Evaluation of drought indices using the 40-percentile threshold for the north-central regions of Namibia

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Abstract

Drought is not uncommon to the Southern African climate and it has become a matter of serious concern in Namibia. For that reason, almost all parts of Namibia have become vulnerable to drought occurrence. Whilst recognising agriculture as a pertinent component of the Namibian economy, it is imperative to underscore the importance of drought early warning products for short- and long-term decision making in various sectors of the country's economy. Following the 1991/92 drought, which ravaged more than 80% of Southern Africa, Namibia now realise the value of meteorological information in weather-sensitive decisions. This severe drought has been described as the worst in living memory. Five stations (Ombalantu, Oshakati, Rundu, Katima Mulilo and Tsumkwe) in the northern part of Namibia were assessed. The researcher used the rainfall decile method to assess drought conditions by evaluating whether the widely used 40-percentile threshold is appropriate for triggering a drought warning in Namibia. Results showed that the threshold might have been set too high to be of use in warning farmers of coming droughts. In order to determine the percentile that would be best serve as trigger for drought warnings, there is need for further examination at 30, 25 and 20 percentile mark thresholds. Based on the 40-percentile threshold, much of the drought and a decrease in rainfall accumulation in Ombalantu and Oshakati in the Omusati and Oshana regions respectively, occurred towards the end of the 20^{th} century.

Introduction

Namibia is situated on the south-western coast of Africa. It is one of the sub-Saharan Africa's most arid countries, and also one of the most arid countries in the world (Byers, 1997). Namibia has a dry climate with highly unpredictable rainfall (Erkkila & Siiskonen, 1992). The rainfall increases from the south-west to north-east, with a mean rainfall range from less than 50mm to 700mm in the same magnitude (Byers, 1997; Erkkila, Siiskonen, 1992). Hence it is important to take into consideration these spatial differences when defining drought.

In the northern regions, which are under study in this paper, the land is held under communal ownership. The communal ownership involves subsistence farming (Erkkila & Siiskonen, 1992). Approximately, more than 60% of the total population lives in this area. Most of the rural population in this region depends on agricultural products and livestock for survival (Erkkila & Siiskonen, 1992). Therefore, the analysis of drought in the northern regions is important for both residents of the areas and for government. The government can use the analysis in the event of drought relief planning.

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The definition of drought differs with respect to areas or regions. Heathcote (1973) argues that drought can mean different things to different people. Referring to the definition of 'severe water shortage' in Heathcote (1973), it is suggested that the word 'shortage' requires more definition. This in turn implies specification of the amount of water needed and this depends on the nature and extent of animal or plant communities using the water. From this definition, Heathcote (1973) deduces that not all water shortages are droughts; unless economic impact results from the shortage, drought may not always be recognised.

Tannehill (1947) defines drought as a phenomenon that belongs to the class of phenomena, which are known as "spell weather". White, Falkland and Scott (1999) define drought as a sustained period of lower soil moisture and water supply than the normal levels to which the local environment and society have adapted. This definition is relevant to the Namibian condition as drought can be different in each region based on the condition of that specific area. Drought affects agriculture, livestock as well as the potable water supply.

There are different rain based drought indices alternatives evaluated by White et al., (1999) for Tarawa, Kiribati that can be applied to Namibia conditions. These methods are Standardised Precipitation Index, Rainfall deciles and Rainfall depreciation. Rainfall deciles will be used and test if it is appropriate to use 40 percentile as criteria for drought warning in the four northern regions of Namibia. The Rainfall decile method is useful because it ignores demand and losses of water, it can be used for comparison between locations, it does not require data transformation, and the meaning is clear and can be easily understood (White et al., 1999). Hence this paper will assess drought in northern Namibia in Ombalantu, Oshakati, Rundu, Katima Mulilo and Tsumkwe (Figure 1). The data used in this report is from the Department of Metrological Services in the Ministry of Transport and Communication, Namibia.

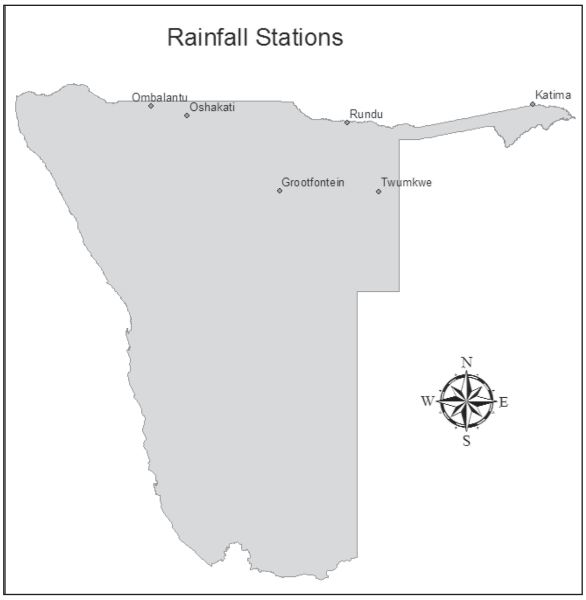

Figure 1: Rainfall Stations on Namibia (northern areas)

Source: Data from (DoF, 2002)

Types of drought

According to Druyan (1996) and Nicholas, Angela, Lake and Arthington (2008) drought can be divided into four different categories Meteorological, Hydrological, Agricultural, and Socio-economic drought. There is no universal definition of drought, but a working definition of meteorological drought is "an extended period - a season, a year, or several years of deficient rainfall relative to the statistical multi-year mean for a region" (Druyan, 1996, p. 256). These four common definitions of drought terms mentioned above are defined below.

Meteorological drought

Meteorological drought is defined by Druyan (1996); Rao, Voeller, 1997 and White *et al.* (1999) as an interval of time where meteorologically appropriate moisture that should have accumulated at a given time was not reached. Therefore meteorological drought is the degree of dryness and the duration of the dry period, which is region specific because the atmospheric conditions resulting in deficiencies of precipitation are highly variable from region to region (UNL, 2003; Robert, 2007 & Khalili, Famound, Jamshidi, Kamgar-Haghighi & Zanda-Parsa*,* 2011). For example, Namibia rainfall varies from region to region with increasing rainfall from southwest to northeast. In the areas where there is high rainfall for instance, meteorological drought can be defined on the basis of days or months during the rainy season. This definition only varies for regions with year-round precipitation. In my own experience, the areas along the coast seldom receive rainfall every year. Hence meteorological drought in those areas might be classified as drought if it has not rained, say, for two years.

Agricultural drought

Agriculture is the backbone of the northern rural areas in Namibia (Byers, 1997; Erkkila & Siiskonen, 1992). Crops are dependent on precipitation during the growing season and a dry summer could produce agricultural drought, even though it would not be classified as a meteorological drought. Agricultural drought affects the majority of the population in Namibia as most of the Namibians live in rural areas (Byers, 1997). It is defined by White as an interval of time when soil moisture cannot meet the evapotranspiration level required for crops to grow, for maintaining and supplying water for livestock and irrigation purposes. UNL (2003); Dubrovsky et al. (2009); Subash, Mohan, (2011) and Yang, Gong, Wang & Hu (2012) argue that a good definition of agricultural drought should be able to account for the variable susceptibility of crops during different stages of crop development. In addition, plants differ in water usage and access. For instance trees with deep roots and shallow root have different drought periods.

Hydrological drought

Hydrological drought involves stream flows and the level of water in both public water supplies, like reservoirs and rivers, and private wells (UNL, 2003; Benson, 2007; Vangelis, Spiliotis & Tsakiris, 2011). It is associated with effects from periods of precipitation shortfall in surface or subsurface water supply (Byers, 1997; UNL, 2003; Nalbantis, Tsakiris, 2009; Xu, Lin, Huang, Zhang & Ran*,* 2011). Even though climate is a primary contributor to hydrological drought, other factors could also contribute. Factors such as land use, land degradation (White et al., 1999; UNL, 2003; Nicholas et al., 2008; Khalili et al., 2011; Kwon & Kim, 2010) and construction of dams (UNL, 2003; Nicholas et al., 2008) all affect hydrological drought. Hydrological drought does not just affect areas where there is precipitation shortfall since regions are interconnected by hydrologic systems and the impact of metrological drought may extend beyond the precipitation deficient area (UNL, 2003; Nalbantis & Tsakiris, 2009).

Socio-economic drought

A drought can have devastating economic effects. Lack of rain can affect crop yields because of insufficient rain as well as insufficient water in streams that are used as an irrigation source. The definition of socio-economic drought is associated with the supply and demand of some economic goods and elements of meteorological, hydrological and agricultural drought (Druyan, 1996; UNL, 2003; White et al., 2004). The demand and supply of economic goods such as water, forage, food grains, fish, and hydropower, depends on the climate in that area (White et. al., 1999; UNL, 2003). Hence if the demand of these goods exceeds supply due to weather conditions and deficit of water, this is called socio-economic drought (White et al., 1999; Khalili et al., 2011).

Impacts of drought

Drought can have both negative and positive effects. The positive effects cited by Heathcote (1973) include a drought in 1903, which nearly killed off the rabbit population of western New South Wales thereby saving expenditure on rabbit control. In areas where there is a problem of overgrazing, drought might have detrimental effect on livestock, but on the other hand vegetation and grasses might respond well following disturbances. These positive effects have an ecological context.

The negative effects of drought are always at the centre of debate. These can be evaluated from the perspective of the different drought types. Meteorological, agricultural and hydrologic drought, determines the nature of socio-economic drought (White et al., 2004; Edossa, 2010). When the drought begins, it is normally the agricultural sector that is the first to be affected because of its reliance on stored soil water (UNL, 2003; Khalili et al., 2011). If there is no precipitation, soil water can be depleted during extended dry periods and if the precipitation deficiencies continue, people that are dependent on surface water reservoirs will be affected first sooner than those dependent on ground water (Xu et al., 2011). But in the longer term, when the precipitation deficiency ends, underground water reservoirs will take longer to recover than ground water reservoirs.

Methods and materials

The decile method was used to estimate the drought indices. This method requires the ranking of data. The data was ranked using PERCETILE function in Excel spread sheets. This adopts the procedure used by White et al. (1999) where the rainfall records are summed for 12 month over the whole rainfall period. Using the sum of 12-months previous month records would give a better estimation of drought occurrences. This is because Namibia has seasonal rainfall that starts probably from September through to April the following year. This avoids classifying months without rainfall, which is normally from May to August, as drought. Hence it follows the definition of droughts, that normal dry periods cannot be classified as drought. But rather unusual events occur in the local environment that have not adapted. For example if a total of six month is to be used to assess the drought for that period, than possibly the months between July and November might be classified as drought months every year, depending on the distribution of rainfall from January to April of the same year. Hence examining the decile ranking of rainfall over a 12-month accumulation period is an ideal situation.

Results and discussion

The 12-month rainfall deciles are shown in Figures 5, 6, 9 and 10 for Ombalantu, Tsumkwe (Figure 2), Oshakati and Rundu respectively. Figures 3, 4 and 5 show results for Katima Mulilo station from 1945 to 1978 and 1987 to 2002. There is a break in rainfall records in 1979 to 1986 in Katima Mulilo. Hence the drought analysis for Katima Mulilo was done only for rainfall from 1945 to 1978. The highlighted instances on the figures are where the percentiles values are less that 10% and below 40%. These values are classified as very much below average in the Australian Drought Watch System (Parakoti & Scott 2002). The Australian Drought Method System was set up as a basis to evaluate the severity and to give warnings of droughts. The lowest 10 percentile designates extreme dry periods. On the other hand, the 40-percentile level can be used as a warning of coming droughts. This will be discussed in more detail in section 4.4.

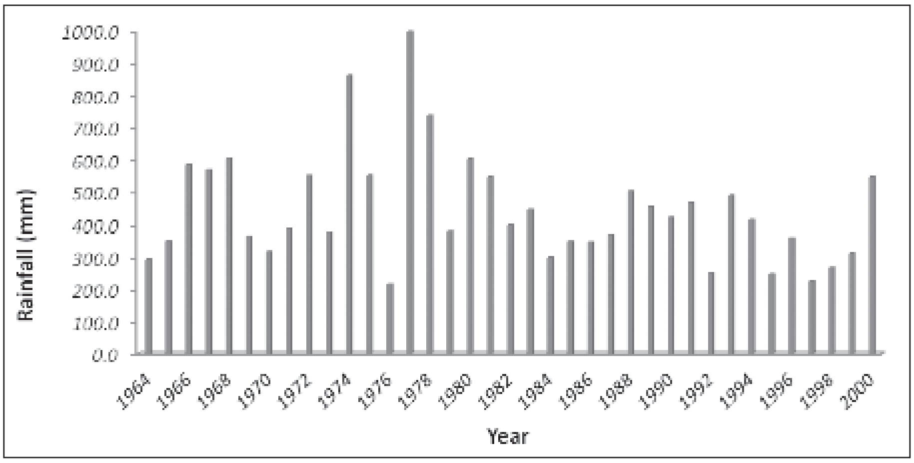

Figure 2: Tsumkwe rainfall records

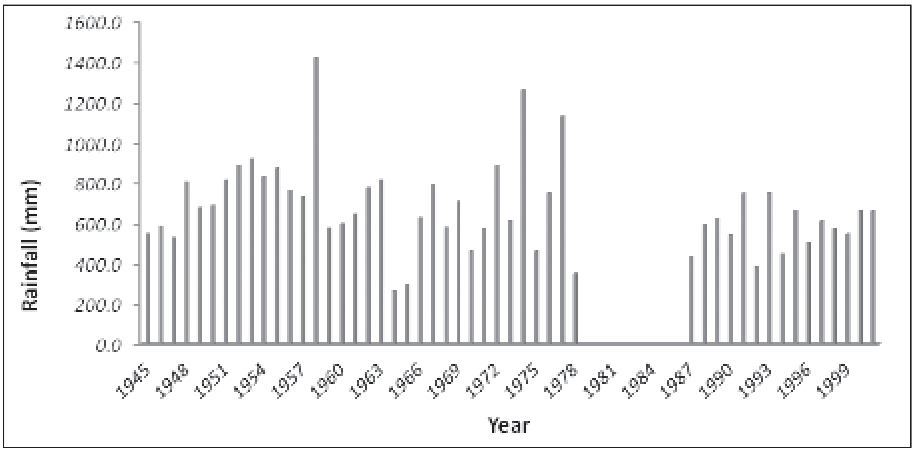

Figure 3: Katima Mulilo Rainfall record

Since stations have different periods in their sets of rainfall records, this makes it difficult to compare drought patterns overtime. But one of the events noticed in all the stations except Katima Mulilo and Rundu, is an apparent drought between 1987 and 1990. In Katima Mulilo, the drought was rather noticeable in 1991, Figure 5. Rundu records show a different pattern from above the 40 percentile except the drought in 1970, which is apparent in all stations. This drought period was more serious in Omabalantu than in other stations. The drought stretched over almost nine years fluctuating below the 20 percentile. The same pattern can be also observed in Oshakati, but the record ends in 1993. Therefore there is no clear indication on how far this drought lasts like other stations.

However, Oshakati and Ombalantu results can be compared because these areas are close to each other. There is no clear pattern of drought trends below the 40 percentile. This is due to the distribution of rainfall during the rainy season and the intensity of rainfall, for instance, if there was a strong thunderstorm in one month rather than spread over several months. In that case, it will have a greater contribution over the months that are summed up. On the other hand, the areas have a similar trend of decreasing rainfall between 1976 and 1982. What can be noticed also are the records from 1987 to 1992. During this period, the rainfall never went over the 60 percentile in all stations. This implies that even though there is a difference in terms of droughts these areas have a similar maximum rainfall.

The data in Figure 5, 6, 7, 9 and 10 are summarised in Table 1. The table shows the lowest, highest, mean rainfall and coefficient of variation for all stations. The table gives also the rainfall figures at 10 percentile, the number of extreme dry times below 10 percentiles, the average time between extremes dry months as well as coefficient of variation and range of times between extreme dry months, and the average duration of extreme dry months as well as the coefficient of variation and the range of duration of those dry periods in months.

The coefficient of variation mentioned above enables comparison of the variability, homogeneity or uniformity of the data distribution (Gupta, 1990). If the coefficient of variation (%) is equal to 100, it means the standardised deviation is closer or equal to the mean. This gives an indication of how the data are distributed around the mean.

There seems to be a uniform variation across the rainfall data from all stations ranging from 32 to 49. Ombalantu has highest coefficient of variation (49). This is due to the lowest record of two millimetre of rainfall in a 12-month period. At 10-percentile level, all rainfall stations have different values of rainfall. The value of Katima Mulilo is more than two times some values at the 10 percentile from other stations. This is an indication that what can be regarded as a drought in Katima Mulilo is not the same as in other areas.

From Table 1, the expected period between extreme dry periods and the expected duration of those dry periods can be deduced for a 12-month period. It shows that, in 66 years, Ombalantu can expect, on average, drought every eighth year and this will be expected to last for eleven months. Both Tsumkwe and Rundu can expect, on average, drought every ninth year and this will last for five and years respectively. While Katima Mulilo and Oshakati can expect, on average, drought every sixth and fifth year and this will last for approximately seven and six years respectively. However each station has a different set of data, different in terms of years. Therefore these approximations should be interpreted with caution. To make a better comparison, the numbers of extreme dry periods were compared within a 25-year period. It came out that even Oshakati has few cases, compared to other areas, and within a 25-year period it has frequent cases of drought similar to Ombalantu. The results are shown in Table 2 below.

From the Table 2 above, it can be concluded that, even though Ombalantu has the lowest rainfall records in 12 month periods, there are expected to be very few cases of drought in that area compared to other areas. This is again referred back to the definition of drought, where White et al. (1999) defined drought as being associated with a sustained period of significantly lower soil moisture and water supply than the normal levels to which the local environment and society have adapted. Looking at Table 1, the mean rainfall in Ombalantu is classified as an offset of 10 percentile in Katima Mulilo. That is all the rainfall records in Ombalantu below the mean (416) would be classified as drought in Katima Mulilo records.

Table 1: Rainfall data for five stations in Northern Namibia

Parameters	Ombalantu (1930-1996)	Tsumkwe (1964-2000)	Katima M. (1945-1978)	Oshakati (1967-1992)	Rundu (1961-2001)
No. of Data points	791	459	397	301	471
Lowest rain (mm)	2	215	244	85	229
Highest rain (mm)	1165	1090	1500	818	1166
Mean rain in period (mm)	416	490	704	410	582
CV%	49	38	33	40	32
10 percentile Rain (mm)	177	246	476	187	325
No of extreme dry times <10 percentile	8	9	6	5	9
Average time between extremes dry months	89	38	51	54	74
CV%	222	133	114	194	169
Range of times between extreme periods	8 to 577	1 to 100	13 to 178	1 to 242	1 to 254
Average duration extremes dry months	11	5	7	6	6
CV%	120	81	101	76	74
Range of durations of extreme dry periods	1 to 36	1 to 11	1 to 17	1 to 10	1 to 12

(Source: Data from Namibia, Ministry of Transport and Communication, Department of Meteorology, 2003)

Table 2: Comparison of estimated number of extremes within 25 years for rainfall records totalling 12 months

	Ombalantu	Tsumkwe	Katima M.	Oshakati	Rundu
Original number no. of extreme dry times <10 percentile	8	9	6	5	9
Estimated no. of extremes dry times in 25 years	3	6	5	5	6

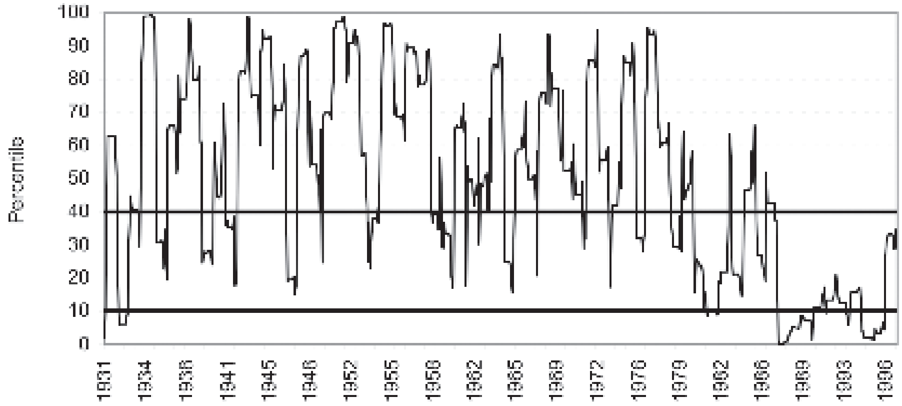

Figure 4: Rainfall totalling 12 months for Ombalantu station

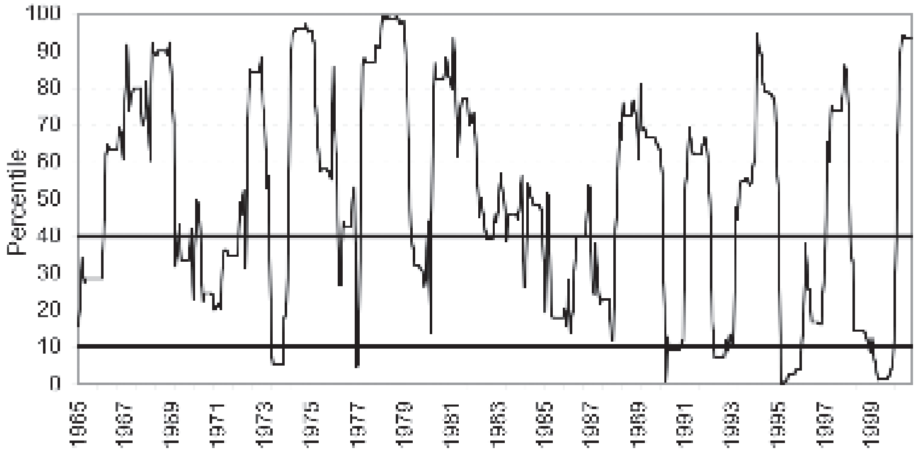

Figure 5: Rainfall totalling 12 months for Tsumkwe station

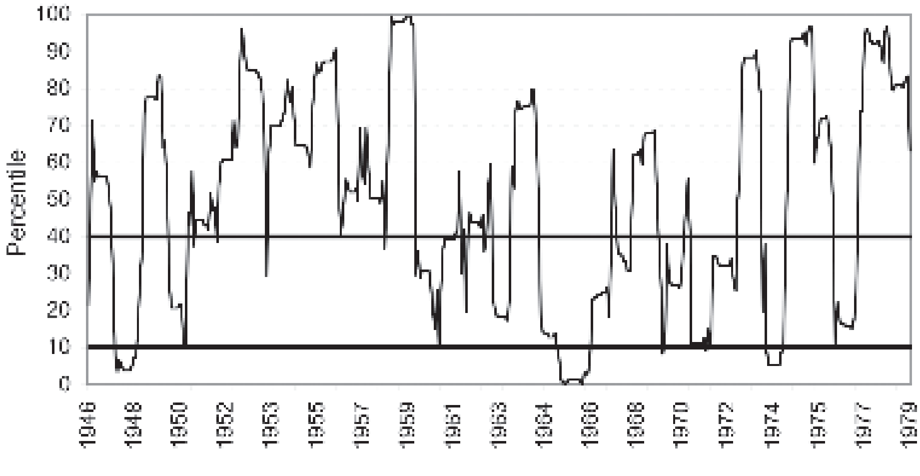

Figure 6: Rainfall totalling 12 months for Katima Mulilo station

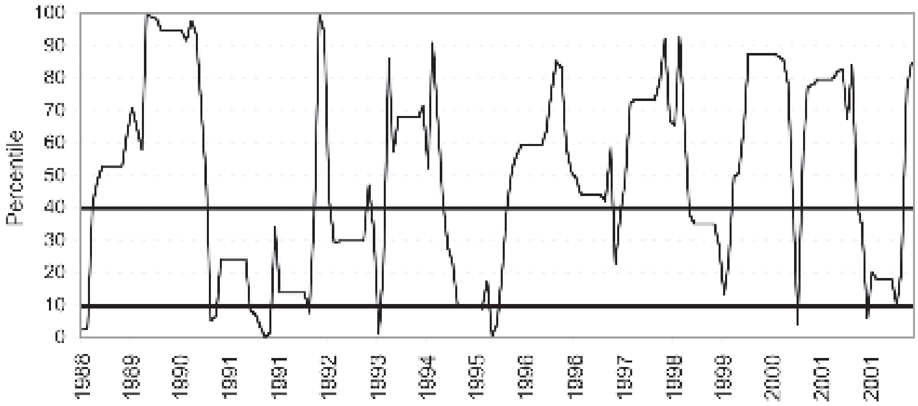

Figure 7: Rainfall totalling 12 months for Katima Mulilo station (1988 – 2002)

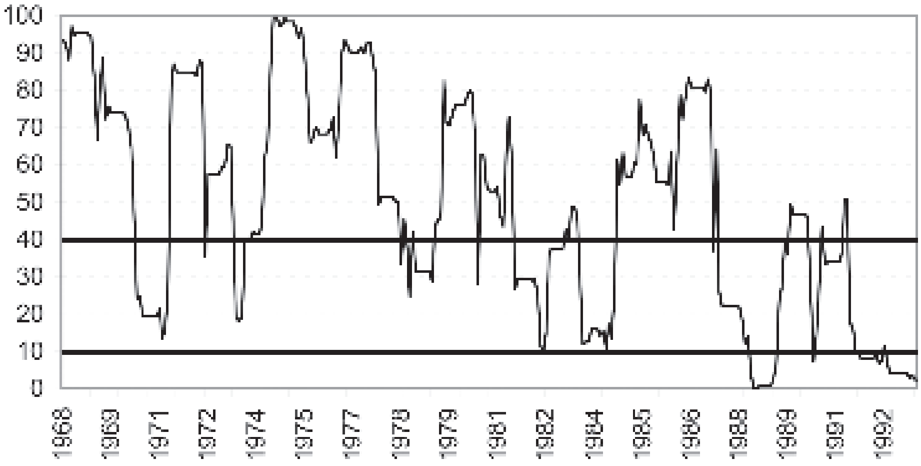

Figure 8: Rainfall totalling 12 months for Oshakati station

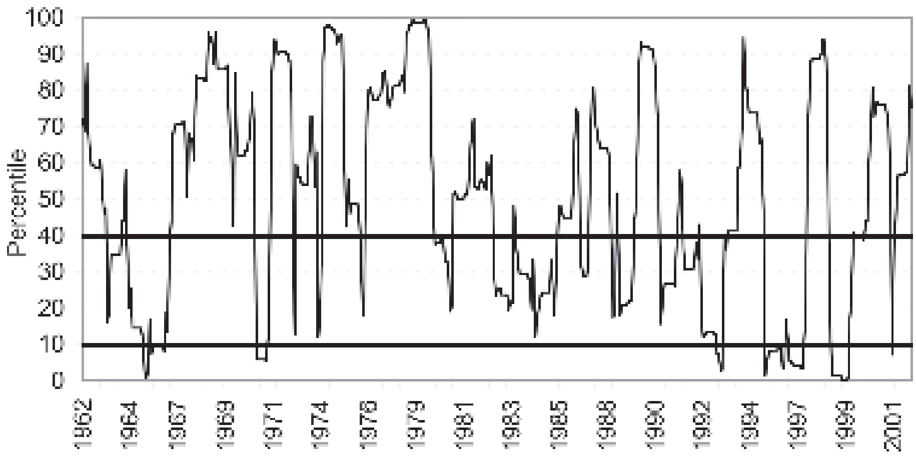

Figure 9: Rainfall totalling 12 months for Rundu station

Severity of droughts

The assessment of severity of drought is important to determine how worse the drought was. The severity can be determined by the lowest percentile and periods of that specific drought. The method described by White et al. (1999) to assess the severity of drought was to look at the lowest percentile ranking obtained, the duration of the drought period below 10%, and the average ranking over the drought period. In this paper, part of White et al. (1999) will be used, for instance, by identifying the lowest percentile and the duration of the drought period. In addition, the ranking of the severity will be assessed by looking at both the lowest ranking obtained and the duration of the drought. These combinations are the strongest criteria used in the table below to rank the severity of drought. The results are presented in Table 3. The data are ranked that the first in the column is regarded as the worst drought in that area.

Table 3: Droughts below 10% in all the stations totalling 12 months

Ombalantu (1930-1996)		Tsumkwe (1964-2000)		Katima M. (1945-1978)		Oshakati (1967-1992)		Rundu (1961-2001)	
Starting period (1900)	Duration	Starting period (1900)	Duration	Starting period (1900)	Duration (MThs)	Starting period (1900)	Duration (mths)	Starting period (1900)	Duration (mths)
Feb '87 to Jan '90	36	Jan to Nov '95	11	Oct '64 to Feb '66	17	Feb to Nov '88	10	Mar to Dec '98	10
Oct '92 to Jan '93	4	Jan to Nov '99	11	Jan to Nov '47	11	Feb to Dec '92	11	Oct '64 to Jan '65	4
Feb to Nov '32	10	Apr to Sept '73	6	Mar to Nov '73	9	Apr to Dec '91	9	Mar to Oct '96	8
Aug to Oct '94	3	Mar to Aug '92	6	Jan '69	1	Dec '89	1	Oct '92 to Jan '93	4
Dec '31	1	Apr to Sep '90	6	Oct '70	1			May to Oct '70	6

Almost two thirds of the worst droughts occurred between 1980 and 2000. Of these, more than half of the cases were between 1990 and 2000. The analysis above excludes data from Katima Mulilo. What can be concluded from this table is that the worst droughts occurred towards the end of the 20th century. This can be attributed to climate change and global warming (UNFCCC, 2002).

In addition, Figure 11 indicates the cumulative rainfall distribution. There is a clear indication that cumulative rainfall in Ombalantu and Oshakati areas is decreasing over time. The results were computed by summing up the rainfall records of the current month and accumulation of previous years or months, as represented in the equation below (White et al., 1999). This coincides with frequent drought events occurring towards the end of 20th century. However, the decreasing of the rainfall in both areas (Ombalantu and Oshakati) began in the early 1980s. Therefore this predicts that the frequency of drought will be prevalent in the coming years compared to the previous years before 1980s, unless the rain changes to its normal pattern.

$$CuR_n = R_o + \sum_{i=1}^{n1} R_i$$

where CuR_n = Cumulative rainfall, R_o = is the rainfall of the current month and R_{-i} = is the rainfall for the previous *i*th month (Adapted from: White et al., 1999).

A decrease of rainfall might have detrimental effects on the ecosystem as well as on the living conditions of farmers. Especially in the areas where rainfall is evidently decreasing is where most of the population live, about 44% of the population (Marsh & Seely, 1992). Marsh, Seely (1992) and Jang et al. (2012) predict that the droughts in the areas might occur in many ways, for example when the rain falls at the wrong time to support the growing of crops. For instance, because of its variability, rain might fall heavily in November, and farmers start ploughing. Because of unpredictability and variability of rainfall, sometimes it happens that the next thunderstorm will come in January. During that period, crops will die of drought. Therefore the need for informed and thorough research might be helpful to farmers to manage their crops. In addition this information is crucial to the farmers, for them to have an idea about the possible decline of precipitation over time.

Drought warnings

Drought warning is one of the methods used to indicate the possibility of coming droughts. This is mostly due to the lack of rain during the previous few months. The drought warning could warn farmers of a coming drought in the following season. This is important for them to take necessary precautionary measures. For instance, if it is predicted that there would be drought during, say, coming two years, farmers will take precautionary measures like restocking their livestock. In addition, this information is also needed by government agencies and other groups having wider regional or national interests and responsibilities (Felch, 1978; Khalili et al., 2011). For example, if there is enough and accurate information, the government will know how much to set aside for drought relief programs. Drought warning in this area should be interpreted with caution. The rainy season starts from October and lasts until April; where almost 99% of the annual rain falls between those months (Marsh & Seely, 1992). Therefore if there were not enough rainfall during summer, this sign will be reflected as a drought during the dry season, which may not necessarily be a warning of drought.

Gibbs and Maher (1967) suggested that the 50 percentile is the appropriate level for drought warning. However this level might be too high for Namibia conditions. This is because Namibia has a highly variable rainfall from year to year and from month to month (Marsh & Seely, 1992). Therefore because of this variability, the mean rainfall is not a good indicator of rainfall conditions and it might give the wrong perception. Hence even the percentile will have to be interpreted with caution. White et al. (1999) use the 40 percentile as the drought warning level in Small Coral Island. Hence, because the 50 percentile suggested by Gibbs and Maher (1967) might not be a viable option in Namibia context, the 40 percentile will be used as a drought warning.

The statistics of drought warning at the 40 percentile are presented in Table 4. Katima Mulilo has the highest rainfall at 40 percentile compared with other areas. This indicates that what can be classified as drought in Katima Mulilo is not the same as in other areas. Using the 40 percentile as warning of drought period, it is expected that the warning time will last for 7 months in Ombalantu, 4, 6, 5 and 5 months in Tsumkwe, Katima Mulilo, Oshakati and Rundu respectively. The coefficient of variation gives an indication of how warning times vary from the mean. The difference of variation between areas is not that significant, but there is a big variation within periods of warning times within the areas. The warning times can be one month for all areas and the maxima are not very far from each other except for Katima Mulilo, which stands at a maximum of 14 months of twenty-one warning times.

The most important thing is how accurate are these warnings. It can be frustrating and costly sometimes to give warnings but the drought never happens. If it happens, it happens seldom. Haas (1978) argues adjustments to agricultural practices are needed towards anticipated droughts. This type information is needed to stabilise agricultural economy losses. Hence using a number of false and correct warning predictions recorded at 40 percentile will enable scientists to evaluate if this method is appropriate.

At the 40 percentile, more than two thirds in each area, the prediction were wrong. This will have a bigger impact on the farmers and community if they are to be presented with this prediction results. Therefore even the 40 percentile is not a good indicator for drought warning predictions in the areas included in this analysis. Further analysis of data is thus needed at the 30 percentile, for instance, to asses and evaluates the drought warnings.

Table 4: Use of the descent of the rainfall record through the 40 percentile level to indicate impending extreme dry periods

	Stations				
	Ombalantu (1930-1996)	Tsumkwe (1964-2000)	Katima M. (1945-1978)	Oshakati (1967-1992)	Rundu (1961-2001)
40% Rain (mm)	351	372	643	370	487
Mean warning time at 40 percentile (mth)	7	4	6	5	5
CV%	70	120	95	101	101
Range of warning periods (mth)	1-19	1-20	1-14	1-18	1-24
Number of warnings times	32	27	21	17	26
No. false/No. correct warnings	25/7	20/7	16/5	13/4	20/6

(Source: Data from Namibia, Ministry of Transport and Communication, Department of Meteorology, 2003)

Conclusion

This paper assessed drought conditions in five stations in the northern part of Namibia. Drought assessment is important for farmers living in the area and also helps the government assess the state of drought conditions for implementing drought relief programs. Results showed that the threshold might have been set too high to be of use in warning farmers of coming droughts. Apart from Katima Mulilo, where rainfall records from 1979 onwards were excluded from the analysis, the results show that much of the drought occurred towards the end of the 20th century. In addition, results showed a decrease in rainfall accumulation in Ombalantu and Oshakati; this is a serious problem in these areas since most of the people living there depend on agricultural products. Precautionary measures may be needed to adjust to this new situation, which opens up some important areas of future research. For example, information will be needed about how the economy will be affected, impacts on community and alternatives that can be found to adapt to the changing climate conditions of these two areas.

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