ASSESSING THE VULNERABILITY OF THE SECTOR OF WATER RESOURCES IN SWAZILAND DUE TO CLIMATE CHANGE

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Abstract:

The southern African region has been projected to receive less precipitation and Swaziland is no exception. The average results (precipitation, potential evapotranspiration) of 12 general circulation models (GCMs) in the future (2021 to 2060) and the observed stream flows were input to a calibrated rainfall runoff model (Watbal model) in order to determine the water resources in four catchments in Swaziland under expected climate change. Simulation results show that, the present streamflow lie within the 95% confidence interval of the projected flows in all the catchments. This implies that there is no significance difference between the observed and projected stream flow at 5% confidence level. However, the runoff change between the 2.5% and 97.5% quantile ranges from -17.4 to 26.6; -31.2 to 18.1; -40.3 to 27.7; and -40.8 to 34.9% in the Komati, Mbuluzi, Usutu and Ngwavuma catchments respectively and the median of the runoff change is negative for most of the months in three catchments (Usutu, Mbuluzi and Ngwavuma) except for the Komati catchment. Thus, there will be less runoff in the three catchments under expected climate change. Therefore, there will be less runoff in the three catchments and adaptation options for Swaziland are proposed.

Keywords: Climate change, streamflow simulation, runoff change, statistical significance, adaptation options

INTRODUCTION

Swaziland is bounded by the Republic of South Africa in the north, west and south and by Mozambique on the East. Therefore, Swaziland is a landlocked country with a size of 17400 km^2. The country is divided into four physiologic regions namely; Highveld, Middleveld, Lowveld and Lubombo. The Highveld and upper Middleveld are characterized by a Cwb climate. The lower Middleveld and Lubombo range have a Cwa climate whilst the western and eastern Lowveld have a Bsh climate (Murdoch, 1970). The Highveld region receives the highest rainfall which ranges from 1200 to 1500mm per year followed by the Middleveld with annual rainfall ranging from 700 to 1200mm. The Lowveld region receives the lowest rainfall which ranges from 500 to 700mm per year while the Lubombo plateau has similar climatic conditions to the Middleveld region.

Therefore, proposed adaptation options to climate change for Swaziland are: efficient water use (at domestic and farm level), wastewater recycling, rainwater harvesting, ground water utilization, implementation of integrated water resources management (IWRM), water resources development and inter-basin transfers.

The water sources in Swaziland are mainly surface waters (rivers, reservoirs), ground water and atmospheric moisture. There are seven drainage basins in Swaziland and these are: Lomati, Komati, Mbuluzi, Usutu, Ngwavuma, Pongola and Lubombo (see Figure 1).

Climate will always change due to the natural forcings of eccentricity. Climate changes occurring over time scales shorter than those associated with the orbital forcing frequencies are defined as short-term. Climate fluctuations on time scales of less than 100 years are usually considered as climatic variability.

It has been considered that the major potential mechanism of climate change over the next few hundred years will be anthropogenic green house gas warming up. A number of gases that occur naturally in the atmosphere in small quantities are known as "greenhouse gases". Water vapour (H_2O), carbon dioxide (CO_2), ozone (O_3), methane (CH_4), and nitrous oxide (N_2O) trap solar energy in much the same way as do the glass panels of a greenhouse or a closed automobile. However, the earth's atmosphere has been kept some 30^o Celsius hotter than it would otherwise be, making it possible for humans and other living things to exist on earth because of the natural greenhouse gases effect.

Human activities, however, are now raising the concentrations of these gases in the atmosphere and thus increasing their ability to trap energy. Carbon dioxide levels have risen from 280 ppm by volume since before the Industrial Revolution to about 360 ppm by 1990 (IPCC, 2001). Man-made carbon dioxide which, is the most important contributor to the enhanced greenhouse gases effect, comes mainly from the use of coal, oil, and natural gas. It is also released by the destruction of forests and other natural sinks and reservoirs that absorb carbon dioxide from the air.

The global green house gas emissions due to anthropogenic activities have increased since pre-industrial times with and increase of about 70% between 1970 and 2004 (IPCC, 2007). The IPCC (2007) also reports that the atmospheric concentrations of CO_2 (397ppm) and CH4 (1774ppb) in year 2005 exceed by far the natural range over the last 650,000 years. Fossil fuel use is the major contributor of global CO_2, followed with land-use change. It has been established that the climate change in the next 100 years will be due to anthropogenic activities (IPCC, 2001). It has also been reported that 1995-2006 are the warmest years in the history of instrumentation (since 1850) and the global surface temperature rise is due to the green house gases effect (IPCC, 2007). The major effect of the increase of anthropogenic green house gas emissions in the atmosphere is global warming and thus changes in precipitation and the environment. The areas that are now dry-humid, semiarid and arid will become semiarid, arid and desert respectively.

According to the IPCC (2007), if countries around the world do not reduce emissions of greenhouse gases by the end of this century:

- Temperatures globally are expected to increase from 2 to 5.8 degree Celsius, depending on population and economic growth.
- Global average sea level has risen since 1961 at a rate of 1.8 mm per year and since 1993 at 3.1 mm per year with contributions from thermal expansion, melting

glaciers and ice caps, and the polar ice sheets. Therefore, using the current rate, the sea level is expected to rise to 31 cm by the end of the century.

- Mortality and illness will have risen as the intensity and duration of heat waves increased and as the tropical habitat of mosquitoes that carry malaria and fever creep northward.
- Precipitation has increased significantly in eastern parts of North and South America, northern Europe and northern and central Asia but declined in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. In summary precipitation is expected to increase in high latitudes and decrease in most subtropical land regions. This will significantly reduce food crop yields in developing countries as a whole.
- The frequency of extreme events (droughts, heat waves, cyclones, floods) is expected to increase. In north Atlantic an increase in intense tropical cyclone activity has been observed since 1970. Heat waves have become more frequent over most land areas and the frequency of heavy precipitation and thus floods has increased over most areas, globally.

Over the past 50 years the average temperature on the earth has risen at the fastest rate in recorded history with the 10 hottest years on record occurring since 1990 (Zabarenko, 2005). Adrianne (2003) reported that the average GCMS forecast a 10 to 20 per cent drop in rainfall in Northwestern and Southern Africa by 2070 and river water levels are expected to drop below 50 per cent and this is no exception to Swaziland. According to Nyong (2005), every record has showed that climate change is happening, as it has been observed in past records and established by predictive models. Nyong (2005) also reported that by the 2080s, climate change is expected to place an additional 80-120 million people at risk of hunger; 70 to 80 per cent of these are expected to be in Africa. Reuters (September 5, 2005) reported that about 50 million more people, most of them in Africa, could be at risk of hunger by 2050 due to climate change and reduced crop yields. It was reported (IRIN, 2005) that climate change could force people in drought prone areas of southern Africa to abandon agriculture permanently in the next 50 years.
Dunham (Reuters, 2008) reported that, some nations of Southern Africa (Angola, Botswana, Lesotho, Malawi, Namibia, South Africa, Swaziland, Zambia and Zimbabwe) could loose about 30 percent of their main staple food, maize, by 2030. African countries will have an expected crop yield reduction ranging from 10-20 percent by 2020 (SciDev.Net, 2008).

Swaziland has been experiencing frequent droughts especially in the Lowveld region. Swaziland area is categorized into three drought risk zones namely: little/none, moderate and severe. The northwest Highveld region is in the little/none drought risk zone. This is consistent with the position that the region receives the highest amount of rainfall (1200–1500mm). The south west Highveld, Middleveld and Lubombo regions are in the moderate drought risk zone, with annual rainfall values ranging from 700-1200mm. The Lowveld region coincides with the severe drought risk zone, with annual rainfall ranging from 500-700mm. This region is characterized by short rainfall seasons, which last for four months, and is often hit by droughts even during years of high rainfall. The late onset of the rainfall season in this region, early cessation of the rains and severe dry spells during the critical crop growth stages often cause crop failure. The above issues necessitated the carrying out of a study to find out the vulnerability of the sector of water resources in Swaziland due to expected climate change.

METHODOLOGY

The expected climatic changes due to anthropogenic activities will cause global warming. The effects of global warming will bring changes in annual average precipitation values in the order of ±20% (IPCC, 1990; IPCC, 2007)). Extreme events (droughts, and floods) now considered rare will occur more frequently in certain regions. General circulation models (GCMs) provide physically based predictions of the way climate might change as a result of increasing concentrations of atmospheric green house gases. The GCMs are mathematically representatives of the earth's climate system and they simulate atmospheric processes at a field of grid points that cover the surface of the earth (IPCC, 1996).

The outputs of these models are: temperature and precipitation values. The GCMs are used in conjunction with hydrologic models in the assessment of the impact of climate change on hydrology and water resources (Benoff *et al*, 1996). For the purpose of evaluating the impact of climate change on hydrology and water resources, the models that are in use usually operate in simulation mode. A river–basin–monthly water balance models are recommended as the primary approach for assessing climate change impacts on river runoff (IPCC, 1996). The CLIRUN set of models is the standard water balance tool selected for the evaluation of the impact of climate change on hydrology and water resources (IPCC, 1996). The WatBall model developed by Yates (1994) is one of the CLIRUN sets of models and was used in this study. This model was also used by Matondo *et al.* (2001).

Catchments of study

In the present study four catchments, being the Usutu, Komati, Mbuluzi and Ngwavuma, were considered. Daily hydro-meteorological data for the four catchments was obtained from the Departments of Meteorology and Water Resources. Within Swaziland the Komati Basin has two major river gauging stations, GS29 at Malolotja on the entrance of the Komati River and GS30 at Mananga on the exit. Unfortunately GS29 was closed in 1989 (with a record of close to 10 years) due to problems of access. The Mananga station has a record of about 23 years. Although not quite an impressive length of record, it was considered the best station that could be used in the absence of a better one. The Mbuluzi basin has several stations among which two can be considered major. These are GS3 at Croydon, and GS32 at Mlawula on the exit into Mozambique. GS3 was selected over the other since it has over 40 years length of record, while GS32 has 22 years approximately. Moreover GS3 has less influence of flow regulation compared to the other. The Ngwavuma Catchment has two streamflow stations, GS8 at Lubuli and GS 27 at Ngololweni. Since GS8 has 30 years length of record while the upstream GS27 has less than 10 years of record, GS 8 was chosen as a representative station for the basin. For the Usutu catchment the hydrometric station at GS6 was used in this study.

Rainfall runoff simulations in the four catchments

A Watbal rainfall-runoff model was used to estimate streamflow in each of the four catchments. The model was first calibrated in order to obtain optimal parameters using historical records of precipitation, potential evapotranspiration (PET) and streamflow in each catchment as input variables. A similar calibration was carried out using output precipitation and derived PET from 12 objectively combined GCM simulations. The GCMs are combined using a Bayesian weighting procedure which assigns unequal weights to each GCM output depending on its bias with respect to observed (1961–2000) precipitation and on the extent to which it is an outlier from the rest in the future (2061–2100) climate. Details of the Bayesian weighting method can be found in Tebaldi *et. al*., (2005). Here, it suffices to mention that in the model weighting procedure, the posterior distribution of the parameters of interest is obtained using a Markov chain Monte Carlo method which iteratively generates a sample of 1000 precipitation and PET values both in the control and the future climate. Corresponding samples of streamflow in each catchment were generated using the WatBal rainfall-runoff model.

RESULTS AND DISCUSSION

The calibrated WatBal rainfall-runoff model was validated in the four catchments in order to test its suitability for future runoff simulations. Figures 2 to 5 compares the annual cycle of GCM-based WatBal generated runoff in the present climate (1961–2000) with that observed in each of the four catchments. It is evident from Fig. 2 that the derived streamflow is biased towards higher flow at the beginning of the rainfall season (October–December) and towards slightly lower flows thereafter up to around April in the Komati catchment. In the Mbuluzi, Usutu and Ngwavuma catchments (Figs. 3 to 5) the simulated streamflow is higher from October to December and lower flows thereafter till around July. These apparent biases notwithstanding, the modelled streamflow in the four catchments captures a realistic annual cycle, which demonstrates that the model can be used to simulate stream flows given GCMs results (precipitation, potential evapotranspiration etc.).

The GCM-based streamflow in the future and present climate was then used to calculate the percentage change in river runoff in the four catchments using the following relationship:

$$Runoffchange\,(\%) = \left(\frac{Q_F}{Q_P} - 1\right)100 \qquad (1)$$

Where: Q_F is the future streamflow and Q_P is the present streamflow. Table 1 shows the statistics of the projected runoff change (between present and 2021-2060) in the four catchments. Figure 6 shows the monthly runoff change between the present and the future (2021-2060) streamflow for the Usuthu catchment.

It can be seen form Figure 6 that at 95% confidence interval the runoff change lies between -22% to 12.1%, -5.4% to 11.8%, -5.6% to 27.7%, -23.4% to 9.3%, -22.7% to 9.9%, -23.6% to 18.7%, -21.9% to 13.2%, -17.3% to 8.3%, -25.5% to 12.8%, -26.8% to 13.1%, -28.6 to 2.8 and -40.3% to 15% for October, November, …, September respectively, in the Usuthu catchment. The median of the runoff change is positive for the month of November and December only and is negative for the rest of the months. Although, the results suggest a likely decrease in flows during most of the year, these decreases fail to attain statistical significance at the 5% level.

Figure 7 is a result of the conversion of the statistical projected runoff changes into streamflow between the present and the future (2021 to 2060) in the Usutu catchment. It can be observed from Fig. 7, that the median future streamflow (red line) lies below the present flows during much of the year except in November and December. This is in qualitative agreement with Figure 6. However, the present streamflow still lie within the 95% confidence interval of the projected flows which emphasizes the lack of statistical significance in the simulated runoff change.

Figure 8 shows the monthly projected runoff change between the present and the future (2021-2060) streamflow for the Komati catchment. It can be seen form Figure 8 that at 95% confidence interval the projected runoff change lies between -10.5% to 6.2%, -4.8% to 6.9%, -10.0% to 18.4%, -3.9% to 4.9%, -7.4% to 6.2% - 6.5% to 8.9%, - 6.4% to 14.1%, - 7.4% to 19.4%, -9.8% to 25.6%, 9.8% to 26.6%, -14.6% to 12.0% and -17.4% to 2.7% for October, November, …, September, respectively. The median projected runoff change is negative for the months of December and September while there is no change for October and November but it is positive from January to August. Although, the results suggest a likely increase in Komati flows during most of the year, these increases fail to attain statistical significance at the 5% level.

Figure 9 is a result of the conversion of the statistical projected runoff changes into streamflow between the present and the future (2021 to 2060) in the Komati catchment. It can be observed from Fig. 9 that the median future streamflow (red line) lies below the present flows in November and December but is above for the rest of the months. This is in qualitative agreement with Figure 8. This indicates that there will be an increase in the flows of the Komati catchment under climate change conditions. However, the present streamflow still lie within the 95% confidence interval of the projected flows which emphasizes the lack of statistical significance in the simulated runoff change.

Figure 10 shows the monthly projected runoff change between the present and the future (2021-2060) streamflow for the Mbuluzi catchment. It can be seen from Fig. 10 that the runoff change at the Median is negative for all the months except for the month of December which indicates a zero change. It can also be seen form Figure 10 that at 95% confidence interval the projected runoff change lies between -21.5% to 4.7%, -11.7% to 4.6%, -16.9% to 15.6%, -20% to 10.3%, -20.2% to 5.2%, -20.3% to 13.4%, -21.6% to 18.1%, -12.7% to 6.5%, -15.4% to 10.6%, -16.6% to 9.4%, -22.7% to 1.2% and -31.2% to 3.8% for the months of October, November, …, September respectively. Although, the results suggest a likely decrease in Mbuluzi flows during most of the year, these decreases fail to attain statistical significance at the 5% level.

Figure 11 is a result of the conversion of the statistical projected runoff changes into streamflow between the present and the future (2021 to 2060) in the Mbuluzi catchment. It can be observed from Figure 11 that the median future streamflow (red line) lies below the present flows during the whole year. This is in qualitative agreement with Figure10. However, the present streamflow still lie within the 95% confidence interval of the projected flows which emphasizes the lack of statistical significance in the simulated runoff change.

Figure 12 shows the monthly projected runoff change between the present and the future (2021-2060) streamflow for the Ngwavuma catchment. It can be seen from Figure 12 that the runoff change at the Median is negative for all the months except for the month of December which indicates a zero change. It can also be seen from Figure 12 that at 95% confidence interval the projected runoff change lies between -22.6% to 15%, -10.5% to 10%, -21.0% to 34.9%, - 20.6% to 20.4%, -26.3% to 11.5%, -24.5% to 21.3%, -22.4% to 27.9%, -21.1% to 7.5%, -27.5% to 10.3%, -29.1% to 11.5%, -31.3% to 4.3% and -40.8% to 10.1% for October, November, …, and September, respectively. Although, the results suggest a likely decrease in Ngwavuma flows during most of the year, these decreases fail to attain statistical significance at the 5% level.

Figure 13 is a result of the conversion of the statistical projected runoff changes into streamflow between the present and the future (2021 to 2060) in the Ngwavuma catchment. It can be observed from Figure 13 that the median future streamflow (red line) lies below the present flows during much of the year except for October, November and December. This is in qualitative agreement with Figure 12. However, the present streamflow still lie within the 95% confidence interval of the projected flows which emphasizes the lack of statistical significance in the simulated runoff change.

Table I shows the projected runoff change (present and 2021-2060) in the four catchments at 2.5%, 50% and 97.5% quantiles. It can be seen from Table 1 that the runoff change (in %) between the 2.5% and 97.5% quantile ranges from -17.4 to 26.6; -31.2 to 18.1; -40.3 to 27.7; and -40.8 to 34.9 in the Komati, Mbuluzi, Usutu and Ngwavuma catchments respectively. Table 1 shows a summary of the results for the present and future streamflow at 50% quantile, runoff change (mm/day and in %) in the Komati, Mbuluzi, Ngwavuma and Usutu catchments. The runoff change between the present and future streamflow at the 50% quantile ranges from -0.327 to 0.468; -0.678 to -0.059; -1.448 to 1.336 and -1.19 to 1.219 % in the Komati, Mbuluzi, Usutu and Ngwavuma catchments respectively. These results show that the projected runoff change at the 50% quantile is not significant in all the catchments.

The above results have shown that there will be no significant changes in the river flows in all the four catchments under expected climate change at the 5% confidence level. However, it can be pointed out here that the variability of the streamflow under expected climate change is due to the fact that it will lie between the 2.5% and 97.5% quantiles as shown in Figs 7, 9, 11 and 13. Therefore, water infrastructure development is one of the adaptation strategies and this is because the country has only three major dams in existence and the Lowveld region is continuously experiencing drought related problems yet there is plenty of water in the Highveld region. Therefore, there is a need for incorporating climate change uncertainties into the long-term planning and adaptation options should be directed at developing robust water resources systems.

ADAPTATION OPTIONS

Adaptation refers to adjustment made in natural or human systems in response to actual or expected climate stimuli or their effects in order to moderate harm or make use of beneficial opportunities (Zaki-Eldeen, 2007). The time horizon of the change that might occur (increased or reduced precipitation) is similar to the time required for planning, approval, funding, construction, and economic life of water resources projects (dams, irrigation canals, drainage systems etc. (Shaake, 1989)). Therefore, adaptation strategies should make sense regardless of the direction and magnitude of change. Miller (1989) contends that "adaptation strategies should be directed at developing robust water resources systems as well as techniques to incorporate climate change uncertainties into the long-term planning". Water resources adaptation options are available in the literature (Strzepek et, al, 1996, Matondo et al., 2001, IPCC, 2007). Water resources adaptation options that are being proposed in order to deal with the effects of expected climate change and variability in the sector of water resources for Swaziland are as follows:

(i) Implementation of efficient water use

Given the fact that water is going to be a scarce resource, it is proposed that Swaziland should put in place measures that will reduce water consumption at all levels. This is only possible through efficient water utilization using water demand management at all levels. The effectiveness of efficient water use as an adaptation strategy is by reducing wasteful water use, cutting leaks in water supply systems and losses in irrigation systems (by using efficient water application methods and reducing evaporation through the use of mulches), and by reducing exaggerated household water use and pollution (which frees up more clean water). Aggressive water conservation programs can obviate the need for dams and other diversion infrastructure as has happened in Bogota, Columbia, in California, and in Boston, Massachusetts. Efficient water use approaches at the household and farm level are available in the literature (Pereira *et al*. 2002, Falkenmark *et al*., 2007, Gleick *et al*. 2007). This adaptation option does not require much funding but it requires the education of the people from household to farm level on efficient water utilization. Water pricing has also been used as a means of encouraging efficient water use. This is because people have the tendency to use less water as the price goes up. However, water pricing will not work if water is going to remain a free commodity. Wastewater recycling in urban areas whose wastewater is about 75% of the supplied water can be a source of water. Wastewater treatment and reuse is an obvious possible solution to cope with the ever increasing water demand especially in addressing drought situations which are exacerbated by climate change. The strategy that is proposed here is to treat wastewater to a level that is intended for a specific use. Wastewater from the cities of Mbabane and Manzini is treated and the effluent is directed into natural rivers where it is used for domestic, industrial and irrigation purposes downstream.

(ii) Strengthening of early warning centers

According to Elasha *et al.*, (2006) early warning systems have been identified as a prerequisite for adaptation to climate change and variability, particularly to predict and prevent the effects of floods, droughts and tropical cyclones as well as for indicating the planting dates to coincide with the beginning of the rainy season. It is argued that if farmers can adapt to current year to year variability through the use of advanced information on the futures season's climate and institutional systems are in place to respond to short-term changes (early warning systems), then communities will be in a position to adapt to longer-term changes (Oludhe, 2005). Swaziland should make use of the information from the Drought monitoring center in Harare, Zimbabwe

(iii) Implementation of Integrated Water Resources Management (IWRM)

IWRM takes into consideration all the sectors of the human endeavour, land use and the environment. The benefits of integrating the various aspects of water resources management have been identified by many researchers, policy makers and water managers (Grigg, 1996). According to Malano (1999), there are four major principles in IWRM and these are:

- Sectoral (and sub-sectoral) integration that takes into account competing and conflicts among various users.
- Geographical integration
- Economic, social and environmental integration that take into account of social, and environmental costs and benefits and
- Administrative integration that coordinates water resources planning and management responsibilities and activities at all levels of government.

The country has established the Swaziland Water Authority and river basin authorities have been formed. This places the country in a better way of implementing Integrated Water Resources Management (IWRM).

(iv) Rainwater harvesting.

Rainwater harvesting can be a source of water for domestic, livestock and irrigation and therefore, it can lead to increased crop production and thus food security in the country especially under expected climate changes. This strategy is long overdue given the water scarcity problems in the Lowveld region. Potential dam sites are as proposed by Matondo and Msibi (2010).

SUMMARY AND CONCLUSIONS

It has been established that the climate change in the next 100 years will be due to anthropogenic activities (IPCC, 2001). It has also been reported that 1995-2006 are the warmest years in the history of instrumentation (since 1850) and the global surface temperature rise is attributed to the green house gases effect (IPCC, 2007). According to the IPCC (2007), temperatures globally are expected to increase from 2 to 5 degree Celsius if countries around the world do not reduce emissions of greenhouse gases by the end of this century.

The impact of climate change on water resources in Swaziland has been studied using observed and GCM generated information (precipitation, evapotranspiration, temperature, etc.). The Watbal rainfall runoff model was calibrated using information from the four catchments namely: Usuthu, Komati, Mbuluzi and Ngwavuma. Future (2021 to 2060) streamflow in the four catchments was simulated using the calibrated Watbal rainfall runoff model with inputs from the GCMs.

The analysis of the simulated streamflows show, that the projected runoff change is negative in Usuthu, Mbuluzi and Ngwavuma catchments except for the Komati catchment. The median future streamflow lies below the present flows especially during the winter months in the three catchments except the Komati catchment. However, the decreases and increase in the stream flows in the four catchments fail to attain statistical significance at the 5% level. It has also been established that the present streamflow still lies within the 95% confidence interval of the projected flows in all the catchments which emphasizes the lack of statistical significance in the simulated runoff change.

It can therefore, be concluded that, the sector of water resources in Swaziland is not vulnerable to climate change at the 5% significance level. However, the projected streamflow in all the four catchments will lie between the 2.5% and 97.5% quantiles (October to September). This shows the variability of the streamflows under expected climate change. Therefore, since the lowveld has been experiencing drought related problems, the Government should implement the available adaptation strategies such rainwater harvesting and inter-basin water transfer, efficient water use especially in the irrigation sector, utilization of early warning information due to shifting planting dates and implementation of Integrated Water Resources Management.

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REFERENCE:

1. Adrianne A. (2003). Global warming may dry up Africa's rivers. Natural Geographical News March 3, 2003.

2. Benioff, R., Guill, S. and Lee, J. (1996). Vulnerability and Adaptation Assessments: Version 1. An International Handbook. Environmental Science and Technology Library, 7. Kluwer Academic Publishers, Dordrecht, The Netherlands. pp 421.

3. Elasha, B.O, Medany, M.M., Niang-Giop, I., Nyong, T., Tabo, R. and Vogel C., (2006). Impacts, vulnerability and adaptation to climate change in Africa. Bacground paper for the

African Workshop on Adaptation Implementation of Decision 1/CP.10 of the UNFCCC Convention.

4. Falkenmark, M., Berntell, A., Jagerskg, A. Lundqvist, J., Matz, M. and Tropp, H., (2007). On the Verge of a New Water Scarcity: A Call for Good Governance and Human Ingenuity. SIWI Policy Brief. SIWI

5. Gleick, P.H., H. Cooley, D. Katz, E. Lee, J. Morrison, M. Palaniappan, A. Samulon and G.H. Wolf, (2007). The World's Water: 2006-2007. Biennial report on freshwater resources. OISLANDPRESS, Washington.Covelo.London.

6. Grigg, N.S., (1996). Water Resources Management: Planning, Regulations and Cases. McGraw-Hill, New York, USA.

7. IPCC (Intergovernmental Panel on Climate Change) (1990). "Climate Change: The IPCC Scientific Assessment." Report prepared by Working Group II. Tegart, W.J., Sheldon, G.W. and Griffiths, D.C. (eds). Australian Government Publishing Service, Caniberra, Australia.

8. IPCC (Intergovernmental Panel on Climate Change) (1996). "Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific – Technical Analyses." Contribution of Working Group II to the second report of the Intergovernmental Panel on Climate Change. Ron Benioff editor, Kluwer academic publishers, Dordrecht, The Netherlands.

9. IPCC, (Intergovernmental Panel on Climate Change) (2001). Summary for policy makers. A Report of Working Group I of the Intergovernmental Pannel on Climate Change.

10. IPCC, (Intergovernmental Panel on Climate Change), (2007). Climate Change 2007: Synthesis Report (Summary for Policymakers).

11. IRIN, (2005). Rising Indian ocean temperature will bring escalating drought in southern Africa. IRIN, Johannesburg, 25 May 2005.

12. Matondo J.I. and Msibi K. M. (2001). " Evaluation of the impact of climate change on water resources in Usutu river basin Swaziland". Uniswa Research Journal of Agriculture, Science and Technology, Vol. 4, No.2 August 2001.

13. Matondo J.I and Msibi K.M. (2010). Water resources development in Swaziland, *In* Tevera, D.S. and Matondo, J.I. (eds). Socio-Economic Development and Environment in Swaziland. pp.76-92, GEP/PrintPark, Mbabane.

14. Miller, B.A. (1989). Global Climate Change – Implications of Large Water Resource Systems".Proceedings of the 1989 National Conference on Hydraulic Engineering, New Orleans,Louisiana.

15. Malano, H. M., Bryant, M.J., and Turral, H,.N. (1999). Management of water resources: Can Australian experiences be transferred to Vietnam? Water International, Vol. 24 (4), 307-315.

16. Murdoch, G. (1970). Soils and land capability of Swaziland. Ministry of Agriculture, Mbabane, Swaziland.

17. Nyong A. (2005). The economic development and livelihood impacts of climate induced depletion of ecosystem and biodiversity in Africa. Proceedings of the scientific symposium on stabilization of greenhouse gases. Meteorology Office, Exeter, UK.

18. Oludhe C. (2005). Coping with climate variability and change in the Greater Horn of Africa: ICPAC'S Experience. WMO side event at the unfccc cop11 montreal, canada, 1 December, 2005

19. Pereira, L.S., Cordery, I. and Iacovides I., (2002). Coping with water scarcity. IHP-VI Technical

documents in hydrology, No. 5 UNESCO, Paris.

20. Reuters. (2005).Climate change rises risk of hunger. Dublin, September 5, 2005.

21. Reuters. (2008). Global warming crop harm predicted in Africa. Washington DC., February 1, 2008

22. SciDev.Net, (2008). Climate change poses drought risk for Africa. February 21, 2008.

23. Shaakee, J.C. (1989) Climate Change and U.S. Water resources: Results from a study by the

American Association, for Advancement of Science. Proceedings of the 1989 National

Conference on Hydraulic Engineering, New Orleans, Louisiana, USA.

24. Strzepek, K.M., L. Sembled, and V. Prishnikya (eds) (1996). Water resources management in the face of Climatic/Hydrologic, Uncertainties. Kluwer, Dordrecht, The Netherlands.

25. Tebaldi, C., Smith, R. L., Nychka, D. and Mearns, L. O., (2005). Quantifying uncertainty in projections of regional climate change: A Bayesian approach to the analysis of multimodel ensembles. J. Climate, 18, 1524–1540.

26. Yates, D. and Strzepek, K.M. (1994). Comparison of water balance models for climate change assessment of runoff. Working Paper. IIASA, Luxemburg, Austria

27. Zabarenko, D. (2005). Greenhouse gases—the heat-trapping chemicals linked to global warming—continued to increase steadily in 2005. Washington (Reuters) May 1, 2005.

28. Zaki-Eldeen S.A., (2007). The need for improved policy process to support climate change adaptation in Africa. International workshop on climate change, humanitarian disasters and international development. Norway April 27, 2007.

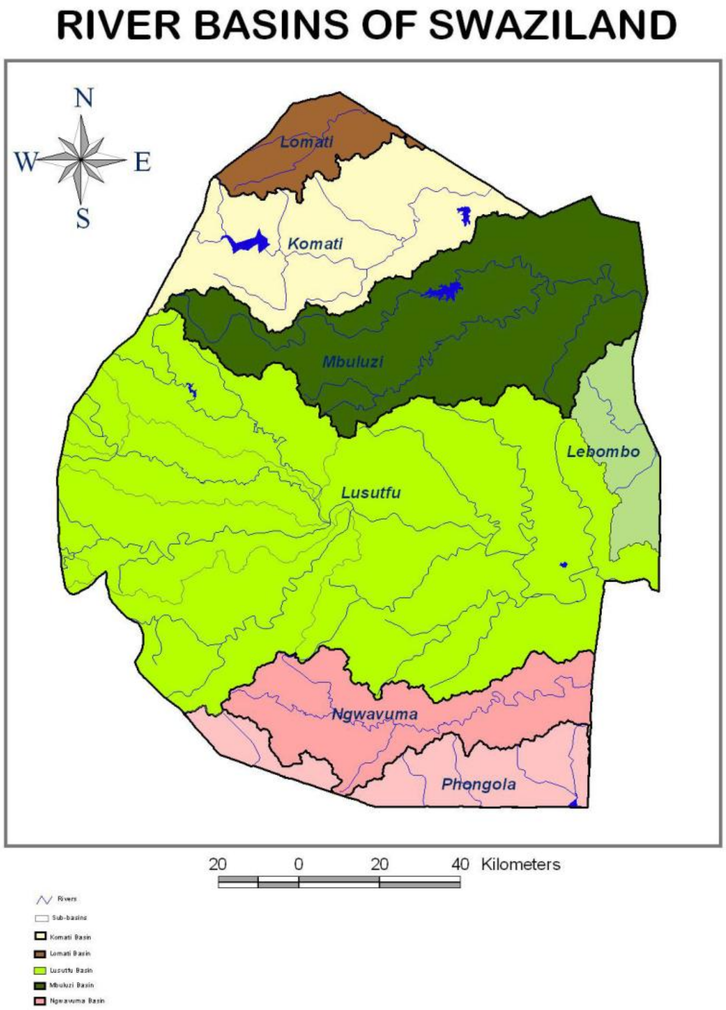

Figure 1: Drainage Basins and location of existing major dams in Swaziland

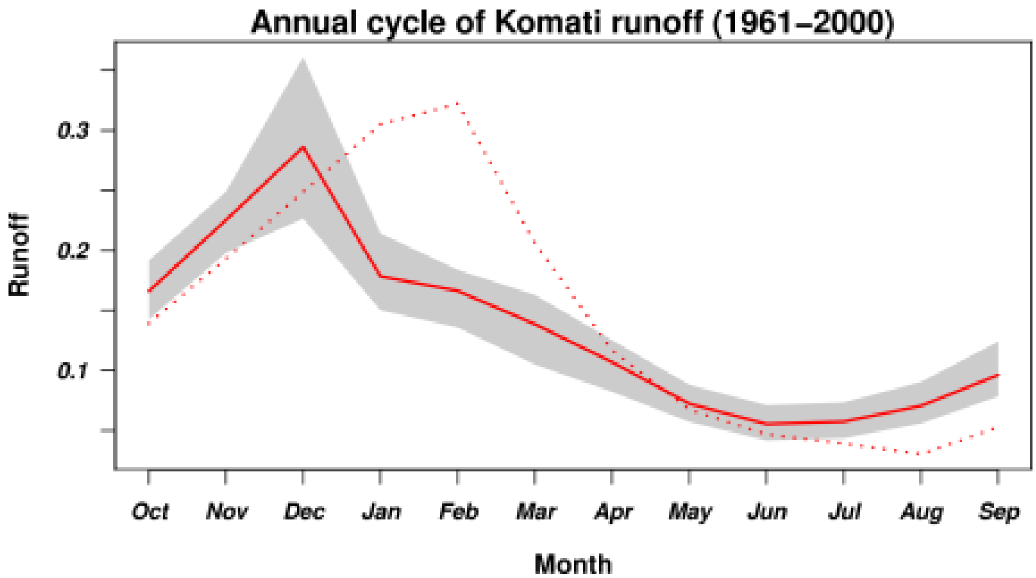

Figure 2. Observed and simulated streamflow in the Komati Catchment during verification

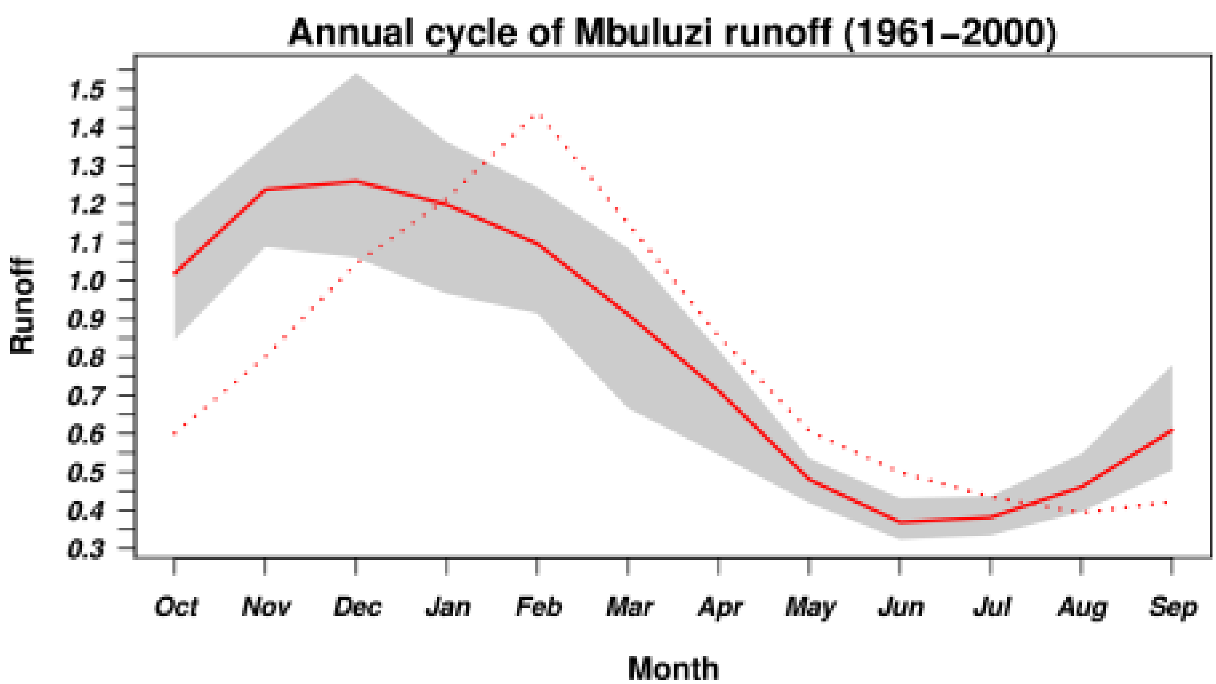

Figure 3. Observed and simulated streamflow in the Mbuluzi Catchment during verification

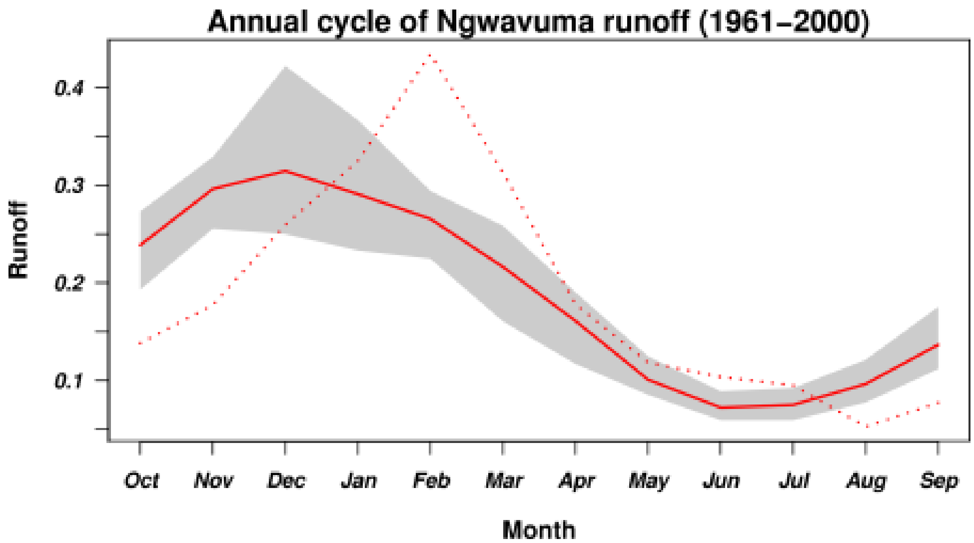

Figure 4. Observed and simulated streamflow in the Ngwavuma Catchment during verification

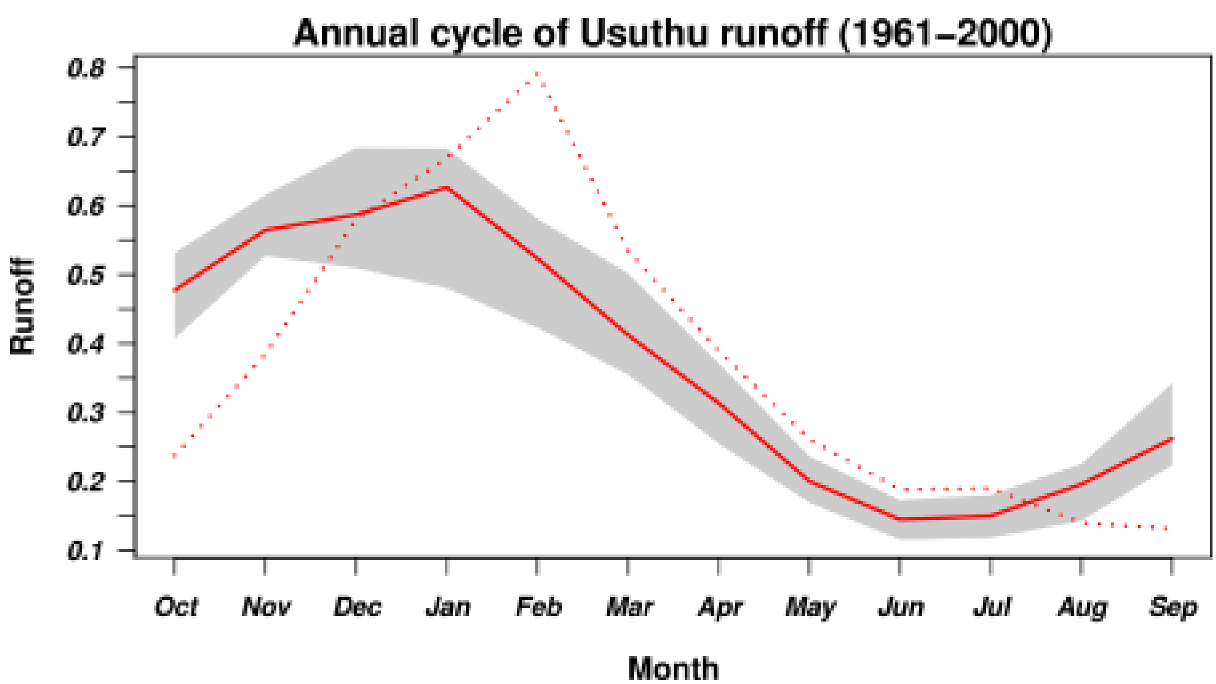

Figure 5. Observed and simulated streamflow in the Usuthu Catchment during verification

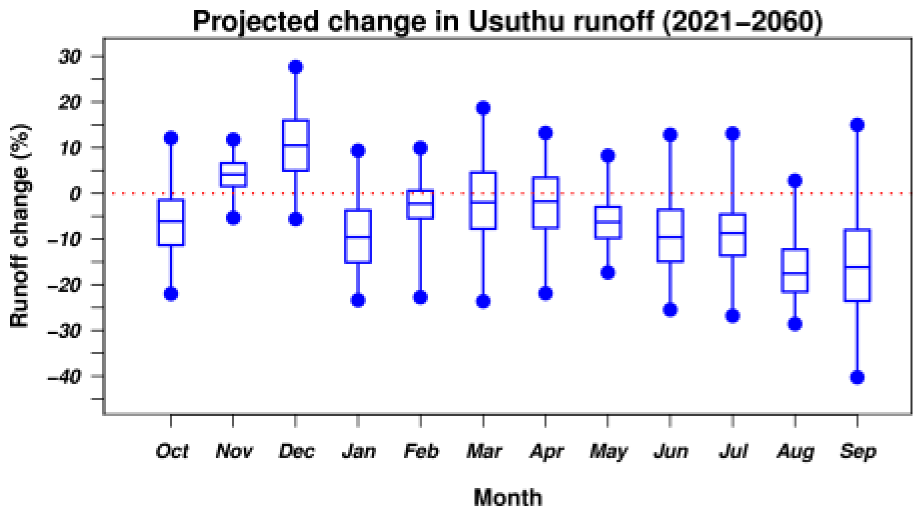

Figure 6: Projected runoff change in the Usuthu catchment. The box plots show the 95% confidence interval extending from the circles, which show the 2.5% and 97.5% quantiles.

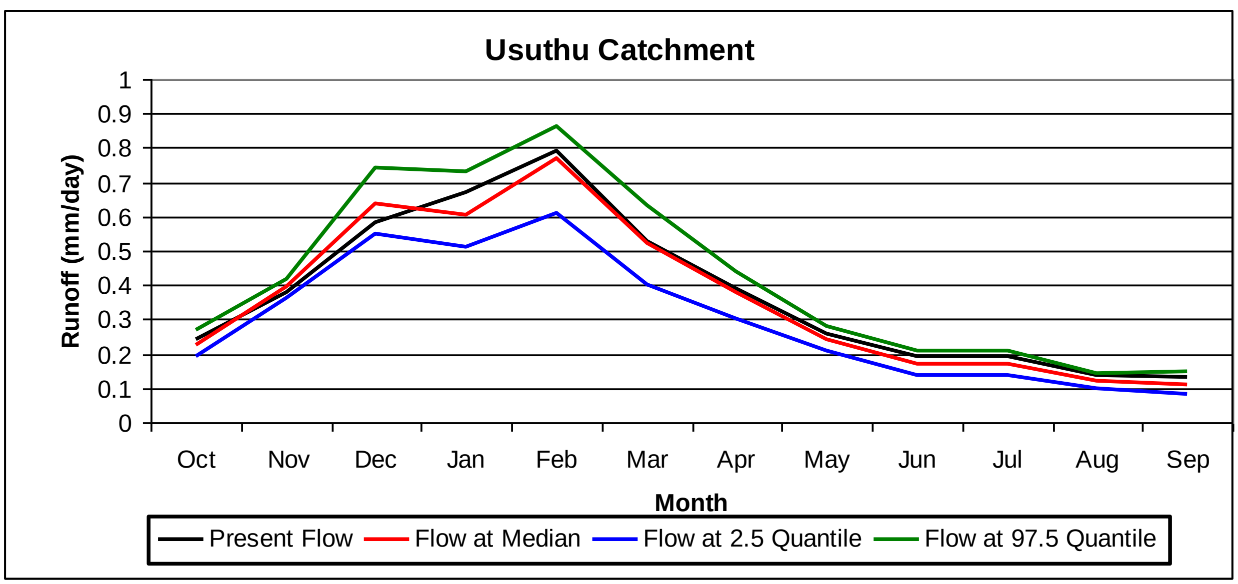

Figure 7: A comparison between present and future flows at the 2.5%, median, and 97.5% quantiles runoff change in the Usuthu catchment.

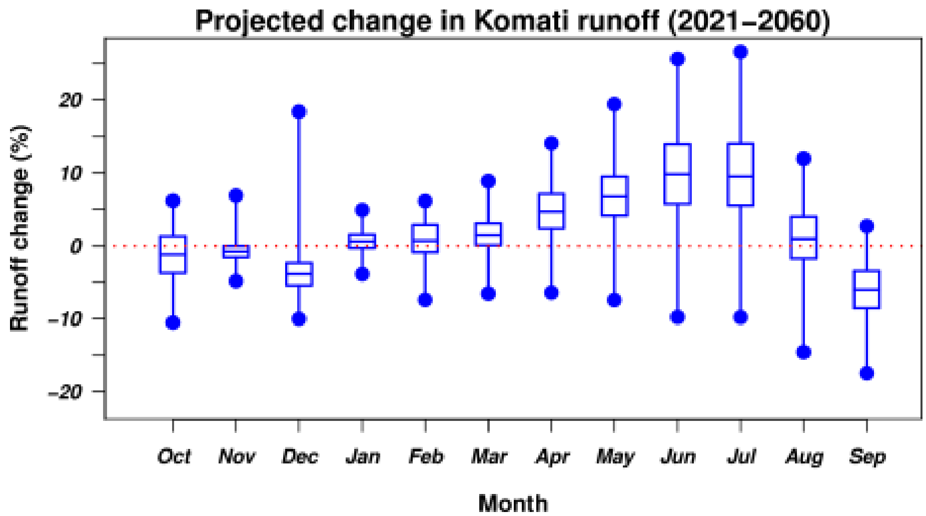

Figure 8: Projected runoff change in the Komati catchment. The box plots show the 95% confidence interval extending from the circles, which show the 2.5% and 97.5% quantiles.

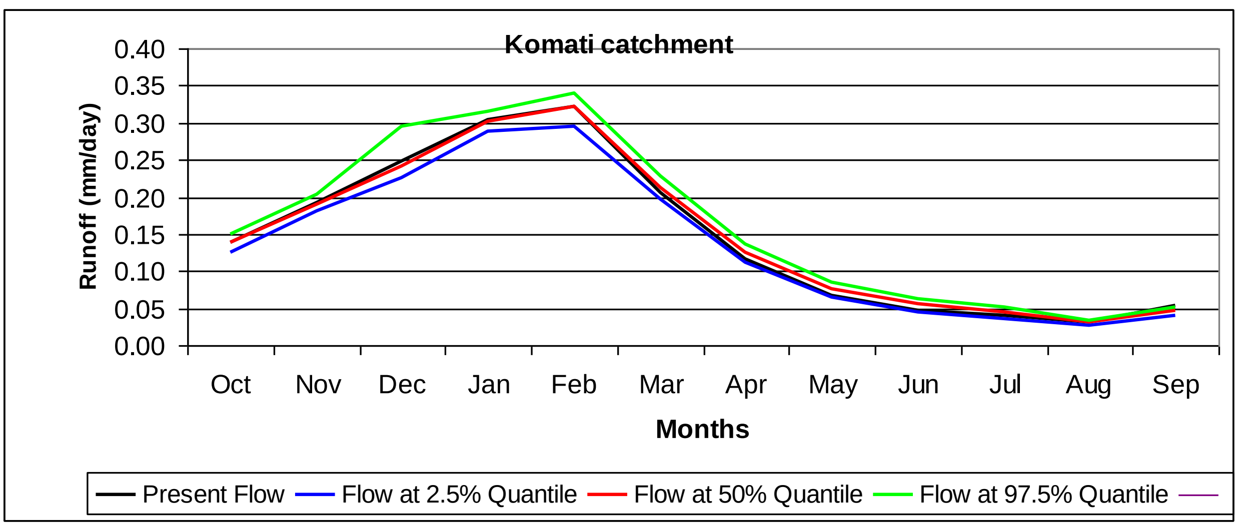

Figure 9: A comparison between present and future flows at the 2.5%, median, and the 97.5% quantiles runoff change in the Komati

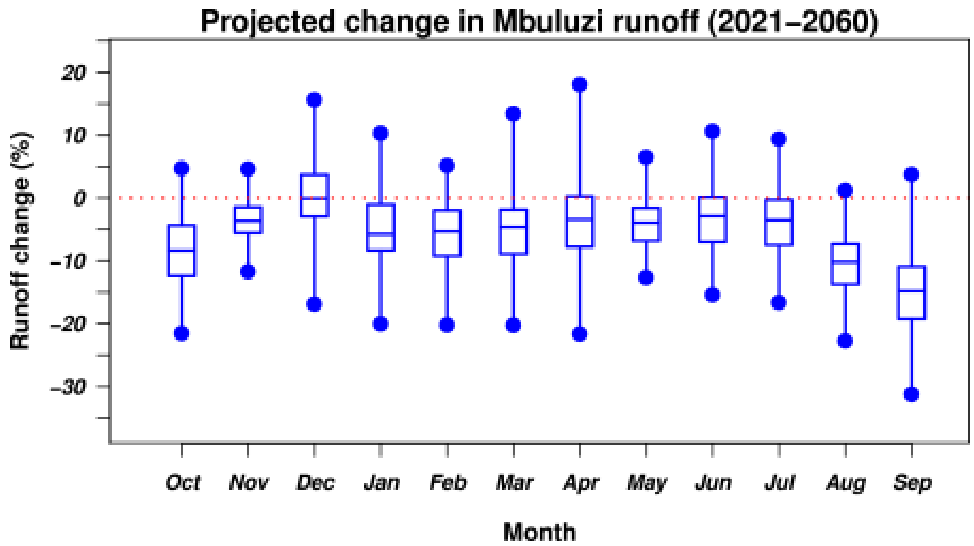

Figure10: Projected runoff change in the Mbuluzi catchment. The box plots show the 95% confidence interval extending from the circles, which show the 2.5% and 97.5% quantiles.

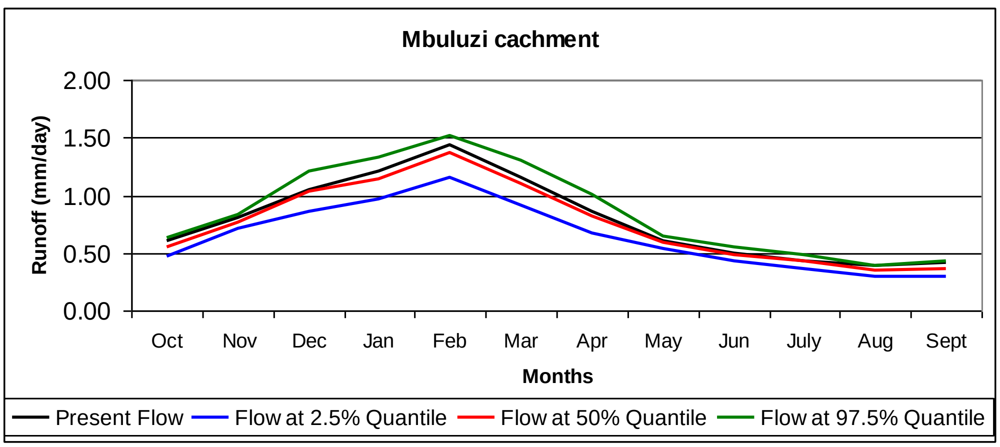

Figure 11: A comparison between present and future flows at the 2.5%, median, and the 97.5% quantiles runoff change in the Mbuluzi catchment

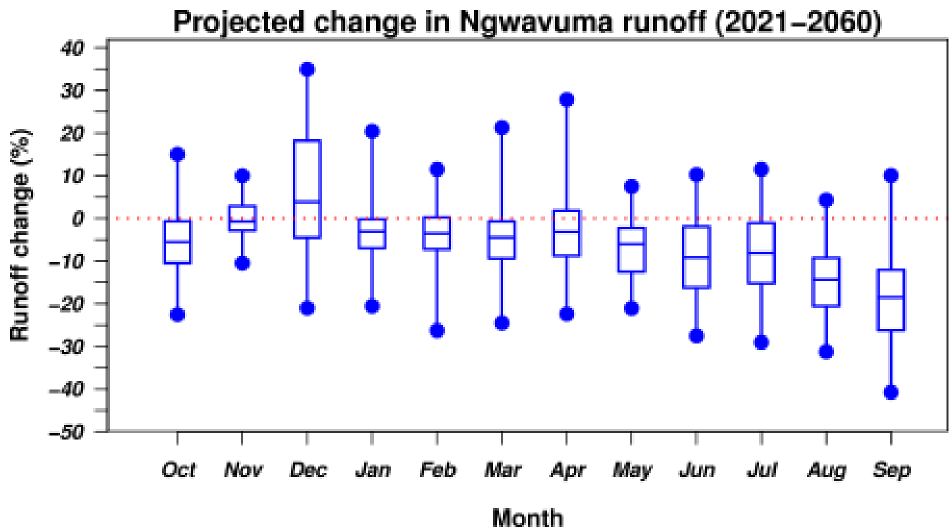

Figure12: Projected runoff change in the Ngwavuma catchment. The box plots show the 95% confidence interval extending from the circles, which show the 2.5% and 97.5% quantiles.

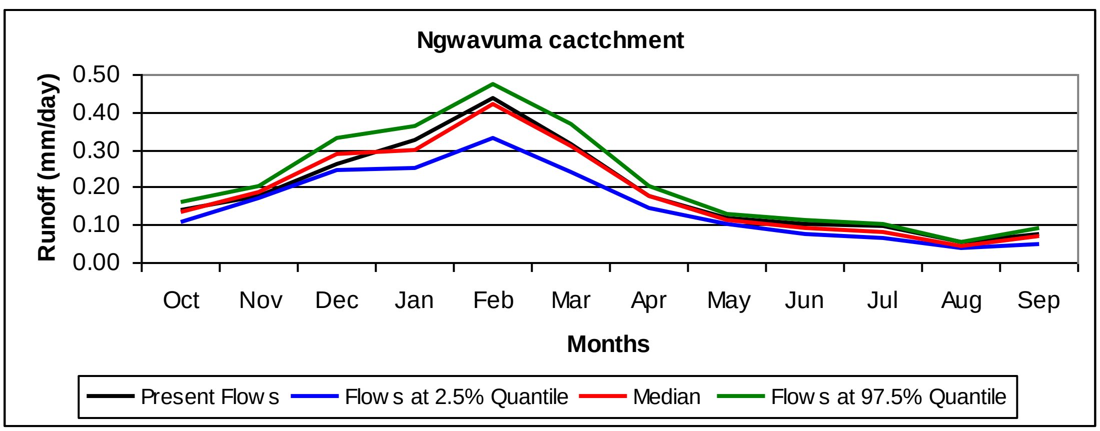

Figure 13: A comparison between present and future flows at the 2.5%, median, and the 97.5% quantiles runoff change in the Ngwavuma catchment

Table 1 Present streamflow, flow at 50% quantile, runoff change (mm/day and in %) for the Komati, Mbuluzi, Ngwavuma and Usutu catchments.

Komati Catchment

	Present Flow (mm/day)	Flow at 50% Quantile (mm/day)	Runoff change (mm/day)	Runoff change (%)
Oct	0.139	0.138	-0.001	-0.062
Nov	0.193	0.189	-0.004	-0.234
Dec	0.249	0.241	-0.008	-0.438
Jan	0.305	0.302	-0.003	-0.164
Feb	0.322	0.322	0.000	-0.007
Mar	0.206	0.213	0.007	0.393
Apr	0.117	0.126	0.009	0.521
May	0.067	0.075	0.008	0.429
Jun	0.047	0.055	0.008	0.468
Jul	0.039	0.044	0.005	0.270
Aug	0.030	0.0303	0.000	0.003
Sep	0.053	0.047	-0.006	-0.327

Mbuluzi Catchment

	Present Flow (mm/day)	Flow at 50% Quantile (mm/day)	Runoff change (mm/day)	Runoff change (%)
Oct	0.60	0.549	-0.05	-0.545
Nov	0.80	0.77	-0.03	-0.321
Dec	1.04	1.039	-0.01	-0.059
Jan	1.21	1.139	-0.08	-0.798
Feb	1.44	1.364	-0.08	-0.811
Mar	1.15	1.097	-0.05	-0.549
Apr	0.85	0.82	-0.03	-0.358
May	0.61	0.586	-0.02	-0.214
Jun	0.50	0.486	-0.01	-0.137
July	0.44	0.425	-0.01	-0.108
Aug	0.39	0.35	-0.04	-0.460
Sept	0.42	0.358	-0.06	-0.678

Ngwavuma Catchment

	Present Flows (mm/day)	Flow at 50% Quantile (mm/day)	Runoff change (mm/day)	Runoff change (%)
Oct	0.14	0.131	-0.007	-0.310
Nov	0.18	0.187	0.010	0.430
Dec	0.26	0.287	0.028	1.219
Jan	0.33	0.298	-0.027	-1.190
Feb	0.43	0.42	-0.014	-0.636
Mar	0.31	0.309	-0.004	-0.172
Apr	0.18	0.177	-0.001	-0.042
May	0.12	0.112	-0.006	-0.278

Jun	0.10	0.09	-0.014	-0.595
Jul	0.09	0.082	-0.013	-0.570
Aug	0.05	0.041	-0.011	-0.504
Sep	0.08	0.067	-0.010	-0.444

Usutfu Catchment

	Present Flow (mm/day)	Flow at 50% Quantile (mm/day)	Ruoff change (mm/day)	Runoff Change (%)
Oct	0.24	0.225	-0.015	-0.334
Nov	0.38	0.40	0.016	0.356
Dec	0.58	0.64	0.060	1.336
Jan	0.67	0.605	-0.065	-1.448
Feb	0.79	0.77	-0.020	-0.445
Mar	0.53	0.52	-0.010	-0.223
Apr	0.39	0.38	-0.010	-0.223
May	0.26	0.24	-0.020	-0.445
Jun	0.19	0.17	-0.020	-0.445
Jul	0.19	0.17	-0.020	-0.445
Aug	0.14	0.12	-0.020	-0.445
Sep	0.13	0.11	-0.020	-0.445