DISASTERS AND CLIMATE RESILIENCE IN UGANDA: PROCESSES, KNOWLEDGE AND PRACTICES

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CHAPTER XI: METEOROLOGICAL DROUGHT OCCURRENCE AND SEVERITY IN UGANDA[1]

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ABSTRACT
Precipitation, a very important weather parameter is often variable, resulting into droughts and floods as extreme weather events in Uganda. These are causing great economic impact especially on agriculture and water resources. Meteorological drought is a creeping hazard; it develops slowly and has a prolonged existence leading to the development of other drought types such as agricultural and hydrological drought. Despite meteorological drought being a major concern in Uganda, drought occurrence and severity is not been well documented. This study determined the occurrence of meteorological drought and assessed the magnitude of its severity in Uganda. The rainfall deciles method was used to analyse monthly rainfall data for 40 years (1943-1982) in the 16 climatological homogenous zones of Uganda. Seven of the 16 climatological zones were identified as drought prone (CE, CW, E, G, H, ME, MW). The annual and monthly rainfall ranges for identification of drought were 274–1157 mm and 10–94 mm respectively. The occurrence of drought oscillated within 10-15 drought events per 5-years over the assessed period while the average drought event interval in any drought prone zone was 1-6 years with an average dominancy in occurrence of 1-year. The event interval for drought to occur concurrently in all the drought prone zones in a year was 12½ years. Severe drought was dominant in zone H with 22.5% occurrences during the December-February season whose drought rainfall range was ≤ 10 mm. The drought prone zones experience a moderate type of drought with highest occurrences (62.5%) in zone MW during the September-November season with a drought rainfall range of > 114 < 150 mm. Zone CW was the only zone that recorded drought with ‘extreme’ drought with 2.5% occurrences. It is therefore imperative that drought management is approached from a prioritization perspective focusing on the hotspot locations experiencing high occurrence of different drought types. Drought managers and decision makers consider using annual and monthly drought rainfall ranges of all the drought prone climatological zones for drought monitoring on an annual and seasonal basis in Uganda.

Key words: meteorological drought, rainfall deciles, drought occurrence, drought severity, climatological zone

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Introduction

In the tropics, precipitation in the form of rainfall is the climatic element with the greatest economic significance especially for agriculture and water resources. Variations in rainfall amounts over seasons have led to droughts or floods as extreme weather events. These extreme weather events have rigorous negative impacts on key socio-economic sectors of a country/region. Bring out some of the impacts/losses and how dangerous they are; here. This is gist of this paragraph

Conceptually, drought describes a situation of limited rainfall substantially below what has been established as a 'normal' value for the area concerned, leading to adverse consequences for human welfare. Considering its complex nature and wide variation across time and space, it is somewhat impractical to develop a universally applicable definition of drought. The definition also depends on the disciplinary perspective. Three such definitions based on meteorological, hydrological and agricultural perspectives are available (Panu & Sharma, 2002). This study considered the meteorological definition of drought in its assessment. It occurs when precipitation received is below the expected normal/actual amount (Van Loon & Van Lanen, 2012; Smakhtin and Hughes, 2004). Meteorological drought usually precedes the other kinds of drought (Tate & Gustard, 2000); thus it is undoubtedly one of man's worst natural enemies. Its beginning is subtle, its progress is insidious and its effects can be devastating.

Meteorological drought may start any time, last indefinitely and attain many degrees of severity. It can also occur in any region of the world, with an impact ranging from slight personal inconvenience to endangering nationhood (Abdou, 2012). The economic, social and environmental impacts of drought are cumulative and vary greatly according to the prevailing climatic conditions and national wealth/vulnerability of the society to the event. The effects are most evident in the Least Developed Countries (LDCs) that have the least capacity to prepare and build resilience. Various sectors are affected including agricultural, industrial, municipal, and recreational (Schipper, 2003). As meteorological drought takes on a description of a deficiency in rainfall below the normal; the extent of rainfall received recorded as below the normal is not uniform temporally and spatially (Logan, Brunsell, Jones, & Feddema, 2010). This creates a difference in the magnitude of severity of drought hence classifying them as 'moderate', 'severe' and 'extreme' (Gibbs and Maher, 1967). The variability in the magnitude of drought severity, therefore also calls for dynamic approaches in managing drought impacts. At a global scale, more people are affected by drought than any other natural disaster (Hewitt, 2014; Guha-Sapir, Vos, Below, & Ponserre, 2011). Drought can have a substantial impact on the ecosystem and agriculture of the affected region. Although droughts can persist for several years, even a short, intense drought can cause significant damage and harm the local economy. Such impacts include loss of fertile soils, mass migration, death due to famines and scarcity in water, economical loss, among others (Australian Bureau of Statistics, 2004; Nicholls, 2004; Davis, 2001).

In Uganda drought has been manifested through the migrations of pastoralists in search for water for survival of their animals. Drought has caused withering of crops hence a shoot up of food prices including beans, meat, maize and milk products as a result of water scarcity to produce adequate food and livestock, leading to malnutrition of tens of thousands of people (MAAIF, 2002). Drought has also resulted into parched fields, dusty roads and failures in water supply in some regions. In its extremes, drought has caused hunger, famine, starvation and hence human death, increase in production costs, among others (NEMA, 2010; UNEP & ICRAF, 2006). On the other hand, the efforts of the government to encourage food production and fight poverty are being let down by limited prediction of the occurrence and duration of extreme weather conditions in the country. This has led to failure of prioritising regions with more frequent and disastrous droughts particularly during emergency assistance. In addition, it has led to inadequate proactiveness to mitigate the impacts of drought among the most vulnerable populations.

Drought is also one the most potent challenges that the dryland ("cattle corridor") areas of Uganda grapple with from to time to time (Water Resources Management Department, 2003). However, the magnitude, severity and hotspot locations of drought are not well documented. This study therefore assessed the occurrence and magnitude of severity of meteorological drought in Uganda through the identification of areas in Uganda prone to meteorological drought. Monthly and annual drought occurrence were also determined and the magnitude of severity of meteorological drought in the identified drought prone areas was assessed.

Understanding the dimensions of Drought

According to Palmer (1965), drought means various things to various people depending on their specific interests. To the farmer drought means a shortage of moisture in the root zone of his crops. To the hydrologist, it suggests below average water levels in the streams, lakes, reservoirs, and to the economist, it means a shortage which affects the established economy. FAO (2004) defined a drought as a departure from the average or normal conditions, sufficiently prolonged (1-2 years) as to affect the hydrological balance and adversely affect ecosystem functioning and the resident populations.

Because drought affects so many economic and social sectors, scores of definitions have been developed by a variety of disciplines. In addition, because drought occurs with varying frequency in nearly all regions of the globe, in all types of economic systems, and in developed and developing countries alike, the approaches taken to define it also reflect regional differences as well as differences in ideological perspectives. Impacts also differ spatially and temporally, depending on the societal context of drought. A universal definition of drought would therefore be an unrealistic expectation (Wilhite, 2000).

Definitions of drought can be categorized broadly as either conceptual or operational. Conceptual definitions are of the dictionary type, generally defining the boundaries of the concept of drought, and thus are generic in their description of the phenomenon. For example, the American Heritage Dictionary defines drought as a long period with no rain, especially during a planting season. Operational definitions attempt to identify the onset, severity, continuation, and termination of drought episodes. Definitions of this type are often used in an operational mode. These definitions can also be used to analyse drought frequency, severity, and duration for a given historical period. An operational definition of agricultural drought might be one that compares daily precipitation to evapo-transpiration (ET) rates to determine the rate of soil water depletion and then expresses these relationships in terms of drought effects on plant behaviour at various stages of development. The effects of these meteorological conditions on plant growth would be re-evaluated continuously by agricultural specialists as the growing season progresses.

Drought is generally reviewed as a sustained and regionally extensive occurrence of appreciably below average natural water availability, either in the form of precipitation, river runoff or groundwater (Hounam et al, 1975). It is a temporary feature caused by climatic fluctuations. The basic cause of drought is not only insufficient precipitation. Depending on the definition used, such as one based on available water, the arid zones of the world would be regarded as almost permanently drought-stricken, but by reference to normal rainfall, they could be classified as no more subject to drought than some heavy rainfall areas (Hounam et al, 1975). The many definitions lead to drought being grouped by type as follows: meteorological, hydrological, agricultural, and socio-economic. These classifications are done according to a number of criteria involving several variables, used either alone or in combination of rainfall, temperature, humidity, evaporation from free water, transpiration from plants, soil moisture, wind, river and stream flow, and plant condition. Generally droughts are grouped basing on, causes, physical characteristics and impact on society (Hounam et al, 1975)

Droughts are perceived as extreme events in climatic systems, whereas in reality they need be recognized as normal occurrences. They have occurred many times already and will continue to occur; yet, due to growing water needs, their adverse consequences are likely to increase in the future (Wilhite and Glantz 1985). Therefore, drought impacts should be handled using the risk-based approach rather than the crisis-based approach.

Numerous definitions tend to consider them as either a natural phenomenon or a hazard to human activities, especially agriculture. Schneider (1996) defines drought as an extended period, a season, a year, or several years of deficient rainfall relative to the statistical multi-year mean for a region. Drought is a natural hazard that can lead to a disaster. On the other hand Tannehill (1947) defined drought as a deficiency of rainfall from expected or normal that, when extended over a season or longer period of time is insufficient to meet the demands of human activities. Bureau of Meteorology (2006) also defined a drought as a prolonged, abnormally dry period when there is not enough water for users' normal needs.

Drought also means scarcity of water, which adversely affects various sectors of human society, e.g. agriculture, hydropower generation, water supply, industry (Kundzewicz, 1997). In this study, drought was mainly regarded as a natural hazard/phenomenon rather than one affecting human activities.

As stressed by Hagman (1984) and Wilhite (2000) drought is a very complex phenomenon and it remains a poorly understood climatic hazard. It installs itself slowly and it is often difficult to detect its onset until some major impacts such as lack of water and food, starts to be noticed. Its effects are cumulative. Bryant (1991) ranked 31 different natural hazards ranging from drought to rock-falls. Drought was clearly the most severe natural hazard in terms of duration, spatial extent and impact.

Drought vs. Aridity

Aridity applies to the situation where there is a high probability of rainfall below a low threshold for a long and indeterminate duration. It refers to the average conditions of limited rainfall and water supplies, not to the departures from the norm, which define a drought (Jackson, 1989).

Drought occurs when there is a low probability of rainfall for a given period below an arbitrarily low threshold (Coughlan 1985). Thus, in arid areas or areas that have marked dry seasons, provided there is a good long-term rainfall record, it is clearly possible to distinguish drought when it occurs in spite of the prevailing regime of low rainfall.

A combination of droughts or sequence of droughts, and human activities may lead to desertification of vulnerable arid, semiarid and dry sub-humid areas whereby soil structure and soil fertility are degraded and bio-productive resources decrease or disappear (Kundzewicz, 1997).

Types of Droughts

Wilhite and Glantz (1985) recognize four types of drought including meteorological, hydrological, agricultural and socio-economic. However, other classifications have also included soil moisture and ecological droughts.

Meteorological drought

Meteorological drought occurs when there is a deficit in the actual amount of precipitation received and the amount that may normally be expected for an extended duration (precipitation received is far below the expected normal). It is dependent in its determination on rainfall falling below threshold levels that are determined from long-term rainfall records. Smakhtin and Hughes (2004) simply consider that meteorological drought is brought about when there is a prolonged period with less than average or expected precipitation. It usually precedes the other kinds of drought (Wilhite and Glantz, 1985).

Definitions of meteorological drought must be considered as region specific since the atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region. For example, some definitions differentiate meteorological drought on the basis of the number of days with precipitation less than some specified threshold. Extended periods without rainfall are common for many regions; such a definition is unrealistic in these instances. Other definitions may include actual precipitation departures to average amounts on monthly, seasonal, year, or annual time-scales (National Weather Service, 2004).

Definitions derived for application to one region usually are not transferable to another since meteorological characteristics differ. Human perceptions of these conditions are equally variable. Both of these points must be taken into account in order to identify the characteristics of drought and make comparisons between regions (Wilhite and Glantz, 1985). This study considered Uganda as one region and assessed meteorological drought rather than any other type of drought because it is the initial type of drought hence its assessment is crucial to better examine the other types of drought.

Hydrological drought

This occurs when the amount of precipitation in a region is insufficient to maintain normally expected flows in stream/river systems or normally expected levels or volumes in lakes/reservoirs systems (NDMC, 2005) like the lowering of Lake Victoria levels and inadequate filling of reservoirs and tanks. Definition of hydrological drought revolves around the effects of dry spells on surface or subsurface waters. Hydrological drought is a period during which stream flows are inadequate to supply established uses under a given water management system (Linsley, et al. 1975).

If the actual flow for a selected period of time falls below a certain threshold, then hydrological drought is considered to be in progress. Such a threshold level can be defined based on the flow characteristics or the water demand scenario of the place and/or basin under consideration. It is brought about when the water available in sources such as aquifers, lakes and reservoirs fall below the average. It is the deficit of runoff into rivers and other surface water resources and in groundwater resources. It involves the description of availability of water, in the form of precipitation runoff, evaporation, infiltration, river systems, and other surface/groundwater inflow/outflow systems, which may be included in the hydrological water balance equation. Thus hydrological droughts are related more with the effects of periods of precipitation shortfall on surface or subsurface water supply (i.e. stream flow, reservoir and lake levels) rather than precipitation shortfalls (National Weather Service, 2004).

Agricultural/ Soil moisture drought

Agricultural drought is typically defined as a period when soil moisture is inadequate to meet evapo-transpirative demands so as to initiate and sustain crop growth (NDMC, 2005; Changnon, 1987). This is related to physiological drought, which is determined from conditions of natural vegetation, crops, livestock, pastures and other agricultural systems. It is a measure of the availability of soil water to plants or animals. It is usually measured by the effects of water deficit in terms of economic losses to agriculturalists. The economic loss terms can include factors like drop in crop production, livestock deaths, industrial losses; plants not planted or replanted changes in land use, emergency relief expenses, as well as losses incurred after the agricultural drought (e.g. losses through wind and water erosion).

Socioeconomic drought

This kind of drought associates the supply and demand of some economic good or service with elements of meteorological, hydrological, and agricultural drought. Some scientists suggest that the time and space processes of supply and demand are the two basic processes that should be included in an objective definition of drought. For example, the supply of some economic goods (e.g. use of water, hay, and electric power in a region) is weather dependent. In most instances, the demand for such goods increases as a result of increasing population and/or per capita consumption. Therefore, drought could be defined as occurring when the demand for an economic good exceeds supply as a result of a weather-related shortfall in water supply (Smakhtin and Hughes, 2004).

Ecological drought

Ecological drought may be considered as the last stage, which comes as the environment gets perpetually stressed when the productivity of the natural eco-system fails. Here cattle eat up even the roots of the grass and trees are cut down to make charcoal for income; even when the rains come, the pasture cannot recover. This can then lead to increasing land degradation and eventually desertification. The longer the drought takes, the more the natural environment transforms. People lose their livelihoods and even migrate (NDMC, 2005).

Common to all types of drought is the fact that they originate from a deficiency of precipitation resulting from an unusual weather pattern. If the weather pattern lasts a short time (say, a few weeks or a couple months), the drought is considered short-term. But if the weather or atmospheric circulation pattern becomes entrenched and the precipitation deficits last for several months to several years, the drought is considered to be a long-term drought. It is possible for a region to experience a long-term circulation pattern that produces drought, and to have short-term changes in this long-term pattern that result in short-term wet spells. Likewise, it is possible for a long-term wet circulation pattern to be interrupted by short-term weather spells that result in short-term drought (NDMC, 2005).

Time Scales of Droughts

The most commonly used time scale in drought analysis is the year followed by the month (Sen, 1980; Bonacci, 1993; Sharma, 1997). Although the yearly time scale is rather long, it can be used to abstract information on the regional behaviour of droughts. The monthly time scale seems to be more appropriate for monitoring drought effects in situations related to agriculture, water supply and groundwater abstractions. For studying the behaviour of short-term droughts within a year or a season, the daily time scale has also been used (Gupta, 1975; Smart, 1983; Zelenhasic, 1987; Sharma, 1996; Tallaksen et al, 1997). This study considered both the annual and monthly time scales in data analysis; the annual to identify the drought prone climatological zones in Uganda and duration of drought on an annual basis, and the monthly to determine the drought months, duration of drought on a monthly basis and the severity of drought.

Drought Variables

Dracup et al. (1980) defines a drought variable as a prime variable responsible for assessing drought effect, and is considered a key element in defining drought and deciding on the techniques for its analysis. The determinant variable for the meteorological drought is precipitation/rainfall, whereas for the hydrological drought it is either river runoff/stream-flow or reservoir levels and/or groundwater levels. For agricultural drought, the governing variables are soil moisture and/or consumptive use. Therefore, the time series of the above variables provide the framework for evaluating the drought parameters of interest (Dracup et al., 1980).

Drought Indices

A drought index or a drought indicator value is typically a single number, far more useful than raw data for decision making (Hayes, 1998). There are several indices that measure how much precipitation for a given period of time has deviated from historically established norms. Drought indices are used to determine the thresholds, the severity, the duration, the position, and the probability of occurrence and the spatial extent of drought episodes (Hayes, 1998).

None of the indices is inherently superior to the rest in all circumstances; some indices are better suited than others for certain uses (Hayes, 1998). For example, the **Palmer Drought Severity Index (PSDI)** created by Palmer (1965) is a measurement of dryness based on recent precipitation and temperature. The Palmer Drought Index is based on a supply-and-demand model of soil moisture. The index has proven most effective in determining long-term drought — a matter of several months — and not as good with conditions over a matter of weeks. However, critics have complained that the utility of the Palmer index is weakened by the arbitrary nature of Palmer's algorithms, including the technique used for standardization. The Palmer index's inability to account for snow and frozen ground also is cited as a weakness. Palmer values may also lag emerging droughts by several months; it is complex and has an unspecified, built-in time scale that can be misleading and less well suited for mountainous land or areas of frequent climatic extremes, hence the PSDI is better when working with large areas of uniform topography (Palmer, 1965).

The **Standardized Precipitation Index (SPI)** developed by McKee et al. (1993), is a probability index that considers only precipitation. The SPI is an index based on the probability of recording a given amount of precipitation, and the probabilities are standardized so that an index of zero indicates the median precipitation amount (half of the historical precipitation amounts are below the median, and half are above the median). The index is negative for drought, and positive for wet conditions. As the dry or wet conditions become more severe, the index becomes more negative or positive. It has a temporal flexibility that is useful in both short-term agricultural and long-term hydrological applications. However, values based on preliminary data may change (McKee et al., 1993).

Another index used in drought analysis is the **Percent of Normal**. It is calculated by dividing actual precipitation by normal precipitation, typically considered to be a 30-year mean and multiplying by 100%. This can be calculated for a variety of time scales. Usually these time scales range from a single month to a group of months representing a particular season, to an annual or water year. Normal precipitation for a specific location is considered to be 100%. One of the disadvantages of using the percent of normal precipitation is that the mean, or average, precipitation is often not the same as the median precipitation, which is the value exceeded by 50% of the precipitation occurrences in a long-term climate record. The reason for this is that precipitation on monthly or seasonal scales does not have a normal distribution. Use of the percent of normal comparison implies a normal distribution where the mean and median are considered to be the same. Because of the variety in the precipitation records over time and location, there is no way to determine the frequency of the departures from normal or compare different locations. This makes it difficult to link a value of a departure with a specific impact occurring as a result of the departure, inhibiting attempts to mitigate the risks of drought based on the departures from normal and form a plan of response (Willeke et al., 1994).

The **Deciles drought analysis method** developed by Gibbs and Maher (1967) arranges precipitation data into deciles. The median (middle) rainfall value gives a better guide in that rainfall can be expected to be less than the median in half of all years and more than the median in the other half. Deciles are an extension of this concept. Instead of dividing ranked rainfall records into two groups to give below and above median rainfall categories, ranked rainfall records are divided into 10 groups, to give a wider range of rainfall categories relative to a defined average range.

The Deciles method divides the distribution of occurrences over a long-term precipitation record into tenths of the distribution, each of these categories called a *decile* as shown in Table 1.The deciles method is relatively modest to calculate and requires only rainfall data and fewer assumptions than any other drought severity index (Smith et al., 1993). It provides an accurate statistical measurement of precipitation and does not require normality of the data distribution, allowing its use at different time scales though accurate calculations require a long climatic data record (Gibbs and Maher, 1967). The decile method has been selected as the meteorological measurement of drought within the Australian Drought Watch System where it has assisted Australian authorities in determining appropriate drought responses.

Table 1: Decile Classification (Gibbs and Maher, 1967)

Deciles	**Decile Class**
Deciles1-2:	lowest 20% - much below normal
Deciles3-4	next lowest 20% - below normal
Deciles5-6	middle 20% - near normal
Deciles7-8	next highest 20% - above normal
Deciles9-10	highest 20% - much above normal

The deciles drought method also considers classification by ranges. The decile ranges are ranges of values between deciles; thus the first decile range is that below the first decile. The sixth decile range spans the interval between the fifth and the sixth decile (Figure 1).

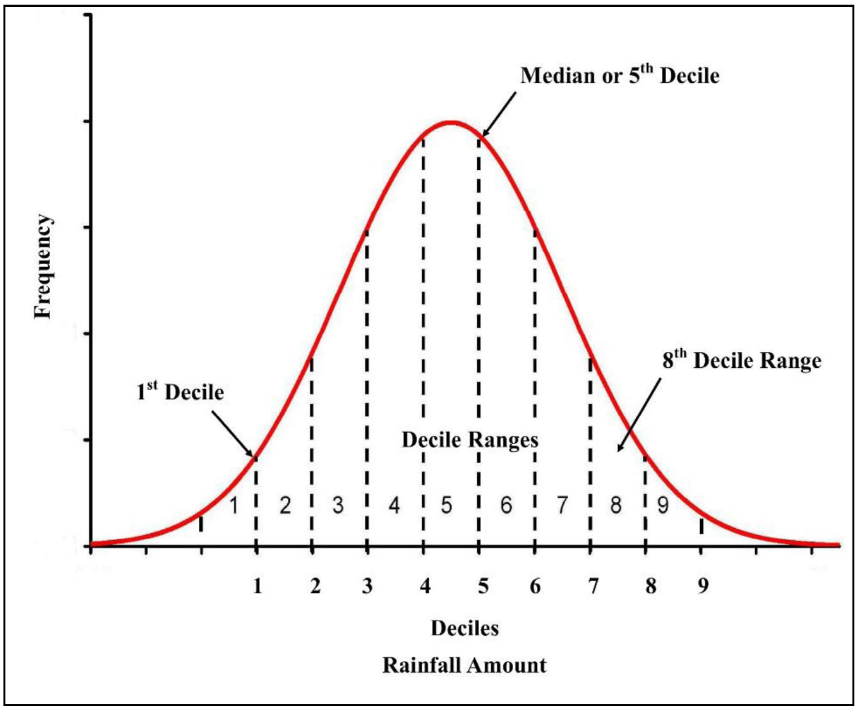


Figure 1: Use of Deciles and Decile Ranges (Gibbs and Maher, 1967)

Deciles also provide a measure of the spread of rainfall experienced in the past. Rainfall in the current year can be compared against decile information to see where it stands in relation to historical records. Deciles can also be used to provide a guide to the likelihood of required rainfall outcomes (Foster, 2002). Arithmetic means (M) and standard deviations (s) can be computed as a measure of dispersion in defining moderate and severe droughts (Gibbs and Maher, 1967) as described in Table 2.

Table 2: Defining Moderate and Severe Droughts (Gibbs and Maher, 1967)

Parameter	**Description**
Arithmetic mean (M)	Normal Rainfall
Standard deviation (s)	Rainfall variability
M-s	All occurrences ≤ M-s indicate moderate droughts
M-2s	All occurrences ≤ M-2s indicate severe droughts

With review of the above drought analysis methodologies, this study adopted the deciles method because of its two-fold advantages; it does not depend on the nature of the distribution as it only states the limits of each ten percent (or decile) of the distribution and it lends itself readily to drought studies (Hayes, 1998).

Materials and Methods

Study Area

Uganda lies within the latitudes $4^0$12'N and $1^0$29'S and longitudes 29^0 34'E and 35^0 0'W. It is a land-locked country located in the eastern part of Africa within the Great Lakes region. Rainfall is the most sensitive climate variable and major determinant of the climatic sub-regions of the country that affects social and economic activities. The major systems controlling rainfall in the country are the Inter – Tropical Convergence Zone (ITCZ), inter-tropical anticyclones, monsoon winds, and the moist westerlies from Congo among several other regional and local factors like water bodies and topographic features.

Rainfall fluctuations in East Africa (Uganda) have had significant short and long-term effects on natural resource systems, particularly lakes, wetlands and rivers. Rainfall over much of Uganda displays a bi-modal regime with rainy seasons in March to May (MAM) and September to November (SON) moderated by coastal and topographic influences (Mutai et al. 1998). The bimodal regime changes gradually into a single season with increasing distance from the equator. The rainfall regimes for both MAM and SON and the transitional periods show varying degrees of influence from the Atlantic, Indian and Pacific oceans. The SON season in East Africa is strongly affected by complex interaction between the Indian and Pacific oceans and exhibits inter-annual variability than MAM. Thus, much of the variation in Uganda rainfall is related to the El Niño Southern Oscillation phenomenon (ENSO).

Data Sources

The study considered assessment of meteorological drought (the initial form of drought that proceeds other types), whose beginning is subtle, progress insidious and has devastating effects. The Meteorological drought variable that was considered in this study was precipitation, specifically rainfall. The 16 homogeneous climatological sub-regions/zones of Uganda (Basalirwa, 1995 and WRMD, 2003) were considered (Figure 2). In each climatic zone, the principal/representative stations were considered for a time period of 40 years (1943-1982 inclusive). The 1943-1982 time period was considered because of the rigorous quality control checks that were done for all the data collected during these years by the Water Resource Management Department (WRMD) and Uganda National Meteorological Authority through the Hydro-climatic study in 2003. The time unit that was used was a month. A greater unit (season or year) may mask the details of rainfall variation while a smaller unit (pentad or dekad) involves multiplication of work quantity beyond the possible means of handling it. Monthly rainfall data (secondary data) for the selected stations in the study area was obtained from the Uganda National Meteorological Authority (UNMA).

Research Approach

This study identified the areas in Uganda prone to meteorological drought by considering the 16 homogeneous climatological zones in Uganda (Basalirwa, 1995 and WRMD, 2003) which was based on deciles values developed by Gibbs and Maher (1967) (Tables 1 and 2).Drought occurrence was one of the meteorological drought characteristics that was considered. It was determined at the monthly and annual time scales. Regression analysis was performed to determine the trends in drought in each climatological zone. Assessment of severity of drought in the drought prone climatological zones of Uganda was considered on a seasonal basis by computing the mean precipitation (M) and standard deviation (s) for each season in each drought prone zone. The frequency of occurrences and mean rainfall for each drought type and season were also determined, tabulated and then represented graphically.

The seasonal classification in Uganda developed by Griffiths (1972) was utilised as:
Season 1: December – February (generally dry period) - DJF
Season 2: March – May ('Long-rains', main rainy season) - MAM
Season 3: June – August (Dry except in Northern Uganda) - JJA
Season 4: September – November ('Short-rains' season) - SON

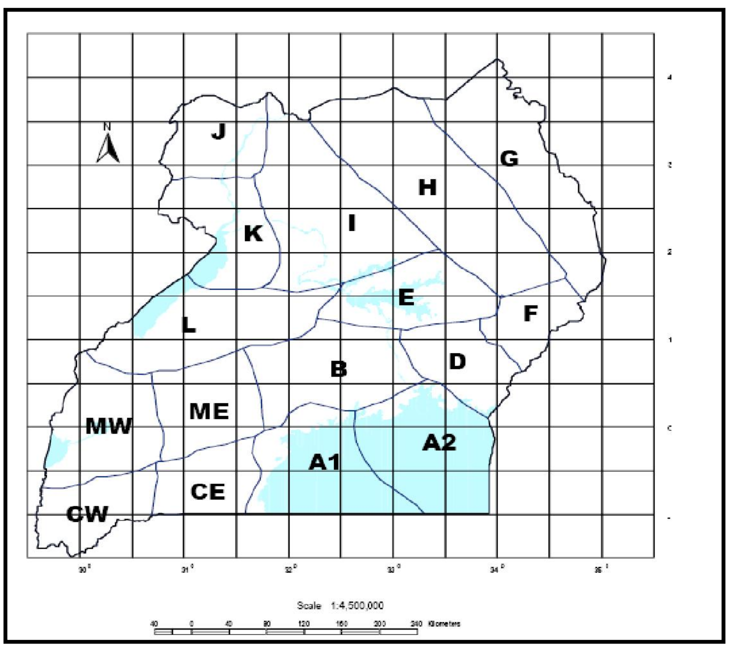


Figure 2: Climatological Zones of Uganda (*Source: Basalirwa, 1995 and WRMD, 2003)*

Results

Drought prone areas of Uganda

There are seven drought pone zones in Uganda. These included zones CE, CW, E, G, H, ME and MW (Figures 3 and 4). These climatological zones showed deciles less than 5; as such they are drought prone. Zones CE, CW, G and ME received "much below normal rainfall" (deciles 1-2) while zones E, H, and MW received "below normal rainfall" (deciles 3-4).

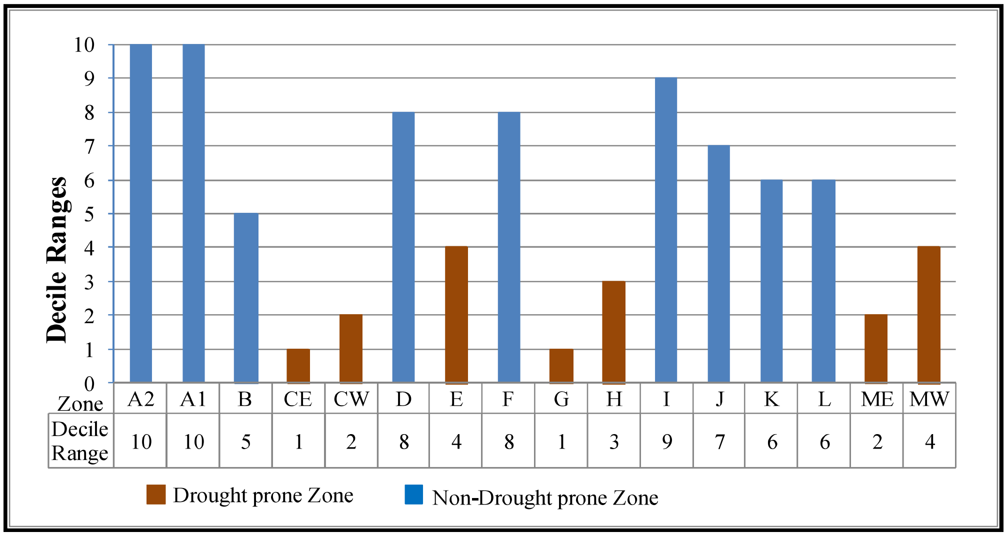


Figure 3: Zone Drought Indices

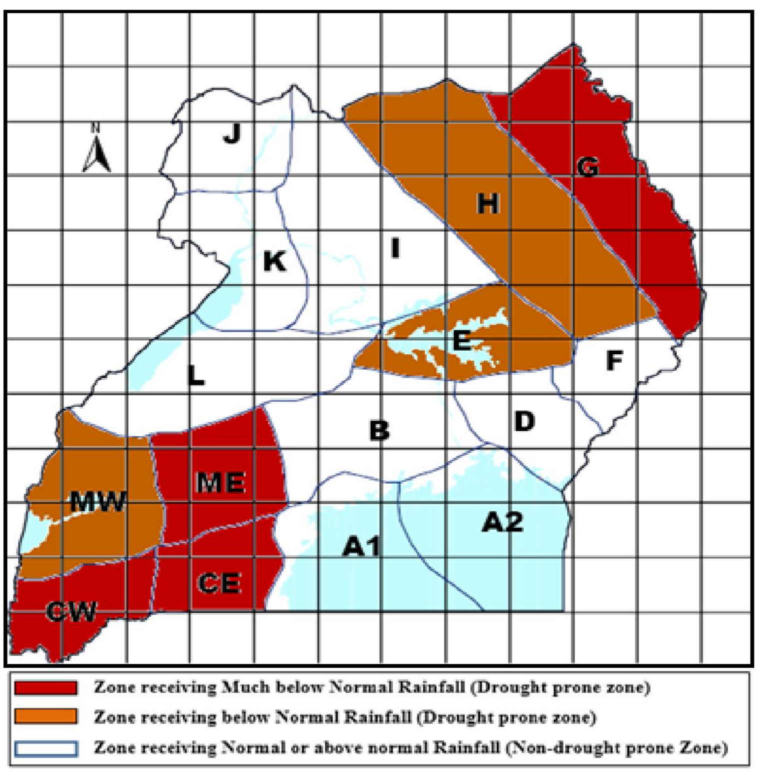


Figure 4: Drought Prone areas of Uganda

Drought Occurrence

Drought was experienced in all the drought prone regions of Uganda in the years of 1952, 1965 and 1979 which showed that drought event interval on an annual basis for all regions to experience drought in a year was about 12.5 years. On the contrary 1947, 1948, 1951, 1961, 1963 and 1977 were not affected by drought, which showed a non-drought event interval for Uganda to range between 1 to 13 years.

Much below normal rainfall was identified in 1952 in zones CW, ME and MW, in 1965 in zones CE, CW, G, H and ME and in 1979 in all the drought prone climatological zones. The 'below normal' deficit in rainfall was experienced in 1952 in zones CE, E, G and H while in 1965 it occurred in zones E and ME. There was no 'below normal' drought classification witnessed in 1979, all the drought prone zones experienced 'much below normal' rainfall. Considering the annual occurrence of drought in the drought prone zones, it shows that the deficit in rainfall increased leading to a 'much below normal' than 'below normal' drought. However, the trend was non-significant in all the climatological zone.

Annual Drought Rainfall Ranges

Table 3 shows that Zone CE had the lowest rainfall amount for the lower boundary for the much below normal class of > 274mm while zone G had the lowest rainfall amount for the upper boundary for the much below normal class of > 614mm. Zone MW and E had the highest annual drought rainfall ranges of > 1093 ≤ 1157mm and > 1074 ≤ 1157mm respectively. For the annual drought rainfall averages zone G had the lowest of 614mm while zone MW had the highest of 1101mm, hence zone G is more drought prone than zone CE though zone CE has the lowest rainfall amount for the lower boundary for the much below normal class.

Table 3: Drought Rainfall Ranges and Averages for each Drought prone zone.

Drought Prone climatological zone	Annual Rainfall Ranges (mm)		
	Much Below Normal	Below Normal	Average
CE	> 274 ≤ 796	> 796 ≤ 840	755
CW	> 823 ≤ 1002	> 1002 ≤ 1090	996
E	> 958 ≤ 1074	> 1074 ≤ 1157	1065
G	> 478 ≤ 614	> 614 ≤ 697	614
H	> 941 ≤ 1075	> 1075 ≤ 1112	1048
ME	> 783 ≤ 930	> 930 ≤ 967	907
MW	> 1040 ≤ 1093	> 1093 ≤ 1157	1101

The annual drought rainfall range for all the drought prone zones is 274 – 1157 mm. The drought rainfall averages in Table 3 shows the thresholds in annual rainfall totals for a year to be considered a drought year; where if rainfall is received equal to or below that annual average of the range in each of the drought prone climatological zone that year could be considered a drought year.

Table 4: Monthly Drought Rainfall Ranges and Occurrence

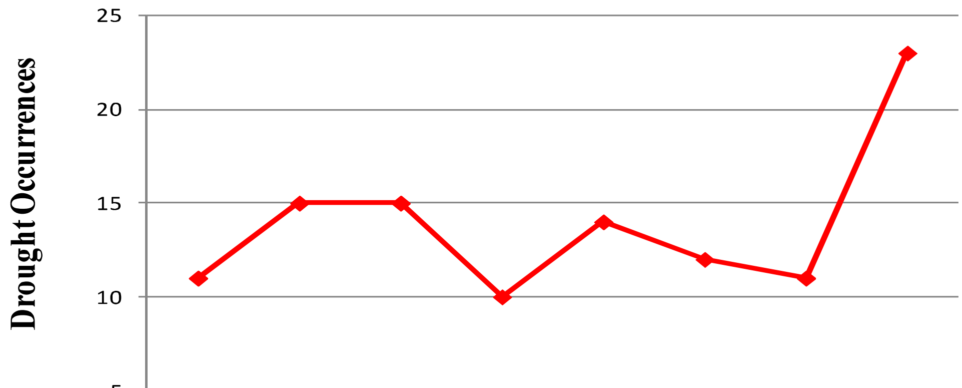
Climatological Zone	Monthly Drought Rainfall Ranges and Occurrences									
	Much Below Normal (deciles 1&2)					Below Normal (deciles 3&4)				
	Month	Mean Rainfall(mm)	Rainfall Range(mm)	Rainfall Occurrences (X/40years)	% Occurrence (X/40)*100%	Month	Mean Rainfall(mm)	Rainfall Range(mm)	Rainfall Occurrences (X/40years)	% Occurrence (X/40)*100%
CE	June	26	> 19 ≤ 42	32	80.0	January	46	> 42 ≤ 59	7	17.5
	July	19		37	92.5	February	59		8	20.0
	August	42		22	55.0					
CW	January	68	> 30 ≤ 68	22	55.0	February	76	> 68 ≤ 76	3	7.5
	June	37		32	80.0	August	70		4	10.0
	July	30		35	87.5					
E	December	45	>24 ≤ 45	26	65.0	March	88	> 45 ≤ 94	14	35.0
	January	24		36	90.0	November	94		13	32.5
	February	43		24	60.0					
G	December	16	> 10 ≤ 18	27	67.5	March	46	> 18 ≤ 46	15	37.5
	January	10		32	80.0	November	37		14	35.0
	February	18		28	70.0					
H	December	30	>16 ≤ 32	27	67.5	March	70	> 32 ≤ 70	13	32.5
	January	16		32	80.0	November	67		12	30.0
	February	32		25	62.5					
ME	January	46	> 44 ≤ 49	26	65.0	February	50	> 49 ≤ 60	7	17.5
	June	44		31	77.5	December	60		7	17.5
	July	49		22	55.0					
MW	January	48	> 48 ≤ 61	31	77.5	February	64	> 61 ≤ 77	10	25.0
	June	61		21	52.5	December	77		11	27.5
	July	50		24	60.0					

Annual Drought Occurrence

Drought frequency occurrence showed that between1943-1947, there were 11 drought episodes in all the drought prone areas of the country while in 1978-1982 period there were 23 drought episodes. The results show (Figure 5) that the frequency of occurrences of drought oscillated within 10-15 drought events per 5-years over the period of study (1943-1982). There was a sudden increase in the frequency in the period 1978-1982 to 23 events in the 5-year period.

Monthly Drought Rainfall Ranges

The study revealed that decile classes 3 and 4 (below normal) for zone G had a range of > 18 ≤ 46mm, the lowest in the classification while that for zone E was > 45 ≤ 94mm, the highest among the drought prone areas of Uganda (Figure 4). The monthly drought rainfall range for all the drought prone zones is 10-94mm. The decile classes as well as the decile rainfall ranges act as indicators in any year to monitor the variation in rainfall amount and hence can give a basis of prediction whether to expect a drought episode in a particular climatological zone.



5 - year Intervals	1943-1947	1948-1952	1953-1957	1958-1962	1963-1967	1968-1972	1973-1977	1978-1982
Drought Occurrences	11	15	15	10	14	12	11	23

Figure 5: Frequency of occurrence of drought in every 5-year period

Monthly Drought Occurrence

The monthly drought occurrences for each month were determined and presented as percentages over the 40 year period of study (Table 4). The 'below normal' decile class had the highest number of occurrences in zone G (37.5%) during the month of March while zone CW had the lowest number of occurrences in February (7.5%). For the 'much below normal' decile class, zone CE in July (92.5%) had the highest number of occurrences while zone MW in June had the lowest percentage of occurrences (52.5%). There was a deficit in rainfall leading to the drought becoming 'much below normal' than 'below normal'. Whereas there are chances of normal rainfall being received in the drought prone areas of Uganda, the probability of drought conditions increasing is more in all the drought prone climatological zones as shown by the number of occurrences. This is consistent with increasing frequency of droughts in Uganda as shown in Figure 5.

Severity of Drought in the Drought Prone areas of Uganda

The results for assessment of drought severity in all the drought prone climatological zones are presented in Table 5. Moderate and severe drought occurrences in each season were observed.

Zone CW Drought Severity

Zone CW experienced highest number of occurrences of moderate drought during the MAM season (52.5%) with mean drought rainfall amount of 105mm (Figure 6). Severe drought had highest number of occurrences during the DJF and SON seasons (10% each) with mean drought rainfall amounts of 46mm and 89mm respectively. Even though the smallest mean (9mm) and drought rainfall range (≤ 16mm) was recorded during the JJA season, this season together with MAM had the least number of occurrences (2.5% each) in the severe drought type. CW three deviations of rainfall from the mean (M-3s) were identified during the DJF season with 2.5% occurrences.

Table 5: Drought Severity in the drought prone areas of Uganda

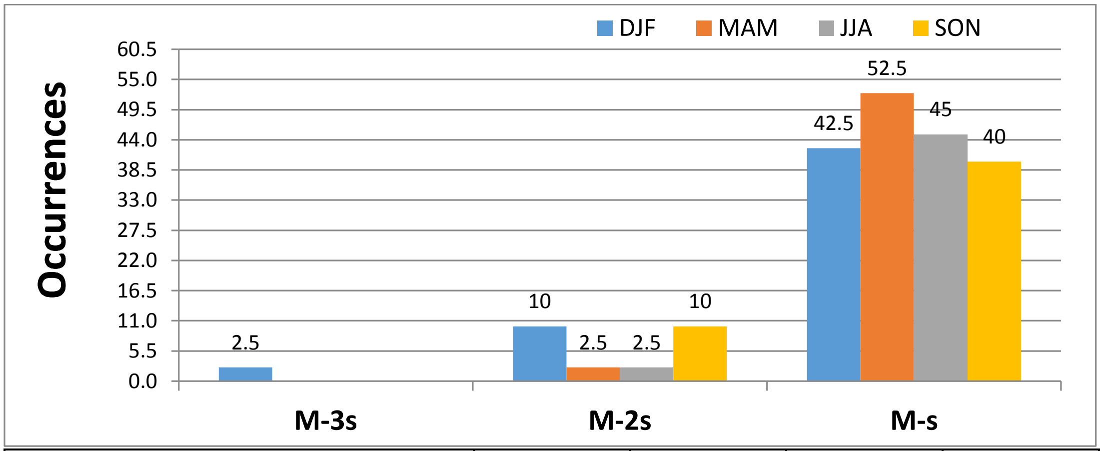
Climatological Zone	**Drought Severity (Dominancy/%, Season & Rainfall range/mm)**	
	Severe Drought	**Moderate Drought**
CE	50%, JJA (≤ 19)	50%, MAM (> 80 < 121)
CW	10%, DJF (≤ 58) & SON (≤ 97)	52.5%, MAM (> 83 < 119)
E	17.5%, DJF (≤ 18)	55%, MAM (> 98 < 146)
G	12.5%, DJF (≤ 2)	57.5%, SON (> 13 < 50)
H	22.5%, DJF (≤ 10)	57.5%, SON (> 54 < 101)
ME	15%, DJF (≤ 33)	55%, MAM (> 73 < 104)
MW	17.5%, DJF (≤ 40)	62.5%, SON (> 114 < 150)

Zone H Drought Severity

Moderate droughts in zone H were more evident in the season of SON (57.5% occurrences) while severe droughts were more evident in DJF season (22.5% occurrences) as illustrated in Figure 7. In the severe drought type, though JJA and SON seasons had the same frequency of occurrence of 5%, their mean drought rainfall amount differed where JJA had the highest value both in the moderate and severe drought types; 134mm and 109mm respectively. While the SON season in zone G did not record any severe droughts, in zone H, the MAM season also recorded none. DJF had the lowest drought rainfall range as ≤ 10mm for severe drought and > 10 < 26mm for moderate drought.

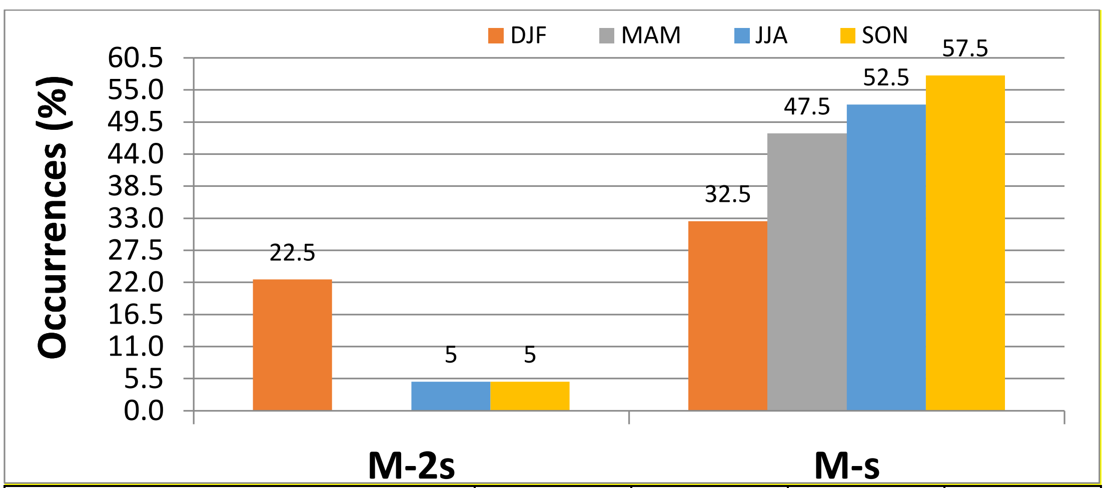
Zone MW Drought Severity

Zone MW recorded highest occurrences of moderate and severe drought during the seasons of SON (62.5%) and DJF (17.5%) respectively (Figure 8). It is also evident that the occurrence of moderate droughts is higher than the severe ones; giving an indication that moderate drought was more dominant in zone MW than severe drought. Considering the drought rainfall ranges for zone MW, JJA season had the lowest for severe drought ≤ 43mm while SON recorded the highest of > 114 < 150mm for moderate drought.



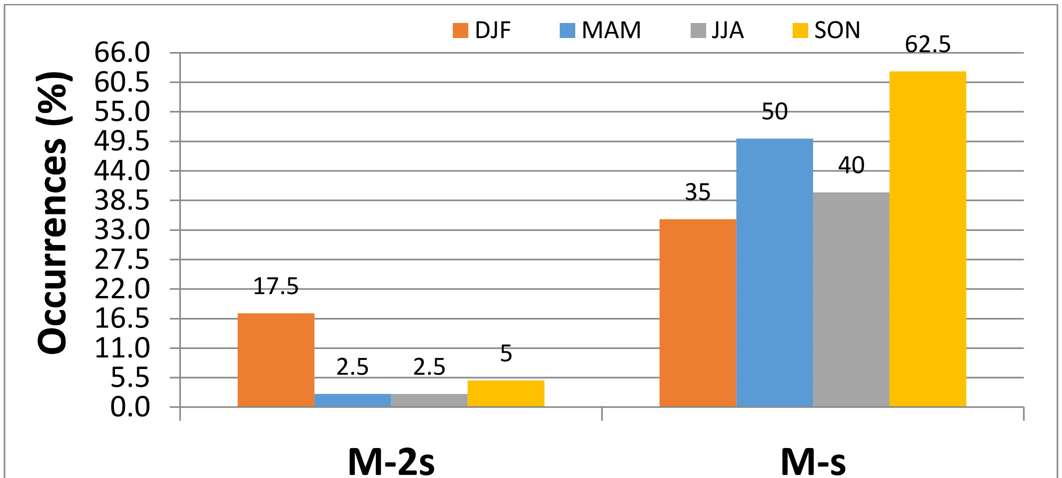
Season	DJF	MAM	JJA	SON
Mean Rainfall(M)/mm	79	119	46	130
Standard deviation(s)/mm	21	36	30	33
Mean Rainfall(M-s)/mm	70	105	32	118
Mean Rainfall(M-2s)/mm	46	78	9	89
Mean Rainfall(M-3s)/mm	36			

Figure 6: Zone CW Moderate and Severe Droughts events



Season	DJF	MAM	JJA	SON
Mean Rainfall(M)/mm	26	123	149	101
Standard deviation(s)/mm	17	45	38	47
Mean Rainfall(M-s)/mm	19	104	134	86
Mean Rainfall(M-2s)/mm	8		109	46
Mean Rainfall(M-3s)/mm				

Figure 7: Zone H Moderate and Severe Droughts events



Season	DJF	MAM	JJA	SON
Mean Rainfall(M)/mm	63	123	71	150
Standard deviation(s)/mm	23	34	43	36
Mean Rainfall(M-s)/mm	52	110	56	139
Mean Rainfall(M-2s)/mm	35	84	28	108
Mean Rainfall(M-3s)/mm				

Figure 8: Zone MW Moderate and Severe droughts events

Discussion of Results

Meteorological Drought Prone Areas of Uganda

This study has been able to confirm the classification of Uganda's 'cattle corridor' region as dryland area. The drylands classification of Uganda considers parts of climatological zones of B, CE, CW, D, E, G, H, I, K, L, ME, MW to be affected by drought which was based on the number of rain days, variation in seasonality and the dominant type of activity in the region (pastoralism). This approach is different from the deciles method adopted in this study that considered deficit in rainfall and deviations from the mean, which identified zones CE, CW, E, G, H, ME and MW as drought prone. This agrees with the cattle corridor classification with seven out of twelve climatological zones being affected by drought.

Meteorological Drought Occurrence

Results of this study capture the major meteorological drought events which have been reported by other studies (UNEP, 1997; IFAD, 2000). This study showed that partly agree with FAO (2004) and Kakuru (2004) classifications. In Table 4.12, the study determines the annual rainfall range for the drought prone areas of Uganda as 274-1157mm and drought event intervals of more than one year. The drought periods obtained in this study captured most of the events previously reported by Dai *et al.* (2004), Nicholson (2005), Lebel and Ali (2009) that indicated decile index is able to identify the major historical droughts over the cattle corridor of Uganda.

NAPA (2007) suggested a steep increase in the occurrence of drought in Uganda based on a study of 1911-2000. DFID (2008) report expressed that there is insufficient information presented in the NAPA to allow judgement on the quality of the data, nor is the source revealed. Important questions include the criteria used to describe drought; the geographical extent affected and duration; and whether data was based on verbal reports or meteorological observation. Goulden (2006) whose research linked rainfall variability in East Africa to ENSO and sea surface temperature variations in the Indian and Atlantic oceans, showed drought with cycles of approximately 2.3, 3.5 and 5 years, which periodicity of cycles was also reflected in this study.

Severity of Meteorological Drought

Drought severity in Uganda mainly ranges between moderate and severe. Zone H was the most affected with severe drought conditions while zone MW was the most affected by moderate droughts. However, it is worth mentioning that this factor of rainfall deficit alone does not explain all the variation in the drought regime in zone H and a considerable proportion of the variation still remains to be determined by other underlying factors (Gasm-el-Seed, 1987). In his review of drought of the last millennium, Dai (2011) states that the southward shift of the warmest Sea Surface Temperatures (SSTs) in the Atlantic, receipt of dry and hot winds from the Azores and Arabian regions, warming in the Indian Ocean, reduced vegetation cover and surface evaporation are responsible for the recent Sahel droughts. Zone H being at the boundary between Uganda, South-Sudan and North-western Kenya, also receives the effect of the drought in the Sahel region hence more severity in drought than any other zone in Uganda.

On the contrary, zone MW experiences more moderate droughts among the drought prone zones of Uganda, which result could also be attributed to the topography of the area where leeward-windward effect could have a role to play in justifying moderate droughts in this area. However, since this study did not consider other factors like vegetation, movement of air masses, water balance effects, among others, as those that may cause drought, further research is required to determine the factors contributing to this drought classification. Some studies like the NAPA (2007) and IPCC (2001) report the impacts of climate change and show that sustained and fastest-warming in Uganda is particularly over the southern parts of the country (Zone MW), in particular regions in the south-west where the rate is approximately 0.3^0C per decade resulting into the minimum temperature rising faster than the maximum. In line with the topographic factors contributing to the moderate drought conditions in MW, these may be also the reason for the 'extreme' droughts (M-3s) identified in zone CW although they were not included in Gibbs and Maher (1967) classification.

Conclusions

The study aimed at identifying drought prone areas in Uganda and assessing the severity of drought in the identified areas. It can be concluded that there are seven drought prone climatological zones in Uganda, namely CE, CW, E, G, H, ME and MW. These areas partly coincide with some Uganda drylands classification like that of the cattle corridor, an area that has reported a considerable number of drought incidences. It takes approximately 12½ years for all drought prone zones to experience drought at the same time, while the average drought event interval in any one drought prone zone is 1-6 years with an average dominancy in occurrence of 1-year. This oscillation of events almost coincides with El Niño and La Niña episodes. The annual and monthly drought rainfall range for all the drought prone zones are 274–1157mm and 10–94mm respectively. The decile classes as well as the decile rainfall ranges act as indicators in any year/month to monitor the variation in rainfall amount and hence can give a basis of prediction whether to expect a drought episode in a particular climatological zone. There was an increase in drought events in the country, recurring at an interval of 10 to 15 drought events per 5-years where the deficit in rainfall has increased hence drought becoming more classified as ‘much below normal’ than ‘below normal’. Most climatological zones experience ‘moderate’ drought events during the MAM season, except zone H and CW where the drought events are notoriously ‘severe’ and ‘extreme’ respectively during the DJF season.

Despite drought being ‘severe’ during the DJF season (dry season in Uganda), meteorological drought also ‘moderately’ occurs during the MAM (wet season).

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