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Trends and Variability Assessment of Rainfall in Vhembe South Africa

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ABSTRACT This study focuses on assessing trends and variability in rainfall of Vhembe District South Africa. Mann-Kendall trend analysis and Sen's slope estimator are used in determining the changes in the rainfall climatology. The interesting observation is that humid zone and semi-arid zones in the district exhibit different behaviour as far as trend analysis is concerned. Due to diverse rainfall zones, this study provides major evidence that rainfall is highly variable within local settings. The direction of rainfall trend was, in general, downward and statically significant across the semi-arid zone. Statistically significant (downward) trends (95% to 99%) were observed in densely populated areas affected by urban sprawl, depleted vegetation cover, or other human development such as large-scale farming and construction. Generally, changes in rainfall characteristics were mostly observed to start in the mid-1990s. Global climate change influence on the changes in rainfall characteristics was not conclusive. However, the local anthropogenic climate change was obviously one of the causes of changes in rainfall.

INTRODUCTION

This study presents the analysis and results of the non-parametric Mann-Kendall test at the $\geq$95% significance level of rainfall in Vhembe District, South Africa. Temporal rainfall data for the individual stations in a rainfall zone (Nenwiini 2010), are subjected to the Mann-Kendall test. The results presented are based on the Mann-Kendall trends analysis using the Makesens template application (Salmi et al. 2002). In order to determine the magnitude of change per unit time of the trends detected, the Sen's estimator was adopted (Sen 1968).This non-parametric aligned rank test was considered appropriate because no underlying frequency distribution of data could be assumed. According to Salmi et al. (2002), in the cases where important significant trends are observed, statistical computation gives high level of significance with narrow angles between the confidence lines. In this paper the trend is significant at the point where the 95% confidence bounds and the Sen's estimate line meet.

Nenwiini (2010) demarcated Vhembe District into three local-scale homogeneous rainfall zones which are humid, sub-humid and semi-arid. This paper adopts these rainfall zones and evaluates the significant changes in two zones of humid and semi-arid. Combining the zones adds uncertainty to any conclusions drawn and may produce not only highly-biased results but also greater variance. The sub-humid zone was left out because it features the characteristics of both humid and semi-arid zones; thus resulting into multiple ties, the consequence of which is the situation of significant trend but zero slope (Smith and McCann 2000). Relevant reviews on trend-related studies in precipitation time series include the studies of Mason (1996), Kabanda (2004), Kruger (2006), Thomas et al. (2007) and Partal and Kahya (2006). According to Jain and Kumar (2012), to understand rainfall variability and trend is crucial and necessary in order to appreciate the impacts of climate change and also as a basic and important requirement for the planning and management of water resources.

Objectives

The purpose of this paper is to investigate the variability of rainfall of Vhembe District located in northern South Africa. It includes the understanding of the area's rainfall trends or changes. This approach is in agreement with Lumsden et al. (2009) who recommended that changes in the seasonal distribution of rainfall should be examined in support of efforts to adapt to climate change in the Southern African regions. The information on changes in rainfall of the area in question will provide a base that is crucial for further climate change research.

MATERIAL AND METHODS

Study Area

The study is centred on 22°S to 24°S and 29°E to 31.5°E (Fig. 1). It covers an area of approximately 60,500 km^2 which is characterised by unique diverse topography which have a significant influence on the rainfall of the area. The Soutpansberg is the most prominent mountain range in the study area. According to Hanssen-Bauer et al. (1997), precipitation amount and variability may differ largely over small distances, due to orographic effects which are sensitive to small differences in circulation patterns.

Monthly rainfall data for 23 stations in Vhembe District were obtained from the South Africa Weather Services (SAWS). Some rainfall stations had gaps which were filled using the interpolation from data of the nearest high correlating neighbouring stations (Nyenzi 1988). Long-term station records of 40 years (1970 to 2009) were obtained from two rainfall zones (humid and semi-arid). All acquired data were subjected to 5-year moving average in order to filter out climatic forcing such as El Niño southern Oscillation (ENSO) and sunspot effects that irregularly influences the area rainfall.

The Mann-Kendall Test

This method tests if there is a trend in the time series data. The data values are evaluated as an ordered time series. Each data value is compared to all subsequent data values. The initial value of the Mann-Kendall statistic, S, is assumed to be 0 (for example, no trend). If a data value from a later time period is higher than a data value from an earlier time period, S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S.

Let $x_1, x_2, \ldots x_n$ represent n data points where x_j represents the data point at time j.

Then the Mann-Kendall statistic (S) is given by

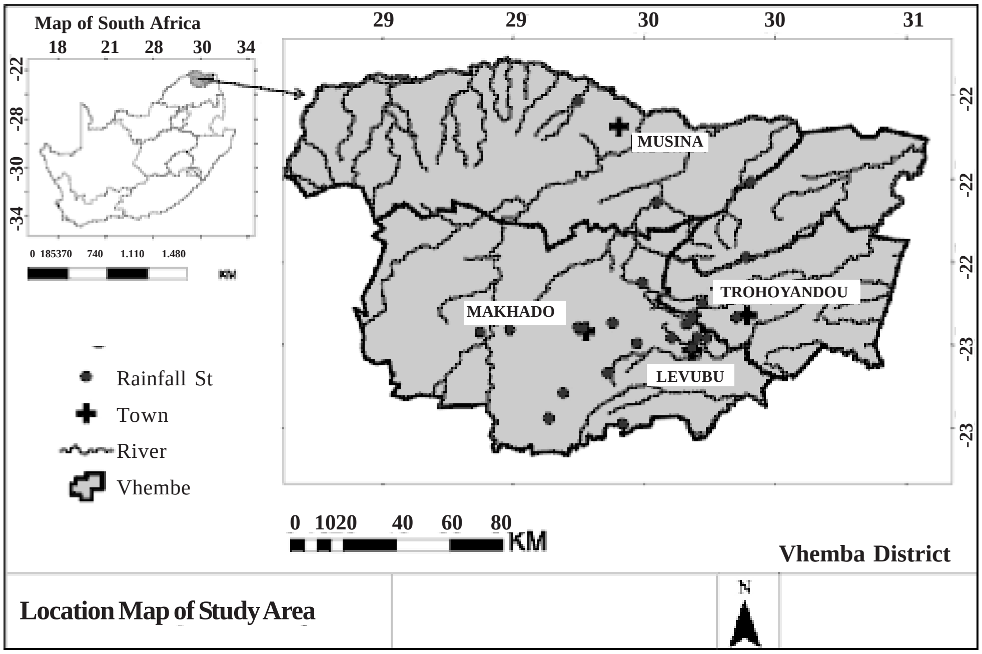


Fig. 1. Vhembe District

$$S = \sum_{k-1}^{n} \sum_{j-k+1}^{n} \text{sign}\,(X_j - X_k) \qquad (1)$$

where: $sign\,(x_j\text{-}x_k) = 1 \text{ if } x_j\text{-}x_k > 0$
$= 0 \text{ if } x_j\text{-}x_k = 0$
$= -1 \text{ if } x_j\text{-}x_k < 0$

When S is high and positive it implies that the trend is increasing, and a very low negative value indicates a decreasing trend. However, to statistically quantify the significance of the trend it is necessary to compute the probability associated with S and the sample size n. The procedure to compute this probability is described in Kahya and Kalayci (2004) and Partal and Kahya (2006).

The Sen's Estimator of Slope

The method of calculating the Sen's slope estimator requires a time series of equally spaced data. Sen's method proceeds by calculating the slope as a change in measurement per change in time, as shown here in Equation (2):

$$Q = \frac{X_j - X_k}{j - k} \qquad (2)$$

Where: Q = slope between data points X_j and X_k

X_j = data measurement at time j

X_k = data measurement at time k

j = time after time k, X_j and X_k constitute the pairs of observations identified by place in the series. The median of these estimates is Sen's estimator of slope.

RESULTS

Variation in Rainfall Trends for Humid Zone

The results for humid-zone rainfall trend analysis are presented in Table 1 and in Figure 2. Of the twelve stations in the humid zone, four stations had a significant trend at ≥95% with test statistic Z ranging from -1.98 to -2.98. The trend is said to be decreasing if Z is negative and the computed probability is greater than the level of significance, and increasing if Z is positive and the computed probability is greater than the level of significance. If the computed probability is less than the level of significance, there is no trend. From Table 1, it is evident that most stations in the humid zone show no significant trend. However, Tshakuma and Setali show a very pronounced negative trend at Z equals to -2.98 and -2.9 respectively. Entabeni and Kruger had relatively weaker negative trends at -2.41 and -1.98 respectively.

Although there are many stations in Table 1 that showed relatively large downwards trends, only four are statistically significant. These are Tshakuma (-18.3 mm/year), Entabeni (-12.5 mm/year) Setali (-9.95 mm/year) and Krugerwildtuin (-3.95 mm/year). The magnitude of Sen's slope estimate is shown in bracket for each station. There is no any station which showed a statistically significant upward trend. In Figure 2, four stations with statistical significant trend are presented. The arrow indicates the position were the trend show high level of significance; at the point where the 95% confidence bounds and the Sen's estimate line meet.

Variation in Rainfall Trends for Semi-arid Zone

Trend direction, magnitude and significance in the semi-arid zone are shown in Table 2 and Figure 3. Nine of the eleven stations, covering more than 80% of the semi-arid zone, showed

Table 1: Trend analysis for humid zone

Time series	*Mann-Kendall trend*				*Sen's slope estimate*	
	First year	*Last year*	*N*	*Test Z*	*Significance*	*Q (mm/year)*
Tsianda	1970	2009	40	-0.78		-3.479
Palmayville	1970	2009	40	0.37		1.488
Entabeni	1970	2009	40	-2.41	*	-12.522
Rambuda	1970	2009	40	0.01		0.071
Levubu	1970	2009	40	-1.48		-5.61
Tshakhuma	1970	2009	40	-2.98	**	-18.28
Matiwa	1970	2009	40	-0.75		-4.545
Setali	1970	2009	40	-2.9	**	-9.947
Krugerwildtuin	1970	2009	40	-1.98	*	-3.952
Vondo	1970	2009	40	0.12		0.585
Mphephu	1970	2009	40	0.5		0.915

*** = 0.001 level of significance; ** = 0.01 level of significance;
* = 0.05 level of significance

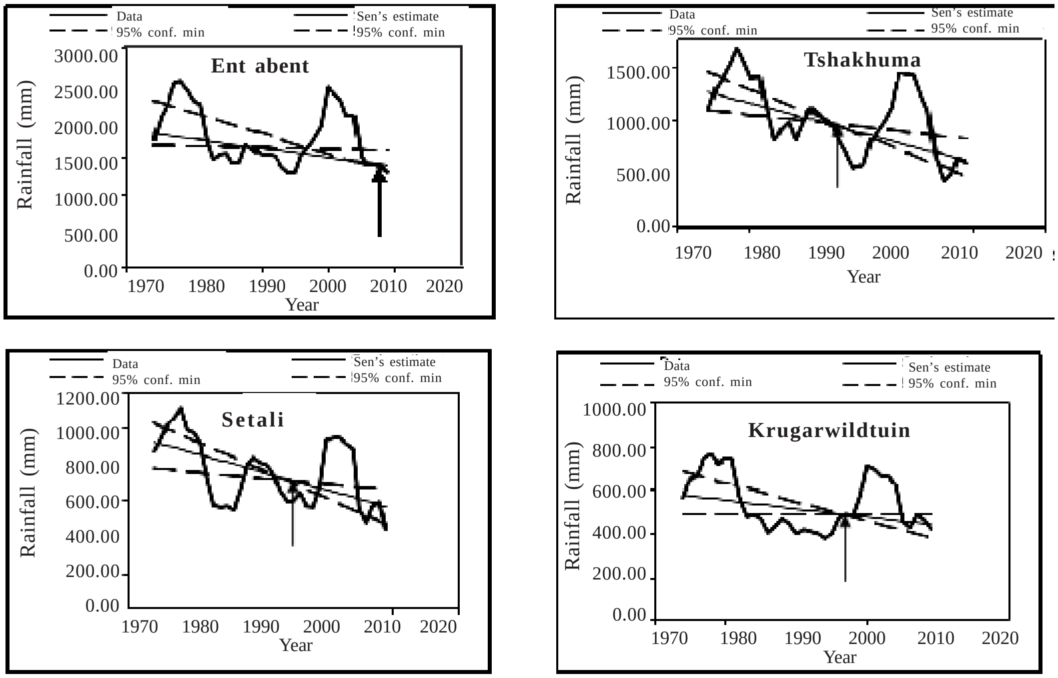


Fig. 2. Humid-Zone rainfall trend; the arrow indicates the position were the trend show high level of significance (≥95%)

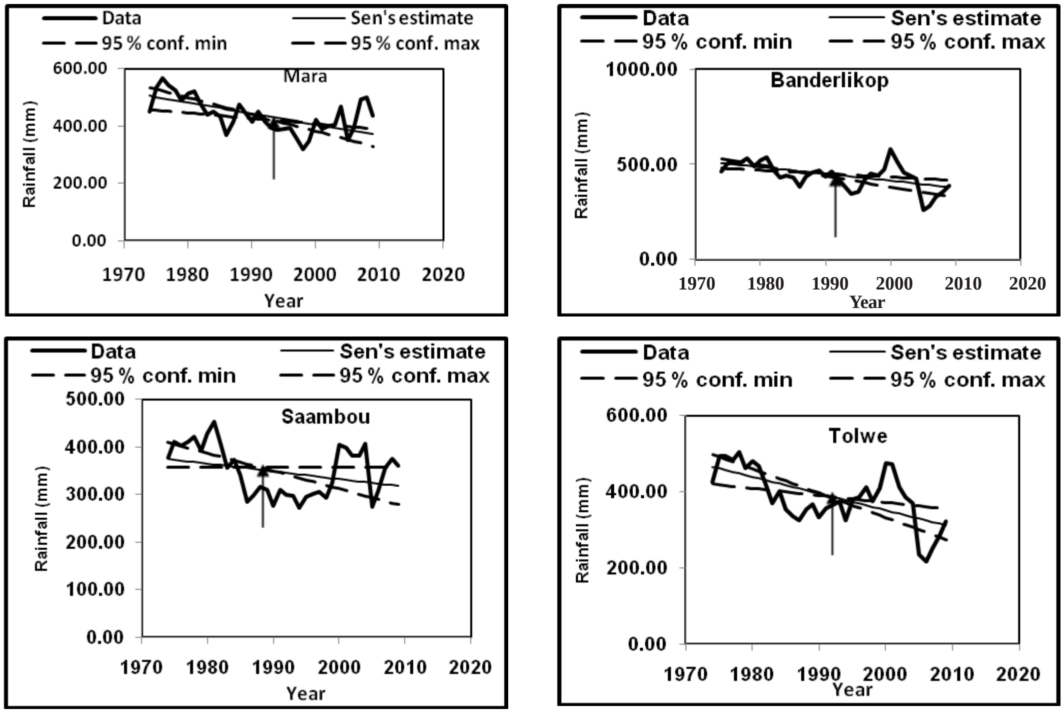
Table 2: Trend analysis for semi-arid zone

Time series	*Mann-Kendall trend*				*Sen's slope estimate*	
	First year	*Last year*	*N*	*Test Z*	*Significance*	*Q (mm/year)*
Mara	1970	2009	40	-3.57	***	-3.841
Saambou	1970	2009	40	-1.98	*	-1.623
Mara Pol	1970	2009	40	-2.90	**	-3.916
Tshipise	1970	2009	40	-2.68	***	-4.309
Banderlikop	1970	2009	40	-3.36	**	-3.605
Tolwe	1970	2009	40	-3.26	**	-4.395
Una-agric	1970	2009	40	-3.20	**	-3.792
Pontdrift	1970	2009	40	-3.15	**	-3.642
Messina	1970	2009	40	-2.68	**	-2.948
Elim	1970	2009	40	-1.02		-1.985
Folovhodwe	1970	2009	40	-0.10		-0.159

*** = 0.001 level of significance; ** = 0.01 level of significance;
* = 0.05 level of significance

negative trends at ≥95% statistical significance. Of those nine stations, two (Mara and Banderliekop) reported a negative trend at 99.9% level of significance; six stations (Mara-Police, Tshipise, Tolwe, Una-agric, Pont Drift and Messina) accounted for 99% level of significance while Saambou reported a 95% significance level. Also, two stations (Elim and Folovhodwe) showed negative trends although not statistically significant.

Most of the stations in the semi-arid zone show decreasing linear trends which are statistically significant. The Sen's estimator (Q mm/year) summarises the results of change per unit time of the trends detected. Sen's estimator value ranges from -4.4 mm/year at Tolwe station to -0.2 mm/year at Folovhodwe. Stations having a large negative trend (≤-3.0 mm/year) were identified as Mara, Saambou, Mara Police, Tshipise, Banderlikop, Tolwe, Una-agric, Pontdrift and



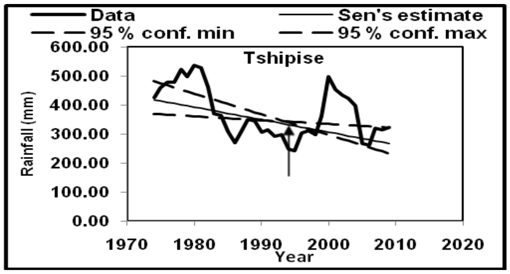


Fig. 3. Semi-arid-zone rainfall trend analysis; the arrow indicates the position were the trend show high level of significance (≥95%).

Messina. Five of these stations are shown in Figure 3. It is noted that the significant trends start (Arrow position) in the years between 1985 and 1995 and mostly centred on 1990.

DISCUSSION

By applying trend detection on homogenous zones rainfall data in Vhembe District South Africa, has resulted in identifying some significant trends. It is interesting to note that humid zone and semi-arid zones exhibit different behaviour as far as trend analysis is concerned. The direction of rainfall trend was, in general, downward and statically significant across the semi-arid zone. In the humid zone only one- third of the stations showed downward trends with significance at ≥95%. For the stations that showed highly significant trends, Sen's slope estimates varied between -3.95 and -18.3 mm/year in the humid zone and between -1.623 and -4.395 mm/year in the semi-arid zone. However, the semi-arid zone showed an increase in the statistical significance from 95% to 99.9% through 99%. There was no station which reported a positive Sen's estimator value in the whole of semi-arid zone.

Generally, a significant negative trend was observed to start in the mid-1990s in almost all the zones. These results demonstrate the impacts of anthropogenic developments in the study area in agreement with the observations by Kabanda and Munyati (2010), Munyati and Kabanda (2009), and Department of Environmental Affairs and Tourism (DEAT) (2003). The changes in rainfall were linked with human influence such as; using wood for energy, urban expansion and agriculture which are some of the major causes of deforestation in the area.Due to deforestation, the water cycle is affected which lead to reduction in rainfall. Government settlement policies prior 1994 saw the relocation and concentration of native South Africans in 'homelands'. In the Vhembe District, these high human concentrations affect the eastern edge of the Soutpansberg mountain range and have resulted in localised pressure on woodlands and forests for purposes of settlement and subsistence agriculture (Munyati and Kabanda 2009).

Upward trends were found in some few places, starting in the late 1980s, although these were not statistically significant. The increase in rainfall in those areas can be associated with exotic forest plantations such as eucalyptus, pine and tropical fruits and nuts which expanded in the 1970s and 80s (Lahiff 2000).

CONCLUSION

This study has clearly demonstrated that climate studies focusing on localised areas are possible and important, since local-scale climate has direct relevance to large populations dependent on subsistence agriculture. A continuous decrease in rainfall can be explained by lack of strong local influences on rainfall formation like vegetation on mountains, also increase in population that use more land for agriculture and settlement (urban sprawling). Climate change effects at global to local scale might also be playing a role.

Another concluding remark is that; continuous significant decline (at the $\geq$95% level) of rainfall, suggests that the humid areas will continue to dry while the semi-arid might develop into arid zone. However, if overexploitation of forests will be avoided; for example, through assistance to meet communities' basic needs with income generation opportunities, vegetative cover can be restored. Poverty mitigation measures can include planting trees (for their products and services) in major afforestation schemes, woodlots, linear plantations, windbreaks and agroforestry.

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