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Modelling risk recurrence intervals for agricultural projects from theoretical probability distribution and SPI: Semonkong, Lesotho, South Africa

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ABSTRACT

Drought events are major natural hazards that occur in various climate regimes with significant agricultural, environmental and socio-economic adverse impacts. These hazards are insidious, obstinate and slow-onset with creeping nature that lead to drought disasters mostly in agriculture dependent communities. In this study, the recurrence intervals of drought were studied from theoretical probability distribution and Standardised Precipitation Index (SPI) at Semonkong station in Lesotho. Firstly the spring (Sep, Oct and Nov) monthly precipitation data obtained from Lesotho Meteorological Services, was tested for outliers and homogeneity (2 tailed p-value = 0.286) for quality control purposes. Secondly, Mann Kendall trend test and probability distribution fitting were both determined by XLSTAT software. No significant trend was revealed. A normal probability distribution fitted well to the data using a Kolmogorov-Smirnov test (p-value = 0.869) with a risk of 86.9% of rejecting the null hypothesis. DrinC software was then used to compute drought monitoring parameters at three months' time scale (SPI-3) as shown in equation 1. The normal distribution parameters were then inputted in INSTAT software to determine exceedance probabilities and corresponding precipitation values. All precipitation values exhibited by INSTAT were matched with their SPI values. Given the focus of the current study, both recurrence intervals in years and non-exceedance probabilities were determined. The results showed that the study area is highly likely to experience moderate, severe and extreme or more drought events in 3.33, 5 and 10 years respectively at any given period. This is really a short period that these events will occur at any given year, therefore, the study recommends that authorities, Government, participating private and NGO's put livelihood diversification measures in place given that over 80% of Lesotho population's livelihood depends on rain-fed-agriculture.

Key words : *Recurrence interval, Drought, SPI, Drought modelling, Risk*

Introduction

Drought and desertification are serious challenges and threats that are facing sustainable development in Africa and these have far-reaching negative consequences on human health, food security, economic activities, physical infrastructure, natural resources and the environment (UNECA, 2008: Hamdi *et al.*, 2016; World Meteorological Organisation, 2016). In 2011, the Horn of Africa needed humanitarian assistance following drought that affected 13 million people (Action Aid, 2011: Gebretsidik and Takele, 2015). Lesotho has not been an exception and although Lesotho's per capita income has increased, poverty is still one of the major challenges facing this country, which is attributed to adverse effects of drought on agricultural production since agriculture is the backbone of Lesotho's economy (African Development Bank Group, 2013).

In a report by the Lesotho Department of Planning (2008), on the Compilation of Crucial Information for the Maseru ruralcommunities with the highest percentage, namely 7.8%, of people that needed food aid (Department of Planning, 2008). This council has 2 754 households with an average size of 7 people per household. In terms of the number of the households that have Agricultural plots, it is the third with 2158 in total and with an average plot of 1.6 hectares per household. This council is one of the largest in terms of agricultural land ownership which, when hit by drought is likely to affect people in large numbers. Furthermore, FAO (2011) and Engeland, *et al.* (2004) show that drought is considered the most severe cause of food shortages in developing countries, and most reports and research in Lesotho indicate most rural areas most vulnerable to climate changes in the country. However, none of these studies are drought-specific and approach drought risk assessment in from a regional level. The results from this study can be used by government and authorities in planning against drought and building of community resilience to drought. In 2012, the Prime Minister of Lesotho Thomas Thabane declared a state of emergency due to food crisis in Lesotho and made an appeal to the international community for assistance (WFP, 2012). It is reported that more than a third of the population was in a food crisis and about 230 000 people were judged to be more vulnerable to hunger since the maize production, the country's staple food, was negatively impacted upon by drought; it was also estimated that domestic agricultural production would contribute less than 10% of the annual national cereal requirements for the years 2012/2013 (WFP, 2012). In 2011 and 2012 Lesotho experienced more than a 70% drop in domestic agricultural production due to late rains and floods (UNICEF, 2013). The report states that Semonkong was one of the rural areas that were mainly affected. *"I have come here today because we don't have enough food at home," says MasenateBereng, a mother of four. "This is the second year in a row that we haven't had a good yield from our land. This year the rains came too late."* (WFP, 2012). Red Cross Food security officer, Debra Nkoane-Pokothoane said that a project in conjunction with the Ministry of Forestry and Land Reclamation and the District Disaster Management Team was initiated in Semokong area's worst affected villages which benefited over 800 people in this area. People were given food (50kg maize meal, four litres of cooking oil and 8kg beans every month) for work done by planting trees (Maphathe, 2013: Hlalele, 2017). This project lasted only four months (Maphathe, 2013). Despite this intervention, the project provided a short-term relief to community members leaving a question of sustainable development, as to how these affected community members will sustain their livelihood throughout the prolonged drought period and beyond. These will provide relevant decision makers and NGO's with information for improvement on systems or intervention to manage droughts in the area.

Materials and Methods

Monthly precipitation data were requested from Lesotho Meteorological Services (LMS). This data set a few gaps which were filled by Expectation Maximum Algorithm (EM) aided by SPSS. EM is an effective data analysis technique that overcomes several limitations of all other missing data techniques that produce biased estimations such as mean and regression substitutions (Schafer *et al*. 1998). The procedure was followed by determining outliers in the data set. SPSS was used to generate descriptive statistics where both lower (Q1) and upper quartiles were determined to set outlier range as;

$$(Q1-1.5 \times IQR; Q3+1.5 \times IQR) \quad \text{.. Eqn (1)}$$

Only one value was identified as an outlier. EM was again applied to refill the missing datum gap. Given that over 80% of Lesotho population's livelihood is depended on rainfed agriculture, Semonkong station was selected as one of the rural areas that mainly relies on agriculture as a means of livelihood (Hlalele, 2016). A monthly precipitation data was summed for all four seasons namely; winter, spring, summer and autumn. This study therefore focused on spring (September, October and November), although the growing seasons in the high lands in Lesotho starts earlier than other parts of the country, these three months are still very important for growing major crops such as, maize, beans and other cash crops (Belle and Hlalele, 2015). After the summation of the three months precipitation, Homogeneity test was conducted.

Any climate data set must be subjected to homogeneity test before any further statistical tests can be conducted in order to avoid spurious results (IRI, 2017). Changes in the data sets maybe gradual or abrupt depending on the nature of the disturbance, however obtaining a perfectly homogenous data is almost impossible as unavoidable changes in the area surrounding the observing station often affect the data sets (Ahn and Wang, 2013). For this reason, a non-parametric homogeneity test, Pettitt's test was applied to test whether the data set was homogeneous or not. The Pettitt's test revealed the data set was homogenous over a period of 33 years from 1982 to 2014. In order to further explore the data set, a descriptive analysis was conducted. Mann Kendall (MK) test is a statistical technique used to determine the existence of both monotonic downwards and upwards trends in variables of interest (Kendall, 1975). The author further asserts that MK test is best viewed as an exploratory analysis and is most appropriately used to identify stations where changes are significant or of large magnitude and to quantify these findings. An XLSTAT software was used for both MK and fitting a suitable probability distribution and its parameters. Drought Calculator (DrinC) software was used to compute Standardised Precipitation Index (SPI) on three months' time scale (SPI-3) which lead to drought monitoring parameters determination from equation 2.The three months (Spring Season) precipitation totals were fitted to a suitable probability distribution came out to be normal distribution with the following parameters as shown in Table 1 below.

Table 1. Normal distribution parameters

Parameter	Value	Standard error
μ	179.691	
sigma	74.150	0.419

These obtained parameters were used in INSTAT climate software to determine percentiles (recurrence intervals) with corresponding seasonal precipitation values. The determined percentiles are explained as the probability of obtaining a particular precipitation value or more in any given year in spring. Given the objective of this study the focus ii not on probability of exceedance but non-exceedance since larger values of precipitation are inversely proportional to drought intensity levels as determined by SPI.

Results

Table 2 below depicts a full description of Semonkong Spring rainfall, from this table the study area receives a minimum and maximum precipitation of 21.4 mm and 334.7 mm respectively. The average rainfall is 179.691mm which is classified as near normal from Table 7 below. The minimum rainfall can be classified as extremely dry condition.

Table 2. Descriptive statistics of Semonkong rainfall

Statistic	Parameters
Minimum	21.400
Maximum	334.700
Std. deviation	74.150
Mean	179.691
Variance	5675.51
Skewness (Pearson)	0.000
Kurtosis (Pearson)	0.000

Prior to further data analysis, a non-parametric homogeneity Pettit's test was applied to detect if any changes in data sets existed either due to climatic changes or other factors such as change in instruments. Table 3 below shows the results of this test with a 2-tailed p-value =0.286 which is greater than the selected significance level of 0.05. This therefore implies that the data set was indeed homogenous and further tests and analysis could follow without any errors. For this reason homogeneity tests was used as a means for validating and ensuring reliability of the final results. Figure 1 also provided a visual presentation of the homogeneity tests over the study period (1982-2014).

Table 3. Homogeneity Test (Pettitt's test)

K	111.000
t	1999
p-value (Two-tailed)	0.286
alpha	0.05

After homogeneity test, the researcher deployed another non-parametric Mann Kendall's teats to determine if any significant trends existed in the data. Table 4 shows the results of this test which revealed a non-significant trend in the data set with a 2-tailed test of 0.33>0.05.

The Semonkong Spring time series was then fit-

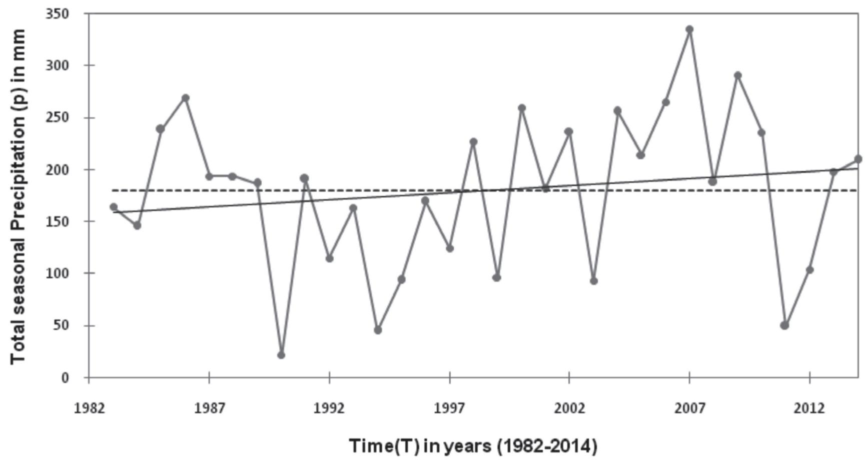

Fig. 1. Semonkong homogeneity precipitation series plot

Table 4. Mann-Kendall trend test (Two-tailed test)

Kendall's tau	0.123
S	61.000
Var(S)	3801.667
p-value (Two-tailed)	0.330
alpha	0.05

ted to a theoretical probability distribution tests using a Kolmogorov-Sminov tests as shown in Table 5. A normal probability distribution fitted so well to the data set with parameters mean (μ) = 179.691 and standard deviation (ó) =74.15 as shown in table 6 below. The risk of rejecting these results while true was estimated to be 86.9%.

Table 5. Probability distribution criterion test

Kolmogorov-Smirnov test	
p-value	0.869
alpha	0.05

Table 6. Normal probability distribution Estimated parameters

Parameter	Value	Standard error
μ	179.691	
sigma	74.150	0.419

SPI = c. In{Σp}+b .. Eqn (2)

Where *b* and *c* are specific SPI-3 determined drought monitoring constants

b =-12,54259

c =2,271125

For monitoring purposes equation 2 was used where constant b and c were determined from the data set. Equation 2 is a monitoring tool in the DrinC software for drought monitoring purposes. INSTAT is a software used climate data analysis, such rainfall and temperature. The normal probability distribution parameters were therefore used in INSTAT to generate exceedance probabilities and corresponding precipitation values a shown in Table 7. All the precipitation values were then inputted in equation 2 to determine the corresponding SPI values and drought classifications using Table 8. Given the focus of this study which was to model the drought recurrence intervals, non-exceedance probabilities were generated as shown in the last column of Table 7.

Conclution and recommedations

In conclusion, unlike floods, droughts build up slowly, creeping and steadily growing (Serinaldi *et al.*, 2009: Cheng-Feng *et al.*, 2015). This natural disaster cast heavy burdens on water resources management and planning, soil moisture and agricultural productivity. Planning against drought effects therefore plays a vital role in society (Tskiris and Vangelis, 2005: Leslie and Corporal-Lodangco, 2016). The current study therefore selected one of the most important seasons in Semonkong, Lesotho. The main aim in this study was to model the drought recurrence intervals in order to lay a basis for proactive water resources management and the protection of both social amenities in the area and community lives and their livelihood means. The results showed an 80%, 90% and 95% probability of

Table 7. Recurrence intervals and SPI drought Classification

Probability of exceedance	Precipitation/ rainfall (mm)	SPI	SPI drought classification	Recurrence intervals (year)	Probability of non-exceedance
5%	58.381	-3.31	Extreme	20	95%
10%	85.165	-2.448	Extreme	10	90%
20%	117.72	-1.713	severe	5	80%
30%	141.19	-1.3	moderate	3.33	70%
40%	161.25	-0.999	Near normal	2.5	60%
50%	180	-0.749	Near normal	2	50%
60%	198.75	-0.524	Near normal	1.7	40%
70%	218.81	-0.305	Near normal	1.4	30%
80%	242.28	-0.074	Near normal	1.25	20%
90%	274.83	0.212	Moderate wet	1.11	10%

Table 8. SPI classifications

SPI Value	Class
$SPI \geq 2.00$	Extreme wet
$1.50 < SPI \leq 2.0$	Severe wet
$1.00 < SPI \leq 1.50$	Moderate wet
$-1.00 < SPI \leq 1.00$	Near normal
$-1.50 < SPI \leq -1.00$	Moderate dry
$-2.00 < SPI \leq -1.50$	Severe dry
$SPI < -2.0$	Extreme dry

Source: Mckee *et al*. 1993

receiving 117.72 mm, 85.165 and 58.381 mm respectively or less of precipitation in 5, 10 and 20-year periods that correspond to severe to extreme drought episodes. The study therefore recommends that authorities, Government, participating private and NGO's put livelihood diversification measures in place given that over 80% of Lesotho population's livelihood depends on rain-fed-agriculture.

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