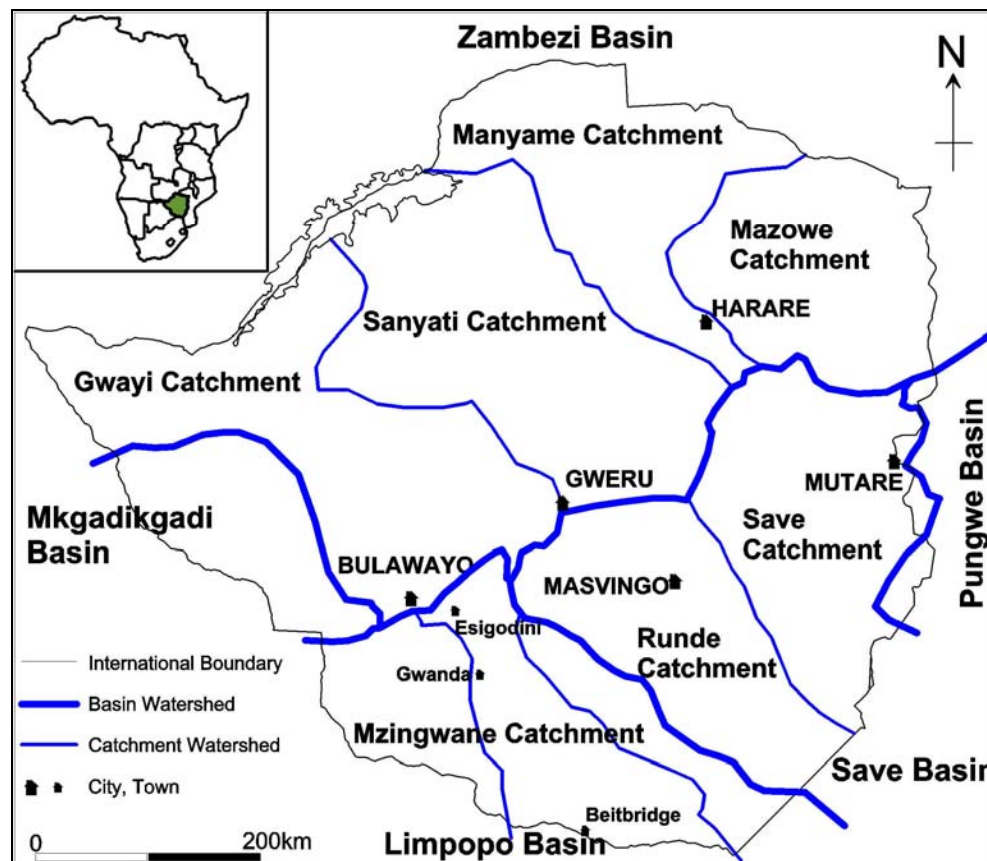

Fig. 1. Location of study area.

Occurrence of rainfall in Zimbabwe is mainly controlled by the Inter Tropical Convergence Zone (ITCZ). It is a zone of intense rain cloud development when the southeast trade winds (from South) collide with the north-east trade winds. The movement of the ITCZ from the equator marks the start of the rainy season in the southern hemisphere. In a normal year, it fluctuates half way between Tanzania and Zimbabwe but never moves beyond Limpopo River in the south (9). The ITCZ moves with the sun, southwards at the start of summer (October/November) and northwards in

late summer (March/April). Because of this, the wet season in the southern parts of Zimbabwe (such as Mzingwane Catchment) starts later and ends sooner than in the northern areas. Furthermore, the northern winds in the convergence are moister than the southern winds, leading to less frequent rainfall in the southern areas than the north, for a given air moisture level (15).

Rainfall in southern Zimbabwe thus occurs over a limited period of time, and often a large portion of the annual precipitation can fall in a small number of events (15). These short, intense rainspells, if they occur at critical stages during crop growth, can exercise a strong positive control on yields (16).

Within the Mzingwane Catchment, annual rainfall generally decreases from the North to the South, from around 620 mm at Esigodini to 530 mm at Filabusi, to 360 mm in Beitbridge (based on 1961-1990 rainfall data). The rainfall is erratic, with annual rainfall at Esigodini ranging from 1200 to 200 mm over the last 70 years, and at Beitbridge from 500 to 50 mm for the same period. A drought year may easily record less than 250 mm, such as the 2004-2005 season in southern Zimbabwe and Mozambique.

This north-south gradation in rainfall, together with variation in soils, is responsible for a strong north-south agro-ecological division. In the north (agro-ecological region IV), rainfall is higher and soils better. In the south, (agro-ecological region V), the rainfall is lower and the soils shallower and more nutrient-defficient (17). For much of agro-ecological region V, total reference evapotranspiration is often higher than total rainfall for the growing season of October to March, while in agro-ecological region IV the two parameters are generally close to equal (13).
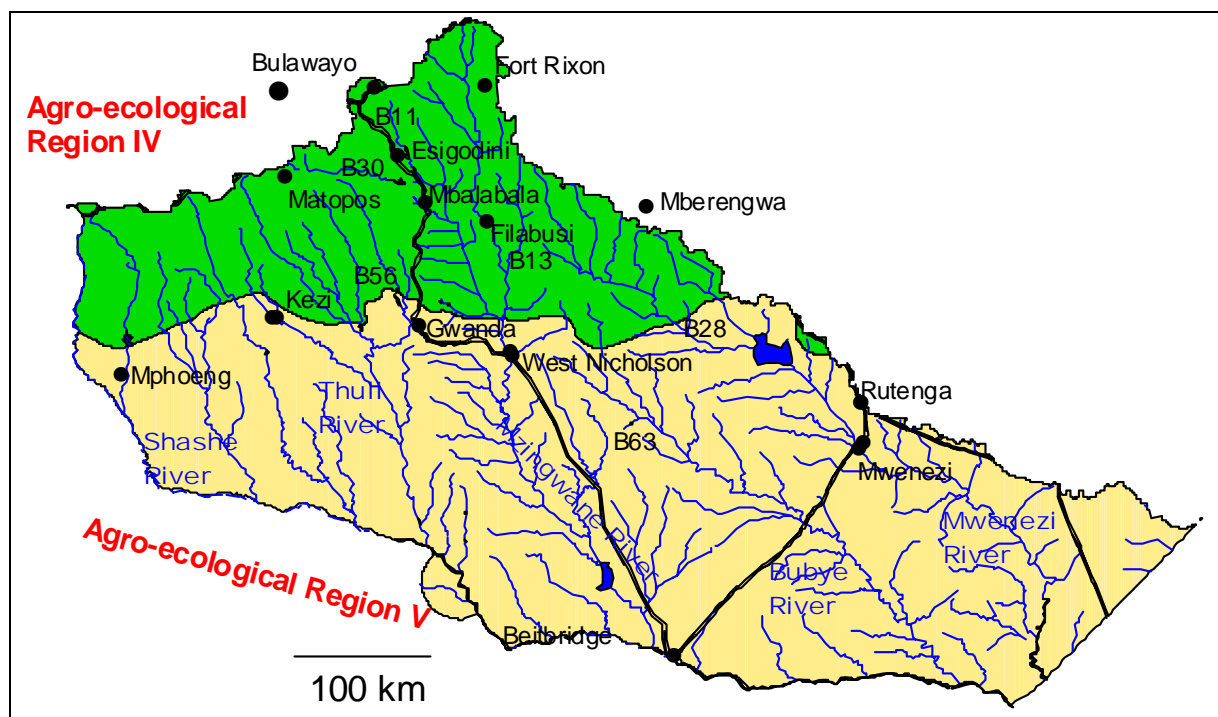
Fig. 2. The Mzingwane Catchment, showing main rivers and dams (blue), agro-ecological zones, settlements and meteorological stations, hydrological stations (B#) and railways (black).

The Mzingwane Catchment is covered mainly by a mixture of croplands, pastureland and woodland. Land use is mainly communal lands (smallholder farming) and commercial/resettlement lands (medium to large scale farming). Commercial agriculture

in Region IV in the north includes rainfed crops such as maize and irrigated crops such as wheat and vegetables. In the south, commercial agriculture is mostly ranching, with some large irrigated estates growing citrus or sugar cane. Commercial agriculture may be on privately owned land, ranging in size from 400 hectares upwards, or under model A2 resettlement commercial farming land, ranging in size from 200 to 400 hectares, depending on natural region (18).

On the communal land, most agriculture is rainfed farming with farm sizes generally one to five hectares, and with productivity ranging from low to minimal, depending on rainfall and availability of inputs such as seed and fertiliser. There are also irrigation schemes managed by farmer committees (19), and irrigated household vegetable gardens using mostly drip kits (20,21).

Five large dams have been constructed on the upper Mzingwane and its tributaries, to supply water to Bulawayo, Zimbabwe's second largest city. Large dams have also been built on the Mwenezi, Mzingwane, Shashe and Thuli and their tributaries to provide water for irrigation and mining. There are a large, but unknown, number of small reservoirs in the Mzingwane Catchment, mostly providing water for livestock, irrigation or both.

METHODS

A statistical analysis was carried out of temperature, precipitation and runoff data from several locations in the Mzingwane Catchment. The selected stations' data availabilities are shown in Table 1.

Table 1. Climatic and hydrological station pairs used in this study.

| Climate station	Precipitation Time Series	Hydrological station and River (Sub-Basin)	Runoff Time Series
Bulawayo	1930-2003	Not paired with a hydrological station	
Esigodini	1930-2002	B11, Ncema (Mzingwane)	1951-2003
Esigodini	1930-2002	B30, Mzingwane	1958-2003
Filabusi	1920-2003	B13, Nkankezi (Mzingwane)	1951-2003
Filabusi	1920-2003	B28, Mwenezi	1957-2003
Mbalabala	1930-1999	B56, Thuli	1965-2003
West Nicholson	1975-2003	Not paired with a hydrological station	
Beitbridge	1969-2005	B63, Bubyiana (Bubye)	1966-1989
Source: Meteorological Services Department, Zimbabwe		Source: Zimbabwe National Water Authority	

The hydrological stations selected are upstream of any major dams. Data quality is variable and years where one or more months' data is missing, or where a note has been made in the file that readings were unreliable (e.g. due to siltation) have been excluded.

Temperature data are available from 1970-2001. The trends in precipitation, rainfall and runoff were analysed separately, and regression analysis was performed to determine relationships between precipitation and runoff.

RESULTS

It can be seen that rainfall has been declining across the catchment for the last 70 years, see Figs. 3 and 4 (although the trends have low R^2 values, probably due to sub-decadal cyclicity).

The annual rainfall anomaly, compared to mean annual rainfall 1961-1990, Fig. 4, shows substantial variation over time for all stations, and cycles of wetter vs. drier years of five years and less. There is also a longer cycle of 15-18 years which could be similar to the 18 year cycle between dry and wet periods observed by Tyson and Dyer (23), and which they linked to the influence of the El Niño – Southern Oscillation phenomenon on the region.
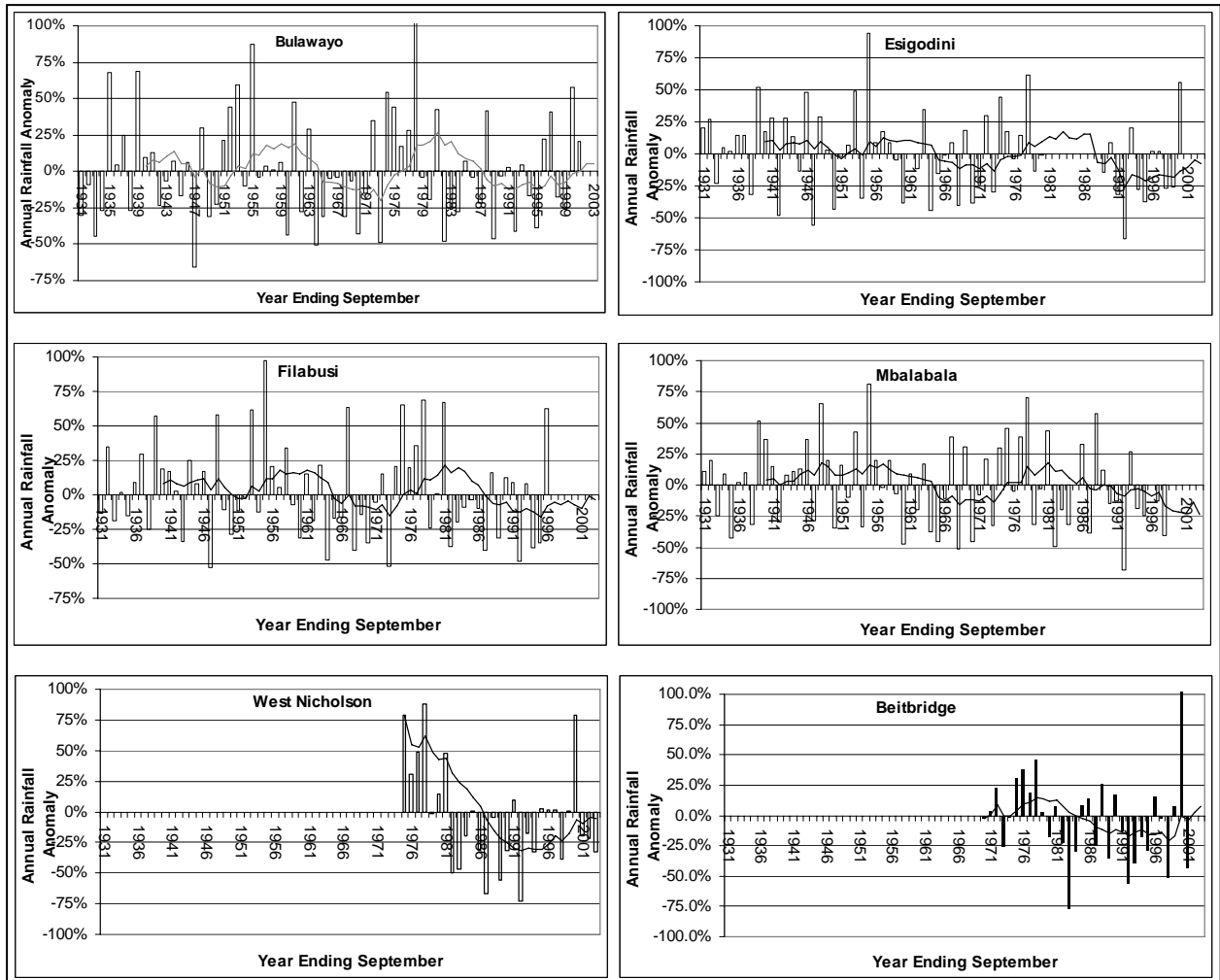
Fig. 4. Annual rainfall anomalies against 1961-1990 mean, from 1930/31 to 2000/01. The curves result from application of a ten year moving average.
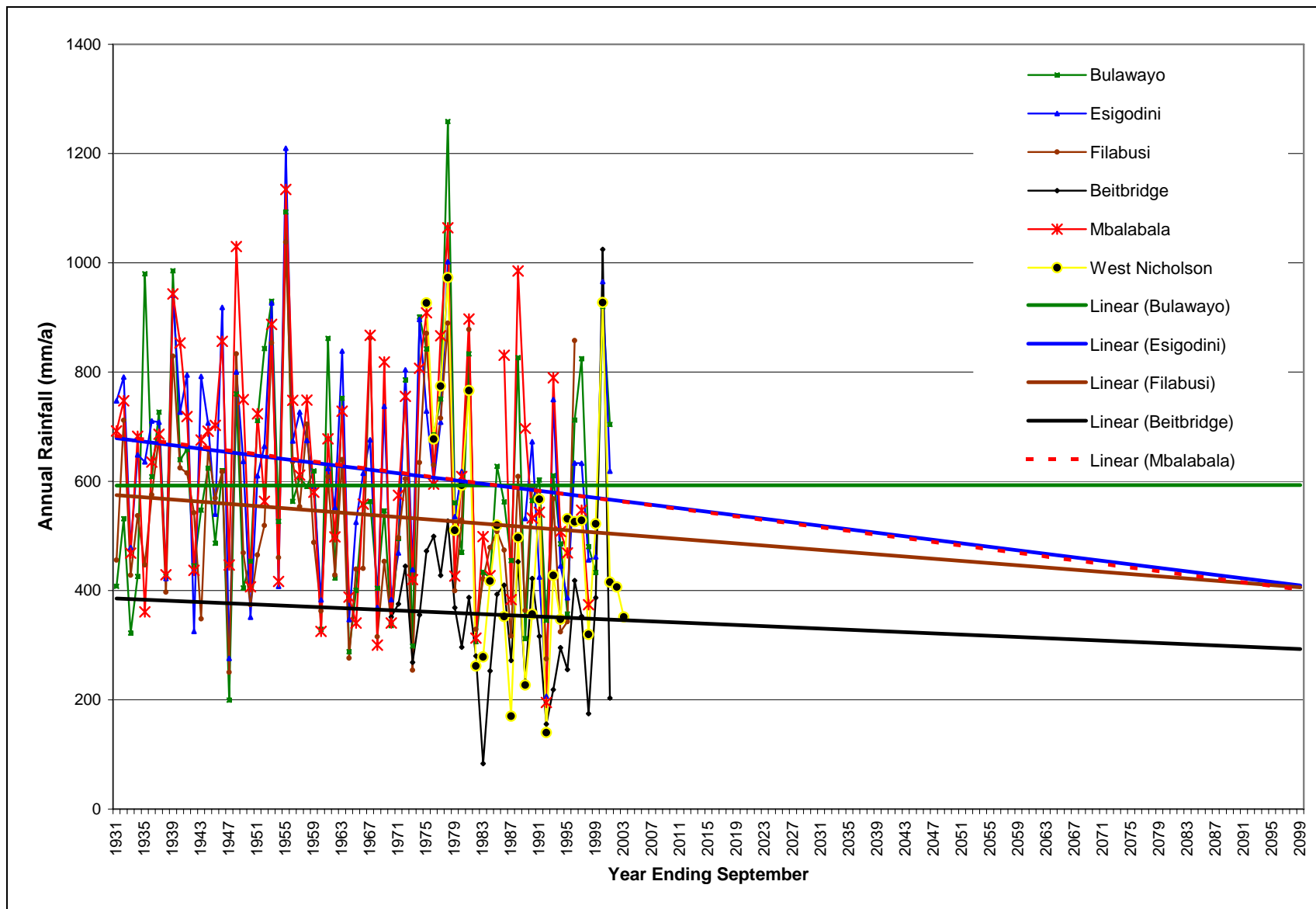
Fig. 3. Annual rainfall, recorded from 1930/31 to 2000/01 and projected to 2099, assuming a constant linear trend.

Comparison of recorded mean annual rainfall for 1961-1990 and mean annual rainfall projected to 2099 from the rainfall trend across the time series shows substantial declines in all stations, except for Bulawayo (Table 2). The greatest reduction is 34 % at Esigodini, which is the highest rainfall area in the catchment. However, the R^2 values are low for most stations.

Table 2. Recorded and projected mean annual rainfall in the study area.

Station	Mean annual rainfall (start of time series)	Recorded mean annual rainfall, 1961-1990	R^2	Projected mean annual rainfall, 2099	Rainfall reducti on
Bulawayo	590 mm/a (1930)	584/a mm	2×10^{-7}	580/a mm	0.7 %
Esigodini	680 mm/a (1930)	621/a mm	0.029	410/a mm	34.0 %
Filabusi	580 mm/a (1920)	527/a mm	0.011	410/a mm	22.1 %
Mbalabala	680 mm/a (1930)	624/a mm	0.024	410/a mm	34.3 %
Beitbridge	380 mm/a (1970)	361/a mm	0.001	300/a mm	16.8 %

Temperatures have been rising over the last 30 years, see Fig. 5.
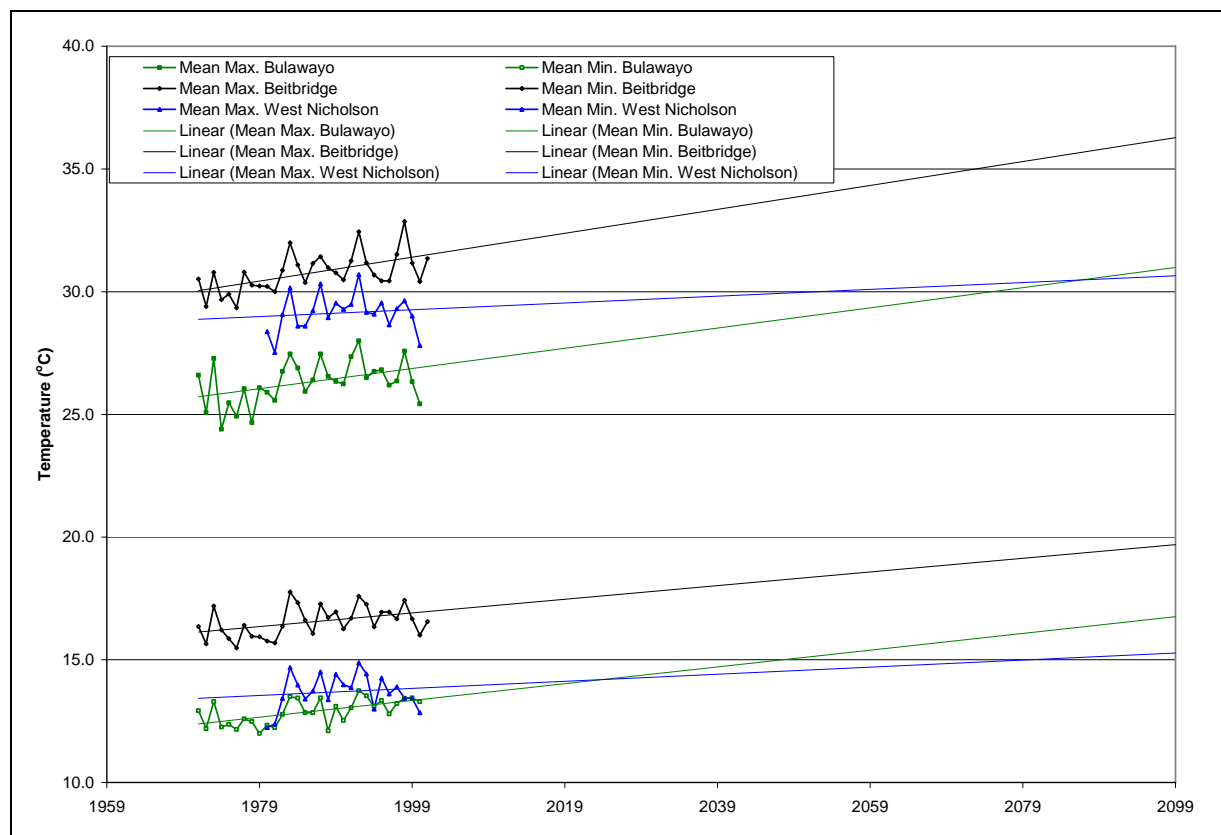
Fig. 5. Annual means of daily maximum and minimum temperatures, recorded 1970/71 to 2000/01 and projected to 2099.

Increases range from 0.1 to 0.4 °C per decade, see Table 3.

Table 3. Recorded and projected annual means of daily maximum and minimum temperatures in the study area.

| Station	Annual mean of daily temperature,	Projected annual mean of daily temperature,	R^2 value	Temperature increase per decade

	1970		2099					
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Bulawayo	25.5 °C	12.5 °C	30.5 °C	17.0 °C	0.1681	0.3403	0.29 °C	0.26 °C
West Nicholson	28.5 °C	13.5 °C	0.15 °C	0.12 °C	0.0129	0.0160	0.15 °C	0.12 °C
Beitbridge	30.0 °C	16.0 °C	0.41 °C	0.21 °C	0.3177	0.1706	0.41 °C	0.21 °C

Declines in annual unit runoff (normalised by catchment area) are recorded for four of the six stations studied (Figs. 6). Comparison of recorded mean annual unit runoff for the start of the time series, for 1961-1990 and for 1975-2004 shows declines in five of the six stations (Table 4). Projections to 2055 were not made, since low R^2 values were obtained from linear regression.

Table 4. Recorded mean annual unit runoff in the study area.

Station	Mean annual unit runoff (1952)	Mean annual unit runoff, 1961-1990	Mean annual unit runoff, 1975-2004
B11, Ncema (Mzingwane)	110 mm/a	94.6 mm/a	93.5 mm/a
B30, Mzingwane	250 mm/a	172.2 mm/a	62.3 mm/a
B13, Nkankezi (Mzingwane)	40 mm/a	44.4 mm/a	66.8 mm/a
B28, Mwenezi	40 mm/a	40.5 mm/a	33.7 mm/a
B56, Thuli	100 mm/a	69.5 mm/a	64.2 mm/a
B63, Bubyiana (Bubye)	20 mm/a	11.6 mm/a	9.5 mm/a
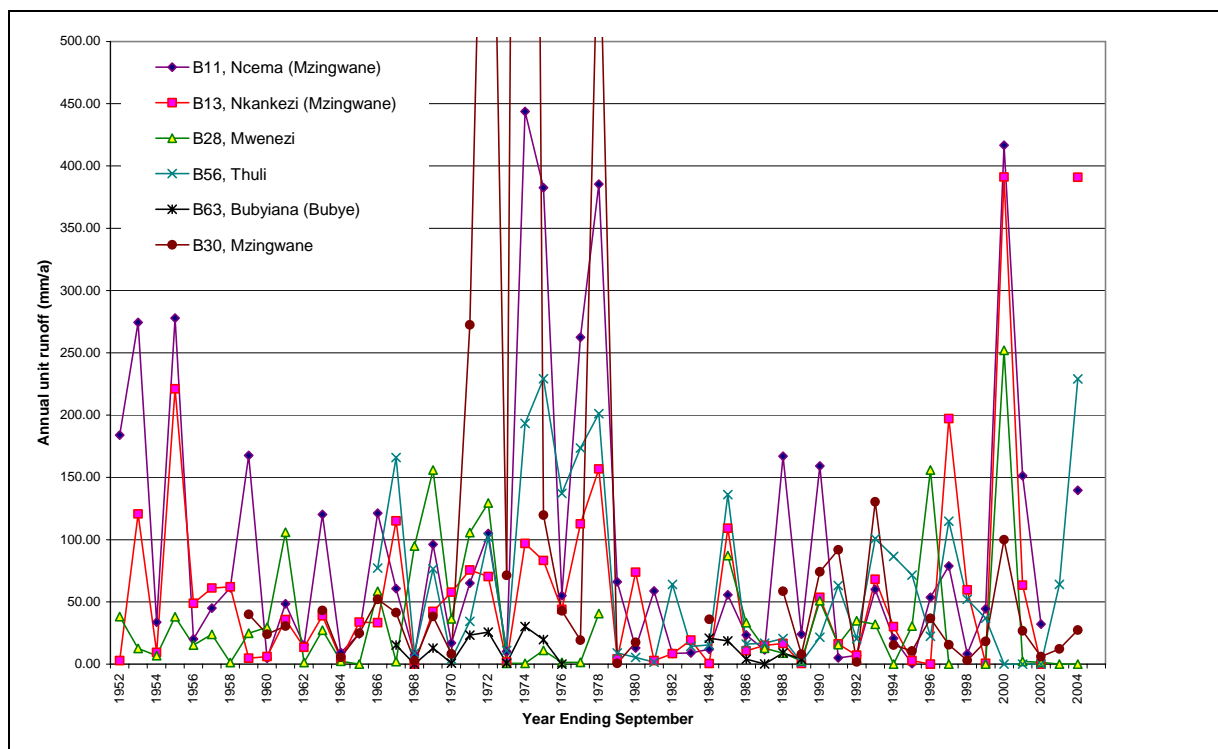
Fig. 6. Annual unit runoff, recorded 1951/52 to 2003/04. Projections to 2055 not shown due to low R^2 values.

Regression analyses show the relationships between climate variability and change and decreasing runoff: a positive relationship is recorded for all stations (Fig. 7), although the R^2 values are low for three of the stations.
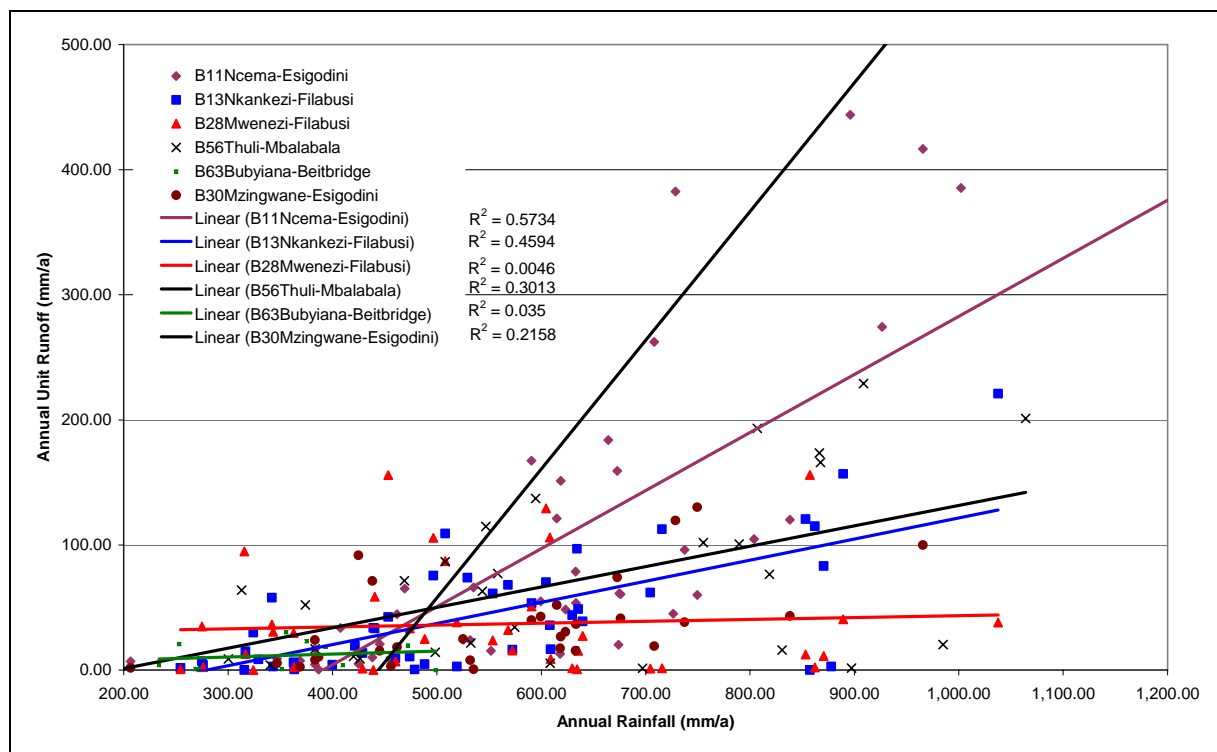
Fig. 7. Linear regression of rainfall-runoff relationships within the study area, 1951/52 to 2003/04.

DISCUSSION

The trends observed in rainfall (decline of 15 – 35 %) for all stations except Bulawayo fall within the range predicted from models based on the IPCC SRES. The trends observed in temperature (increase of 0.1 – 0.4 °C per decade) are likewise comparable, while those for runoff are more extreme. However, the low R^2 values on many of the regressions mean that the results should be treated with caution. The assumption of a simple linear trend in climate change is probably oversimplified, and a further work is required in order to derive an alternative model. It is also necessary to analyse a greater number of stations, in order to better resolve spatial variations.

The projected decline in rainfall appears worse for the better agricultural areas in the north, and is likely to push large parts of what is currently agro-ecological region IV to below 450 mm/a rainfall. This means the southern boundary of Region IV may move north from Gwanda-West Nicholson-Kezi to around Esigodini-Matopos. This has serious implications for the majority of the population in the Mzingwane Catchment, who are smallholder farmers, dependant largely on rainfed agriculture, and who largely grow maize. Rainfed maize production is generally considered to require about 500 mm rainfall per growing season. Mean annual rainfall is projected to drop below 500 mm/a at Filabusi by 2010, at West Nicholson during the same period, and at Esigodini and Mbalabala by 2040. By 2099, it is likely that maize production in the Mzingwane Catchment will fail in most years. Reduction of rainfall to around 300 mm/a in the south will make maize production almost impossible or heavily dependent on irrigation – either way, requiring a major change in the agricultural system.

However, possible increases irrigation will be limited. Projected declines in runoff are worse for the southern areas – precisely those areas where reliance on rainfall is more problematic and capturing of runoff in dams for irrigation purposes is more important. In the northern areas, increased abstractions for urban water supply may further limit water availability for agriculture (24).

The yield of small dams, which supply water for livestock and smallholder irrigation, are more strongly effected by evaporation; hence the yield reduction due to increased evaporation rates may be greater in these dams. This has major livelihood implications as the majority of rural residents of the Mzingwane Catchment rely on livestock sales or irrigated agriculture for their largest sources of income (25). In general, increases in competition for water between people, livestock and crops can be expected.

Given the significant control of upstream runoff by precipitation received (as shown by the regression analyses), projected declines in rainfall in the upper Mzingwane sub-basin (Esigodini-Filabusi area) are likely to result in similarly significant declines in water availability in the upstream dams. Declines in rainfall may translate to more than proportional declines in runoff due to non-linear processes, including for example interception thresholds. A 10 % drop in rainfall in Zimbabwe has been predicted to result in a 20 % reduction in runoff (40). Moyo *et al.* (24) showed that the current trend in dam yields in the five reservoirs supplying Bulawayo will result in a deficit for an average rainfall year of 35 Mm^3/a by 2030, compared to the current situation where average rainfall can adequately supply the city (the current problems the city is experiencing relate to a drought and infrastructure issues).

The large gold mines, cement factory, citrus plantations and sugar plantations are also supplied by dams: Blanket Dam near Gwanda, Silalabuhwa Dam on the Insiza River, Zhove Dam on the Mzingwane River and Manyuchi Dam on the Mwenezi River respectively. Declines in the yields of these dams could have a major effect on exports of gold, citrus and sugar, and a corresponding impact on employment. Declining water availability in Silalabuhwa Dam would have a negative effect on employment at West Nicholson and on the construction industry.

Mitigating the severe predicted impacts of climate change on atmospheric and surface water resource availability requires a package of strategies in each sector. In the agricultural sector, soil water management strategies are likely to play a role, especially for smallholder farmers (26,27). These can include in-field water management strategies (28), short-term supplementary irrigation during dry spells (29,30), and off-field rainwater harvesting and runoff farming (31,32,33).

However, given the projected declines in rainfall, a change in cropping pattern may be more realistic. More drought-resistant grains, such as sorghum and millet, need to be grown in place of maize. Given that many communities strongly prefer maize meal for home consumption (25), the produce could be traded to purchase the preferred staple. Other crops should also be considered, such as *Jetropha*, which is currently being promoted for production of biodiesel. As an alternative to cropping, drought resistant fodder crops could be promoted, to support livestock-based livelihoods.

For urban areas, water demand management will be the key strategy to avoid negative livelihood impacts. Water demand management, combining changes in attitudes towards water use with punitive measure for over-use, has been shown to provide for a decrease in consumption (or steady-state) despite rising population (34,35,36). This

requires information and education programmes and should be executed by technical, legal and economic mechanisms (37). Large water users, such as heavy industry and mines, should be encouraged (legislatively and fiscally) to recycle grey water (38,39). In conclusion, it is necessary that less water-intensive livelihoods should be promoted, in both the agricultural sector and in urban areas.

ACKNOWLEDGEMENTS

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