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Impacts of climate change on water resources in southern Africa: A review

Samuel Kusangaya [a,*], Michele L. Warburton [a], Emma Archer van Garderen [b], Graham P.W. Jewitt [a]

[a] University of KwaZulu Natal, Centre for Water Resources Research, School of Agriculture, Earth and Environmental Sciences, Private Bag X01, Scottsville, Pietermaritzburg 3209, South Africa

[b] Climate Studies, Modeling and Environmental Health, CSIR Natural Resources and Environment, Building 1, Corner Carlow and Rustenburg Roads, Emmarentia 2195, South Africa

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ABSTRACT

The Intergovernmental Panel on Climate Change concluded that there is consensus that the increase of atmospheric greenhouse gases will result in climate change which will cause the sea level to rise, increased frequency of extreme climatic events including intense storms, heavy rainfall events and droughts. This will increase the frequency of climate-related hazards, causing loss of life, social disruption and economic hardships. There is less consensus on the magnitude of change of climatic variables, but several studies have shown that climate change will impact on the availability and demand for water resources. In southern Africa, climate change is likely to affect nearly every aspect of human well-being, from agricultural productivity and energy use to flood control, municipal and industrial water supply to wildlife management, since the region is characterised by highly spatial and temporally variable rainfall and, in some cases, scarce water resources. Vulnerability is exacerbated by the region's low adaptive capacity, widespread poverty and low technology uptake. This paper reviews the potential impacts of climate change on water resources in southern Africa. The outcomes of this review include highlighting studies on detected climate changes particularly focusing on temperature and rainfall. Additionally, the impacts of climate change are highlighted, and respective studies on hydrological responses to climate change are examined. The review also discusses the challenges in climate change impact analysis, which inevitably represents existing research and knowledge gaps. Finally the paper concludes by outlining possible research areas in the realm of climate change impacts on water resources, particularly knowledge gaps in uncertainty analysis for both climate change and hydrological modelling.

1. Introduction

The African continent has been identified as particularly vulnerable to the changing climate due to its envisaged low adaptive capacity and vulnerability (Callaway, 2004). The southern African region is regarded as one of the most vulnerable regions in Africa (IPCC, 2007b). Within the climate change matrix, water resources are at the epicentre of projected climate change impacts. If the observed changes in climate in the last century (IPCC, 2007a,b) persist into the future, the potential impacts on water resources are likely to increase in magnitude, diversity and severity. Given the already large spatial and temporal variability of climatic factors in southern Africa (Gallego-Ayala and Juízo, 2011); climate change impacts on water resources are likely to be more pronounced in the near future than previously foreseen (IPCC, 2007b). Climate change impacts on water resources will have both direct and indirect effects on the socio-economic and the biophysical environments (Arnell, 1999; Bates et al., 2008; Kundzewicz et al., 2008; Rutashobya, 2008; Schulze, 2005a,b). Already, this is evident in several sectors, such as agriculture (Crane et al., 2011; Pielke et al., 2007; Vermeulen et al., 2012), health (Bunyavanich et al., 2003; Gage et al., 2008), ecosystems and biodiversity (Eriksen and Watson, 2009) and energy generation (Magadza, 1994, 2000; Yamba et al., 2011).

The assessments of the Intergovernmental Panel on Climate Change (IPCC, 2007a,b) have demonstrated that, due to increasing greenhouse gases, the Earth's climate is changing. Future experiences are likely to include higher sea levels, more intense storms and heavy rainfall events (McBean and Ajibade, 2009). Climate hazards are already occurring and impacting human settlements causing loss of life, social disruption and economic hardships (Desanker, 2002; Hulme, 1996; IPCC, 2001; McBean and Ajibade, 2009). Such hardships are already being heavily felt by the poor in most Southern African Development Community (SADC)

* Corresponding author. Tel.: +26 3772918174.
E-mail addresses: kusangayas@yahoo.com (S. Kusangaya), WarburtonM@ukzn.ac.za (M.L. Warburton), earcher@csir.co.za (E. Archer van Garderen), jewittg@ukzn.ac.za (G.P.W. Jewitt).

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countries as reported by Magadza (1994), Ngigi (2009) and Simms and Reid (2005).

While there are diverse views regarding the magnitude of change of climatic characteristics in southern Africa, and the possible impacts at the scale at which land and water resources are managed, several scholars have however noted that there is certainty, that, climate change will impact on the availability and use of water resources (see for example Desanker and Magadza, 2001; Matondo et al., 2005; Ngigi, 2009; Omari, 2010; Schulze, 2000b, 2005a; Yamba et al., 2011).

What is certain is that in southern Africa, our climate is changing. To date, however there are only few studies examining the hydrological responses of climate change in Africa (Boko et al., 2007) and southern Africa (Manase, 2010) in particular, upon which base generalisations about the future availability of water resources can be made for planning and management purposes. There are also a myriad of other supply and demand pressures such as land degradation, pollution and population and urban growth, affecting water resources (Arnell, 1999; McMullen, 2009; United Nations, 2011). Climate change has the potential to exacerbate these pressures in southern Africa. The region encompasses the following countries: Angola, Botswana, the Democratic Republic of Congo, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe. To our knowledge, there is no comprehensive review of studies assessing impacts of climate change on water resources in southern Africa. The objective of this paper is to review literature on detection of changes in climate and impacts of climate change on water in southern Africa, as well as identifying and highlighting research gaps and needs.

2. Detection of climate change

Long term trend analysis of atmospheric variables such as temperature, rainfall and evapotranspiration have been used extensively [e.g. rainfall by Warburton and Schulze, 2005; Dore Mohammed, 2005; temperature by Kruger and Shongwe, 2004; New et al., 2006; Warburton et al., 2005; evaporation (and soil moisture) by Malisawa and Rautenbach, 2012], as proxies for detecting changes in climate. The increased frequency of occurrence of extreme events such as droughts, floods and cyclone activity in southern Africa has also been cited as evidence of a changing climate. Most scientists (e.g. Mirza, 2003; Rosenzweig et al., 2001; Reason and Keibel, 2004; Reason, 2007; Warburton et al., 2005) are of the view that the increased frequency of extreme events may be attributable to increasing greenhouse gas (GHG) emissions. The following section reviews some of the studies undertaken on climate change detection particularly on rainfall and temperature.

2.1. Temperature

Analyses of both remote sensing derived and observed temperature records in southern Africa agree that over the last decades the region has been experiencing a warming trend. Several scholars, including Kruger and Shongwe (2004), Hughes and Balling (1996), Warburton et al., (2005), Unganai (1996) and New et al., (2006) analysed observed temperature trends. The basic conclusion drawn from these studies is that temperatures are rising, with minimum temperatures rising faster than maximum temperatures. The overall result has thus been a warming trend.

An increase in temperature typically causes the intensification of the hydrological cycle, as a result of the increase in evaporation as well as rainfall (Warburton et al., 2005). That is, temperature changes may lead to changing patterns of rainfall, the spatial and temporal distribution of runoff, soil moisture, and groundwater reserves, as well as (increase) the frequency of occurrence of droughts and floods (Schulze, 2011). Consequently, temperature changes have a direct bearing on water resources availability within southern Africa.

Most studies analysing temperature changes were carried out in South Africa. For example, Kruger and Sekele (2012) concluded that warm extremes increased and cold extremes decreased for South Africa. Kruger and Shongwe (2004) concluded that 23 (of 26) stations analysed showed positive trends in annual mean maximum temperature, 13 statistically significant, with trends higher for central stations than those closer to the coast. Levy (1996) showed an upward trend of 10% (+1.5 °C) noted in the winter series. Jones (1994) showed a warming rate of 0.31 °C per decade whilst Karl et al. (1993) concluded that an increase in both maximum temperatures and minimum temperatures was observed. Tshiala et al. (2011) in studying catchments in the Limpopo Province of South Africa showed an increase of 0.12 °C/decade in the mean annual temperature. However, Mühlenbruch Tegen (1992) concluded that the data were inconclusive as to whether South Africa was warming or cooling for the duration of the study.

On regional and country level studies, Collins (2011) concluded that significant increasing temperature trends were found in southern hemisphere of Africa. Morishima and Akasaka (2010) in studies in southern Africa concluded that annual mean surface temperature showed an increasing trend across the whole region, with particularly large rates of increase in Namibia and Angola. New et al. (2006) analysed daily (maximum and minimum) temperature between 1961 and 2000 for the SADC region and concluded that temperature extremes show patterns consistent with warming over most of the region with diurnal temperature range (DTR) showing consistent increases in a zone across Namibia, Botswana, Zambia, and Mozambique, coinciding with more rapid increases in maximum temperature than minimum temperature extremes. Hulme et al. (2001) concluded that for southern Africa temperatures during the 1990s were higher than they were earlier in the century and are currently between 0.2 and 0.3 °C warmer than the 1961–1990 average.

Overall, for southern Africa we can conclude that temperatures are rising, with minimum temperatures rising faster than maximum temperatures for the whole region. As a result there is also a notable decrease in cold extremes and an increase in warm extremes. From the temperature studies, apart from the general trend of increasing temperatures, still unresolved in the magnitude of change which is variable across the region.

2.2. Rainfall

Climate change detection studies on rainfall that have been carried out to date used observed, interpolated and remote sensing derived rainfall. For Malawi, Ngongondo et al. (2011), using 42 rainfall stations showed that most stations revealed statistically non-significant decreasing rainfall trends for annual, seasonal, monthly and the individual months from March to December at the 5% significance level. For Zambia, Sichingabula (1998) showed an increasing 11-year coefficients of variation (CVs) for selected stations and decreasing rainfall trends observed in southern Zambia after 1975. For Zimbabwe, Mazvimavi (2010) concluded that rainfall in Zimbabwe has high inter-annual variability, and currently any change due to global warming is not yet statistically detectable.

Several studies in South Africa showed that rainfall in South Africa is characterised by high inter-annual variability. For example, Kane (2009) showed that annual rainfall had considerable year-to-year fluctuations (50–200% of the mean), while 5-year running means showed long-term fluctuations (75–150% of the mean).