Science Park Journals

Vol. 4(1), pp. 020-030, April 2018
ISSN 2315-5396
DOI: 10.14412/SRI2018.030

Available online at http://www.scienceparkjournals.com/SRI

Scientific Research and Impact

Full Length Research Paper

Rainfall variability at decadal time scale and Temperature trend in two distinct Agro-ecological zones of Lesotho

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Abstract: The rainfall pattern in Lesotho is very erratic, unpredictable and it is driven by the regional expression of global atmospheric circulation systems over southern Africa and moderated by the topographic position of Lesotho (1 388 m to 3 482 m above mean sea level) on the southern African plateau. The goal of this study was add to the already existing knowledge on rainfall variability and trends in Lesotho by examining climate data (rainfall and temperature) for two locations situated separately in two agro-ecological zones (AEZs) of Lesotho and highlight some few impacts that may be induced by the observed variability. Results showed that rainfall distribution was highly variable for a 10 year period (1997 – 2007) on both sites with a projected decline for next decade (2007 – 2017). Temperature trend showed a decreasing trend for minimum temperature in Thaba-Putsoa and an increasing trend for T'sakholo. Maximum temperature was observed to follow the same trend on both sites. It was thus concluded that results agree with earlier work denoting inconsistent and uneven rainfall distribution and temperature trends towards a warmer climate over Lesotho. Therefore the avoidance of drawbacks associated with variable rainfall and increasing temperature may involve government to provide farmers with advanced climate and weather information that improves outcomes and seasonal forecasting should be dynamic, starting with a threemonthpre-planting seasonal forecast and becoming progressively finer, providing weekly and even daily forecasts during critical periods to aid operational decision making at farm level.

Key words: Rainfall, temperature, Lesotho, variability.

Introduction

The rainfall pattern in Lesotho is very erratic, unpredictable (Pomela, 1999) and it is driven by the regional expression of global atmospheric circulation systems over southern Africa and moderated by the topographic position of Lesotho (1 388 m to 3 482 m above mean sea level) on the Southern African plateau (Marake et al., 2011). Lesotho is among many southern African countries considered as semi-arid. Semiarid climates display complex patterns of spatial and seasonal rainfall variability exacerbated by the unpredictability of rainfall from year to year, within the year, and even during a single rainfall event (Ramos & Martinez-Casasnovas, 2006). The variability of rainfall makes it difficult to assess contemporary trends in rainfall distributions and potential impacts of climate change.

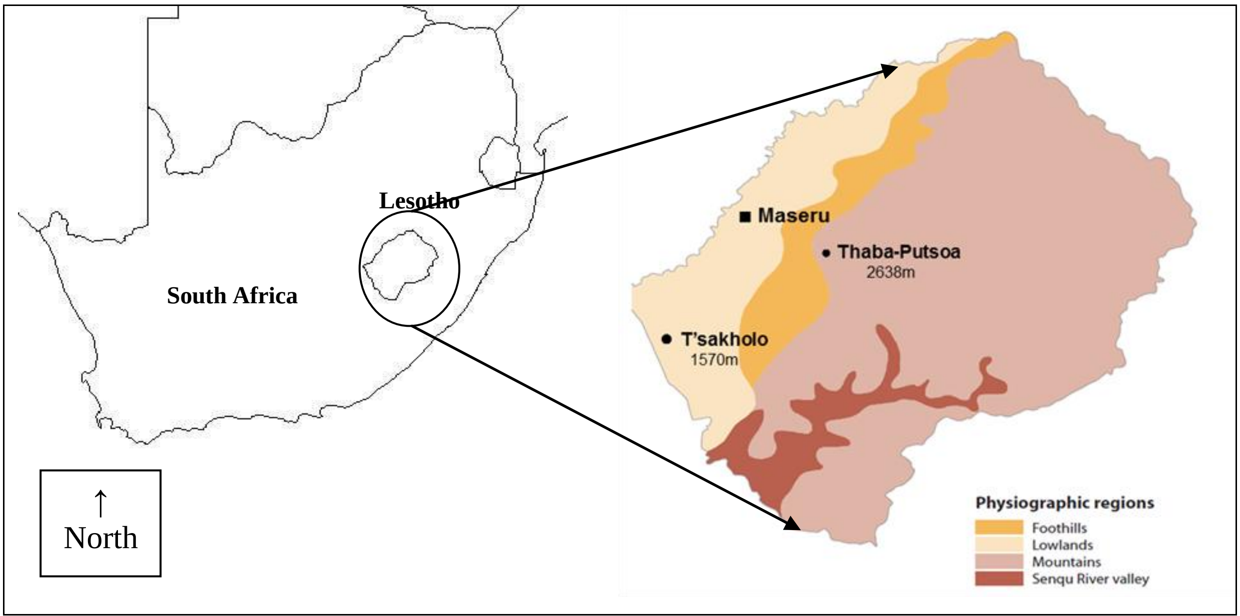
In addition the warming trend for the entire globe (1850 to 2005) is 0.04 decade-1 (Lehmann et al., 2011). This trend is equally evident in Lesotho; the Ministry of Natural Resources (2000) showed that global circulation models using historical data for the years 1961 to 1994 predict warmer future climatic conditions over Lesotho. The high altitude characterising Lesotho means that the country experiences some of the lowest temperatures in southern Africa, especially along the mountainous zone. A significant proportion of Lesotho experiences a mean annual temperature of <10 °C and mean daily maximum and minimum temperatures mostly do not exceed 22.5–25 °C and 10-12.5 °C, respectively, except in the south-western lowlands where temperatures can reach 27.5–32.5 °C and 15–17.5 °C, respectively (Marake et al., 2011).

Thus, research on historical changes in the climatic system is necessary because historical climate records provide the context on natural variation for detecting anthropogenic ally forced climate change which result into rainfall variability. Several studies have analysed rainfall trends in semi-arid regions, for instance Silva (2004) observed sharp increases in rainfall variability in semi-arid north-eastern Brazil and noted trends towards annual rainfall increases in semi-arid parts of China. Building on these ideas, a goal of this paper was to add to the already existing knowledge on rainfall variability and trends in Lesotho by examining climate data (rainfall and temperature) for two locations situated separately in two agro-ecological zones (AEZs) of Lesotho and highlight some few impacts that may be induced by the observed variability.

Materials and Methods
Study Areas

The study was conducted using climate data of two locations situated separately in two agro-ecological zones (AEZs) of Lesotho (Figure 1) namely the mountains (Thaba-Putsoa) and the lowlands (T'sakholo). The two locations Thaba-Putsoa and T'sakholo lie roughly between latitudes 27°58.234 and 27° 10.360 east and longitude 29° 25.798 and 29° 40.469 south respectively at 2638m and 1570m above sea level respectively.

Fig 1: The placement of Lesotho within South Africa and locations of study sites in respective AEZs.



Thaba-Putsoa is characterised by very low temperatures in winter ranging between – 8 °C to 7 °C with frequent occurrences of snow. Mean annual temperatures range between – 8 °C and 30 °C and receiving highest annual rainfall (1000mm – 1400mm). The area is represented by a sequence of clastic sedimentary formations (Burgersdorp formation, Molteno formation, Elliot formation and Clarens formation) overlain by a laterally continuous section of basalt up to 1600 meters thick with a steep-rolling topography. Lithosols are the major soil group in this area.

T'sakholois characterised by maximum temperatures varying between 32 °C in summer to – 7 °C in winter; average temperatures are 25 °C and 15 °C respectively. Rainfall occurs predominantly between October and April ranging between 600mm to 900mm annually. Geology of the site consists of rocks belonging to the Burgersdorp formation which underlie the western part of the country, highly erodible duplex soils characteristic of the area and topography is flat to gentle. Rainfall and temperature data for both sites is presented in Table 1.

Table1: Mean annual rainfall and temperature for Thaba-Putsoa and T'sakholo†

Year	Thaba-Putsoa			T'sakholo		
	Rainfall (mm)	Minimum Temp (°C)	Maximum Temp (°C)	Rainfall (mm)	Minimum Temp (°C)	Maximum Temp (°C)
1997	59.8	6.0	18.93	51.0	8.5	22.53
1998	60.3	6.5	19.68	68.0	8.7	23.22
1999	41.2	6.7	19.52	44.2	8.8	24.09
2000	56.4	6.3	18.37	73.9	8.3	21.31
2001	69.8	6.2	18.69	96.7	8.5	22.35
2002	42.7	6.0	18.80	74.5	8.3	22.95
2003	43.8	6.3	19.58	42.3	8.7	24.00
2004	53.2	5.7	16.95	39.2	8.9	23.04
2005	48.1	6.4	19.56	49.6	9.1	23.13
2006	72.8	6.4	18.49	83.0	8.4	21.75
2007	46.7	6.2	19.27	45.4	8.3	23.30

†Source: Lesotho Meteorological Service.

Data and Methods

Climate data (rainfall and temperature) for the two study locations were collected between 1997 and 2007 (for rainfall) and between 1967 and 2009 (for minimum and maximum temperature) from the Lesotho Meteorological Service (LMS). The data set included the monthly rainfall and temperature readings which were averaged to determine values per annum. Basic descriptive statistics calculated to evaluate rainfall variability within each year were mean, standard deviation (SD) and coefficient of variation (CV). Intervention analysis was carried out using the Cumulative Summation (CUSUM) technique (Parida et al., 2003) to determine inconsistencies in rainfall and temperature data. The computed CUSUM value (y_i) at any time *i* was given as:

$$y_i = \left(x_i + x_{i-1} + x_{i-2} + ... + x_n\right) - i ... \bar{x}$$

where *n* = sample size; $\bar{x}$ = average of the total series. When the series under test is free from any interventions, the plot of y_i versus *i* should normally oscillate around the horizontal axis. A steady decline or rise of this plot (or drastic departure from oscillatory patterns in that regard) would suggest the possibility of intervention from the year of observation (corresponding to the relevant '*i*') of such a change. Positive slopes on these charts indicate a period of above average values of rainfall (hence a 'wet' period in this context) with a negative slope indicating otherwise (Whiting et al., 2003). A ten year rainfall forecast (2007 – 2017) was evaluated for both study sites using Mystat time series tools (version 12). Trend has been analysed using the Mann–Kendall method which has been found to be useful and widely used for detecting trends in climate and environmental sciences (Sneyers, 1990; Kadiolgu, 1997). The Mann–Kendall-statistic S is given as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}\left(x_j - x_k\right)$$

Where $sgn(x_j - x_k)$ = 1 if $x_j - x_k > 0$

= 0 if $x_j - x_k = 0$

= - 1 if $x_j - x_k < 0$

The variance of S denoted by (σ_S^2) is computed as:

$$\sigma_S^2 = \frac{n(n-1)(2n+5) - \sum_{j=1}^{q} t_j(t_j - 1)(2t_j + 5)}{18}$$

where *n* is the number of data points, *q* is the number of tied groups in the data set and t_j is the number of data points in the *j*th tied group.

Then S and σ_S^2 were used to compute the test statistic Z_S as:

$$Z_S = \frac{S-1}{\sigma} \quad \text{if } S > 0$$
$$= 0 \quad \text{if } S = 0$$
$$= \frac{S+1}{\sigma} \quad \text{if } S < 0$$

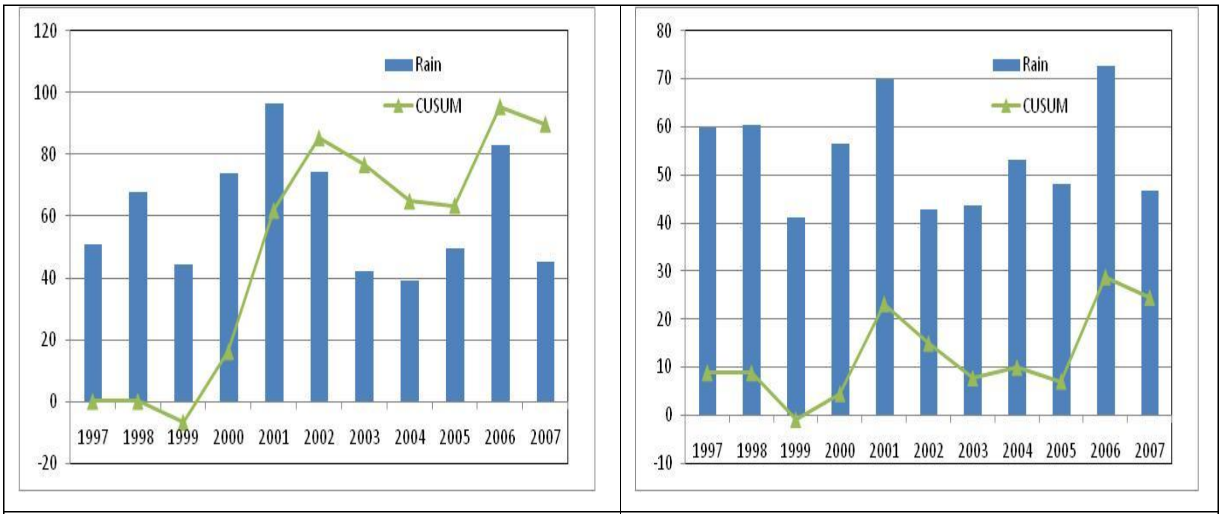
Results

The descriptive statistics for annual rainfall across the years for sites are presented in Table 2. The mean annual rainfall across the years on both sites ranged between 39.25mm and 96.66mm (Thaba-Putsoa) and between 41.16mm and 72.83mm (T'sakholo).The standard deviations (SD) are surprisingly low, ranging from 33.09mm to 87.85mm in Thaba-Putsoa while in T'sakholo they range from 26.31mm to 63.20mm. The CV values for year are high (> 30%) indicating extreme rainfall variability within each year for both sites.

Table 2: Descriptive statistics for all years on both sites

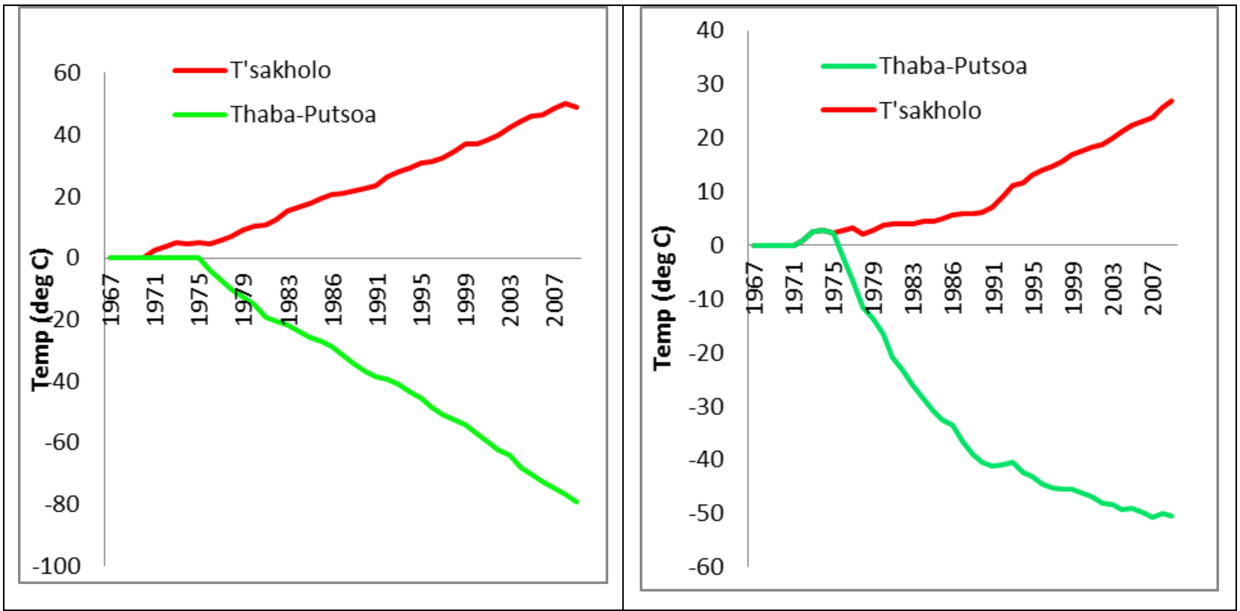
Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Thaba-Putsoa											
SD*	50.14	66.25	52.52	87.85	74.92	70.87	41.71	33.09	47.17	63.67	43.32
Mean	51.04	67.96	44.20	73.95	96.66	74.53	42.27	39.25	49.63	83.01	45.35
CV†	0.98	0.97	1.19	1.19	0.78	0.95	0.99	0.84	0.95	0.77	0.96
T'sakholo											
SD	44.96	59.75	35.80	43.61	63.20	26.31	43.51	41.55	37.63	59.07	40.32
Mean	59.77	60.29	41.16	56.38	69.80	42.73	43.80	53.16	48.12	72.83	46.68
CV	0.75	0.99	0.87	0.77	0.91	0.62	0.99	0.78	0.78	0.81	0.86

*SD= standard deviation; † CV= Coefficient of variation



CUSUM graph for rainfall in Thaba-Putsoa	CUSUM graph for rainfall in T'sakholo

Fig 2: CUSUM plot for rainfall analysis (1997 – 2007)



Minimum Temperature (1967 – 2009)	Maximum Temperature (1967 – 2009)

Fig 3: CUSUM plot for both minimum and maximum temperature on both sites.

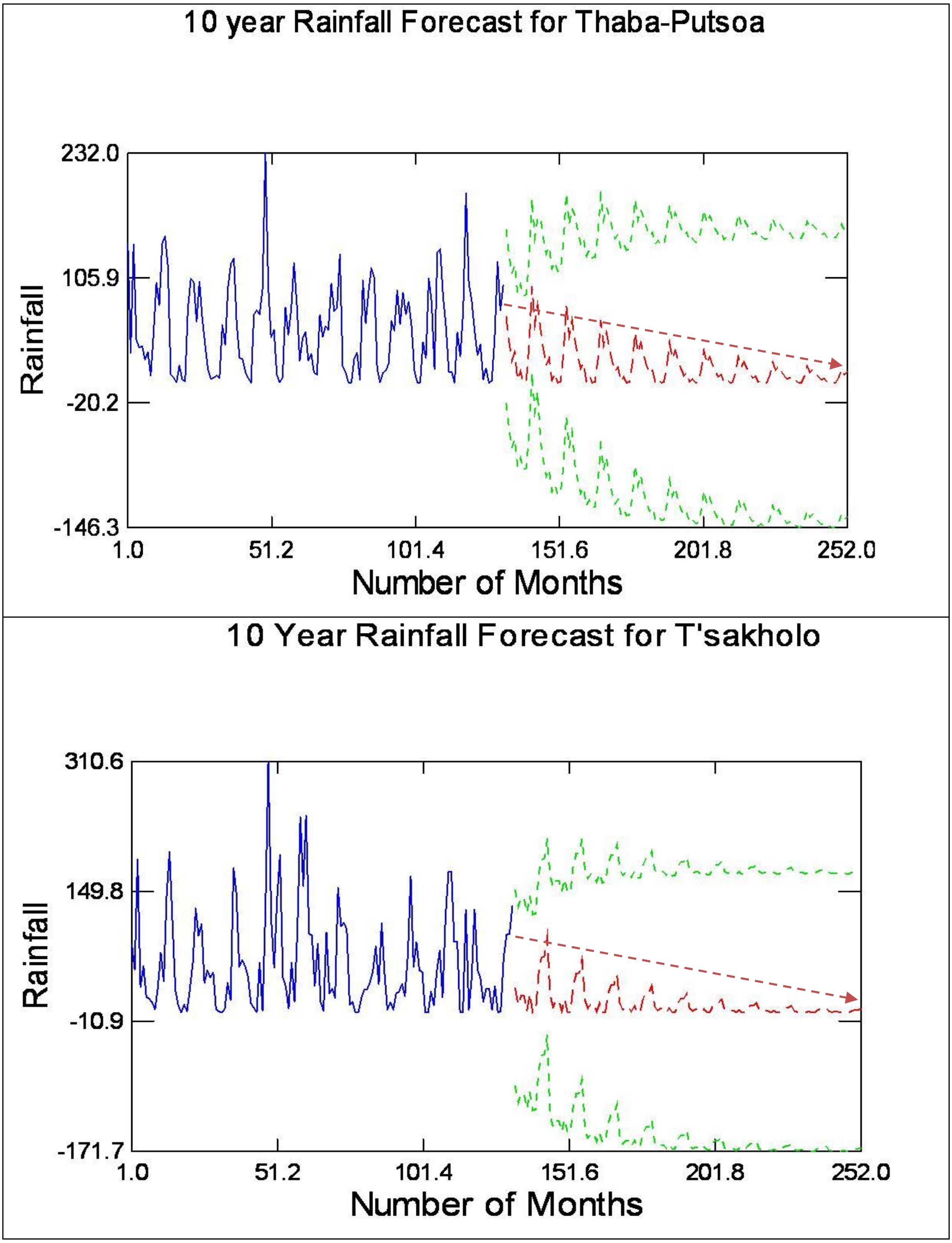


Fig 4: A 10 year rainfall forecast for Thaba-Putsoa and T’sakholo

Cumulative sum (Cusum) analysis of rainfall and temperature

An examination of the CUSUM plot (Figure 2) showed that for the period 1997 – 2007 there was a very low and highly variable distribution of rainfall on both sites and these results are in line with recent finds by other workers such as Marake et al (2011) that there is highly an uneven rainfall distribution over Lesotho. The CUSUM plot (Figure 3) also showed that minimum temperature has been decreasing since 1975 up to 2009 at Thaba-Putsoa, while in T'sakholo, it has been increasing. Maximum temperature is following the same trend in both sites.A further analysis using MYSTAT time series tools was carried to forecast rainfall trend for the next decade (2007- 2017). The results revealed a decreasing trend of rainfall on both sites (Figure 4). Furthermore the CUSUM analysis was run for temperature (maximum and minimum) for the two study sites. According to Mann-Kendall test (Table 3) minimum temperature in both sites is statistically significant (Thaba-Putsoa = $p < 0.01$and T'sakholo $p < 0.05$). Although the trends for rainfall are not significant, it is generally decreasing as evident from negative values of the Mann-Kendall statistics, T, for T'sakholo and zero for Thaba-Putsoa (Table 3).

Table 3: Trend analysis using Mann–Kendall method

*p < 0.1, **p < 0.05, ***p < 0.01

	---Thaba-Putsoa Lesotho---											
ne ries	**Test Z_S**	**Signific.**	**Q**	**Qmin99**	**Qmax99**	**Qmin95**	**Qmax95**	**B**	**Bmin99**	**Bmax99**	**Bmin95**	**Bmax**
nTemp	5.51	***	0.073	0.043	0.110	0.050	0.100	4.32	4.84	3.52	4.73	3
xTemp	0.44		0.006	-0.028	0.047	-0.020	0.034	18.86	19.56	18.30	19.42	18
infall	0.00		-0.700	-4.209	3.227	-2.723	2.172	58.10	69.05	34.75	64.57	38

*p < 0.1, **p < 0.05, ***p < 0.01

	---Tsakholo Lesotho---										
Time series	**Test Z_S**	**Signific.**	**Q**	**Qmin99**	**Qmax99**	**Qmin95**	**Qmax95**	**B**	**Bmin99**	**Bmax99**	**Br**
MinTemp	3.29	**	0.027	0.008	0.047	0.013	0.042	7.79	8.25	7.42	
MaxTemp	1.33		0.017	-0.023	0.045	-0.012	0.036	22.37	23.05	21.69	
Rainfall	-0.16		-0.475	-8.556	9.590	-4.885	3.743	53.40	99.57	25.02	

Discussion

Results of this study have shown that there has been a noticeably variable and inconsistent rainfall distribution in two study sites for a period of 10 years (1997 – 2007) and a projected decrease in rainfall for the next decade (2007 – 2017). Secondly results have shown that minimum temperature is decreasing in Thaba-Putsoa while they are increasing in T'sakholo with maximum temperatures following the same trend on both sites. These results are in line with significant changes in climate that have been noted in recent decades in many parts of the world and the most significant change has been a decrease in rainfall resulting in a step down decrease in surface runoff and groundwater recharge rates. According to Marake et al., (2011) variability of rainfall (inter-annual coefficient of variation) is high, ranging from 20% to more than 40% and this variability is among the main climatic constraints to agricultural production. This has severe consequences for individuals and societies, causing crop failures, loss of livestock, and associated loss of income and even famine (Meinke et al., 2005). It also results in considerable environmental degradation particularly when combined with inappropriate management strategies (Hammer 2000; Allan 2000; Meinke et al. 2003). The consequences of rainfall variability and increasing temperature trends may even be worse on water resources such as wetlands. Climatic variables particularly temperature and precipitation are strong determinants of wetland ecosystem structure and function (Mulholland et al., 1997). Interannual variability in precipitaion affect wetland conditions by altering both water levels and habitat structure (Weller, 1999). Lesoth is notoriously a water-rich countr however the results of this study highlight a threat of uneven rainfall distribution and a projected to decline in the near future. It is anticipated that these outcomes may likely have a severe impact on future water projects in Lesotho.

Conclusions and Recommendations

As a contribution to understand rainfall variability in Lesotho this paper explored rainfall variability and temperature trends in two locations of Lesotho. The results agreed with earlier work denoting inconsistent and uneven rainfall distribution and temperature trends towards a warmer climate over Lesotho. Therefore the avoidance of drawbacks (low crop production and drying up of wetlands) associated with variable rainfall and increasing temperature may involve government to provide farmers with advanced climate and weather information that improves outcomes and seasonal forecasting should be dynamic, starting with a threemonth pre-planting seasonal forecast and becoming progressively finer, providing weekly and even daily forecasts during critical periods to aid operational decision making at farm level.

Acknowledgement

This research was funded by the Regional Universities Forum for capacity building in Agriculture (RUFORUM) RU/CGS/GRG/30/06/09. We acknowledge the field and laboratory assistance of Mrs Mashao and Mr Mafona including the rest of the under-graduate students who were always supportive.

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