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Climate change and variability: a review of what is known and ought to be known for Uganda

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Abstract

Purpose – In view of the consensus that climate change is happening, scientists have documented several findings about Uganda's recent climate, as well as its variability and change. The purpose of this study is to review what has been documented, thus it gives an overview of what is known and seeks to explain the implications of a changing climate, hence what ought to be known to create a climate resilient environment.

Design/methodology/approach – Terms such as "climate", "climate change" and "climate variability" were identified in recent peer-reviewed published literature to find recent climate-related literature on Uganda. Findings from independent researchers and consultants are incorporated. Data obtained from rainfall and temperature observations and from COSMO-CLM Regional Climate Model-Coordinated Regional Climate Downscaling Experiment (CCLM CORDEX) data, European Centre for Medium-Range Weather Forecasts (ECMWF) Interim Re-Analysis (ERA-Interim) data and Global Precipitation Climatology Centre (GPCC) have been used to generate spatial maps, seasonal outputs and projections using GrADS 2.02 and Geographic Information System (GIS) software for visualization.

Findings – The climate of Uganda is tropical in nature and influenced by the Inter-Tropical Convergence Zone (ITCZ), varied relief, geo-location and inland lakes, among other factors. The impacts of severe weather and climate trends and variability have been documented substantially in the past 20-30 years. Most studies indicated a rainfall decline. Daily maximum and minimum temperatures are on the rise, while projections indicate a decrease in rainfall and increase in temperature both in the near and far future. The implication of these changes on society and the economy are discussed herein. Cost of inaction is expected to become huge, given factors like, the growing rate of the population and the slow expanding economy experienced in Uganda. Varied forms of adaptation to the impacts of climate change are being implemented, especially in the agricultural sector and at house hold level, though not systematically.

Originality/value – This review of scientific research findings aims to create a better understanding of the recent climate change and variability in Uganda and provides a baseline of summarized information for use in future research and actions.

Keywords Uganda, Climate projections, Recent climate, Representative concentration pathways

Paper type Literature review

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Introduction

Uganda is a landlocked country situated in the eastern part of Africa (Nsubuga *et al.*, 2014c). It covers an area of nearly 241,548 km^2, comprising 0.8 per cent of the total geographical area of the continent. Geographically the country is located between 1°30′S-4°N latitude and 29°30′E-34°E longitude, hence existing astride the Equator, making it more Equatorial than neighbouring countries. Studies for Uganda to detect changes in climate, especially with regard to the two parameters of rainfall and temperature; have been going on within the country, as well as in other parts of the world. The characteristics of climate and the impact of climate change in Uganda show similarities to other regional, national and global studies documented. Regional studies for Africa (such as those by Aguilar *et al.*, 2005; New *et al.*, 2006; Hulme *et al.*, 2001; Domroes and El-Tantawi, 2005) contextualize what has been found for the Uganda.

Considerable work has been done at a national level (Anyah and Semazzi, 2004; Osbahr *et al.*, 2011; Nsubuga *et al.*, 2011, 2014a, 2014b, 2014c, 2015; Bomuhangi *et al.*, 2016), which has revealed various climatic changes in Uganda. The present work attempts to review various works in peer-reviewed articles and other forms of publication which have documented climate change in Uganda. Hence forms a basic framework for further investigation of climate change in Uganda. It highlights what we might expect the climate to be like in future under different climate change scenarios and the associated impacts that ought to be known are also discussed. Hopefully, the information presented in this study will provide a basis for future action.

Methodology

This study reviews recent publications that document climate change in Uganda. It concentrates on recent literature published in times when the climate signal has intensified. Recent literature is also based on new scientific evidence and better climate change projections than have been available in the past. The review used word search for terms like *climate*, *climate variability* and *climate change* in Uganda. Such terms were found not only in peer-reviewed literature but also in published work of independent researchers and in consultants' reports. Secondly, the study linked references in classic articles and book chapters on the topic of climate change. However, our search was not expected to provide a comprehensive picture of climate change because of the limited research being undertaken in Uganda and lack of continuous climatic data. Thus, authors integrated iterative approaches of data analysis to visualize results. Observational data reflecting hydro-climatic conditions collected from 36 stations have been used to construct an overall picture of the mean monthly rainfall distribution. In addition, data obtained from the Global Precipitation Climatology Centre (GPCC) and from the European Centre for Medium Range Weather Forecasting Re-analysis Data (ECMWF) respectively were used for rainfall and temperature observations, in order to produce seasonal outputs. For climate change projections, average of data from an ensemble of four models of the Consortium for Small-scale Modelling Climate Mode (COSMO) and data from the Climate Limited-area Model (CLM), as well as simulations from the Coordinated Regional Climate Downscaling Experiment (CORDEX) initiative were used. Spatial maps were generated using GrADS and GIS software.

Mechanisms that affect Uganda's climate variability

A sound observational basis with a detailed description of the mechanisms that govern the space and time characteristics of rainfall and temperatures over Eastern Africa, where Uganda is located, can be constructed from information provided in a number of articles

(Ogallo, 1984, 1988, 1993; King'uyu *et al.*, 2000; Hastenrath, 2001; Schreck and Semazzi, 2004). Because of its geo-location (astride the Equator), temperatures Uganda are predominantly determined by heat emission from the Earth's surface.

On the other hand, the most important systems responsible for Uganda's rainfall include: the Inter-Tropical Convergence Zone (ITCZ), subtropical anticyclones, monsoonal winds and the moist westerly winds from the Congo basin (Nsubuga *et al.*, 2011). According to Beltrando (1990), Basalirwa (1995), Nicholson (1996), Schreck and Semazzi (2004), Anyah and Semazzi (2004) and Mubiru *et al.* (2012), local influences, such as large water masses, human activities, topography and other surface features also play a role in the climate experienced in the country. A combination of these factors, especially the bi-annual propagation of the ITCZ across the country, results in four broad rainfall seasonal patterns over most parts of Uganda (Figure 1). This pattern was widely reported in the report of the East African Meteorological Department in 1963 (Basalirwa, 1995) and supported by subsequent work by Indeje *et al.* (2000), Phillips and Mcintyre (2000), Hastenrath (2001), Kizza *et al.* (2009), USAID (2013) and the recent assessment of the economic impact of climate change in Uganda (GOU, 2015). For example, December, January and February (DJF) are generally dry (Figure 1-DJF), when the ITCZ is located to the south. Any rain during this time is locally driven (e.g. by Lake Victoria's lake/land breeze effect). March to May (MAM) is commonly known as the "long rains" season (Figure 1-MAM), which is

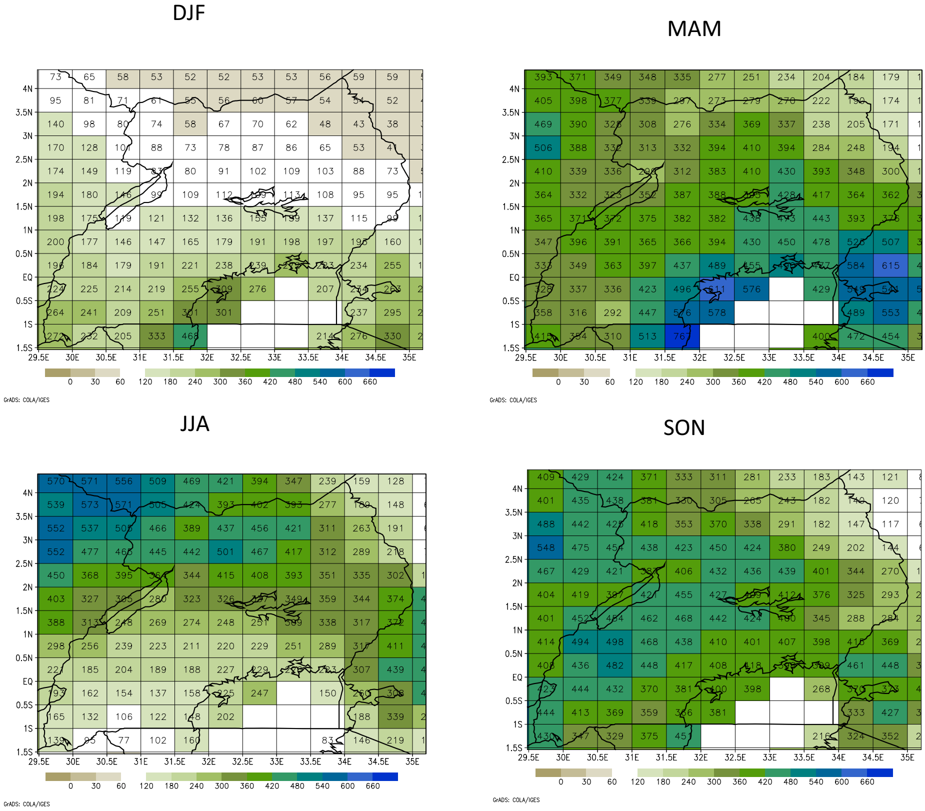

Figure 1.
Estimated average (1981-2010) seasonal total rainfall (mm) for Uganda as derived by the Global Precipitation Climatology Center (GPCC)

modulated by synoptic scale circulation associated with the ITCZ and the Mascarene anticyclone (Basalirwa, 1995; Nicholson, 1996; Nsubuga *et al.*, 2011).

The Mascarene anticyclone is a high-pressure cell over the Indian Ocean, which is also the driving force behind the southeast monsoon, whose full force is felt during July and August. June to August (JJA) is generally a dry season, except for parts of northern Uganda where rains are associated with the influx of a moist westerly air mass from the Congo, modulated by the Atlantic anticyclone (see Figure 1-JJA). The September to November season (Figure 1-SON), also known as the "short rains", is the second rainy season and associated with meridional ITCZ propagation.

Because of these systems, most of Uganda has a mean annual rainfall of approximately 1,200 mm (Nicholson, 1996; Nsubuga *et al.*, 2014b). Previous studies provide some evidence that a bimodal rainfall regime dominates the south of Uganda, while a unimodal distribution is more apparent above 3° North (Komutunga and Musiitwa, 2001).

Rainfall

Uganda experiences varied rainfall, with some areas receiving heavy rains that in some instances have resulted in property destruction, while other areas have experienced drought. In some seasons, the rains start late and end late, while in other cases the rain comes early and stops when it is still expected to continue (Mubiru *et al.*, 2012). This pattern of variance has prompted studies aimed at detecting whether rainfall patterns have been changing. But few of these studies involve long-term series using daily observations and often use data which are aggregated to monthly, seasonal or annual time scales.

Nevertheless, a report produced by NEMA (2008), estimates the varying annual rainfall to be between 500 and 2,800 mm, with an average of more than 1,180 mm. The variability in distribution of rainfall according to Nsubuga *et al.* (2014c), arises from a series of interactions as indicated above. These mechanisms cause two rainfall seasons, also known as short and long rains, which often follow the movement of the ITCZ. This movement brings rainfall a month after the sun's migration north or south (Kizza *et al.*, 2009).

The seasonal pattern tends to be bimodal near the Equator and phases into a unimodal system as one moves away from the Equator (Conway, 2005; Asadullah *et al.*, 2008). Inter-annual variability of rainfall correlates with sea surface temperatures (SSTs) in the Pacific through atmospheric teleconnections and the ENSO phenomenon (Schreck and Semazzi, 2004; Mubiru *et al.*, 2012; Nsubuga *et al.*, 2014c). (El Niño–Southern Oscillation or ENSO is an irregularly periodic variation in winds and sea surface temperatures over the tropical eastern Pacific Ocean, affecting much of the tropics and subtropics.) Nicholson (1996) identifies a seasonal preference for the ENSO-related rainfall anomalies in East Africa where Uganda is located. She notes that positive anomalies are prevalent during the short rains of an ENSO year and drought during the long rains of the year that follows a finding supported by subsequent studies in Uganda. For example, periods of severe drought have since been identified by Phillips and Mcintyre (2000) and Nsubuga *et al.* (2014c) as 1945/1946, 1952-1924 and 1980-1984. This identification aligns with the ENSO- related anomalies.

A precipitation concentration index applied over Uganda by Nsubuga *et al.* (2014c), using the river basin approach, revealed that the north and north -west of the country (above 3° north of the Equator) experience a uniform to moderate seasonal distribution of rainfall. Other parts of the country experience a uniform seasonal rainfall, and this has not changed with time. There is no single month in Uganda where rainfall is not received (Figure 2). The highest percentage of rain comes in August, during the MAM and SON seasons. The highest rainfall totals are generally observed in mountainous regions of the central to north-west and central east of Uganda and Lake Victoria vicinity (Figure 2). The lowest rainfall totals

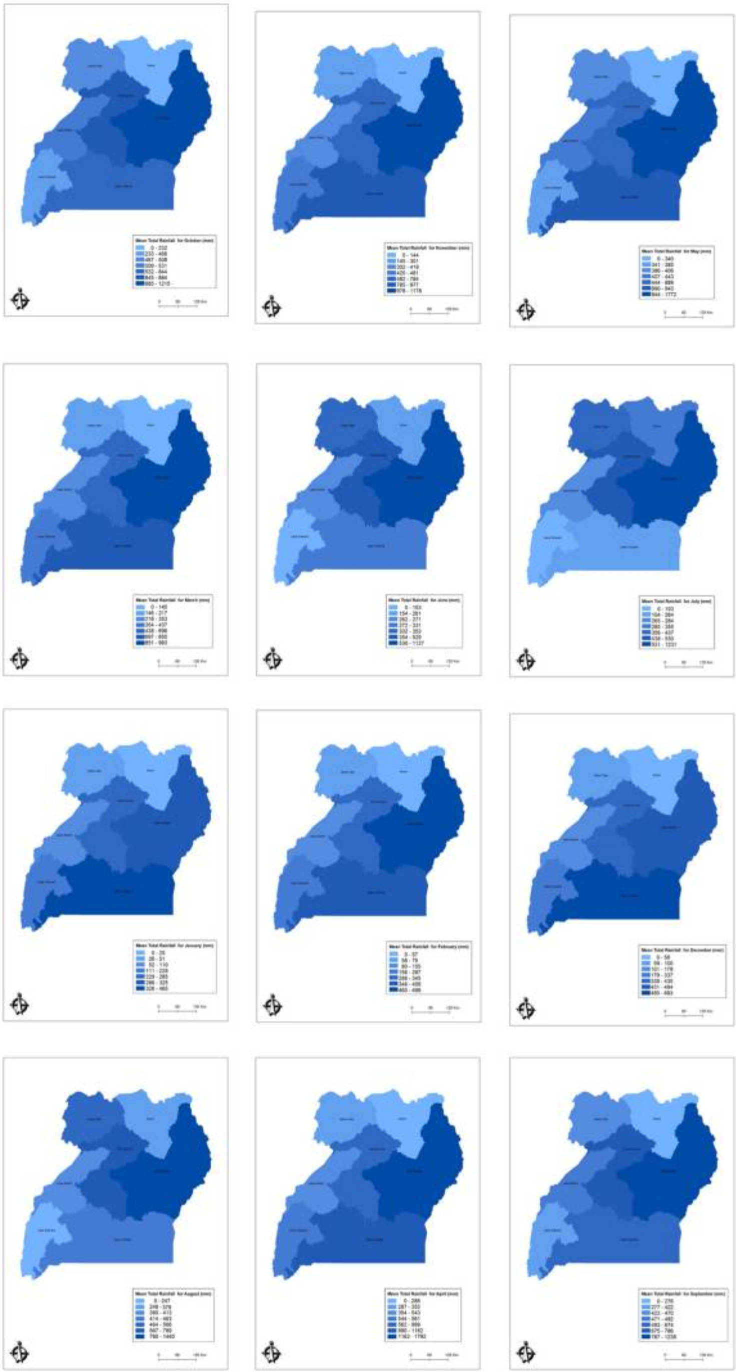

Figure 2.
Spatial distribution of mean monthly total rainfall for Uganda, January to December

are found in the north-east of the country, along the border with Kenya and Sudan (Karamoja region) where drought is a common occurrence (NARO, 2001). It is also drier in the south-west where Uganda borders Rwanda.

Studies using daily records for Uganda are still scarce due to inhomogeneity found in station records. This problem has affected research using daily records on aspects such as the cessation and onset of rainfall. There is a need to establish the cessation and onset of rainfall changes so that we can determine the effects that may arise. Onset and cessation dates have been associated with the large-scale systems that influence regional weather, such as the El Niño Southern Oscillation (ENSO), cyclones and monsoons (Mubiru *et al.*, 2012).The onset and cessation of rainfall has an impact on agricultural practices in a country like Uganda. Rainfall studies also do not tell us much about the magnitude of change with significant confidence. However, it has been noted that rainfall may decrease by 5 mm (mostly in the north) to 10 mm (southern part) per month below the median (1985-2005). This is based on the assumption that there is a moderate level of mitigation taking place (Representative Concentration Pathways- RCPs4.5) in the next fifty years and up to 70 mm over lake Victoria in 80 years to come (GOU, 2015). Apuuli *et al.* (2000) also report about rainfall reduction in the northern districts and the cattle corridor, which extends to the southern part of Uganda. The GOU (2015) report further reveals that projected rainfall totals will differ from what the country is receiving at present. Seasonal rainfall will increase significantly in the DJF and could lead to a longer wet season. Detailed explanation of the modelling and science can be found in GOU (2015), and the subsequent projections for business as usual scenario are presented in the report.

Temperatures

Uganda is pleasantly cool with a long-term mean near-surface temperature of around 21°C. However, monthly temperatures range from a minimum of 15°C in July, to a maximum of 30°C in February (Nsubuga *et al.*, 2014a, 2014b, 2014c).The highest temperatures are observed especially in the north-east, while lower temperatures occur in the south. The JJA season is the coolest, while the DJF and MAM seasons are the warmest (Figure 3). Nyenje and Batelaan (2009) found an interesting relation of near-surface temperatures and their impact on ground water systems in the upper Ssezibwa catchment of Uganda, especially from 1990 onwards. This was confirmed by Nsubuga *et al.* (2014b) who demonstrated that Uganda experienced positive trends in minimum and maximum temperatures over the period 1960 to 2008. It was also found that the nights are warming faster than the day-time temperatures. The GOU (2015) report projects temperatures to increase by 2°C to 2.5°C in fifty to eighty years under the RCP4.5 scenario. The same report projects temperatures to increase more during the MAM and JJA seasons, compared to the DJF and SON seasons. The situation will be worse if business stays as usual (RCP8.5 scenario) for both daily and seasonal temperatures. However, smaller changes over Lake Victoria are expected (GOU, 2015). The effect of an increase in temperature, however small, will have a disastrous impact, for example on coffee growing (Jassogne *et al.*, 2013), fish stocks and fish-based livelihoods (Badjeck *et al.*, 2010) among others. Some studies (Lindsay and Martens, 1998; Hay *et al.*, 2002; Tanser *et al.*, 2003; Alonso *et al.*, 2010) have shown the role of temperature increase in the spread of mosquitoes and malaria. They also discuss the strengths and weaknesses of the past approaches to studying malaria transmission. Heal and Park (2014) underpin the unequal effects of higher temperatures on per capita output between warmer countries, of which Uganda is one and colder countries. Their study estimates lower output per capita for warmer countries compared to higher output per capita for nations with colder

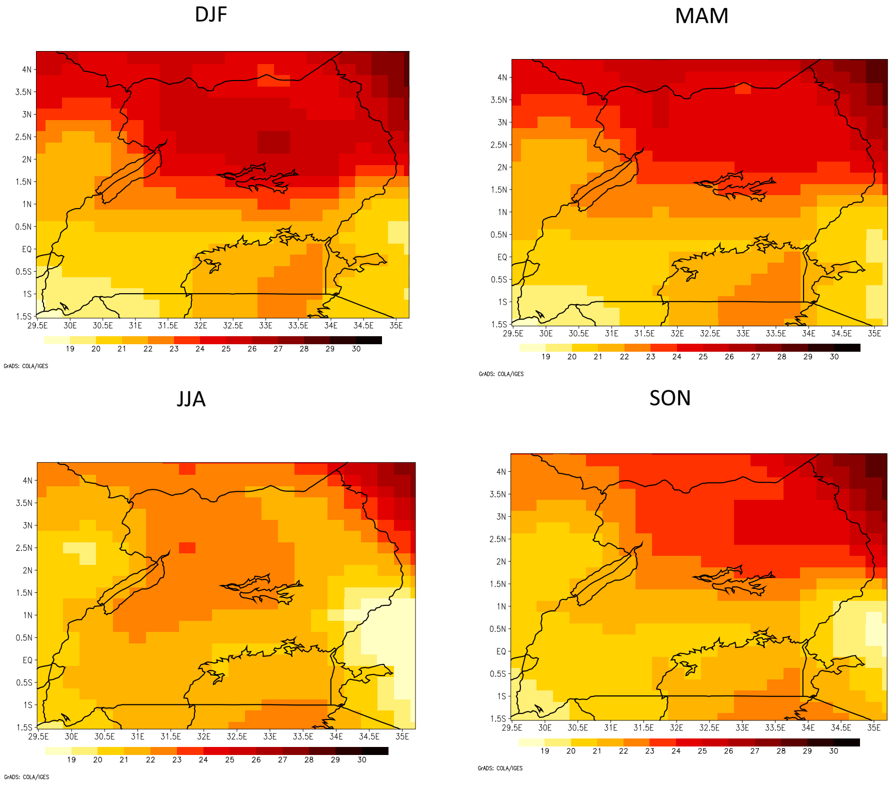

Figure 3.
Average (1986-2005) seasonal near-surface (2 m above surface) temperature (°C) as captured using ERA Interim Reanalysis data

Sourcce: GOU (2015)

climates. This aspect requires further investigation to establish its relevancy on Uganda's economy.

Greenhouse gas emissions

The Ministry of Water and Environment's climate change department launched a national greenhouse gas (GHG) inventory system in October 2016. The system helps Uganda track, report and to prioritise emission reduction actions in key sectors to address climate change. Previously Apuuli *et al.* (2000), using 1990 as a base year, reported that carbon dioxide (CO_2) and methane emissions had amounted to 740 and 1,160 Gg, respectively, while noting that fossil fuels combustion contributed 0.78 million tonnes of carbon dioxide in 1990. Using the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC), Lwasa (2017) reports that, using 2012 as the base year, a study by USAID put total GHG emissions for the country at 49MtCO_2e (0.10 per cent of the world total), with a per capita contribution of 1.36tCO_2e. Much of these emissions were identified by world resources institute climate analysis indicator tools as coming from agriculture, forestry and other land use changes in 2012. In formulating policies to enforce Uganda's determination to control emissions, the country has to investigate and develop a combination of appropriate policies and measures.

Observed recent climate variability

A number of studies that we identified recently have informed us of the following about climate change and climate variability in Uganda, hence it forms part of what is known.

There is now evidence that the country as a whole is experiencing observable shifts in rainfall and temperatures (Kizza *et al.*, 2009; DEWPoint, 2012; FEWSNET, 2012; Mubiru *et al.*, 2012; Kilimani, 2013; Nsubuga *et al.*, 2014a; GOU, 2015). Less information is available on other variables such as wind, solar hours and humidity among others. As noted by King'uyu *et al.* (2000), most studies in the past have investigated temperatures and precipitation to explain present climate change patterns, thus giving a global picture that points to an increasing trend in temperature and reduced rainfall, which is not far from what has been observed in Uganda. Changes in rainfall and temperatures can influence changes in other factors of climate or the other way round.

In Uganda, impacts of extremes in weather are reported by the national media without a quantitative assignment, an aspect Apuuli *et al.* (2000) also recognised. For example, Hisali *et al.* (2011) refer to the unusual rains recorded in 1961/62, 1997/98 and 2007 and severe drought that hit the country in 1993/94. Work by Apuuli *et al.* (2000), however, gave some estimated values on how much rain fell during that drought period and also pointed out how people were displaced, that food was excessively priced and mentioned other negative effects of the drought. Similar findings are reported by Schreck and Semazzi (2004) but with no quantitative values of how severely the country had been affected. There are also indications that droughts have become more frequent, that the onset and cessation of rainfall is becoming more variable; and some models predict wetter conditions in the far future. Drought and heavy erratic rains are perceived by respondents to be extreme climate variability events. Events of high magnitudes are dated and reported by Bomuhangi *et al.* (2016) in the eastern districts of Uganda. Similar results have been reported by Osbahr *et al.* (2011) for south-west Uganda of farmers' perception of climate trends and variability according to their local knowledge. As far as extreme events are concerned, drought events represent an average annual damage in the past decade of US$237m (GOU, 2015).

Reports produced by the Ugandan Ministry of Water and Environment (2007) and LTS International (2008), anticipate that Uganda may experience changes in rainfall patterns with the second rains becoming more intense. A study by Mubiru *et al.* (2012), indicates that farmers in Uganda characterize the rains during the MAM season to be short, localized and with occasional hot and dry spells. Dry spells are reported by Nsubuga *et al.* (2014a) to be increasing in Uganda. This climate variability has been detected in fluctuations in the water resources, e.g. during the 2004/5 drought period, which correlated with Lake Victoria water levels dropping by a metre below the 10-year average (Kull, 2006). We have to remember that water resources are a proxy for climate variability (Nsubuga *et al.*, 2015).

Published peer-reviewed studies have found a decreasing trend in total rainfall during the long rains in MAM, which was also associated with a decrease in the number of wet days in and around Namulonge agricultural research station (Nsubuga *et al.*, 2011). Kizza *et al.* (2009) again identified positive rainfall trends at most stations located in the northern part of the Lake Victoria basin, especially during the short rains season of SON. However, no significant trends exist in annual total rainfall records. A study on community perceptions of variability in precipitation (Bomuhangi *et al.*, 2016) revealed that groups of farmers in eastern Uganda realised that rains came late in the season, and the seasons of rainfall were short but intensive and erratic. Anyah and Semazzi (2004) indicate that surface temperatures on Lake Victoria were warmer by more than 0.5°C during the 1990s compared with the 1960s.

While investigating the nature of rainfall in Uganda using historical data, Nsubuga *et al.* (2014c) identified decades of below-normal, normal and above-normal annual rainfall anomalies over the period 1940 to 2009. Three long epochs of below-normal rainfall occurred between 1940 and 1960, around the 1970s and again around the 1980s and 1990s. Above-normal rainfall periods occurred during the early 1960s and late 1970 and late 1990s. It is interesting to note that episodes of exceptionally high rainfall totals during the 1960s and 1970s were preceded by relatively long low rainfall periods (Nsubuga *et al.*, 2014c).

According to Hulme (1992), inter-annual variability or, on the other hand, consistency, of rainfall are important indicators of the risk of change (associated with higher variability) or reassurance of rainfall consistency or sustainability (associated with lower variability) in Africa. Percentages of coefficient of variation at 36 selected stations across Uganda are in the range of 13 to 29 per cent (Nsubuga *et al.*, 2014c).

High variations occurred at the Kakooge, Kotido and Kangole stations (south and north-east of Uganda), while the Aduku, Kirima Forest, Masindi Meteorological and Ngetta Farm stations experienced the lowest variations (south-west and north-west of Uganda) in inter-annual rainfall (Nsubuga *et al.*, 2014c). What is important from a similar study conducted in Turkey by Turkeş (1996) is that areas where percentages of the coefficient of variation is >20 per cent are more likely to experience frequent and severe droughts (or floods), while areas associated with lower coefficients of variation have more consistent or sustainable rainfall. Analysis indicated that rainfall, for example at the Kakooge station, has varied more over the past 30 years (1980-2009) than before (e.g. 1940-1969), consequently implying that the central region is at risk of experiencing more droughts in the future (Nsubuga *et al.*, 2014a). The USAID (2013) report contains a comprehensive analysis of the general characteristics of the observed climate over Uganda. Using data from 16 weather stations across Uganda, it concluded that no significant change in annual total rainfall occurred over the past 60 years. Another study (DEWPoint, 2012) came to the same conclusion as far as rainfall is concerned, but also found that near-surface temperatures appeared to have increased by approximately 0.2°C per decade in past 60 years. In addition, FEWSNET (2012), using the 1975-2009 climate normal conclude that temperatures increased by more than 0.8, while rainfall was approximated to have decreased by 8 per cent between 1900 and 2009 (Kilimani, 2013).

Climate variability in Uganda is multifaceted because Uganda lies astride the Equator and mechanisms identified above, control its climate. There is little information from models about changes in future variability on all climatic aspects. Nevertheless, the studies have given us some insight into what the situation is like in Uganda. Below are climate projections also reported in GOU (2015) which ought to be known.

Climate projections for Uganda

Climate projections are based on representative concentration pathways (RCPs), specifically scenarios RCP4.5 and RCP8.5. RCPs are four greenhouse gas concentration (not emissions) trajectories adopted by the Intergovernmental Panel on Climate Change (IPCC) for its fifth Assessment Report (AR5) (IPCC, 2013). RCP4.5 shows a moderate level of mitigation of greenhouse gases, resulting in some shifts in climate patterns globally, while under RCP8.5 far less mitigation takes place, resulting in much stronger changes in climate globally (Riahi *et al.*, 2011). In other words, RCP4.5 is an optimistic scenario, while RCP8.5 is more of a “business as usual” scenario in terms of carbon dioxide (CO_2) emissions.

Maps of the annual mean near-surface temperature and total rainfall change from the median, projected over 50 years and 80 years from the present, under both the RCP4.5 and the RCP8.5 concentration scenarios (Figures 4-7).

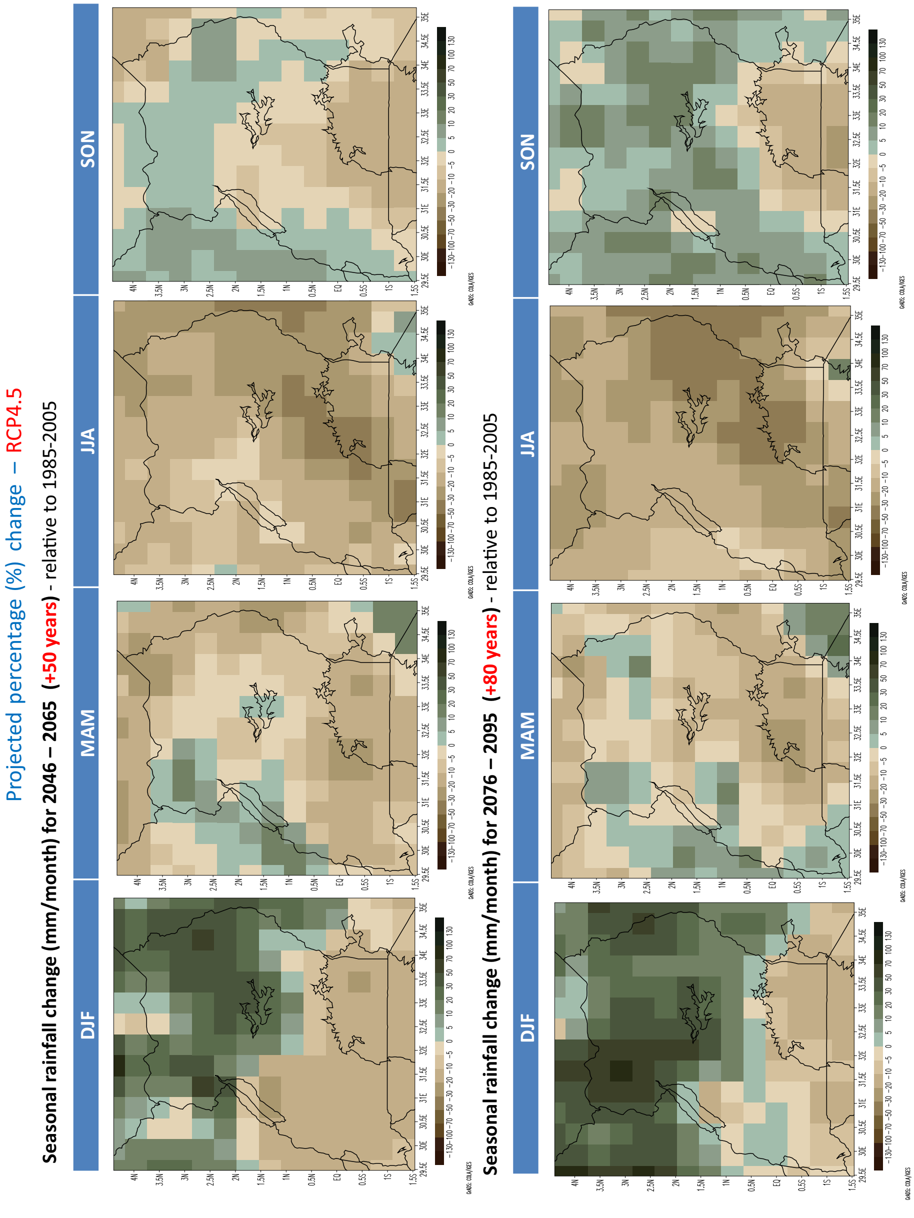

Figure 4.
Projected percentage change of seasonal rainfall change for 2046 -2065 relative to 1985- 2005 of the RCP4.5 scenario

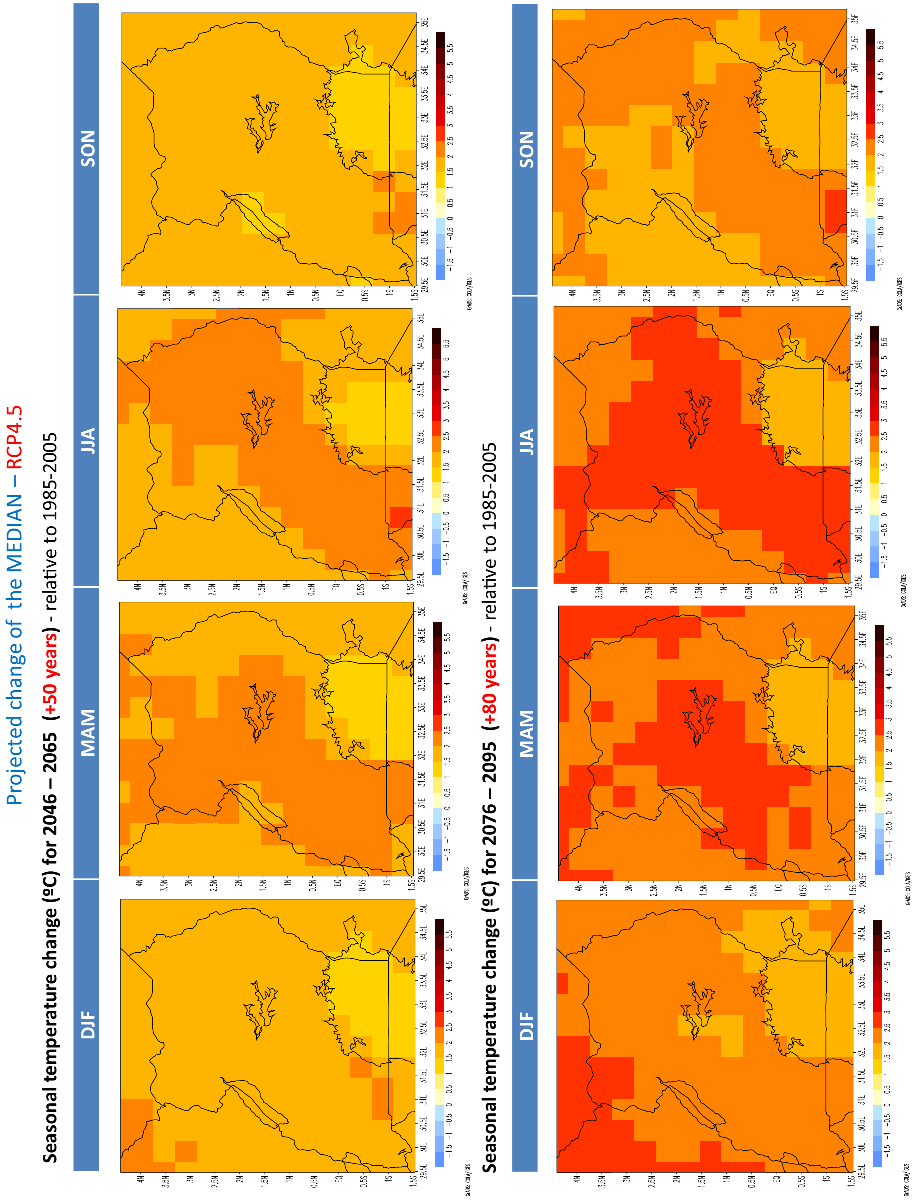

Figure 5.
Projected percentage change of seasonal temperature change for 2046-2069 relative to 1985-2005 of the RCP4.5 scenario

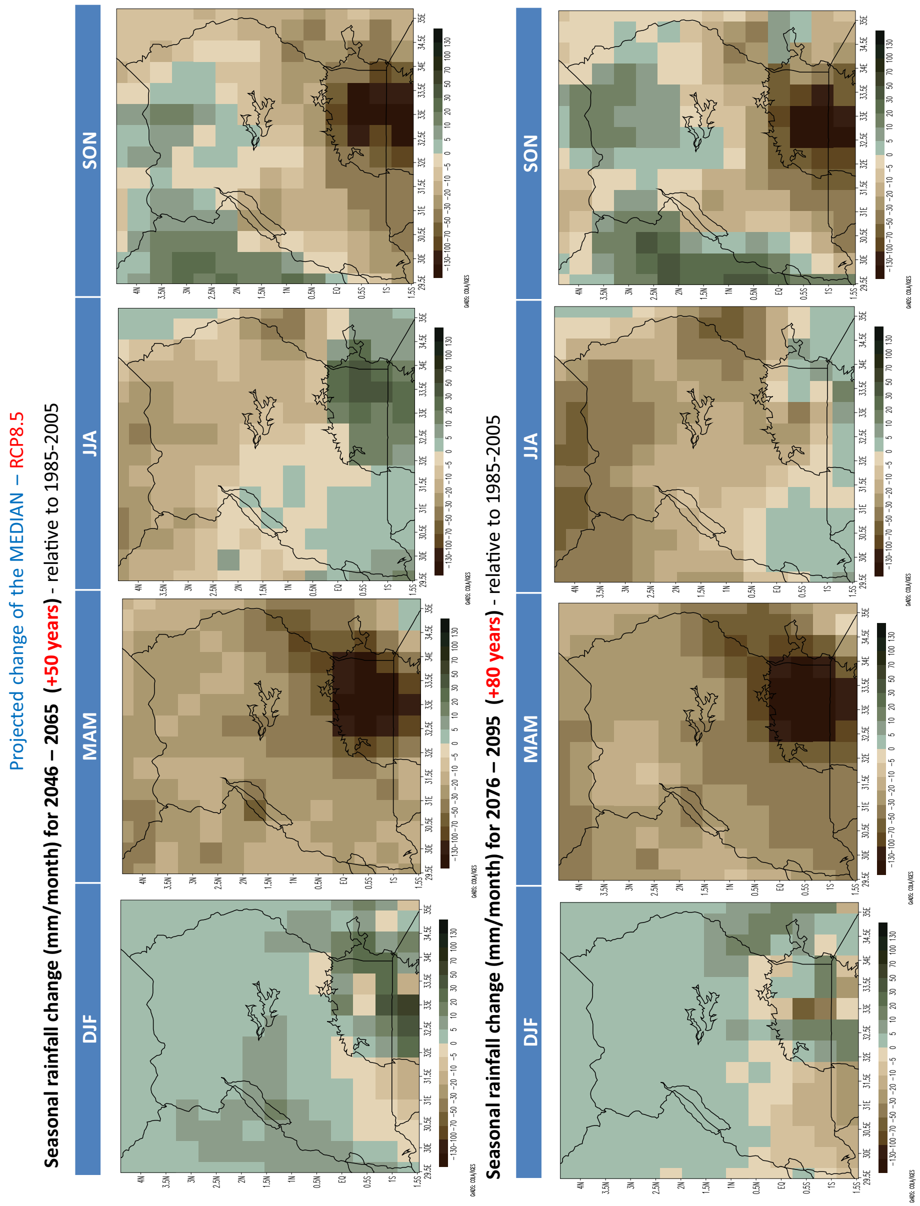

Figure 6.
Projected percentage change of seasonal rainfall change for 2046-2065 relative to 1985-2005 of the RCP8.5 scenario

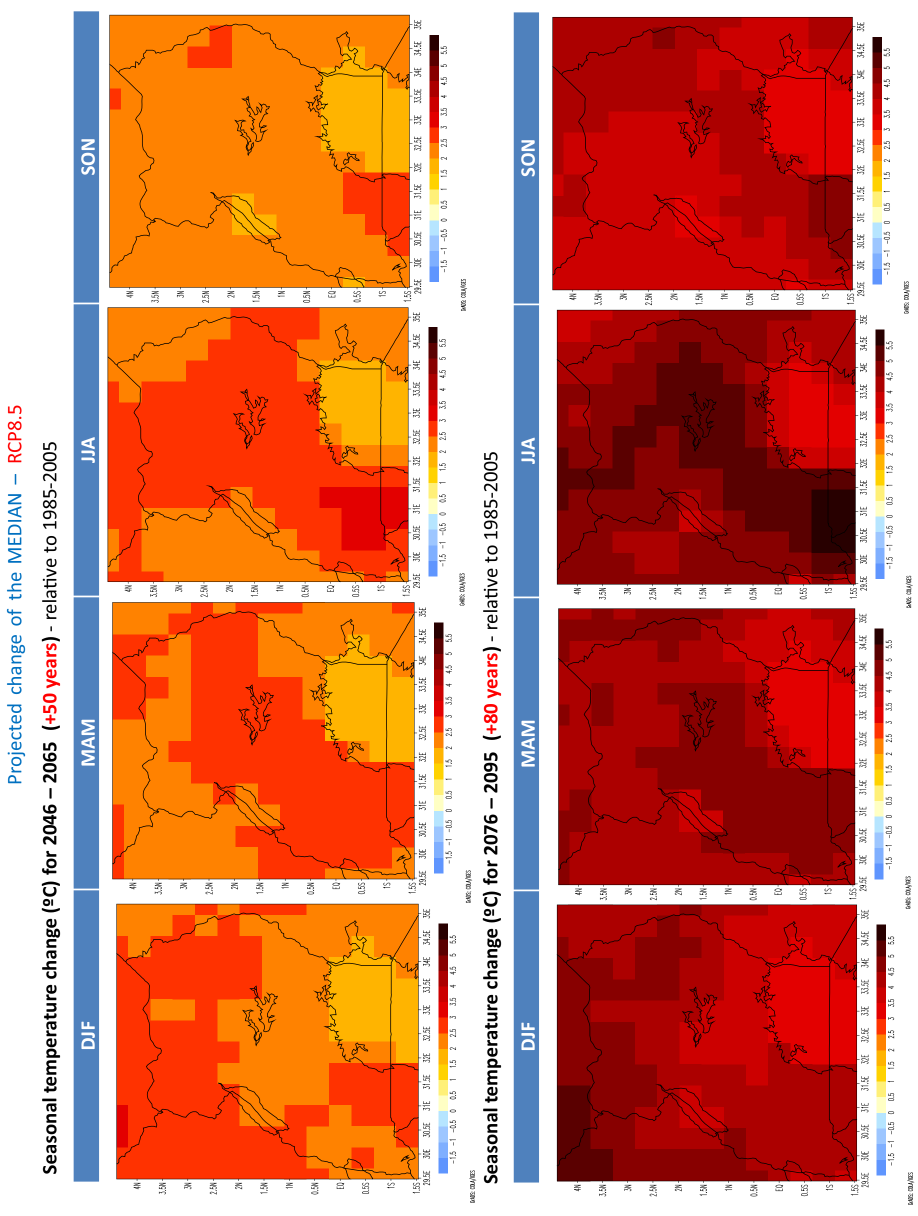

Figure 7.
Projected percentage change of seasonal temperature change for 2046-2069 relative to 1985-2005 of the RCP8.5 scenario

Under the moderate RCP4.5, projected annual rainfall totals will differ a little from what is presently experienced. Projected changes within a range of less than plus or minus 10 per cent from present rainfall are expected. However, less rainfall is to occur over most of Uganda, with slightly wetter conditions over the west and north-west. Rainfall totals might drop by 20 per cent from the present levels over Lake Victoria. What is significant on a seasonal time scale, is the projected increase in seasonal rainfall for the DJF season (up to 100 per cent from the present), which is indicative of a longer wet season that extends from SON towards DJF (Figure 4).

Projected near-surface temperatures are of +2°C in 50 years from the present and of +2.5°C in 80 years from present averages. Temperatures will rise more during the MAM and JJA seasons in comparison to the DJF and MAM seasons (Figure 5) if moderate levels of mitigation are implemented. A lower temperature increases of about 1°C is expected for the Lake Victoria basin.

Under the extreme RCP8.5 scenario, projected annual rainfall total changes are very similar to that of the RCP4.5 projections, and therefore still close to what is currently observed. On a seasonal time scale, the MAM and JJA seasons might expect slightly less rainfall (Figure 6), while the percentage increase in DJF rainfall, as in the RCP4.5 projections, is again very significant. A similar drop (−20 per cent) over the Lake Victoria basin is projected.

In the "business as usual" scenario, projected near-surface temperatures are in the order of +3°C in 50 years from the present and in the order of +5°C in 80 years from the present. Seasonal temperatures will increase between +2°C and +3°C for DJF, MAM and JJA in 50 years from present values, with a slightly lower increase for SON (Figure 7). In 80 years from the present, temperatures might rise as much as +5.5°C during the JJA season (currently the coolest season), while increases of between +4°C and +5°C are expected for the seasons DJF, MAM and SON. Smaller changes over the Lake Victoria basin are expected.

What should be known

The above-summarized expected changes in near-surface temperatures and rainfall levels will feed into the economic performance of the country and affect the well-being of people, with serious implications for the present and the future. The main sectors that will be affected, and consequently have an impact on the economy, include water resources, agriculture, health, energy sources, infrastructure and tourism, with associated effects on livelihoods.

The decrease in rainfall in most of Uganda, combined with significant temperature increases, especially during the MAM and JJA seasons, will result in significantly drier conditions. A longer wet season that extends from SON towards DJF will have adverse implications for the country. For example, a significant drop of total rainfall over Lake Victoria (−20 per cent from present levels), combined with about 1°C temperature increase, will affect the Lake's water level and the associated livelihoods of nearby communities depending on activities such as fishing. Overall, the projected changes will require a number of adaptation strategies.

A study by Nsubuga *et al.* (2014b) points to the reoccurrence of extreme rainfall events similar to those of the 1960s. Given the current population growth, an overload of the sewer and storm-water drainage systems is inevitable, to the detriment of the environment. In East Africa, according to Nyenje and Batelaan (2009), runoff is to increase by 10 to 20 per cent by the 2050s, and Uganda is the wettest of the East-African countries. Floods are to increase in some parts of the country, which will have cost implications that require quantifying. Researchers such as Pillay and Van den Bergh (2016), quantified the cost in billions of

Euros, for treating depression due to flooding in 27 countries of the European Union. Uganda is increasingly adopting the use of fertilizers and pesticides in farming activities. Heavy rains will lead to surface overflows, fluid erosion and mobilization of agricultural fertilizers, pesticides, manure and animal waste into surface water resources, which affects stream and ecosystems health. Heavy rains can also cause earth mass movements, especially in the mountainous and hilly areas, which could even lead to dam and riverbank failures as observed on the Nyamwamba River in western Uganda and the Elgon mountains recently. Changes in weather patterns can have pronounced effects on food availability and on the income of agriculture-dependent households. There are situations currently in Uganda resulting from rainfall variability, which has reduced yields of major staple foods such as maize in the 2014/2015 growing season. Unfortunately, the consequences are not quantified in line with economic performance, but those are often reflected in inflationary tendencies. When it rains in Uganda, roads often become impassable and food does not reach the market easily. Similarly, when it does not rain, food is scarce on the market because of drought, which leads to price fluctuations reported in Uganda Bureau of Statistics (UBOS) quarterly bulletins. Given the declining trends in rainfall, new plant varieties that are able to withstand low rainfall were introduced but not evaluated. Climate variability has disrupted the growing conditions in the agricultural sector. Farmers often plant late or early, ending up with a failed crop. The disruption has serious implications for food security, water availability, agricultural productivity and exports.

The climatic differences in Uganda influence the geographic distribution of crops grown. For example, the coffee-banana system thrives in the wetter parts, while the sorghum- millet system grows well in the drier areas. A change in climate is going to create a shift in the cropping system so that new varieties, which are tolerant to less rain and warmer conditions, such as cassava, will replace the traditional systems. Crops like maize, grow in areas of high rainfall and require wet conditions upon being planted. When rainfall is unreliable, crops that require water at critical phases of development suffer greatly. As observed by Molua (2006), moisture stress during flowering, pollination and grain filling is harmful to staple crops such as maize and beans, thus making rain-dependent agriculture challenging. Where natural conditions required for the growth of food and cash crops are no longer suitable, irrigation options have to be explored. Locally designed drip irrigation technology is already in play especially among the coffee growers in the central parts of Uganda as an adaptation to changing climate. The demand for water in this case would also increase in a warming climate, resulting in competition among water uses. The water aspect reminds us of how, for example, 61 per cent of Uganda's safe water is from groundwater especially around Lake Victoria and in the southern and northern parts of the country (Nyenje and Batelaan, 2009). Total water demand is expected to increase from 408 million cubic metres a year (MCM/y) in 2010 to 3,963 million MCM/y in 2050 (GOU, 2015).

Like most traditional African societies, Ugandan farmers do not routinely use weather forecasts and early warning systems are inadequate, while climate information is usually not trusted or often not taken seriously. Worst of all, government involvement in planning what to grow and helping farmers to understand and adapt to climatic changes is very minimal.

The GOU (2015) study on the impact of climate change on the economy informs us of consequences that may result from a "business as usual" scenario. For example, the study has worked out that climate change could reduce biomass availability by 5 to 10 per cent between 2020 and 2050. This will be a difficult situation, especially if there are no efforts to electrify the rural areas, where most Ugandans use biomass for much of their energy requirements. In addition, there is a possibility that hydropower potential will decrease due to a reduction in precipitation, estimated to be around 26 per cent by 2050 according to the report.

There are a number of medical journals highlighted by Pillay and Van den Bergh (2016) which have published frequently on the relation between human health and climate change. The health risks associated with climate change vary according to age and gender (women, children and the elderly tend to be more at risk) and regions, especially in developing countries such as Uganda. Anticipated climate-related health risks can be either direct or indirect, such as those, which depend on climatic conditions (malaria, dengue fever, diarrhoea and cholera). Climate change can also affect allergic respiratory diseases, as argued by Ziello *et al.* (2012) and cardiovascular and respiratory diseases. Extreme heat and air pollution are important causes of health risks, especially in urban areas. Unfortunately, available economic studies of the costs of climate change have not emphasized this aspect, but Pillay and Van den Bergh (2016) expect the cost to be considerable.

The impact of climate change on infrastructure is felt in two dimensions:

1. lost resilience of buildings, roads and other artefacts owing to increased temperature and precipitation; and
2. damage caused by extreme events, including loss of life and injury, damage to assets, costs to persons due to displacement and inconvenience and expenses incurred for disaster relief.

There may be other problems related to climate change that we do not know about at present, but through research, we can inform ourselves about unforeseen problems and advise governments about necessary planning.

Concluding remarks

This review sought to place into context a diversity of evidence on climate change over the past years, and thereby to call attention to pending issues that need exploring in order to adapt to and mitigate possible threats. Pertinent are mechanisms that influence the climate of Uganda and long-term observations using gauging and modelled data. Of great interest is the seasonal and bimodal distribution of rains following the movement of the ITCZ. From reasonably well documented literature, an understanding of the annual, inter-annual and long-term variability of the climate has been reached. There is a clear signal in the climate data that temperature has been increasing and, to a lesser extent, evidence that the reliability of rains in the first season has decreased slightly. However, rainfall measurements do not show a downward trend in rainfall amount, a significant shift in the intensity of rainfall events or in the start and end of the rainy seasons (Osbahr *et al.*, 2011). The MAM rains are more abundant and will increase in the near future according to the RCP 4.5 scenario as well as the measured temperatures. Evidence from various studies is tenuous regarding the change in climate for the past three decades. Fieldwork by Osbahr *et al.* (2011), revealed that farmers felt that temperature had increased and seasonality and variability of rainfall had changed, with the first rainy season between March and May becoming more variable.

However, lack of adequate continuous ground-based observations hampers objective and comprehensive diagnostic and numerical characterization of climate change in Uganda. Having said that, scientists are circumnavigating the problem through iterative methods to produce credible outputs using the available data. Recent studies point to the significant costs of not taking action on climate variability and future climate change in Uganda. National studies e.g. GOU (2015), show annual costs that could be in the range of US$3.2 to 5.9bn within a decade. The biggest impacts will be on water, followed by energy, agriculture and infrastructure. In the case of energy and agriculture, the greater uncertainties relate to the physical effects of climate change, whereas in the case of infrastructure they relate more to the valuation of the consequences of climate change. Even if there were no further increases in temperature, precipitation or frequency of extreme events, the costs of inaction would rise over time, because of an increase in population (expected to grow by more than 2 per cent per annum over the next 40 years) and GDP (expected to grow at around 7 per cent to 8 per cent per annum over the same period).

Nevertheless, we foresee Ugandans taking on varied forms of adaptation to the effects of climate change in the near future-especially in the agricultural sector. These will include adapting to crop types that are drought tolerant and varieties that mature fast, using fertilizers, applying crop management techniques that limit soil moisture loss and finally, improving marketing and storage techniques.

Uganda being predominantly agricultural, the manufacturing sector will need to revisit the manner in which it acquires inputs. Financial institutions have to devise strategies to determine when to provide credit and crop insurance, while transporting companies have to improve efficiency in delivering inputs and outputs. Research institutions also need to step up and engage in similar pro-active efforts, especially in the problematic areas identified in this review.

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