University of Pretoria
Department of Economics Working Paper Series

Vulnerability to Climatic Variability: An Assessment of Drought Prevalence on Water Resources Availability and Implications for the Ugandan Economy

Nicholas Kilimani
University of Pretoria
Working Paper: 2015-62
August 2015

Department of Economics
University of Pretoria
0002, Pretoria
South Africa
Tel: +27 12 420 2413

Vulnerability to climatic variability: An assessment of drought prevalence on water resources availability and implications for the Ugandan economy

Nicholas Kilimani*

August 28, 2015

Abstract

The volatile changes in climate are increasingly becoming a threat to many economies globally. This study assesses Uganda's vulnerability to climatic variability in the context of how these volatile changes in climate are likely to affect long-run water resources availability. This is done by using household survey data, rainfall data as well as findings from a water resource accounting study on Uganda. First, we use the results from the water accounts to establish the current level of demand for available water resources. Second, these findings are mirrored to the drought prevalence results with a view to highlight the potential adverse affects on water availability, and ultimately economic activity in Uganda.

Whereas the country's water resource accounting position shows that the current level of water resources is still adequate to meet current demand, drought is affecting economic activity primarily in the agricultural sector since it is rain-fed. It is also affecting the water recharge system as a big proportion of precipitation is lost through evapo-transpiration. This has implications for long-run water availability for the country. The findings point to the need for policy interventions that can ensure optimal water use in the economy. These may include improved hydrological planning and the development of water supply infrastructure.

JEL Classification code: E01, Q56

Keywords: Water accounting; Drought; Standardized Precipitation Index; Economic activity; Uganda

1 Introduction

This paper seeks to highlight the vulnerability of the Ugandan economy to the observed changes in climatic trends. The concept of vulnerability has been

*Department of Economics, University of Pretoria, Private Bag X20, Hatfield 0028, South Africa. Email: n_kilimani@yahoo.com; nick.kilimani@up.ac.za. Tel: +27718334525; +256772440724

used in different contexts when analyzing the impacts of climate change and climatic variability. Its foundations are based in the study of natural hazards (see Janssen et al., 2006; Dong et al., 2015). Conventionally, vulnerability has been associated with concepts such as resilience, marginality, susceptibility, adaptability, fragility, and risk (Liverman, 1990). Other studies have extended it to include exposure, sensitivity, coping capacity, criticality, and robustness (Fussel, 2007; Dong et al., 2015). In this paper, vulnerability is used to highlight the potential effects on the economy of the unfavorable disturbances caused by climate variability (see e.g., Li et al., 2008). In this case, vulnerability is analyzed as the extent of damage which the economy could potentially suffer when exposed to the adverse effects of climate variability over the medium to long term. According to IPCC (2001), "vulnerability is the degree to which a system is susceptible to, or is unable to cope with the adverse effects of climate change, including climate variability and extremes, is a function of the character, magnitude and rate of climate change and variation to which a system is exposed to, its sensitivity, and its adaptive capacity" (IPCC, 2001). Adaptive capacity is defined as "a system's ability to adjust to climate change (including climate variability and extremes), moderate potential damages, take advantage of opportunities, or cope with consequences" (Dong et al., 2015). In this paper, vulnerability and adaptive capacity of the state of the economy are assessed in terms of renewable water resources availability, spatial distribution and water supply infrastructure. In the end, actions which need to be taken in order to enhance adaptive capacity are highlighted.

The volatile changes in climate are increasingly becoming a threat to the social economic set up of many economies globally. This has raised a lot of attention for researchers and policy makers (Dong et al., 2015). Most importantly, empirical evidence cites developing counties as the most susceptible to these volatile changes in climate. This is largely driven by their inability to cope with the hostile changes in climate which manifest in the form of frequent and severe climatic shocks as well as shifts in temperature, rainfall patterns and water availability (IPCC, 2007; IPCC, 2013; Hepworth and Goulden, 2008). Whereas some studies argue that these changes in climate would bring positive outcomes in terms of yields of certain crop varieties, the positive effects could be outweighed by the negative effects of these changes (Lobell and Field, 2007; IPCC, 2007; Hepworth and Goulden, 2008). These changes present a major risk to agriculture which the majority of the world's population especially those in the developing countries highly depend on (World Bank, 2007; Seo et al., 2009). Bhavnani et al. (2008) note that in sub-Saharan Africa, droughts and floods account for approximately 70-80 percent of losses, both human, and economic. Frequent drought occurrences have hence reduced the economic growth of many African countries (see Jury, 2000; World Bank, 2005; Brown et al., 2011) and threaten their long term development prospects (Hellmuth et al., 2007).

The largest portion of agricultural activity in sub-Saharan Africa is based on rain-fed smallholder farming. This exposes the sector and people's livelihoods to weather and climate vagaries (Shiferaw et al., 2014; Macours et al., 2012). Furthermore, the region's adaptation capacity is still low (Hassan and Nhemachena

2008). As a result, households, especially those that depend on agriculture risk being stuck in the vicious cycle of poverty. The consequences of this are huge drops in household welfare, in terms of significant reductions in household consumption and asset depletion (Macours, 2013; Janzen and Carter, 2013). It can also hamper households' nutrition, productivity, and upward mobility, with inter-generational consequences. In their study of shocks and their consequences in Zimbabwe, Hoddinott (2006) shows that women's Body Mass Index (BMI) fell as a result of drought due to nutritional deficiencies. Furthermore, households with fewer opportunities for engaging in non-agricultural activity were found to have been severely affected by the drought as there was little scope for drought shock mitigation through engaging in other income generating activities.

Drought has a direct impact on production, health, livelihoods, household assets, and infrastructure which in turn leads to food insecurity and poverty (Shiferaw et al., 2014). However, it is critical to note that its indirect impacts on the environment and the resulting decline in household welfare through its impact on crop and livestock prices could often be larger (Zimmerman and Carter, 2003; Holden and Shiferaw, 2004). Whereas drought accounts for approximately 8 percent of global natural disasters, it is a major threat in Africa, accounting for approximately 25 percent of all natural disasters on the continent for the period 1960-2006 (Gautam, 2006). The Sahel, Greater Horn of Africa and Southern Africa have been cited as the regions experiencing frequent and prolonged droughts which have led to increased vulnerability at a household and national level (Hansen et al., 2004). Gautam (2006) notes that over the past 50 years, the frequency of droughts has steadily increased in the East Africa but declined in West Africa.

Kurukulasuriya and Rosenthal (2003) argue that the distribution of impacts of climate shocks is influenced by a given economy's ability to respond to such impacts. In this regard, it is more likely that developing countries will be more vulnerable to the effects of climate variability than the developed countries. IPCC (2007) in its fourth assessment report warns that by 2100, parts of sub-Saharan Africa are likely to emerge as the most vulnerable, with likely agricultural losses of between 2 and 7 percent of annual GDP. These impacts have been projected to occur along with high population growth rates which is estimated to reach approximately 2 billion by 2050 (UNDP, 2007). This vulnerability is also due to the fact that current trends in climate are already severe in most parts, and technological change has been dismal .()(Mendelsohn & Dinar, 2009). For instance, the eastern and southern Africa regions are characterized mainly by semi-arid and sub-humid climates with long dry seasons (Shiferaw et al., 2014). In contrast with West Africa, the variability in precipitation is concentrated on relatively short annual timescales and it is directly influenced by the El Niño and La Niña-Southern Oscillation (ENSO) (Nicholson, 2001).[1]

[1] El Niño and La Niña, respectively refer to the warming and cooling of surface temperatures (SST) in the equatorial Pacific Ocean. These influence atmospheric circulation and hence rainfall and temperature in specific regions around the globe. Since the changes in the Pacific Ocean (El Niño and La Niña) and changes in the atmosphere (Southern Oscillation) are inseparable, the acronym ENSO is used to describe the resulting atmospheric changes (Singh,

ENSO events strongly influence the inter-tropical convergence zone (ITCZ), regional monsoon wind circulation, and patterns of rainfall anomalies over many parts of sub-Saharan Africa (Jury, 2000; Singh, 2006).

As studies on vulnerability continue to emerge, it is vital to keep identifying findings and trends for the economies in regions which have been cited as the most vulnerable. The outcome of such investigations is that lessons learned from current and future assessments about vulnerability can provide essential insights into the processes and actions that need to be taken in order to enhance our understanding of the link between climate change and social-economic activity especially in developing country context. The trends in climate variability with implications for vulnerability which are considered in this paper primarily focus on changes in rainfall patterns. In addition, there is an exposé on other extreme weather events such as the rising temperatures and floods. For an agro-based economy like Uganda, temperature and rainfall are the climate variables that directly affect the economy through their primary effects on agricultural production (see Ziervogel et al. 2006). Empirical evidence suggests that increases in average temperatures can shift the duration of a typical growing season thereby affecting crop growth in regions where heat already limits production.

1.1 Rationale

Approximately 25 percent of Uganda's population lives in poverty. This situation is exacerbated by the high spatial and temporal climatic variability in a country whose economy is agro-based. In addition, the inadequate institutional capacity, and limited infrastructure are likely to expose the already vulnerable sections of the population to the adverse effects of the increasing climate related shocks. It is therefore critical that an assessment of vulnerability to climate variability is undertaken as it will be essential for developing and implementing mitigation strategies. According to IPPC (2001), the agricultural sector is under serious threat as a result of the increasingly volatile changes in climate. This threat is nowhere more serious than in Uganda where the agricultural sector is a major source of foreign exchange earnings through agro-based exports. In addition, the sector supplies inputs to other sectors and is a critical source of employment for the majority population since over 80 percent live in rural areas. Most importantly, the sector is the primary source of food security and is therefore key to human survival (MFPED, 2011). A study by the Uganda Office of the Prime Minister cites how rainfall deficits severely affect food security in the country (OPM, 2012). The decline in agricultural output not only presents a knock-on effect on food prices but it has often to led to economy-wide macroeconomic instability. For instance, the OPM (2012) study estimated that the value of damage and losses caused by a typical rainfall deficit in a given year was approximately US$ 1.2 billion, equivalent to 7.5 percent of GDP.

Although expansion of irrigated agriculture would serve as an important strategy for mitigating vulnerability to climate variability, there are existing

2006).

challenges with respect to the temporal and spatial distribution of water resources. Moreover, Uganda like many African countries is projected to be water stressed by 2025 (see Bekele et al., 2014 p. 69). Evidence indicates that the unsustainable use of land and other natural resources had increased the vulnerability of people especially in sub-Saharan Africa. This has resulted in smallholder farmers and pastoralists having to live off small parcels of degraded and fragmented land which makes them to be highly vulnerable to climatic shocks, especially droughts. Land degradation and fragmentation has often stemmed from poverty, population pressure and the lack of capacity to invest in sustainable agricultural practices (Shiferaw and Okello, 2011). In Uganda, average landholding per household is less than 1.5 hectares (UBOS, 2012). This limited land acreage coupled with the rudimentary farming practices and climate variability has often implied that the odds of crop failure are higher. In the absence of alternative livelihoods, the poors' recourse is often encroachment on fragile protected areas such as forests and wetlands. The result is further environmental degradation and desertification.

No study has used a combination of biophysical and social economic data on Uganda to highlight the vulnerability of the economy to climate variability. This study uses the biophysical and social economic data to identify the regions which are more vulnerable to the adverse effects of climate variability. The key objective is to characterize the spatial and temporal pattern of drought hazards, identify the vulnerability of various regional populations to the impact of droughts by highlighting the most vulnerable regions of the country. The Standardized Precipitation Index (SPI) (see McKee et al., 1993) is used for the identification of drought hazard patterns in Uganda. Vulnerability of population to droughts has been identified from various socio-economic and physical/structural indicators.

1.2 Objectives

1. (a) Use the existing water resource accounting results to determine water availability.
   (b) Demonstrate the country's vulnerability to climate variability by analyzing drought prevalence in Uganda.
   (c) Use the social-economic and biophysical data to highlight the regions which are most vulnerable to the effects of drought shocks.
   (d) Highlight key policy issues which arise from the findings.

This study employs the conventional statistical methods of drought identification to analyze drought prevalence in Uganda. The major objective is to demonstrate the country's vulnerability to climatic variability despite the apparent availability of renewable water resources. This is resulting from the erratic rainfall caused by the increased climate variability and the spatial differences in the availability versus need for the existing renewable water resources across regions. The theoretical approach to risk assessment can be broken down into a combination of hazard and vulnerability (Shahid and Behrawan, 2008). As it is the case with other climatic risks, drought risk depends on a combination of the physical nature of a drought and the degree to which a community or activity is vulnerable to its effects. Therefore, to study how communities and the economy are vulnerable to drought, it is vital to investigate its frequency, severity, and spatial extent as well as the infrastructural and socioeconomic ability of the country to anticipate and cope with the drought. In this paper, the following steps are used to identify the vulnerability of the economy to climatic variability through the drought prevalence patterns across the country. First, we identify the drought hazard with regard to its spatial extents, frequency and severity; and second, we identify vulnerability to drought, i.e., how communities, the economy and its structure when exposed to the drought shock may not be in a position to cope given the status quo. This is articulated in section 2.

This paper is organized as follows. Section 2 provides insights into the factors which are driving vulnerability to climate variability in Uganda. Section 3 presents the link between Uganda's hydro-climatic conditions and the economy, while the methodology is articulated in Section 4. Section 5 discusses the findings, while Section 6 provides the conclusions and emerging issues.

2 Situational analysis of vulnerability in Uganda

Understanding household vulnerability to climate variability is not straight forward as it depends on biophysical and socioeconomic factors, with the latter being the key determinants for a community or household's ability to cope (Naumann et al., 2013). In this paper, vulnerability is assessed by highlighting the socioeconomic and biophysical characteristics of the different regions of the country which makes them to be vulnerable to the adverse effects of climate variability. From a welfare point of view, the 2009/10 survey data shows that 24.5 percent of Ugandans are poor, which translates into approximately 7.5 million people. Table 1 provides results of a detailed breakdown of poverty dynamics by region and rural-urban status from two household surveys. It is clear that the incidence of poverty remains higher in rural areas than in urban areas. It is also important to note that it is the rural areas whose sources of livelihood are rooted in climate sensitive economic activity. A decomposition of national poverty by region shows that the incidence of income poverty varies significantly. The regional ranking is consistent with the previous poverty studies on poverty dynamics in Uganda (UBOS, 2012). Results show that the incidence of poverty remains highest in the Northern region and is least in the Central region. A comparison of results from UNHS IV with those of UNHS III reveals that the percentage of the people living in absolute poverty declined by 7 percentage points. The proportion of poor households declined from 26.5 percent in 2005/06 to 19.3 percent in 2009/10, corresponding to 1.4 million households in 2005/06 and 1.2 million households in 2009/10. However, the increased volatility in climate trends might jeopardize these marginal welfare improvements.

Vulnerability of a community to climate hazards e.g., droughts depends on factors such as population, social behavior, water use, and level of economic development (Bekele, et al., 2014). From the results in Table 1, it is clear that the largest proportion of the population lives in rural areas where the main economic activity is smallholder rain-fed agriculture. Furthermore, poverty data shows that these rural households have the largest prevalence of poverty in the country. Esikuri (2005) notes that up to 60 percent of sub-Saharan Africa's agricultural sector, is heavily dependent on rainfall. This makes the sector to be susceptible to the effects of severe droughts. Miguel et al. (2004) found that rainfall shocks constitute a good proxy to household income shocks in Uganda.[2] Since agricultural activity in Uganda is rain-fed, changes in climatic conditions have important implications for the households' agricultural production; income and welfare (see Asiimwe and Mpuga, 2007). Björkman-Nyqvist (2013) shows that rainfall deviations from the long-term mean are associated with deviations in crop yields in Uganda. The increase in vulnerability to climate shocks is largely a result of their increased frequency and severity. In Table 2, we see that the largest percentage of climate shocks reported by households emanates from drought prevalence.

The findings in Table 2 have implications for the overall economy and household welfare. According to DWRM (2011), drought episodes present huge moisture deficits for all crops in the nine distinct farming systems in the country. This implies that any sustained period of drought can have adverse effects on economic activity. In fact, Shad et al. (2013) used the Standardized Precipitation Index (SPI) in which results showed that drought episodes significantly influence water resources even for drought occurrences over short periods.

3 Hydro-climatic situation and Uganda's economy

Issues of water resources availability for any country have to start with an assessment of the ability for these water resources to replenish. In Uganda, the recharge of surface and ground water sources— key components of renewable water resources depends on rainfall. Rainfall which is a key input into the hydrological cycle is increasingly becoming variable, both regionally and globally (Nsubuga et al., 2014). Such variations have implications for the availability of water resources especially for those water sources whose recharge is derived from it (Ngongondo, 2006). This is a serious threat to water availability through the reduction in the recharge of both surface and ground water sources. Similarly, river basins which depend on the monsoon type regime, such as the Nile river in Africa and the Ganges in India have been cited as vulnerable to changes in the seasonality of run-off. This has implications for water resources availability

[2] Note that Miguel et al. (2004) finds a close relationship between rainfall and GDP. Moreover, Levine and Yang (2006) find that deviations in rainfall from the district level mean were positively associated with agricultural output in Indonesia in the 1990s.

in countries which lie within these basins (World Bank, 2012). In the case of Uganda, the average seasonal cycle in precipitation rate for the period 1940-2009 over seven sub-basins exhibits a marked contrast in seasonality between the sub-basins that lie above and below latitude 2°N[3] (Nsubuga et al., 2014).

Studies of rainfall fluctuations have demonstrated that total rainfall during the March to May season and the number of wet days in a number of weather stations have been decreasing (see Nsubuga et al., 2011). Similarly, FEWSNET (2012) in a study of climate trends in Uganda shows that the period 1975-2009 witnessed an increase in temperature and a reduction in rainfall. Average temperatures in Uganda are projected to increase by up to 1.50° C in the next two decades (LTS International, 2008). The increasingly unreliable rainfall coupled with the uneven distribution of surface and ground water sources is threatening the sustainability of economic activity in a big part of the country. Empirical evidence shows that average annual rainfall exceeds potential evaporation in only 11 percent of the land area. For the other 20 percent, the average rainfall deficit is less than 200mm per annum, while in another 35 percent, it is in the range of 200-400 mm (DWRM, 2011). In addition, the Northeastern region (approximately 35 percent of the country) experiences an annual rainfall deficit exceeding 400 mm. With these increases in temperature and variable rainfall, the sustainability of economic activity is under threat.

3.1 Water demand projections and water availability in Uganda

Water demand can be defined in economic terms as the ability and willingness of users to pay for water and the services it provides. Since this paper seeks to highlight issues of water scarcity, water demand in this case, is taken as an expression of water requirements necessary for the functioning of the different social-economic sectors given the level of water supply. It is vital to note that water demand is driven by factors which by and large, are anthropogenic. For instance, population growth and changes in consumption patterns directly affect demand for water via the demand for goods and services. In addition, population pressure on water resources rises as its income grows. Increasing incomes are leading to a rise in the percapita demand for food. As a consequence, percapita food consumption is increasing on average in most regions of the world (FAO, 2012). It is therefore expected that both the proportion of cropland under irrigation and the share of irrigated production will increase, resulting in greater demand for agricultural water (Bruinsma, 2009). Such emerging trends are important in shaping future demand for agricultural water. Table 3 presents the growth in percapita water availability in the country against the conventional benchmarks for water stress.

In Table 3, the Falkenmark and Widstrand, (1992) and UN-Water, (2006) indicator of national water scarcity is used to compare the available percapita renewable water in Uganda against the water stress threshold values of 500, 1,000,

[3] i.e., the Northern and Southern sub-basins. Also see Figure 1 for a look at these patterns.

and 1,700m^3/percapita/year. Water stress is an indicator of water scarcity or shortage. It takes the form of widespread, frequent and serious restrictions on use, growing conflict between users and competition for water, declining standards of reliability and service, harvest failures and food insecurity (FAO, 2012). Based on this criterion, countries or regions are considered to be facing absolute water scarcity if their renewable water resources are <500 m^3 per capita; chronic water shortage if renewable water resources are between 500 and 1,000m^3 percapita and regular water stress if resources are between 1,000 and 1,700m^3 per capita. Based on this criterion, Uganda will be water stressed by 2020.

However, it is critical to note that although this measure has its merits; it is largely based on estimates of the number of people that can reasonably live with a certain unit of water resources (see Falkenmark, 1984; FAO, 2012). This approach omits critical local factors that determine access to water, as well as the feasibility of solutions aimed at water provision in different locations. Most importantly, it does not account for the prevailing climatic conditions; inter and intra-annual variability of water resources and environmental water requirements, which tend to vary from region to region and also affect water availability (Kilimani et al., 2015).

In the case of Uganda, national averages may be indicative but not fully informative since the country has strong regional variations in the spatial distribution of water resources. What is vital to note is that the indicators show that the country will be water stressed by 2020. However, when we factor in the adverse effects of climatic variability via the interference with the recharge system[4] and the rising temperatures, it implies that the stress levels become evident, faster than projections reveal. Similarly, the level of severity is bound to be more acute than otherwise thought. Additional pressure on water availability is bound to emanate from economic growth, population growth and rapid urbanization. A combination of these factors is likely to lead to extraction of significant amounts of water thereby further contributing to water scarcity.

4 Methodology

In this section, we highlight the different methods used to achieve our research objectives. First, we establish the amount of water consumed vis-à-vis the available water resources using the System of Environmental and Economic Accounting for Water (SEEAW)[5] in sub-section 4.1, and later, the findings in sub-section 5.1.1. Later, we demonstrate in sub-section 5.2.2 the country's water resource vulnerability from the analysis of drought prevalence using meteorological data but first, an exposition on the climatic set up of the country is provided in sub-section 5.2. This is largely derived from the results of a technical study by the Department of Water Resources Management of the Ministry of Water and Environment (DWRM, 2011). The sub-section is aimed at using these empirical findings from DWRM (2011) as a primer for understanding the empirical results

[4] See Table 3.
[5] See: http://unstats.un.org/unsd/envaccounting/SEEAWDraftManual.pdf.

of drought occurrence derived from the Standardized Precipitation Index (SPI) in sub section 5.2.2.

4.1 The System of Environmental and Economic Accounting for Water (SEEAW)[6]

The SEEAW is a comprehensive water accounting system which has been developed with the objective of standardizing concepts and methods in water accounting (UNSD, 2012). The SEEAW provides a conceptual framework for organizing economic and hydrological information thereby permitting a consistent analysis of the contribution of water to the economy, and the impact of the economy on water resources (FAO, 2012). These accounts are vital for they furnish information to policy-makers about the impact of current economic policies and growth patterns on environmental resources. In that way, judgment can be made as to whether or not such policies are sustainable. In addition, information from these accounts helps us to gauge the impact on the economy of policies taken for environmental reasons. Finally, one of the fundamental aims of this accounting framework is to assess how much of economic 'growth' as it is normally measured, is actually capital consumption due to resource depletion (World Bank, 2006 in FAO, 2012).

4.2 Climate shocks data

Monthly precipitation data in millimetres (mm) from the Department of Meteorology was taken for the period 1980-2011 from 13 meteorological stations distributed across the different regions of the country in the 12 agro-ecological zones. The break down is presented in Table 4. These data used to calculate the Standardized Precipitation Index (SPI)[7]— a measure for drought occurrence.

4.2.1 Measurement and identification of drought shocks

There are a number of definitions in the literature regarding what constitutes a meteorological drought. Regardless, there is a general consensus that a drought should be seen as an 'abnormal' event and should therefore not be confused with dry spells (Karl et al., 2011). An event is categorized as a drought when the precipitation or soil moisture levels are sufficiently below the long-run mean[8]. In this paper, the Standard Precipitation Index (SPI) developed by McKee et al. (1993) is used. The SPI is a robust technique for defining and monitoring drought. In fact, the US National Drought Mitigation Center has used it to replace the Palmer Drought Severity Index (Keyantash and Dracup, 2002; Khan and Gadiwala, 2013). This index uses precipitation data in the measurement

[6] This section draws from a detailed study on water resource accounting for Uganda (see Kilimani et al., 2015). The reader is urged to see this study for details on the accounting process for Uganda including the Supply and Use Tables as well as the Resource flow Matrix.

[7] See McKee et al. (1993) for a thorough exposition on this index.

[8] See Heim (2002) for an extensive review of the drought identification indices.

of drought intensity, magnitude or severity as well as duration. Its analytical set up is based on the probability of an event occurring within a certain year as estimated on the basis of historical data (Heim, 2002). The SPI provides a comparison of precipitation over a specific period with the precipitation totals from the same period for all the years included in the historical record. In order to compute the SPI, historic rainfall data of each station are fitted to a gamma probability distribution function. Formally:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)}\chi^{\alpha-1}e^{-x/\beta} \quad for \quad x > 0 \tag{1}$$

The analysis assumes that rainfall at each station follows a gamma distribution $X_i \sim \Gamma(\alpha_i, \beta_i)$, where $x > 0$ is the amount of rainfall at a given station; $\alpha > 0$, and $\beta > 0$ are shape and scale parameters respectively, of rainfall event x at a given weather station. This probability distribution function is largely considered to be a good fit for precipitation distributions (McKee et al., 1993). The parameters are estimated using maximum likelihood estimation as follows:

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \tag{2}$$

$$where \quad \beta = \frac{\overline{x}}{\alpha} \tag{3}$$

$$A = \ln(\overline{x}) - \frac{\sum \ln(\overline{x})}{n} \tag{4}$$

n is the number of rainfall observations.

This allows the rainfall distribution to be represented as a cumulative probability function. Formally:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^{\alpha}\Gamma(\alpha)}\int_0^x x^{\alpha-1}e^{-x/\beta}dx \tag{5}$$

Since the gamma function is undefined for $x = 0$, and the rainfall distribution may contain non-rainfall events especially as the time scales tend to zero, the cumulative probability distribution is modified in order to include such events. In that case:

$$H(x) = q + (1 - q)G(x) \tag{6}$$

where q is the probability of zero rainfall on a specified time scale; $G(x)$ is the cumulative probability of the incomplete gamma function. The cumulative probability $H(x)$ is then transformed into a standard normal random variable Z with mean zero and standard deviation 1. This yields the value of the SPI in terms of number of standard deviations to the left (dry events) or right (wet events) from zero. Panofsky and Brier (1958) contend that it is the essential feature for transforming a variate from one distribution (i.e., gamma) to a variate with a distribution of prescribed form (i.e., the standard normal). In that case, the probability of being less than a given value of the variate shall be the same as the probability of being less than the corresponding value of the transformed variate.

The resulting Z-score as is it widely used in statistical analysis expresses the x score's distance from the average in standard deviation units. This transformation process in equation (6) enables the SPI result to be directly interpreted as a Z score, i.e., a standard normal random variable. The values of the SPI, and the nominal class descriptions are provided in Table 5. While the value of SPI is theoretically unbounded, it is uncommon to observe values greater than +3.0 or less than -3.0 in any typical dataset (Giddings et al., 2005). However, it is important to note that the wetness or dryness of a given period is relative to the historical average for the station and not the absolute total of rainfall.

The SPI has fixed expected values and standard deviation. This is a key condition for comparing index values between different locations or regions. In this way, frequencies of extreme drought events are comparable between different locations. McKee et al. (1993) provide a criterion for drought identification for any of the time scales. Specifically, a drought event occurs any time the SPI is continuously negative and reaches an intensity of -1.00 or less, later ending when the SPI becomes positive. The sum of the SPI for all the months within a drought event gives us the magnitude of the drought.

In the analysis and identification of droughts, a time scale of 36 and 48 months is used in this paper. The results indicate an increase in drought occurrence over time. For purposes of reporting, only results for the 48 months are reported here. The choice of time scale was guided by existing empirical literature on drought analysis. For instance, whereas Wu et al. (2005) indicate that differences in the SPI values computed using different time scales were not signficant, they add a caveat that the precipitation pattern for their study period was stable. In addition, they caution that researchers should be careful when adopting short time scale SPI results for arid regions. In such instances, the analysis should focus on the duration of the drought rather than on its severity (Molanejad et al., 2014). In an empirical investigation of drought events over Sindh-Pakistan, Khan and Gadiwala (2013) used precipitation data from 1951-2010 and found that time scales which were less than 12 months had enormous fluctuations. As a result, identifying droughts and wet periods proved a challenge. However, the 36 and 48 month time scales yielded SPI values where droughts and wet periods would clearly be identified by region. Their results also demonstrate that the duration, attenuation, intensity and magnitude for any particular month during historical records were time scale dependent. Since this paper focuses on indentifying drought occurrences, a longer time scale of 48 months has been employed.

5 Results

5.1 Water Accounts

5.1.1 Water Accounts Balance

In this section, we begin by assessing the availability of water resources against the level of current demand. This is undertaken using the Water Balance Equation. The findings regarding water availability in Uganda are obtained from a detailed study on water resource accounting for Uganda (see Kilimani et al., 2015). In the study, water accounts were developed, and a water balance model was also derived. The water balance model is an identity with the following key components: a) Abstraction, which is the process of obtaining water from the environment for use in the economy. At the end of the abstraction process, water is considered a product as it enters into the economic sphere. Abstraction has two components i.e., abstraction for delivery to other users in the economy by say, a water distribution agency, or abstraction by an economic unit for its own use; b) When water is no longer useful in its current state, it is considered a residue. In a water balance model, this component is accounted for under "total returns". Some flows of residues are recorded within the economy (for example, the routing of waste water to treatment plants) but ultimately, all residues are returned to the environment; c) "Consumption" is water that is not returned to water bodies (returns) because it has been absorbed by other economic units.

These indicators follow the rules of the SEEAW (see Kilimani et al., 2015 for details). The water balance model in millions of cubic meters is expressed as:

Total abstraction **(4,511)** + Use of water received from other economic units **(83.4)** = Supply of water to other economic units **(83.4)** + Total returns **(336)** + Water consumption **(4,175).**

Since total water supply to other economic units equals the total water use received from other economic units, the identity can be re-written as:

Total abstraction **(4,511)** = Total returns **(336)** + Water consumption **(4,175)**

5.1.2 Summary of water accounts findings

Flows from the environment to the economy are estimated at 43.2 billion m^3. Agriculture accounts for 63% of total water use with 21.2% going to livestock, 18.4% to irrigation; 47.5% for crops, 13% to fisheries. Industry accounts for 4% of total water use in the economy while households consume 20.4%. The results show an estimated 38.6 billion m^3 in water surplus. This implies that there are available water resources which can be exploited for productive use. Subject to technical hydrological assessments and recommendations say, for riverine habitat [in-stream-flow requirements (IFR)],[9] the existing water resources can be

[9] In their study of the South African economy, King and Crawford (2001) cite an estimate of 30 percent of the Mean Annual Run-off (MAR) as the in-stream-flow requirement.

harnessed and utilized in order to wean the key sectors of the economy such as agriculture off rainfall (Kilimani et al., 2015).

Flows within the economy consist of water supply to other economic units via distribution (approximately 83.4 million m^3) which accounts for a small portion of total use water (6.5%). This is evidence of the limited distribution of water in the country through the piped network. For instance, the NWSC and the Small Towns Water and Sanitation Programme's distribution network is only limited to a few districts in the country and is confined largely to urban areas. Consequently, a big proportion of water use by economic agents is obtained from other sources like springs, deep wells and boreholes among others. The limited water supply infrastructure in the country constrains existing water resource utilization and makes the country vulnerable.

5.2 Climatic shocks analysis

5.2.1 Climate of Uganda[10]

This subsection is presented as a precursor to the results and analysis of drought shocks in Uganda. It is aimed at giving a brief but informative background regarding the nature of climate in Uganda (see DWRM, 2011 for details). Geographically, the country is a continental plateau with much of its area above sea level. It is located in the equatorial zone of low pressure with generally light and variable winds. The climate is characterized by high levels of temperature, humidity, and rainfall. Annual rainfall varies from 500 mm to 2800 mm, with an average of 1180 mm (NEMA, 2008; DWRM, 2011). The spatial pattern of rainfall is complex and stems from the interaction between different factors. These include large-scale patterns which are dominated by convective rainfall from the seasonal migration of the Inter-tropical Convergence Zone (ITCZ). These dynamics result in two main rainfall seasons; the long rains from March to May (MAM) and the short rains from September to November (SON).[11] The country's rainfall patterns are varied, following a bimodal system near the Equator and tending to a unimodal system away from it (Conway, 2005; Asadullah et al., 2008). For instance, the northern region experiences one season of more prolonged rains in the summer months. It is worth noting that the reliability of rainfall generally declines towards the north of the country while intensifying for areas in proximity to the Lake Victoria crescent and the montane areas (see Figure 2).

Inter-annual variability of rainfall correlates with sea-surface temperatures (SST) in the Pacific through atmospheric tele-connections i.e., the El Niño/Southern Oscillation (ENSO) phenomenon (LTS International, 2008; Nsubuga et al., 2014). The highest levels of precipitation are generally observed in the mountainous regions of the Southwest, East and in the neighbourhood of Lake Victoria. On the other hand, the La Nina event associated with a dry phase influences the weather patterns of the Northeast of the country on the border with Kenya

[10] This section draws extensively from DWRM (2011).

[11] See Nsubuga et al. (2014) for a detailed analysis of the nature of rainfall in Uganda.

and South Sudan. As a consequence, these parts experience the least amount of rainfall and it is where drought events are most common (NARO, 2001 in Nsubuga et al., 2014).[12] Temperature levels stand at a long-term mean of 21°C while annual temperature ranges from a minimum of 15°C in July to a maximum of 30°C in February. The conventional properties of large water bodies—i.e., the Lakes: Victoria, Albert and Kyoga— and the differential heating of the adjacent land areas produce localized winds which influence the country's climatology. Furthermore, a combination of the significant elevation differences in the country emanating from the presence of Mountain Elgon on the East, the Rwenzori mountain range and rift valley on the West are responsible for the pronounced spatial variability of the weather patterns in the country (DWRM, 2011). Figure 3 presents the average annual reference evapo-transpiration based on historical data. It ranges from 882 mm/yr on the Rwenzori region (Western Uganda) to 1970 mm/yr in Karamoja (Northeastern Uganda). Much of the country (74.7%) falls within the band 1350-1750 mm/yr.

From Figure 3, it is clear that there are marked seasonal variations in evaporation rates, mainly depending on patterns of cloud cover, but average monthly rates rarely fall below 75 mm, even in highland areas (DWRM, 2011). These high values of evapo-transpiration have serious implications for agricultural activity, ground water recharge, and productivity in the range lands. It also highlights the challenge of maintaining sufficient soil moisture storage capacity to cope with periodic dry spells. With the increasing variability of rainfall and rising temperatures, this situation is expected to jeopardize economic activity in the country. Therefore, measures need to be put into place to mitigate the likely adverse effects. DWRM (2011) uses a rainfall-recharge relation to derive three distinct water recharge zones which are depicted in Figure 4 (see DWRM, 2011 section 4.4.4, and 4.4.6 for details). Essentially, the map shows the distribution of the estimated annual total groundwater recharge in an average year.[13]

With regard to the assessment of rainfall reliability, Hulme (1992) asserts that the coefficient of variation (CV) serves as an important indicator for rainfall reliability in Africa. From Figure 5, Nsubuga et al. (2014) computes CVs for 36 stations in order to investigate the spatial pattern of inter-annual variability of rainfall totals over Uganda. The CV is defined as:

$$CV = (\sigma_S / \overline{R_S}) * 100$$

where $\overline{R_S}$ is long-term mean annual rainfall, and σ_s is the standard deviation of annual rainfall totals for the stations and is used to represent changes in reliability (Türkes, 1996). Figure 5 presents results from this measure of annual rainfall variability change over Uganda. Annual rainfall CVs for the stations in the sub-basins ranges from 13% to 29% (see Nsubuga et al., 2014 pg. 285 for details). According to Türkes (1996), areas with CVs of >20% are likely to

[12] See Figure 5 for a map showing the annual rainfall distribution patterns in the country.

[13] See DWRM (2011) page 92 for details on the estimated sustainable groundwater resource per district and Annex 4.1 for the corresponding data on the average sustainable recharge values per major river basin and Water Management Zone respectively.

have more frequent and severe droughts because of the low reliability of normal rainfall. Conversely, lower CV values imply high rainfall reliability. In fact, a comparison of figure 4 and 5 clearly shows that the areas with the least reliable rainfall are those that have the lowest recharge capacity.

5.2.2 Drought shock results and discussion

This section presents results for drought occurrences at the different meteorological stations across the country by region. Meteorological stations were selected with spatial and lake basin considerations in each region in order to represent a fairly accurate picture of the country's climatic outlook. In Figure 6, we present results from five stations for the central and eastern regions of the country.

In figure 6, we present the trends of SPI results for the five stations in the central and eastern region. The stations in the central region of the country indicate a generally positive trend with a slope of 0.007 for the Makerere station, followed by Namulonge, and Entebbe. It is important to note that the central region lies in the Lake Victoria basin which is in the area supposed to experience intense rainfall (see Figure 2). However, the results still indicate variability and a reduction in rain intensity (see Figure 5). We equally see that even for the Makerere station with the biggest slope, the SPI has been oscillating around near normal for 60% of the time in the past decade. The Entebbe station has been recording droughts starting with mid 2003, getting severely dry in 2006 (-1.55) before a brief reprieve in 2010 (0.32), and later dipping to -0.78 in 2011. This is a worrying development considering that this station is right on the shores of Lake Victoria.

The SPI coefficients for the eastern region show a negative trend for Soroti (in the Teso sub-region) over the study period (-0.0039). The sub-region started experiencing dry episodes starting from 1993, recovering between 1996 and 2000 and slipping into moderately dry episodes in 2001 (-1.11). There was a recovery between 2003 and 2005 only to get into a severe drought in 2006. Over the study period, the worst experience of extremely dry conditions was recorded in 2008 (-2.24). Generally, the start of the last decade has witnessed a worsening of drought events for this sub-region. It is important to note that this sub-region has limited alternative water resources. Therefore periods of sustained droughts have the potential to disrupt economic activity in the sub-region.

In contrast, a look at the Jinja station (Busoga sub-region) indicates that although the precipitation events have been variable, the sub-region has largely escaped from the historical drought episodes which plagued it in the early 1980s to the mid 90s with the worst episodes of severely dry conditions being recorded in 1986 (-2.11) and in 1994 (-2). The spike in precipitation in 1998 was due to the El Niño weather phenomenon which occurred almost across the country with the exception of the northern region. The results from this analysis show that the sub-region has experienced variable climatic conditions with precipitation events oscillating above normal except for 2010. Ironically, this sub-region with less drought episodes has a presence of surface sources such as the River Nile and Lake Victoria. Such sources could be utilised in the event of severe and prolonged drought. This is in contrast with the Teso sub-region with more and severe episodes of drought events but with no immediate alternative sources of water supply. Such developments highlight the challenges of adapting to these volatile changes in climate. Next, the results for the north and western regions of the country are presented in Figure 7 and the discussion follows.

In figure 7, we present results for the north and western regions of Uganda, each represented by four meteorological stations. The rationale for having a larger representation is derived from the diverse nature of climate dynamics within each of these regions. Starting with the north, we see that the stations in the Aswa basin (Gulu and Kitgum) recorded a declining trend in rainfall events, starting from 1997 after the recovery from earlier dry episodes in the 1980s. Specifically, the Kitgum station recorded extremely dry events between 1986 and1992, with an extreme dry event recorded in 1989 (-2.82). It then recovered and recorded severely wet events in 1992 and 1995 before receding and oscillating around near normal conditions from 1996 to 2005. The past decade has witnessed episodes of moderately dry conditions with a slight recovery in 2010 before declining in 2011. This station is in proximity to the arid Karamoja sub-region in the northeast of the country (see Figures 2-5).

However, the general trend for this sub-region has been around near normal with a slope of 0.0011. It is clear that despite the erratic extremely dry and severely wet conditions, the SPI results show that given the historical record of this region, the trend has been marginally positive around zero. This result emphasizes the robustness of the SPI in yielding results which can be compared across different regions with different climatic conditions. A closer analysis of the Gulu station (Acholi sub-region) shows a declining trend in wet events from the historically wet episodes, yielding a slope of -0.0035. The sub-region recorded a shift from wet events between 1987 and 1997, with an extremely wet event of 2.34 in 1993 before later declining at the end of 1997. Since 1998, the sub-region has experienced sustained dry events with the lowest point being in 2001 (-1.48). The last such severely dry event was recorded in 1984 (-1.59). As it is the case with the Teso sub-region in the eastern region, this region does not have presence of surface water resources in its proximity which could easily be utilised whenever such dry events are experienced. Analysis of the Lira station in the Aswa basin shows an increasingly positive trend towards wet events with a slope of 0.0062. This is a departure from its historical dry events which were witnessed in the 1980s right through the early 1990s. The most extremely dry events were witnessed in 1987 (-2.67) and 1989 (2.18). The trend has been that of wet events right through the early 2000s before briefly declining in 2006 and recovering for the rest of the study period.

Similarly, the Arua station in the Albert Nile basin shows a mildly positive trend in wet events with a slope of 0.0029. This sub-region has witnessed more swings between extremely wet and extremely dry episodes throughout the study period. The early 1980s produced dry events, later recovering in the early to mid 1990s before plunging into dry episodes with the worst extremely dry event being experienced in 2001 (-2.31). The sub-region recovered in 2005 and has since been experiencing sustained wet events from near normal to severely wet for the rest of the study period. Whereas the results show a positive trend, the danger is that this extreme variability has implications for economic activity. This is primarily the case for the agricultural sector which is rainfall dependent, the effect on ground and surface water recharge, and the sustenance of soil moisture to support crop production.

Finally, we analyse the trends for the stations in the western region. Mbarara and Kabale stations recorded a positive trend for the study period with Mbarara registering the highest improvement (with a slope of 0.0046), followed by Kabale. Mbarara (in the Ankore sub-region) has a history of mild wet and dry events which are fairly more stable compared to Kabale (in the Kigezi sub-region). Generally, the stations in the west show mild positive trends with Kasese recording the smallest slope of 0.007. On the other hand, the Masindi station (in the Bunyoro sub-region) recorded a negative trend with a slope of -0.0055. The sub-region experienced a shift from wet events recorded in the 1980s right through the end of the 1990s with an extremely wet event being recorded in 1988 (2.6). There was a shift to dry episodes at the beginning of the millennium, briefly recovering between 2002 and 2004, before slipping into dry events in 2005. It is critical to note that the Bunyoro sub-region borders the Acholi sub-region in the north. A closer look at the trend for Masindi (-0.0055) and Gulu (-0.0035) shows that both exhibit similar dynamics.

A general look at the trends across the 13 stations indicates that the most severe drought among all the stations was detected in the western region at the Masindi station with a negative SPI trend of -0.0055. The year 2008 was identified as the driest in terms of drought severity with an SPI value of -2.41). Meanwhile, 13 out of 31 years recorded from near normal to extremely wet conditions (see Figure 7, for the Masindi station). The results appear mixed in terms of trends. From the results, it is clear that the stations which are towards the border of the region tend to exhibit the same trend as the neighboring region. For instance, the Jinja station which is at the border between the east and central region exhibits a positive trend as the stations in the central region. Similarly, the boarder station of Masindi in the western region towards the north exhibits similar characteristics with the stations in the northern region. The same holds for the Kitgum station in the north which borders the arid region of Karamoja in the northeast of the country.

At the Kasese station (in the Bukonjo sub-region), the SPI trend is stable for the period of study. This is generally the trend for most of the stations in the western region of the country except for the border station of Masindi whose characteristics follow those of the northern region. This finding is in line with Taylor et al. (2007) who found no decline in rainfall over the 20^{th} Century for the western region of the country. However, they cited a rapid decline in the area covered by glaciers in the Rwenzori Mountains (Kasese station-Bukonjo sub-region) which they attributed to rising alpine air temperatures, amplifying ice losses through evaporation and melting. Air temperatures observed at the stations in the Western region showed an increase of approximately 0.5°C per decade since the 1960s (Taylor et al., 2007). The same trend is assumed to have occurred on the upper slopes of the Rwenzori Mountains. From the results of this study and findings from similar studies, the challenges faced by the country with regard to climatic variability are clear. This is due to the fact that areas with a positive SPI trend (increased wet events) face increasing temperatures while those which a declining trend (increased dry events) face either declining precipitation levels or rising temperatures or both. This is the case for the Far east and northeast of the country. It is critical to note that despite the positive trend for most stations in the western region, results show that the region has experienced frequent dry events since the early 2000s. This is seen to have been the case for Kabale since 2001, with severely dry episode (-1.83) recorded in 2006. Masindi recorded the most extremely dry episode in 2008 (-2.25). Mbarara recorded a positive but mixed experience with respect to dry and wet events over the last decade. Essentially, the sub-region experienced wet episodes from the beginning of the millennium till 2004, with a severely wet event recorded in 2000. However, there was a shift towards dry episodes from 2005 to 2008 before a steady climb into wet events for the rest of the study period.

6 Conclusion and emerging issues

The study sought to address two key objectives; first, highlight the level and use of the available renewable water resources in the country. The water accounting position shows that there is still adequate supply of renewable water resources compared to the level of utilization. The second objective was to demonstrate vulnerability to climatic variability by analyzing drought prevalence in the country. This was achieved using the Standardized Precipitation Index (SPI) on data for a 31-year period. The SPI index was used to identify the occurrence of dry spells as well as their severity. The behaviour of the SPI in the identified subregions generally shows similar trends in climatic variability. The results for the entire study period show a negative trend i.e., an increase in drought frequency in 23% of the stations studied. However, when a sub-sample starting from the year 2000 is considered, this percentage increases from 23% to 53% of stations with drought events. The slopes for stations in the central and western region stations although positive, indicate a declining trend in wet events and increases in the frequency of dry occurrences. In fact, those with positive trends, notably Mbarara and Kabale exhibit a weak trend from the sub-sample results. On the other hand, Kasese and Masindi show strongly increasing trends towards dry episodes. Meanwhile, a long-term increasing trend towards wet periods is detected in the northern region except for the Kitgum station which is in close proximity with Karamoja, an arid sub-region of northeastern Uganda. Similarly, the central and eastern regions indicate an increasing trend towards dry events. These results clearly show evidence of increasing climatic variability in Uganda.

Given that the results from the water accounts show evidence of water availability, mechanisms need to be put into place to exploit those water resources in order to address the effects of climatic variability on the economy. Among the urgent interventions would include development infrastructure for irrigation and dams for livestock in addition to piped water for households and other economic uses. Currently, only approximately 14,420 ha of the farming area are equipped for formal irrigation with another 53,000 ha of managed wetlands. However, estimates of Uganda's spatial potential for improved irrigation vary between 170,000 ha and 560,000 ha, whereas the total potential arable area for irrigation is approximately 4,400,000 ha (MWE, 2011; Kilimani et al., 2015). From the climatic variability results, it is clear that areas which are increasingly experiencing drought shocks are those whose location is far from the proximity of surface water sources. Similarly, these are the areas with higher incidences of poverty. Hence, there is mismatch between the location of the water resources and the regions where demand is high, notably the arid and semi-arid areas in the East and Northeast of the country. MacDonald et al. (2005) suggest that such areas are best served through development of groundwater sources via natural reservoirs. Finally, once this lop-sided availability of water resources is put into account, the country's vulnerability is bound to increase despite the apparent surplus of renewable water resources. In the absence of the necessary interventions, the Ugandan economy and indeed household welfare may be in jeopardy.

Acknowledgements

This study is part of a wider thesis research theme which will lead to the award of a Doctor of Philosophy Degree of the University of Pretoria. In this regard, the Author would like to thank his thesis Advisors: Prof Jan van Heerden and Dr. Heinrich Bohlmann for their guidance and counsel which made this output possible. This research was undertaken with support from the Carnegie Corporation of New York under the Next Generation of African Academics (NGAA II) project. All errors and omissions remain mine.

References

[1] Asadullah, A., Mcintyre, N., & Kigobe, M. (2008). Evaluation of five satellite products for estimation of rainfall over Uganda. *Hydrological Sciences Journal*, 53, 1137-1150.

[2] Asiimwe, J.B., & Mpuga, P. (2007). *Implications of rainfall shocks for household income and consumption in Uganda.* African Economic Research Consortium (AERC) Research Paper. 168.

[3] Bhavnani, R., Vorzorgebe, S., Owor, M., & Bousquet, F. (2008). *Report on the status of disaster risk reduction in the sub-Saharan Africa region.* Commission of the African Union, United Nations and the World Bank. Available from: (http://www.unisdr.org/files/2229DRRinSubSaharanAfricaRegion.pdf). (Accessed: 28^{th} Nov 2014).

[4] Björkman-Nyqvist, M. (2013). Income shocks and gender gaps in education: Evidence from Uganda. *Journal of Development Economics* 105, 237-253.

[5] Brown, C., Meeks, R., Hunu, K., & Yu, W. (2011). Hydro climate risk to economic growth in sub-Saharan Africa. *Climate Change,* 106, 621- 647.

[6] Chumi, S., & Dudu, H. (2008). *Economics of irrigation water management: A literature survey with focus on partial and general equilibrium models.* Policy Research Working Paper No. 4556, World Bank, Washington D.C.

[7] Conway, D. (2005). From headwater tributaries to international river: Observing and adapting to climate variability and change in the Nile basin. *Global Environmental Change,* 15, 99-114.

[8] Dong, Z., Pana, Z., Ana, P., Wanga, L., Zhanga, J., He, D., Hana, H., & Pana, X. (2015). A novel method for quantitatively evaluating agricultural vulnerability to climate change. *Ecological Indicators,* 48, 49-54.

[9] DWRM (2011). *National water resources assessment draft report.* Directorate of Water Resources Management, Ministry of Water and Environment-Government of Uganda.

[10] Esikuri, E.E. (2005). *Mitigating drought-long term planning to reduce vulnerability.* Environment strategy notes, No.13, The World Bank, Washington D.C.

[11] Falkenmark, M. (1984). *New ecological approach to the water cycle: Ticket to the future.* AMBIO, 13 (3), 152-160.

[12] Falkenmark, M., & Widstrand, C. (1992). *Population and water resources: A delicate balance.* Population Bulletin, Population Reference Bureau, Washington, USA.

[13] FAO (2012). *Coping with water scarcity. An action framework for agriculture and food security.* FAO Water Report 38, Food and Agriculture Organization of The United Nations, Rome-Italy.

[14] FEWSNET (2012). *A climate trend analysis of Uganda.* Famine Early Warning Systems Network. http://pubs.usgs.gov/fs/2012/3062/FS2012-3062.pdf. (Accessed: 25^{th} April 2013).

[15] Fussel, H.M. (2007). Vulnerability: A generally applicable conceptual framework for climate change research. *Global Environmental Change*, 17, 155-167.

[16] Gautam, M. (2006). *Managing drought in sub-Saharan Africa: Policy perspectives.* Invited paper prepared for a Panel session on drought: Economic consequences and policies for mitigation at the IAAE conference, Gold cast, Queensland, Australia, August 12-18, 2006.

[17] Giddings, L., Soto, M., Ritherford, M., & Maarouf, A. (2005). Standardized precipitation index zones for México. *Atmósfera,* 33-56. http://www.scielo.org.mx/pdf/atm/v18n1/v18n1a03.pdf.

[18] Glantz, M.H., Gommes, R., & Ramasamy, S. (2009). *Coping with a changing climate: Considerations for adaptation and mitigation in agriculture.* Food and Agriculture Organization of the United Nations Rome.

[19] Hansen, J.W., Dilley, M., Goddard, L., Ebrahimian, E., & Ericksen., P. (2004). *Climate variability and the Millennium Development Goal hunger target.* IRI Technical Report No. 04-04.

[20] Hassan R., & Nhemachena, C. (2008). Adaptation to climate change in Africa: Multinomial choice analysis of determinants of farm strategies. *African Journal of Agricultural and Resource Economics,* 2(1), 83-104.

[21] Heim, R.R. (2002). A review of twentieth century drought indices used in the United States. *American Meteorological Society,* 83, 1149-1165.

[22] Hellmuth, M.E., Moorhead, A., Thomson, M.C., & Williams, J. (2007). *Climate risk management in Africa. Learning from practice.* International Research Institute for Climate and Society (IRI), Columbia University New York, USA.

[23] Hepworth, N., & Goulden, M. (2008). *Climate change in Uganda: Understanding the implications and appraising the response.* LTS International, Edinburgh. Unpublished.

[24] Hoddinott, J. (2006). Shocks and their consequences across and within households in Rural Zimbabwe *The Journal of Development Studies,* 42:2, 301-321, DOI: 10.1080/00220380500405501.

[25] Holden, S.T., & Shiferaw, B. (2004). Land degradation, drought and food security in a less favoured area in the Ethiopian highlands: A bio-economic model with market imperfections. *Agricultural Economics,* 30, 31-49. http://dx.doi.org/10.1016/j.wace.2014.04.004.

[26] Hulme, M. (1992). Rainfall changes in Africa: 1931-1960 to 1961-1990. *International Journal of Climatology,* 12, 685-699, DOI:10.1002/joc.3370120703.

[27] IFAD (2009). *Research and innovation for smallholder farmers in the context of climate change.* Discussion paper for Round Table 3, Thirty-second session of the Governing Council, Rome, 18-19 February. International Fund for Agricultural Development.

[28] IPCC (2001). *Technical summary.* In: White, K.S., Ahmad, Q.K., Anisimov, O. (Eds.), Climate change 2001: Impacts, adaptation, and vulnerability. Contribution of Working Group II to the Third Assessment Report of the Inter- governmental Panel on Climate Change. Cambridge University Press, Cambridge.

[29] IPCC (2007). *Technical summary.* In: Parry, M.L., Canziani, O.F., Palutikof, J.P., et al. (Eds.), Climate Change 2007: Impacts, adaptation, vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

[30] IPCC (2013). *Approved summary for policymakers.* In: Alexander, L., Allen, S, Nathaniel, L.B., et al. (Eds.), Climate change 2013: The physical science basis summary for policymakers. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

[31] Janssen, M.A., Schoon, M.L., Ke, W., & Borner, K. (2006). Scholarly networks on resilience, vulnerability and adaptation within the human dimensions of global environment change. *Global Environmental Change*, 16, 240-252.

[32] Janzen, S & Carter, M. (2013). *After the drought: The Impact of microinsurance on consumption smoothing and asset protection.* NBER Working Paper No. 19702. Available at: http://www.nber.org/papers/w19702. (Accessed on 11^{th} June 2014).

[33] Jury, M.R. (2000). Economic impacts of climate variability in South Africa and development of resource prediction models. *Journal of Applied Meteorology*, 41, 46-55.

[34] Karl, P., Thurlow, J., Bachu, M., & Van Seventer, D.E. (2011). The economic costs of extreme weather events: A hydrometeorological CGE analysis for Malawi. *Environment and Development Economics,* 16, 177-198, DOI: 10.1017/S1355770X10000471.

[35] Keyantash, J., & Dracup, J.A. (2002). The quantification of drought: An evaluation of drought indices. *Bulletin of the American Meteorological Society,* 83, 1167-1180.

[36] Khan, M.A., & Gadiwala, M.S. (2013). A study of drought over Sindh (Pakistan) using standard precipitation index (SPI) 1951 to 2010. *Pakistan Journal of Meteorology,* 9(8), 15-22.

[37] Kilimani, N., Van Heerden, J., Bohlmann, H. (2015).Water resource accounting for Uganda: Use and policy relevancy. *Water Policy,* xxx (2015) 1-22. DOI: http:// doi:10.2166/wp.2015.035.

[38] King, N.A., & Crafford, J.G. (2001). Towards water resource accounts for South Africa for the period 1991 to 1998, *Agrekon: Agricultural Economics Research, Policy and Practice In Southern Africa,* 40(4), 738-754. Available at: http://dx.doi.org/10.1080/03031853.2001.9524989.

[39] Kurukulasuriya, P., & Mendelsohn, R. (2007). *A Ricardian analysis of the impact of climate change on Africa cropland.* World Bank Policy Research Paper No. 4305, The World Bank, Washington D.C.

[40] Kurukulasuriya, P., & Rosenthal, S. (2003*). Climate change and agriculture: A review of impacts and adaptations.* Climate change series Paper 91, The World Bank, Washington D.C.

[41] Levine, D.I., & Yang. D. (2006*). "A note on the impact of local rainfall on rice output in Indonesian districts".* Mimeo, University of California, Berkeley and University of Michigan.

[42] Li, H., Zhang, P.Y., & Cheng, Y.Q. (2008). Concepts and assessment methods of vulnerability. *Progress in Geography,* 2, 18-25.

[43] Liverman, D.M. (1990). *Vulnerability to global environmental change.* In: Under-standing global environmental change: The contributions of risk analysis and management. Clark University, Worcester, MA, pp. 27-44.

[44] Lobell, D.B., & Field, C.B. (2007). Global scale climate-crop yield relationships and the impacts of recent warming. *Environmental Research,* 2, 1-7.

[45] LTS International (2008). *Climate change in Uganda: Understanding the implications and appraising the response.* Scoping mission for DFID Uganda. Kampala, Uganda.

[46] MacDonald, A.M., Davies, J., Calow, R.C., & Chilton, P.J. (2005). *Developing groundwater: A guide for rural water supply.* Rugby (UK): ITDG Publishing.

[47] Macours, K. (2013). Volatility, agricultural risk, and household poverty: Micro-evidence from randomized control trials. *Agricultural Economics* 44, Supplement 79-84.

[48] Macours, K., Premand, P & Vakis, R. (2012). *Transfers, diversification and household risk strategies: Experimental evidence with lessons for climate change adaptation.* Available from: http://www.cepr.org/pubs/dps/DP8940. (Accessed: 12^{th}June 2014)

[49] McKee, T.B., Doesken, N.J., & Kleist, J. (1993). *The relationship of drought frequency and duration to time scales',* Proceedings of the 8^{th} Conference of Applied Climatology, 17-22 January 1993, Anaheim, CA.

[50] Mendelsohn, R.O., & Dinar, A. (2009). *Climate change and agriculture: An economic analysis of global impacts, adaptation and distributional effects*: Edward Elgar Publishing.

[51] MFPED (2011). *Background to the budget for the 2011/12 Fiscal year.* Ministry of Finance Planning and Economic Development-Government of Uganda, Kampala-Uganda.

[52] Miguel, E., Satyanath, S., & Sergenti, E. (2004). Economic shocks and civil conflict: An instrumental variables approach. *Journal of Political Economy,* 112 (4), 725-753.

[53] Molanejad, M., Soltain, M., & Saadat Abadi, A. (2014). Characteristics and mechanism of extreme climate events under climate change background in Iran–part I: Drought, Global Advanced Research *Journal of Environmental Science and Toxicology* (ISSN: 2315-5140), 3(2), 025-037. Available: http://garj.org/garjest/index.htm.

[54] MWE (2009). *Strategic sector investment plan for the water and sanitation sector in Uganda.* Ministry of Water and Environment-Government of Uganda. Available from: http://mwe.go.ug. (Accessed: 13^{th} November 2013).

[55] MWE (2011). *National irrigation master plan for Uganda (2010-2035).* A final Report by PEM Consult to the Ministry of Water and Environment–Government of Uganda: November 2011.

[56] NARO (2001). *Agriculture in Uganda,* Volume 1. Fountain Publishers' Ltd. ISBN 9789970022434.

[57] NEMA (2008). *National implementation plan of the Stockholm Convention on Persistent Organic Pollutants in Uganda.* National Environment Management Authority (NEMA), Kampala.

[58] NEMA (2010). *State of the environment report for Uganda, 2010.* National Environmental Management Authority, Kampala, Uganda. http://nema-ug.org/reports/national_state_report_2010.pdf.

[59] Neumann, G., Barbosa, P., Garrotte, L., Iglesias, A., & Vogt, J. (2013). Exploring drought vulnerability in Africa: An indicator based analysis to inform early warning systems. *Hydrology and Earth System Sciences Discussions,* 10, 12217-12254.

[60] Ngongondo, C.S. (2006). An analysis of long-term rainfall variability, trends and ground water availability in the Mulunguzi river catchment area, Zomba mountain, southern Malawi. *Quaternary International,* 148, 45-50.

[61] Nicholson, S.E. (2001). Climatic and environmental change in Africa during the last two Centuries. *Climate Research,* 17, 123-144.

[62] NPA (2010). *National development plan 2010/11-2014/15.* National Planning Authority, Kampala-Uganda. URL: http://npa.ug/docs/NDP_April_2010-Prot.pdf. (Accessed: 7^{th} May 2013).

[63] Nsubuga, F.W.N., Botai, O.J., Olwoch, J.M., & Dew Rautenbach, C.J. (2011). Climatic trends at Namulonge in Uganda: 1947-2009. *Journal of Geography and Geology,* 3,119-131.

[64] Nsubuga, F.W.N., Botai, O.J., Olwoch, J.M., Dew Rautenbach, C.J., Yvette, B., & Adebayo, O.A. (2014). The nature of rainfall in the main drainage sub-basins of Uganda. *Hydrological Sciences Journal,* 59 (2), 278-299. DOI: 10.1080/02626667.2013.804188.

[65] OPM, (2012). *The 2010-2011 Integrated rainfall variability impacts, needs assessment and drought risk management strategy.* Department of Disaster Management-Office of the Prime Minister, Government of Uganda.

[66] Shiferaw, B., & Okello, J. (2011) *Stimulating smallholder investments in sustainable land management: Overcoming market, policy and institutional challenges.* In: Bluffstone, R. and Kohlin, G. Determinants of investments in sustainable agriculture in East Africa, Resources for the Future Press.

[67] Scheffran, J., Marmer, E., & Sow, P. (2012). Migration as a contribution to resilience and innovation in climate adaptation: Social networks and co-development in Northwest Africa. *Applied Geography,* 33, 119-127.

[68] Seo, N., Mendelsohn, R., Dinar, A., Hassan, R., & Kurukulasuriya, P. (2009). A ricardian analysis of the distribution of climate change impacts on agriculture across agro-ecological zones in Africa. *Environmental Resource Economics,* 43, 313-332. DOI:10.1007/s10640-009-9270-z.

[69] Shad, S.M., Marvili, D.M., Farsani., A.P. (2013). Zoning droughts by standardized precipitation index in Esfahan province (IRAN), *International Journal of Advanced Biological and Biomedical Research*, 1(5), 2013, 477-481. Available from: http://www.ijabbr.com.

[70] Shahid, S., & Behrawan, H. (2008). Drought risk assessment in the western part of Bangladesh. *Natural Hazards,* 46, 391-413.

[71] Shiferaw, B., Tesfaye, K., Kassie, M., Abate, T., Prasanna, B.M., & Menkir, A. (2014). Managing vulnerability to drought and enhancing livelihood resilience in sub-Saharan Africa: Technological, institutional and policy options. *Weather and Climate Extremes,* 3, 67-79.

[72] Singh, M. (2006). *Indentifying and assessing drought hazard risk in Africa.* Regional Conference on Insurance and Reinsurance for Natural Catastrophe Risk in Africa, Casablanca, Morocco, November 12-14th 2006.

[73] Taylor, R.G., Rose, N.L., Mackay, A.W., Panizzo, V., Mileham, L., Ssemmanda, I., Tindimugaya, C., Nakileza, B., Muwanga, A., & Hau, J. (2007). *Climate change and the aquatic ecosystems of the Rwenzori Mountains.* Uganda final report to the Royal Geographical Society. Environmental Change Research Centre Research Report No.113 ISSN: 1366-7300 Environmental Change Research Centre University College London Pearson Building, Gower St London, WC1E 6BT

[74] Türkes, M. (1996). Spatial and temporal analysis of annual rainfall variations in Turkey. *International Journal of Climatology,* 16, 1057-1076.

[75] UNDP (2007). Human development report 2007/2008: *Fighting climate change: Human solidarity in a divided world.* New York, USA: United Nations Development Programme.

[76] United Nations (1993). *System of National Accounting handbook on integrated environmental and economic accounting.* New York: Statistical Office of the United Nations, Series F (No. 61).

[77] UNSD (2012). System *of environmental-economic accounting for water (SSEA-Water).* UN Statistics Division, New York, USA. Available from: http://unstats.un.org/unsd/envaccounting/seeaw/seeawaterwebversion.pdf. (Accessed 04^{th} July 2014).

[78] UN-Water (2006). *Coping with water scarcity: A strategic issue and priority for system-wide action.* http://waterwiki.net/images/9/92/UN_Water_-_waterscarcity_leaflet.pdf. (Accessed: 3^{rd} July 2012).

[79] WMO (2012). *Standardized precipitation index user guide.* WMO-No. 1090, World Meteorological Organisation. Available: http://www.wmo.int/drought.

[80] World Bank (2005). *Managing water resources to maximize sustainable growth: A country water resources assistance strategy for Ethiopia.* The World Bank, Washington D.C.

[81] World Bank (2007). *World development report 2008: Agriculture for development.* The World Bank, Washington D.C.

[82] World Bank (2006). *Where is the wealth of nations? Measuring capital for the 21st Century.* The World Bank, Washington D.C.

[83] World Bank (2012). *Turn down the Heat: Why a $4^{\circ}C$ warmer world must be avoided.* A report for the World Bank by the Potsdam Institute for Climate Impact Research and Climate Analytics.

[84] Wu, H., Hayes, M.J., Wilhite, D.A., & Svoboda, M.D. (2005). The effect of the length of record on the standardized precipitation index calculation. *International Journal of Climatology,* 25, 505-520.

[85] Ziervogel, G.A.O., Nyong, B., Osman, C., & Conde, C. (2006). *Climate variability and change: Implications for household food security.* AIACC Working Paper No. 20. Available from: www.aiaccproject/working_papers/working%20Papers/AIACC_WP_20_Ziervogel.pdf.

[86] Zimmerman, F.J., & Carter, M.R. (2003). Asset smoothing, consumption smoothing and reproduction of inequality under risk and subsistence constraints. *Journal of Development Economics,* 71, 233-260.

Table 1: Trends in Household poverty in Uganda

Location	Population share		Mean CPAE		Poverty headcount	
	2005/06	2009/10	2005/06	2009/10	2005/06	2009/10
National	**100**	**100**	**55,092**	**62,545**	**31.1**	**24.5**
Residence						
Rural	84.6	85.0	47,031	52,467	34.2	27.2
Urban	15.4	15.0	99,525	119,552	13.7	9.1
Region						
Central	29.2	26.5	79,830	100,441	16.4	10.7
Eastern	25.2	29.6	44,759	49,697	35.9	24.3
Northern	19.7	20.0	31,329	38,988	60.7	46.2
Western	25.9	24.0	55,325	56,232	20.5	21.8
Region (Rural/Urban)						
Central (R)	20.6	17.3	62,759	77,204	20.9	13.5
Central (U)	8.6	9.1	120,807	144,604	5.5	5.1
Eastern (R)	23.2	27.3	41,584	47,616	37.5	24.7
Eastern (U)	2.0	2.3	82,147	74,748	16.9	18.7
Northern (R)	16.9	18.1	28,449	35,996	64.2	49.0
Northern (U)	2.8	1.9	48,603	67,216	39.7	19.7
Western (R)	23.9	22.3	51,894	52,538	21.4	23.1
Western (U)	2.0	1.7	96,959	104,124	9.3	4.2

Source: Computations from UBOS Uganda National Household Surveys.

Table 2: Households' exposure to climate shocks and stresses (Percentages)

Climatic shocks and stresses	2005/06	2009/10	2010/11	2011/12
Droughts	39.8	45.8	45.9	43.3
Floods	13.8	2.1	6.5	11.3
Landslides	N/A	0.8	0.5	1.3
Crop pests and diseases	9.5	4.6	2.6	4.7
Livestock diseases	5.9	2.8	2.4	2.4

Source: (UBOS, 2012): Uganda National Panel Survey data.

Table 3: Water demand estimates and projections against the standard benchmarks for water stress[b]

Year	Water demand projections (Millions m^3)		Benchmarks for water stress	
	Total water demand	Available water percapita (m^3)	Annual renewable fresh water percapita (m^3)	Stress level
2009	707	2,171	>1,700	Occasional water stress
2015	994	1,740	1,000-1,700	Regular water stress
2020	1,266	1,480	500-1,000	Chronic water shortage
2035	2,113	896	<500	Absolute water scarcity

Notes: [b] Conventional definitions of water stress following Falkenmark and Widstrand (1992).
Source: MWE (2009) and FAO (2012).

Table 4: Site characteristics of the selected meteorological stations across Uganda (1980-2011)

Station ID	Station name	Latitude	Longitude	Elevation	District	Basin
North						
87320000	Gulu	02 47 N	032 17 E	1105	Gulu	Aswa
86300000	Arua	03 02 N	030 52 E	1280	Arua	Albert Nile
86320000	Kitgum	03 18 N	032 53 E	938	Kitgum	Aswa
87320390	Lira	02 17 N	032 56 E	1300	Lira	Aswa
East						
88330060	Soroti	01 43 N	033 37 E	1132	Soroti	Lake Kyoga
89330430	Jinja	00 28 N	033 11 E	3840	Jinja	Lake Victoria
Central						
89320660	Entebbe	00 03 N	032 27 E	1155	Mpigi	Lake Victoria
89320670	Namulonge	00 32 N	032 37 E	1130	Mpigi	Lake Victoria
	Makerere	00 20 N	032 34 E	1190	Kampala	Lake Victoria
West						
89300630	Kasese	00 11 N	030 06 E	691	Kasese	Lake Edward
91290000	Kabale	01 15 S	029 59 E	1869	Kabale	Lake Victoria
90300030	Mbarara	00 36 S	030 41 E	1420	Mbarara	Lake Victoria
88310030	Masindi	01 41 N	031 43 E	1147	Masindi	Lake Albert

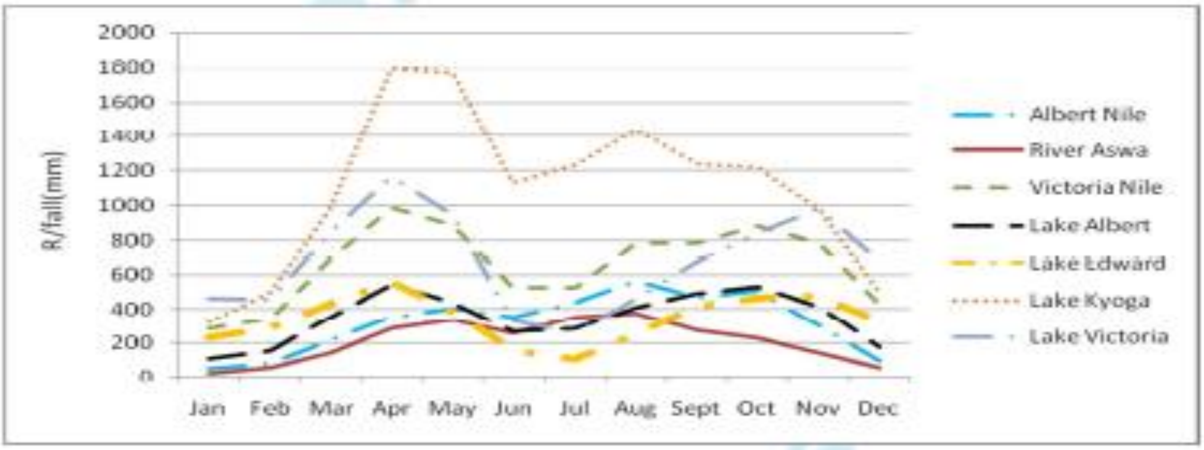
Source: Department of Meteorology

Table 5: Benchmark values for SPI interpretation

SPI Value	Nominal SPI Class
2 above	Extremely wet
1.5-1.99	Very wet
1-1.49	Moderate wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 above	Extremely dry

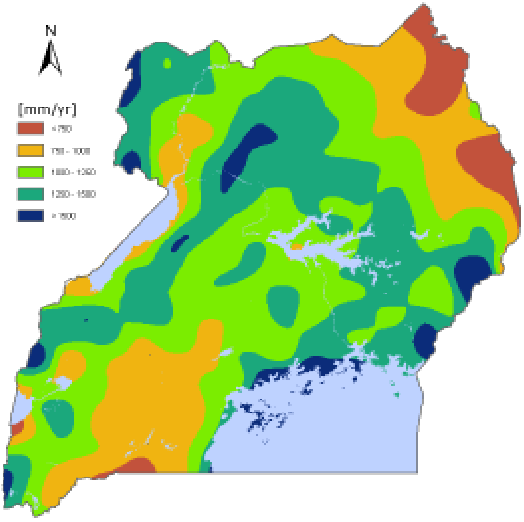
Source: World Meteorological Organization, (2012).

Figure 1: Average monthly rainfall for the seven Sub-basins (1940-2009)



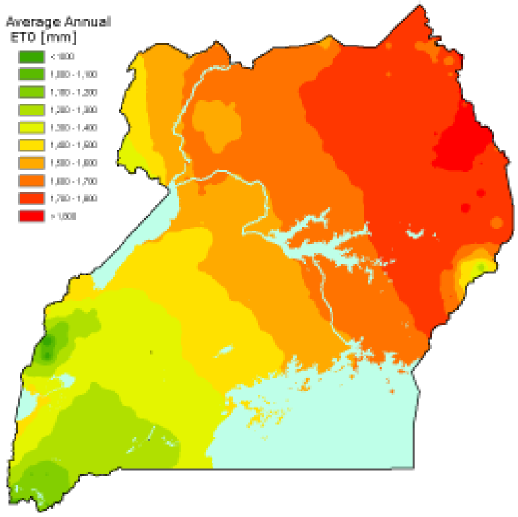
Source: Nsubuga et al. (2014)

Figure 2: Average annual rainfall



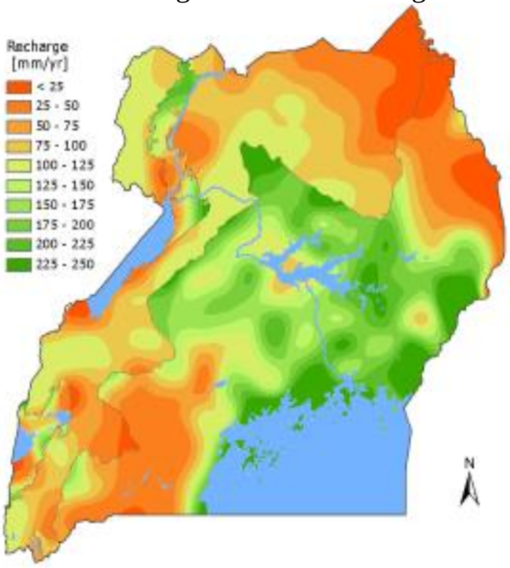
Source: DWRM (2011)

Figure 3: Average annual evapo-transpiration



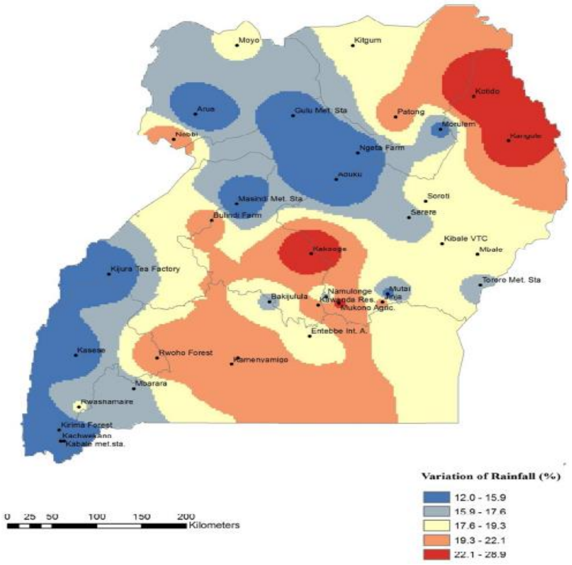
Source: DWRM (2011)

Figure 4: Annual ground water recharge



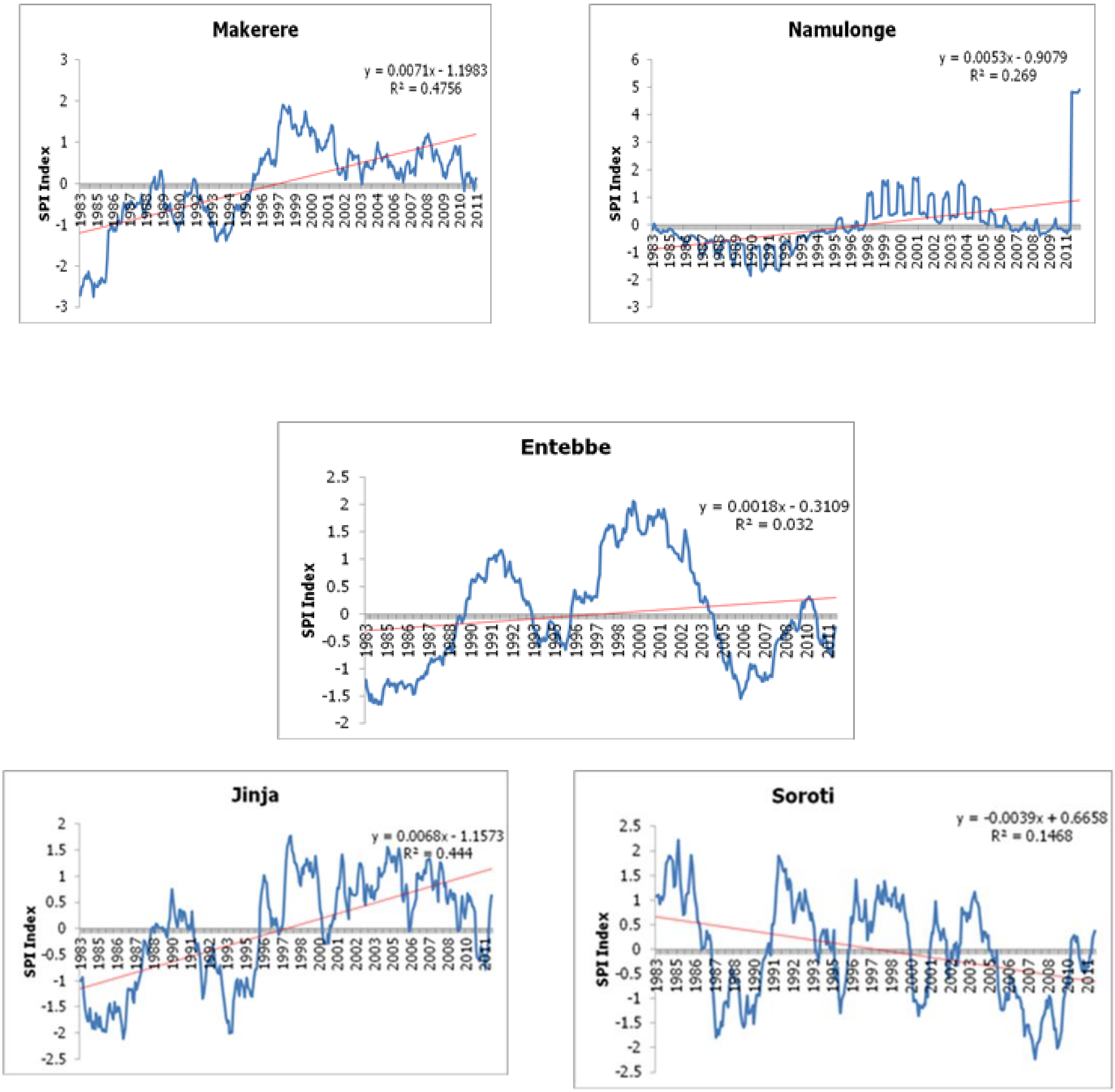
Source: DWRM (2011)

Figure 5: Regional rainfall distribution



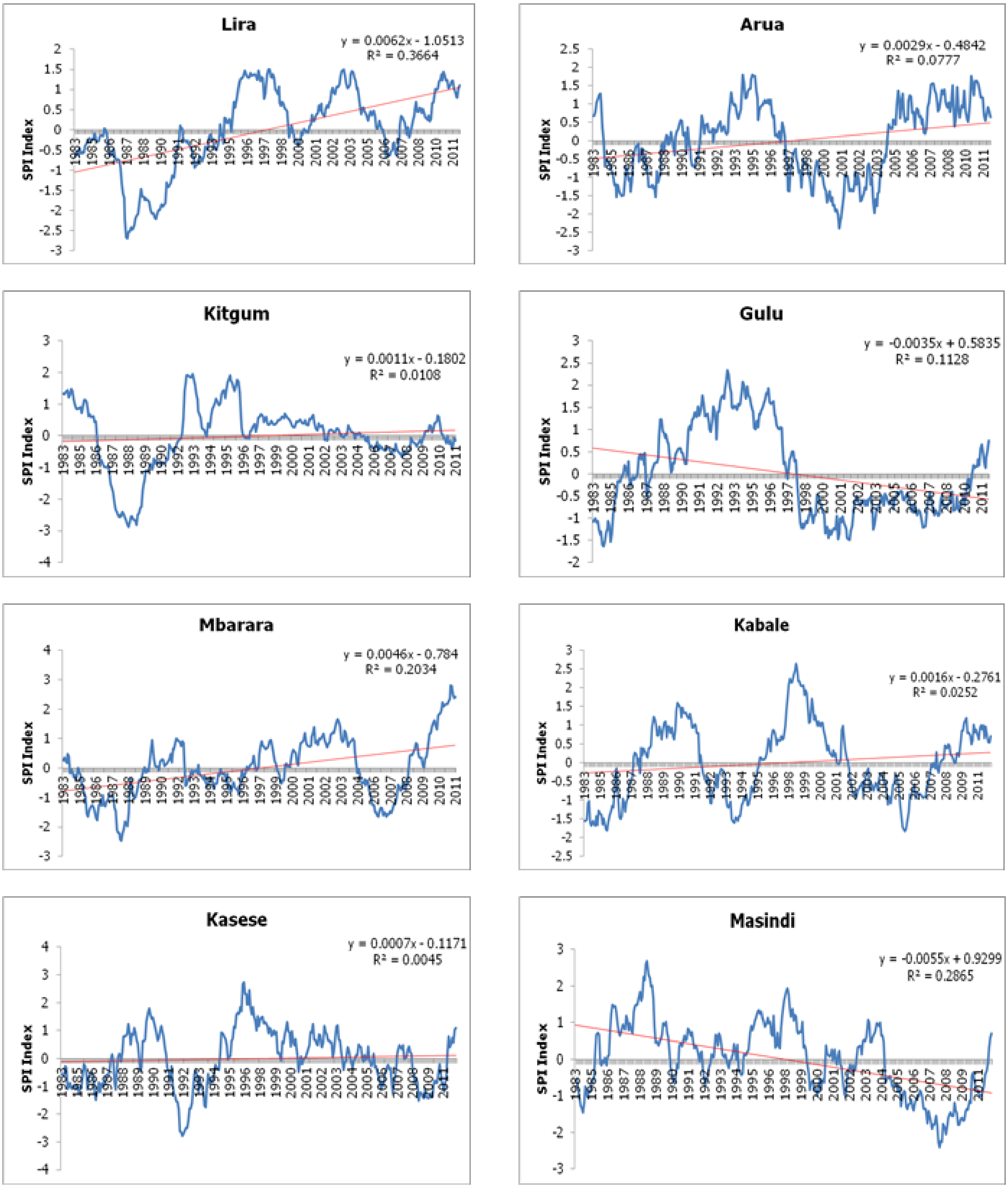
Source: Nsubuga et al. (2014)

Figure 6: Time series and trends for the SPI coefficients for the selected stations in the East and Central regions



Notes: The stations for Central region include (Makerere, Entebbe and Namulonge), while the Eastern region include (Jinja and Soroti).

Figure 7: Time series and trends for the SPI coefficients for the selected stations in the North and Western regions.



Notes: The stations for northern region include (Arua, Lira, Kitgum, and Gulu), while the western region includes (Mbarara, Kabale, Kasese and Masindi).