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Rainfall trend and variability in semi-arid northern Namibia: Implications for smallholder agricultural production

S. K. Awala[1], K. Hove[1,*], M. A. Wanga[2], J. S. Valombola[1,] and O. D. Mwandemele[1]

[1]*Department of Crop Science, Faculty of Agriculture and Natural Resources, University of Namibia, Windhoek, Namibia*
[2]*Division of Crop Research and Production; Directorate of Agricultural Research and Development; Ministry of Agriculture, Water and Forestry; Mannheim Research Station, Tsumeb, Namibia*

Abstract

Rainfall defines livelihood patterns among agrarian communities of the climate-change vulnerable semi-arid Sub-Saharan Africa. However, it remains inadequately studied, resulting in ineffective water management policies and weak agricultural growth in the region. Monthly rainfall data collected between 1987 and 2018 at four stations along a 1200 km climatic gradient in northern Namibia were analysed for annual, seasonal and monthly trends and variability. Descriptive measures and the Mann-Kendall test were used for rainfall characterisation and trend detection, respectively. Results showed an annually increasing rainfall trend, but with a downward trend in the dry season decreasing by -0.14 mm year^{-1} and an upward trend in the rainy season increasing by 7.74 mm year^{-1} across the study area. The rainy-season mean monthly rainfall showed predominantly increasing trends, while the dry-season ones exhibited insignificant decreasing trends. The study detected a decreasing rainfall gradient from the northeast towards the northwest with a range of 156.8 mm and concomitant increasing spatial-temporal variability. The upward rainfall trend has implications for rainy season floods, whereas the downward trend suggests dry season drought intensification in the area. These results could be useful for rainwater management planning in the study area and other dryland regions.

Keywords: Climate change, drought, drylands, flood, subsistence farming.

1. Introduction

Climate change and variability are critical environmental phenomena affecting humanity, especially in dryland regions. They alter natural ecosystems (Hoffman & Vogel, 2008; Gornall et al., 2010; Jiménez et al., 2011) and disrupt agro-ecosystems (Serdeczny et al., 2017), more so in arid and semi-arid regions of the world (Zika & Erb, 2009; El-Beltagy & Madkour, 2012), which are the habitats for about 15% of the human population (Fensholt et al., 2012; Huang et al., 2016). The majority of the people in these regions are smallholder subsistence farmers (Mati, 2000; Montenegro & Ragab, 2012; Roder, Pröpper, Stellmes, Schneibel, & Hill, 2015). In semi-arid Sub-Saharan-Africa (SSA), the subsistence farmers depend primarily on rainfed agriculture, comprising livestock and crop production systems, for food and incomes. Rainfall in this region is generally low and erratic thus characterised by recurrent droughts, causing livestock losses and crop failures, leading poverty and food insecurity in the region (Tsheko, 2003; Tschakert, Sagoe, Ofori-Darko, & Codjoe, 2010). However, increasing rainfall variability has been observed in various parts of SSA, displaying both spatial and temporal variability (Mupangwa, Walker, Masvaya, Magombeyi, & Munguambe,

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2016; Kiros, Shetty, & Nandagiri, 2017). Rainfall trends in the region have also been variable in recent decades. Some countries depict increasing trends (Akinyemi, 2017), others showing a decreasing tendency (Lema & Majule, 2009; Dube & Phiri, 2013; Mavhura, Manatsa, & Mushore, 2015), while some present heterogeneous rainfall trends (Diop, Bodian, & Diallo, 2016; Djaman et al., 2016), due to changes in global climatic systems.

Rainfall variability is a natural characteristic of semi-arid climates, usually manifested in various ways. In semi-arid regions, rainfall variability is associated with delayed rainy season onset, early rainy season cessation, reduced length of the growing season, and frequent or prolonged intra-seasonal dry spells (Sarr, 2012; Vicente-Serrano et al., 2015; Yamusa, Abubakar, & Falaki, 2015), often culminating in low agricultural production. Exasperatingly, the ongoing global climate change is likely to increase rainfall variability, especially in the semi-arid regions of the world. Although drought is known to be the major constraint to agricultural production in the semi-arid regions, seasonal floods irregularly hitting these regions also disrupt the farming activities (Tsheko, 2003; Tschakert et al., 2010). More recently, there have been numerous flood events in the semi-arid SSA region because of high summer rainfalls (Tschakert et al., 2010; Mendelsohn, Jarvis, & Robertson, 2013; Anthonj, Nkongolo, Schmitz, Hango, & Kistemann, 2015), indicating that both droughts and floods cause food deficit to the region. Since agricultural activities in dryland regions mainly depend on rainfall, understanding its behaviour is crucial for the development of sustainable agro-pastoral systems in these areas. Time-series studies are used worldwide to characterise rainfall phenomena and predict climate change (Bhuyan, Islam, & Bhuiyan, 2018; Nema, Khare, Adamowski, & Chandniha, 2018). The results of the time-series studies are evaluated to identify specific rainfall behaviours, such as trends, seasonality, cycles, and irregular fluctuations, which aid in developing models for rainfall forecasting, efficient water resource management and utilisation, and planning for agriculture production (Hadgu, Tesfay, Mamo, & Kasse, 2013; Patle, & Libang, 2014; Feng et al., 2016). Although these studies ought to be more crucial for arid and semi-arid regions, which are more vulnerable to the effects of climate change, some SSA countries lack observational data to study long-term rainfall trends and variability (Lu, Wang, Pan, Kaseke, & Li, 2016). Moreover, rainfall data recorded at remote public research stations are usually left in raw forms, and often inconsistent to warrant long-term time series analyses.

In Southern Africa, semi-arid countries such as Botswana, Zimbabwe and Namibia generally experience recurrent droughts; however, due to the effects of climate change, these countries have recently been faced with the problem of seasonal floods (Bola et al., 2013; Iijima, Awala, Nanhapo, Wanga, & Mwandemele, 2018). Previous time-series studies in Southern African have shown variable spatial and temporal rainfall trends and distribution patterns. For example, a studies carried out in Botswana by Batisani and Yarnal (2010) at 10 stations across the country, using rainfall data for the 1975–2005 period, and by Mphale, Dash, Adedoyin, and Panda (2014) at four of the stations using data for the period 1950–2008, identified trends towards decreased rainfall. A more recent study conducted at another station Palapye by Akinyemi (2017), using data for the 1989–2015 period, showed a trend towards increased annual rainfall amount, but with high inter-annual variability. As for Zimbabwe, Chikodzi, Murwendo, and Simba (2013) found decreasing trends in rainfall amounts at two of three stations studied during the years 1923–2011; while a study carried out in Matobo District by Dube and Phiri (2013), using data for the period 1969–2011, displayed a declining rainfall trend. On the other hand, Mazvimavi (2010) investigated changes over time of annual rainfall in Zimbabwe using data for the period 1930–2000 but found no statistically significant changes in both seasonal and yearly amounts. Mazvimavi, therefore, argued that the general perception about declining rainfall is likely due to the presence of multi-decadal variability associated with alternating rainfall regimes of successive years with above and below-average rainfall.

In the case of Namibia, the driest country south of the Sahel region, studies have been conducted for both rainfall variability (Mendelsohn, Jarvis, Roberts, & Robertson, 2009; Mendelsohn, Jarvis, & Robertson, 2013) and rainfall trends (Rohde & Hoffman, 2012; Lu et al., 2016). However, studies on the rainfall trends have mainly used short-term data from a few stations in commercial farming areas. So far, to our knowledge, only

Persendt, Gomez, and Zawar-Reza (2015) have carried out a long-term rainfall trend study using annual data for the period 1917–2014, also obtained from a commercial farming block, which showed a declining trend and fluctuating decadal rainfall regimes. There is currently no information regarding long-term rainfall trends and variability across northern Namibia communal areas where the majority of the population lives. Meanwhile, researchers (e.g. Awala et al., 2016; Iijima et al., 2018) have proposed new agricultural methods, include crop diversification and ridge-furrow planting, adaptable to the prevailing conditions of unpredictable droughts and floods in northern Namibia.

Even though rainfall is the principal climatic factor determining livelihoods among rainfed subsistence farming communities in SSA, other weather variables are also equally important. Temperature and rainfall are the two most crucial weather variables used to describe climate change (Huang, Guan, & Ji, 2012). Some long-term climatological studies have shown a strong relationship between these two variables. A study conducted in West Bengal, India by Mukherjee (2017) using data for the period 1901–2000, exhibited a negative relationship between annual rainfall and temperature and between annual rainfall and potential evapotranspiration. Addisu, Selassie, Fissha, and Gedif (2015) also found a negative correlation between annual rainfall and temperature after analysing 40-year weather data from Lake Tana sub-basin, Ethiopia.

On the other hand, Cheo (2016) investigated seasonal trends in rainfall and temperature in northern Cameroon over the period 1957–2006 and observed insignificant declining rainfall and rising temperature trends during the rainy season, and a decreasing tendency in both variables during the dry season. Scientific evidence exists concerning rising temperature and variable rainfall, both spatially and temporally, with wet areas becoming wetter and dry areas becoming drier (El-Beltagy & Madkour, 2012). When rainfall shows a decreasing tendency, then there is a high probability of drought intensification and vice-versa (Cheo, 2016). Rising temperature, on the other hand, has the disastrous effect of increasing evapotranspiration rate, causing degradation of ecological systems and reduction in agricultural productivity (Huang, Guan, & Ji, 2012), consequently undermining food security, especially in arid and semi-arid regions of SSA.

In the present study, we analysed rainfall data from four locations across a subsistence farming zone of the semi-arid northern Namibia to characterise local rainfall to aid any future planning for water management in the area and to contribute to global knowledge on climate behaviour in dryland regions.

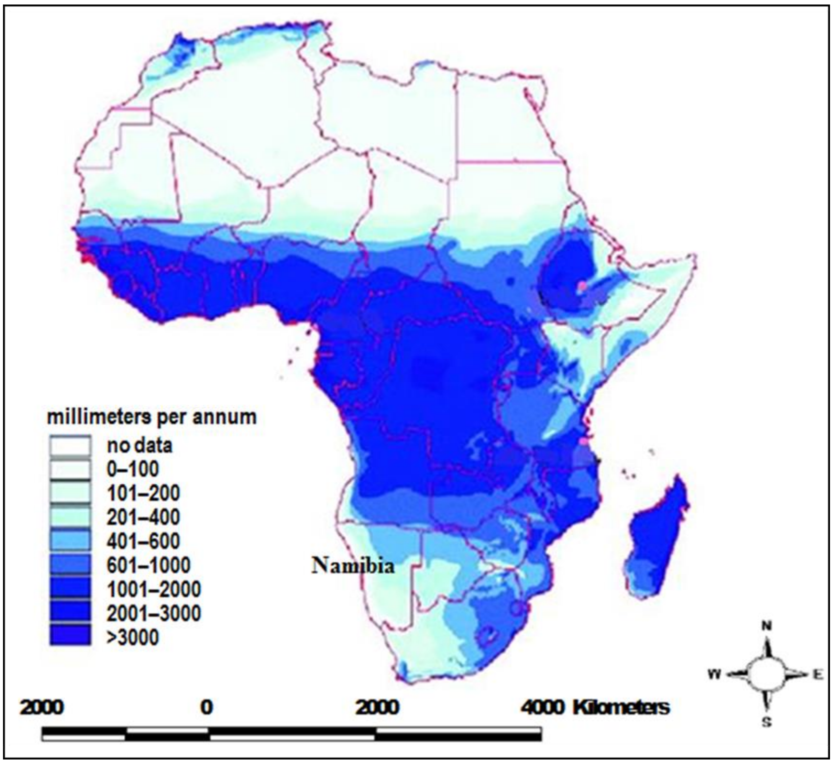

Figure 1. Rainfall variability in Africa. Source: Adapted from FAO/Agrhymet Network and ESRI.

2. Study area and data

2.1 Description of the study area

Namibia, characterised by arid to semi-arid climate (Fig. 1), is situated between latitude 17– 29° S and longitude 12–25° E, with a surface area of approximately 823, 680 km^2. The country's location exposes it to air movements driven by three major climatic systems namely the Intertropical Convergence Zone (ITCZ), Subtropical High-Pressure Zone (STHPZ) and Temperate Zone (Mendelsohn et al., 2009; Eckardt et al., 2013; Mendelsohn et al., 2013). The STHPZ is characterised by cells of high pressure including the Botswana Anticyclone and South Atlantic Anticyclone that make Namibia's climate so dry. Moreover, the country is flanked by two world-famous deserts, the Namib Desert in the west along the Atlantic coastline and the Kalahari Desert in the east. Its hydrological conditions are therefore characterised by a desert climate of low rainfall, high temperatures, and high evaporation rates, making water a scarce resource in the country. Generally, the country has a mean annual rainfall of 250 mm, but most of this rainfall is received in northern areas (Fig. 1).

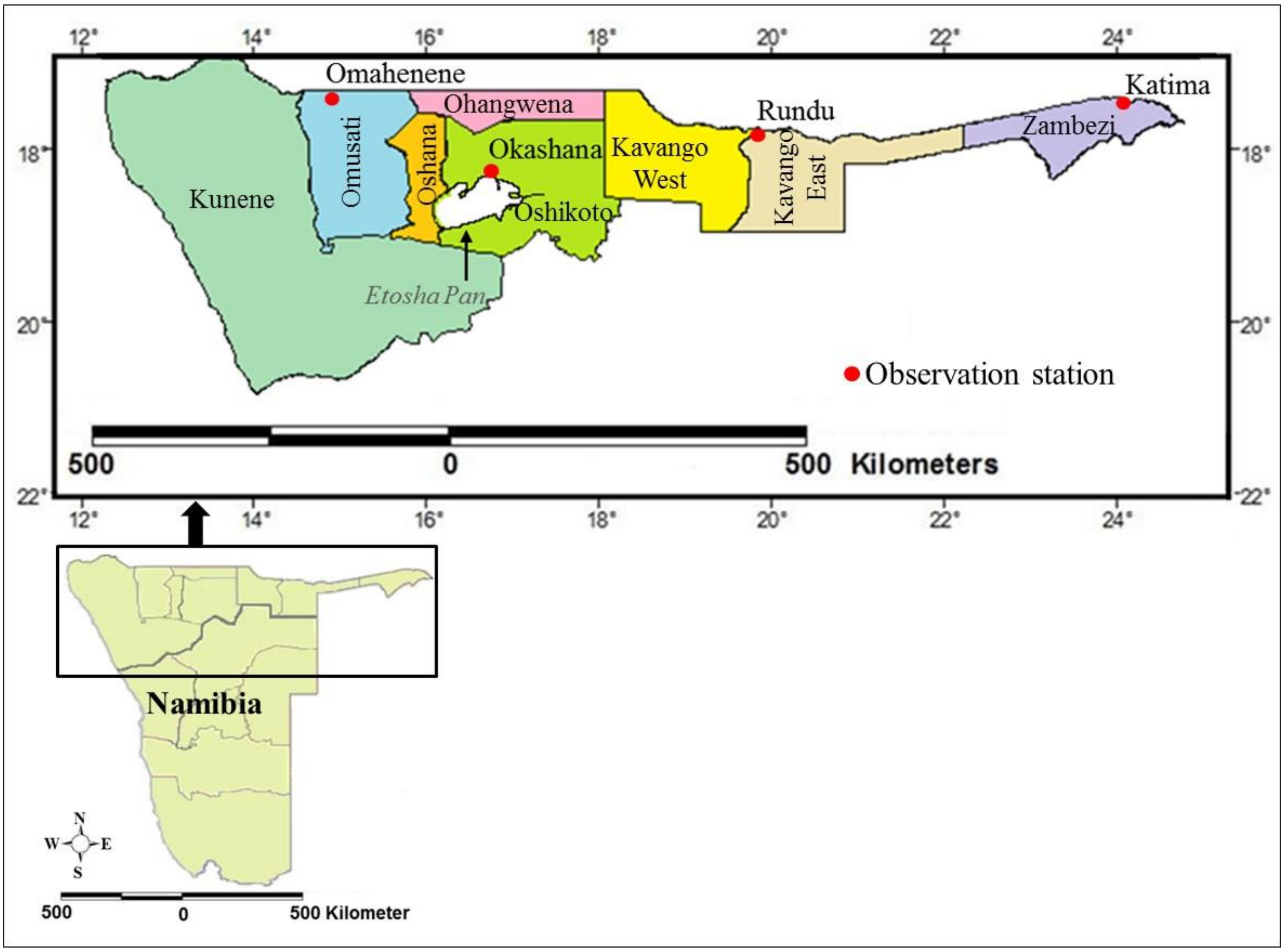

Figure 2. The spatial location of rainfall observation stations across northern Namibia.

The northern areas of Namibia, located between latitude 17– 21° S and longitude 12–25° E (Fig. 2), have a surface area of 262 866 km^2, representing 32.2% of the country's total area (National Planning Commission, 2012). They consist of eight administrative regions—Zambezi (far northeast), Kavango East, Kavango West (northeast), Oshikoto, Ohangwena, Oshana, Omusati (north central) and Kunene (northwest). Mean annual rainfall across northern Namibia varies from about 650 mm in the Zambezi Region to less than 50 mm along the Atlantic coast in the Kunene Region (Mendelsohn, 2006; Mendelsohn et al., 2013; Fig. 1). Mean annual temperature exceeds 22 °C, while average evaporation increases from 1 680 mm year^{-1} in the Zambezi Region to 2 240 mm year^{-1} in the Kunene Region (Mendelsohn et al., 2009). Home to more than 60% of the population, the northern regions are characterised by communal areas with the highest human population and settlement density (NPC, 2012). The majority of the inhabitants are resource-poor subsistence farmers, mainly living on natural resources, livestock farming, and rainfed agriculture.

Due to the relatively higher rainfall received in the northern regions, almost 98% of the local farming households are involved in crop production (Namibia Statistics Agency, 2015), consisting of drought-tolerant crops of pearl millet (locally called *mahangu*), maize, sorghum and cowpea, with pearl millet being the staple crop. However, these regions are also believed to have the highest livestock population in the country. Approximately 95% of the local agricultural households own livestock such as cattle, goats, sheep and donkeys (NSA, 2015), relying on natural rangelands for grazing. Like the entire country, the northern regions have an arid to semi-arid climate and hence characterised by drought phenomena. However, recently, these regions have been experiencing summer floods caused by high-intensity local rainfall and floodwater from Angolan and Zambian highlands, where rainfall is usually higher (Mendelsohn et al., 2009). As rainfed agriculture is one of the primary livelihood activities in northern Namibia, a knowledge of the regions' rainfall trends and variability is a vital prerequisite for stimulating and guiding initiatives for enhanced local agricultural productivity. Such information would help scientists and development planners to design and expedite implementations of community resilience strategies that bolster agricultural production in the face of global climate change and variability.

2.2. Data source

Rainfall data collected over varying periods between 1987 and 2018, from four observation stations, namely Katima Mulilo, Rundu, Okashana and Omahenene, dispersed over a distance of about 1 200 km across the northern areas of Namibia were used for climatological and trend analyses. Katima Mulilo and Rundu are meteorological stations under Namibian Meteorological Agency, while Okashana and Omahenene are rain gauge stations under the Ministry of Agriculture, Water and Forestry. These stations were selected because of their consistency in data collection and reasonable length of observation periods, providing datasets valuable for time series analyses. There were no missing data in the datasets used, so the data were considered to be adequate for the estimation of local rainfall behaviour. Daily or monthly rainfall data were obtained from the individual stations. The geographical descriptions and periods of available rainfall data for each station are given in Table 1. The monthly data series, from May of one year through April of the subsequent year, was prepared for each station. The northern areas are characterised by two major seasons (Mendelsohn et al., 2009; Hooli, 2015), the dry winter season entailing the May–October period and the rainy summer season (or rainy season) spanning the November–April period. Rainfall analyses for the individual stations were carried out at annual, seasonal and monthly time scales. Monthly rainfall data were summed accordingly to generate data series for seasonal and annual rainfall.

Table 1: Location of rainfall observation stations in northern Namibia

Station	Eco-region	Latitude (S)	Longitude (E)	Altitude (m)	Data period	Data duration (year)
Katima Mulilo	Far North East	17° 29′	24° 16′	939	1987–2018	31
Rundu	North East	17° 55′	19° 46′	1065	1997–2018	21
Okashana	North Central	18° 24′	16° 37′	1106	1995–2018	23
Omahenene	North Central (towards west)	17° 27′	14° 47′	1114	1988–2018	30

3. Methods

3.1 Assessing the degree of dependence/randomness

Measuring the temporal dependence structure is of fundamental importance in time series analyses (Zhou et al., 2017). The sample Autocorrelation Function (sample ACF) by Box and Jenkins (1970), measures the strength of the linear dependence in time series data. Computing autocorrelations for data values at different time lags ascertains independence or randomness (Modarres & de Paulo Rodrigues da Silva, 2007). In this study, ACF = 0 if the measured observations are random. If data are non-random, then one or more autocorrelation values shall differ from 0.

3.2 Skewness and kurtosis

Skewness and kurtosis coefficients were computed to test whether annual and seasonal rainfall data follow a normal distribution function. Skewness measures the symmetry of distribution or the lack of it. A distribution, or dataset, is symmetric if it looks the same to the left and right from the centre point (mean, mode or median). For univariate data $Y_1, Y_2, Y_3, Y_4, \ldots, Y_N$ the Fisher-Pearson's equation for skewness is:

$$g_1 = \frac{\sum_{i=1}^{N}(y_i - \bar{Y})^3 \Big/ N}{S^3} \tag{1}$$

Most statistical packages compute the Modified Fisher-Pearson's skewness given by equation 2 as:

$$G_1 = \frac{\sqrt{N(N-1)}}{N-2} \frac{\sum_{i=1}^{N}(y_i - \bar{y})^3 / N}{S^3} \tag{2}$$

In both equation 1 and 2, ȳ is the mean, *s* is the standard deviation and *N* is the number of data points. For large sample size (N > 150), G_1 may be distributed approximately normally, with a standard error of approximately $\sqrt{6/N}$ (Wuensch, 2016). The normal distribution curve has a skewness of zero, or near zero, negative skewness coefficient indicates left-skewed data (left tail longer than right tail), while positive skewness coefficient indicates right-skewed data (right tail longer than left tail). If skewness is G_1 between -0.5 and 0.5, then the data are relatively symmetrical; if skewness is between -1 and -0.5 or between 0.5 and 1, then data are moderately skewed; if skewness is less than -1 or higher than 1, the data are highly skewed.

Kurtosis**,** as introduced by Pearson (1905), is defined as a measure of how flat the top of the symmetric distribution is in comparison to the normal distribution of the same variance. The degree of kurtosis is defined by equation 3 as:

$$\eta = \beta_2 - 3 \tag{3}$$

where β_2 is given by equation 4 as:

$$\beta_2 = \frac{\sum_{i=1}^{N}(y_i - \mu)^4}{N\sigma^4} \tag{4}$$

Equation 3 denoted by γ_2 is often known as kurtosis excess or Fisher's kurtosis, whereas equation 4 is referred to as Pearson's kurtosis (Wuensch, 2016). A positive kurtosis value indicates a sharper than normal peak distribution, while a negative kurtosis value denotes a flatter than normal peak distribution. Kurtosis value of 0 ($\gamma_2 \approx 0$), less than 0 ($\gamma_2 < 0$) and greater than 0 ($\gamma_2 > 0$) represent normal (mesokurtic) distribution, light-tailed (platykurtic) distribution and heavy-tailed (leptokurtic) distribution, respectively.

3.3 Standard deviation, mean and coefficient of variation

Absolute dispersion of the data represents the standard deviation (SD), the average of the data represents the mean, and the relative dispersion is called the coefficient of variation (CV) or the coefficient of dispersion (Brown, 1998). In this study, the CV was used to assess the degree of dispersion of individual data values of annual and seasonal rainfall around their long-term means. For a continuous random variable Y, with moments existing up to order 4, let $\mu = E(Y)$ be the mean of Y, denoted by equation 5 as:

$$\mu_i = E(y-\mu)^i, i = 2,3,4 \tag{5}$$

μ is a location parameter; it tells the location of the distribution. μ_2 represents the variance, which explains the variation in the distribution. $\sqrt{\mu_2}$, which is the standard deviation is a scale parameter used to define a unit of measurement for Y. The standard deviation (SD) to the mean μ ratio is the coefficient of variation (CV), represented by equation 6 as:

$$CV = \frac{\sigma}{\mu} \times 100 \tag{6}$$

The CV is used to classify the degree of variability of rainfall events as less variable (CV < 20), moderately variable (20 < CV < 30), and highly variable (CV > 30) (Hare, 2003). In this study, the CV values of the different stations were used to comparatively assess the extent of spatial variability in rainfall across the study area.

3.4 Mann-Kendall (MK) test

Mann (1945) pointed out that given n consecutive observation of a time series $z_t, t = 1, \dots, n$, the Kendal rank correlation (τ) of z_t, where $t = 1, \dots, n$ can be used to test for monotonic trends. The MK test assesses the null hypothesis of no trend versus the alternative hypothesis of the existence of an increasing or decreasing trend. In the present study, we performed the MK trend test by computing the statistic (S) given by:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign\left(y_i - y_j\right) \dots j > 1 \tag{7}$$

where y_j denotes the sequential data values and n represents the size of the time series sample. The sign function is given as:

$$sign\left(y_i - y_j\right) = \begin{cases} -1, y_i - y_j < 0 \\ 0, y_i - y_j = 0 \\ 1, y_i - y_j > 0 \end{cases} \tag{8}$$

Since $n > 8$, we obtained estimates of σ^2 also, μ for S as suggested in Mann (1945) and Kendall and Stuart (1967), that is:

$$E(S) = 0 \tag{9}$$

$$Var\ (S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} q_i(q_i-1)(2q_i-5)}{18} \tag{10}$$

where m is the number of tied groups in the data set, q_i is the number of data values in the ith group and i the sums from 1 to m, the total number of tied groups. Then,

$$S \sim N(0,1) \tag{11}$$

The significance of standardised S in equation 11 was estimated from the Gaussian cumulative distribution function using the following equation:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\operatorname{var}(S)}}, S > 0 \\ 0, S = 0 \\ \dfrac{S+1}{\sqrt{\operatorname{var}(S)}}, S < 0 \end{cases} \tag{12}$$

A positive Z value $(Z > 0)$ denotes an increasing trend; whereas a negative Z $(Z < 0)$ indicates a decreasing trend. In testing for the significance of increasing or decreasing monotonic trend at α level of significance, the decision rule here is to reject the null hypothesis (H_o) if:$|Z| > Z_{1-\alpha/2}$; and $Z_{1-\alpha/2}$ is obtained from the normal distribution tables.

3.5 Sen's slope estimate

The magnitude of the non-parametric trend in the time series data is determined using Sen's estimator (Sen, 1968), widely adopted in hydro-meteorological time-series studies (Hirsch, Slack, & Smith, 1982; Modarres & de Paulo Rodrigues da Silva, 2007; Gabriel, 2013). Therefore, this method was used in this study to estimate the magnitudes of the slope of annual, seasonal and monthly trends, using the following equation:

$$sen-slope = Median\left(\frac{y_a - y_b}{a-b}\right), \forall b < a \tag{13}$$

with Y_a and Y_b being rainfall amounts respectively measured in time a and b.

4. Results

4.1 Independence of rainfall

Fig. 3 presents autocorrelation plots of rainfall for verifying the independence of annual and seasonal rainfall series at the four stations. Both annual and seasonal rainfall showed a mixture of negative and positive serial correlations. All stations showed significant positive correlations, which we removed before applying the MK test.

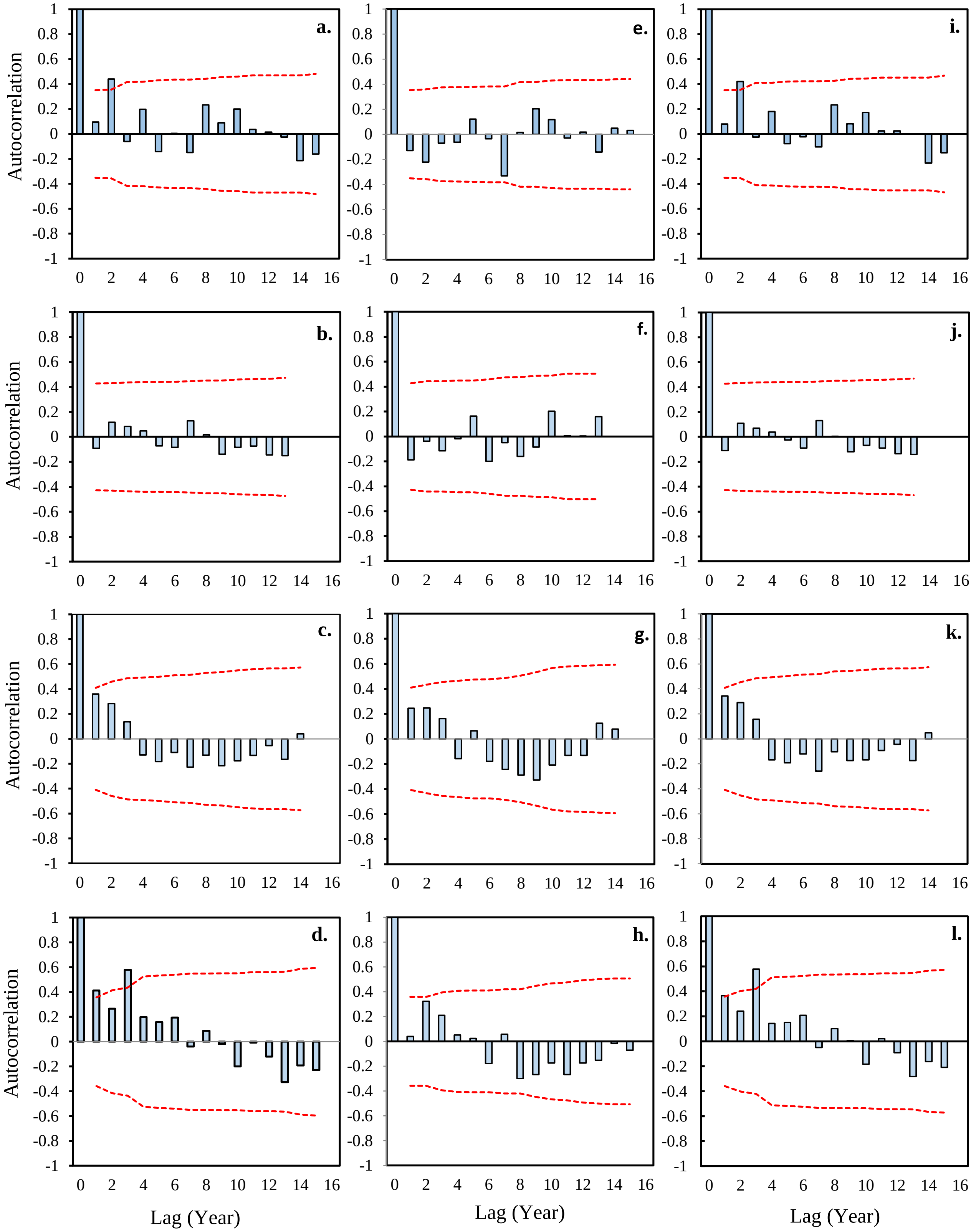

Figure 3. Autocorrelation plots for annual rainfall (left): **a**. Katima Mulilo, **b**. Rundu, **c**. Okashana and **d**. Omahenene; dry season rainfall (middle): **e**. Katima Mulilo, **f**. Rundu, **g**. Okashana and **h**. Omahenene; and rainy season rainfall (right): **i**. Katima Mulilo, **j**. Rundu, **k**. Okashana and **l**. Omahenene in northern Namibia during the years 1987–2018. Upper and lower dashed lines are 95% Fiducial limits.

Table 2: Statistical characteristics of the annual and seasonal rainfall in northern Namibia during the years 1987–2018

Season	Station	Mean (mm)	Median (mm)	S.D. (mm)	CV (%)	Min. (mm)	Max. (mm)	Range (mm)	Skewness (C_s)	Kurtosis (C_k)
Annual	Katima Mulilo	636.7	621.6	150.6	23.6	329.2	942.4	613.2	0.34	-0.65
	Rundu	595.5	614.1	135.4	22.7	264.3	825.9	561.6	-0.56	0.22
	Okashana	474.6	455.4	178.3	37.6	192.8	917.5	724.7	0.61	0.27
	Omahenene	489.8	483.1	163.3	33.3	218.0	907.8	689.8	0.75	0.29
Dry	Katima Mulilo	20.8	13.0	19.0	91.2	0.0	67.9	67.9	0.97	-0.13
	Rundu	17.8	16.1	13.8	77.5	0.5	65.9	65.4	1.98	5.98
	Okashana	15.5	10.4	20.5	132.1	0.0	88.0	88.0	2.21	5.79
	Omahenene	10.7	6.2	16.2	151.6	0.0	73.9	73.9	2.55	7.31
Rainy	Katima Mulilo	615.9	580.4	149.0	24.2	306.8	926.0	619.2	0.33	-0.58
	Rundu	577.7	595.8	142.0	24.6	198.4	795.1	596.7	-0.80	0.80
	Okashana	459.1	446.0	177.3	38.6	192.8	917.5	724.7	0.80	0.63
	Omahenene	479.2	456.0	162.0	33.8	217.0	907.8	690.8	0.90	0.58

S.D., standard deviation; CV, coefficient of variation; Min., minimum; Max., maximum.

4.2 Descriptive characteristics of annual and seasonal rainfall

Descriptive statistics for annual rainfall show two distinct temporal zones, the rainy summer zone and dry winter zone, with apparent spatial variations among the four stations across northern Namibia (Table 2). About 97% (or 533.0 mm) of annual rainfall in the study area occurred during the rainy season, whereas the remaining proportion of 3% (or 16.2 mm) occurred during the dry season. As for the dry season, rainfall showed higher spatial variation, with the highest mean rainfall of 20.8 mm recorded at Katima Mulilo, and the lowest rainfall of 10.7 mm observed at Omahenene, thus spatially declining from far northeast towards the northwest (Table 2 middle). Coefficients of variation were high across the stations but much higher for Okashana and Omahenene. The mean minimum rainfall was 0.0 mm at Katima Mulilo, Okashana, and Omahenene but Rundu recorded at least 0.5 mm. The mean maximum rainfall varied among the stations, being the lowest at Rundu (65.9 mm) and the highest at Okashana (88.0 mm). All stations showed positive coefficients of skewness, moderately skewed at Katima Mulilo (0.97) and highly skewed at the other three stations (1.98–2.55). Similarly, kurtosis coefficients were the lowest at Katima Mulilo (-0.13), indicating a light-tailed platykurtic distribution pattern and the highest at the three stations (5.79–7.31), indicating heavy-tailed leptokurtic rainfall distribution.

Since the rainy-season rainfall accounted for most of the annual rainfall, its descriptive statistics at all the stations were virtually similar to those for annual rainfall (Table 2 upper and lower). With a range of 156.8 mm, mean rainy-season rainfall was the highest at Katima Mulilo and the lowest at Okashana, while the corresponding values of standard deviation and coefficient of variation showed a reverse pattern. The mean minimum rainfall for the season was the highest at Katima Mulilo (306.8 mm) and the lowest at Okashana (192.8 mm) with a range of 114.0 mm. However, the patterns of the rainy-season mean maximum rainfall differed from those of annual rainfall, as the mean maximum rainfall was the lowest at Rundu (795.1 mm) and the highest at Katima Mulilo (926.0 mm). Rainfall range among stations was the lowest at Rundu and the highest at Okashana.

Furthermore, rainfall distribution during the rainy season was positively skewed at Katima Mulilo, Okashana and Omahenene but negatively skewed at Rundu. Rainfall at Katima Mulilo displayed a relatively symmetric distribution, whereas the rest of the stations exhibited moderately skewed distributions. Unlike annual rainfall, the rainy season's kurtosis coefficients were the highest at Rundu (0.80), followed by Okashana (0.63) and Omahenene (0.58)—indicating heavy-tailed leptokurtic distribution patterns—but the lowest at Katima Mulilo (-0.58), denoting a light-tailed platykurtic distribution. Overall, the rainy season accounted for most of the rainfall received in the region, whereas the dry-season rainfall was comparatively remarkably lower. The dry-season rainfall was characterised higher temporal or year–to–year variations, higher spatial variability, and skewed, heavy-tailed leptokurtic distributions.

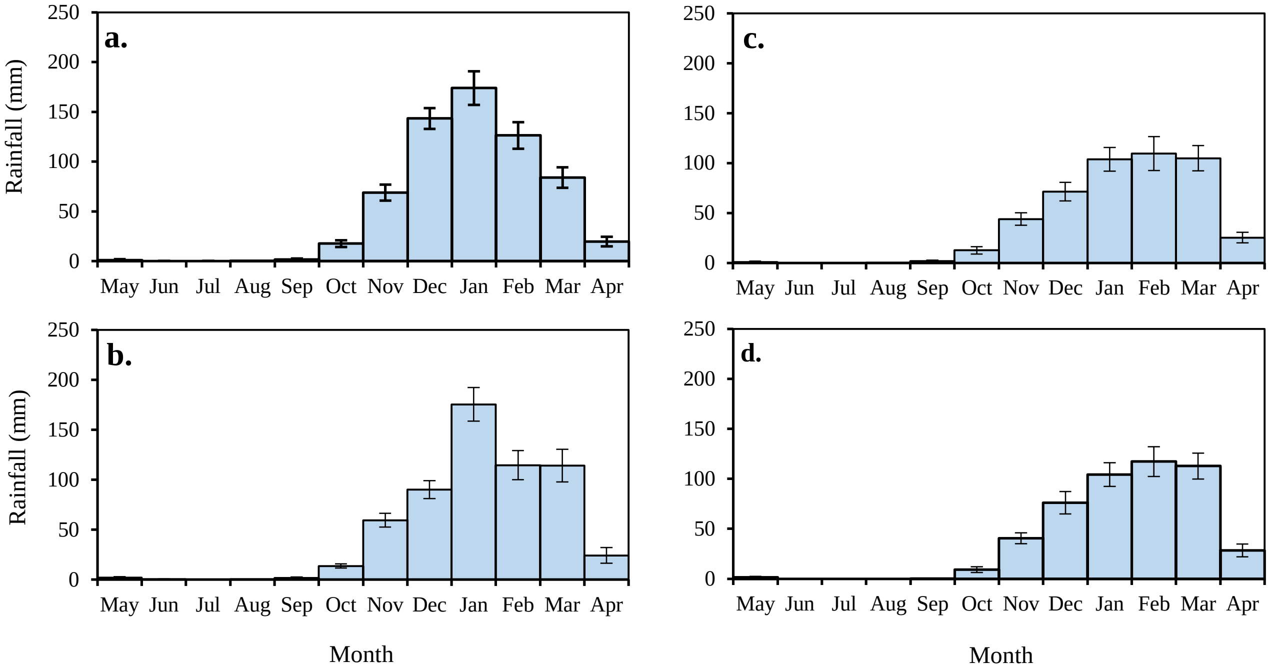

Figure 4. Mean monthly rainfall for **a**. Katima Mulilo, **b**. Rundu, **c**. Okashana and **d**. Omahenene stations in northern Namibia during the years 1987–2018. Bars represent ±standard errors of the means.

4.3 Monthly rainfall distribution

Fig. 4 presents the mean monthly rainfall of the time series data for the period between 1987 and 2018 for four stations in northern Namibia. Across stations, May–October months received minor showers ranging between 9–18 mm mainly occurring in May, September, and October and accounting for 3% of annual rainfall. The remaining months of November–April received most of the rainfall occurring in the area, with more than 80% of it concentrated from December to March. In effect, the May–October period represents the dry season, while the November–April period represents the rainy season. The rainy season’s monthly rainfall distribution patterns varied among the stations. However, Katima Mulilo and Rundu displayed similar rainfall distribution patterns. Rainfall at these stations gradually increased from 69 mm (Katima Mulilo) and 59 mm (Rundu) in November to reach the peaks in January of 174 mm and 175 mm, respectively. Afterwards, rainfall at both stations declined to cease in April with 20 mm at Katima Mulilo and 24 mm at Rundu. However, at Rundu, February and March had the same rainfall amounts of 114 mm.

Moreover, the distribution patterns of the rainy season’s monthly rainfall for Okashana and Omahenene were similar but different from those observed for Katima Mulilo and Rundu. Rainfall increased from 44 mm (Okashana) and 41 mm (Omahenene) in November to reach the highest amounts during the January–March months, averaging 106 mm (Okashana) and 111 mm (Omahenene). Subsequently, rainfall abruptly dropped to stop in April with 25 mm and 28 mm at Okashana and Omahenene, respectively. Although all the stations received more than 80% of annual rainfall during December–March period, the stations in the eastern parts of the country, Katima Mulilo and Rundu, had more rainfall during the first half of the season (November–January), receiving 63% and 56% of the rainy season rainfall, respectively. Whereas Okashana and Omahenene, which are both located in north-central, received slightly more rainfall during the second half of the season (February–April), accordingly receiving 52% and 54%.

4.4. Rainfall trends

4.4.1 Trends in annual and seasonal rainfall

Table 3 presents the results of MK and Sen’s slope estimator tests for annual and seasonal rainfall data series for the four stations. For annual rainfall, all stations displayed positive Z values, implying a general increase in rainfall across the study area over the past two to three decades. Our data showed statistically significant increase in the amounts of annual rainfall at Katima Mulilo (7.8 mm year^{-1}, P = 0.038) and Omahenene (10.1 mm year^{-1}, P = 0.002), but at Rundu and Okashana, the increases were not significant (P > 0.10) despite notably high Sen’s slope estimator values of 6.7 and 7.8 mm year^{-1}, respectively. These results were similar to that of the rainy season. As for the dry season rainfall, except Katima Mulilo, all stations had decreasing trends as shown by the negative Z values, but none of such decreases was statistically significant.

Maximum reduction of -0.48 mm year^{-1} was observed at Okashana, followed by -0.11 mm year^{-1} at Omahenene and the least reduction of -0.02 mm year^{-1} at Rundu. At Katima Mulilo, the dry-season rainfall pattern was relatively constant over the last 31 year. The time series plots fitted with linear trends in Figs. 5a–l further elucidated the spatial-temporal variability in annual and seasonal rainfall at the four stations. Figs. 5a–d and Figs. 5i–l depicted homogenous, upward (increasing) trends in annual rainfall and rainy-season rainfall, while Figs. 5e–h showed predominantly downward (decreasing) trends in the dry-season rainfall across the study area. The time series plots for the annual rainfall and rainy-season rainfall also showed that the study area experienced a higher rainfall regime between 2008 and 2012 and noticeably lower rainfall regimes before and after this period. Overall, the spatial trend patterns of the rainy-season rainfall were similar to those of annual rainfall, depicting increasing rainfall amounts, while the spatial trend patterns of the dry season rainfall seemed to show decreasing rainfall amounts across northern Namibia.

Table 3: Mann-Kendall statistic (Z_{MK}), Sen’s slope estimator (mm year^{-1}) and percentage change for annual and seasonal rainfall in northern Namibia during the years 1987–2018

Station	Statistic	Annual	Dry	Rainy
Katima Mulilo	Z_{MK}	0.265	0.009	0.308
	P-value	0.038*	0.959	0.015*
	Sen's slope	7.776	0.006	7.289
	% change	37.860	0.030	35.490
Rundu	Z_{MK}	0.210	-0.010	0.190
	P-value	0.198	0.976	0.244
	Sen's slope	6.637	-0.019	7.136
	% change	23.400	-0.070	25.160
Okashana	Z_{MK}	0.162	-0.139	0.154
	P-value	0.295	0.379	0.320
	Sen's slope	7.850	-0.477	7.371
	% change	38.040	-2.310	35.720
Omahenene	Z_{MK}	0.398	-0.183	0.421
	P-value	0.002**	0.178	0.001**
	Sen's slope	10.111	-0.111	9.180
	% change	61.930	-0.680	56.230

*, **, significant at P < 0.05 and < 0.01.

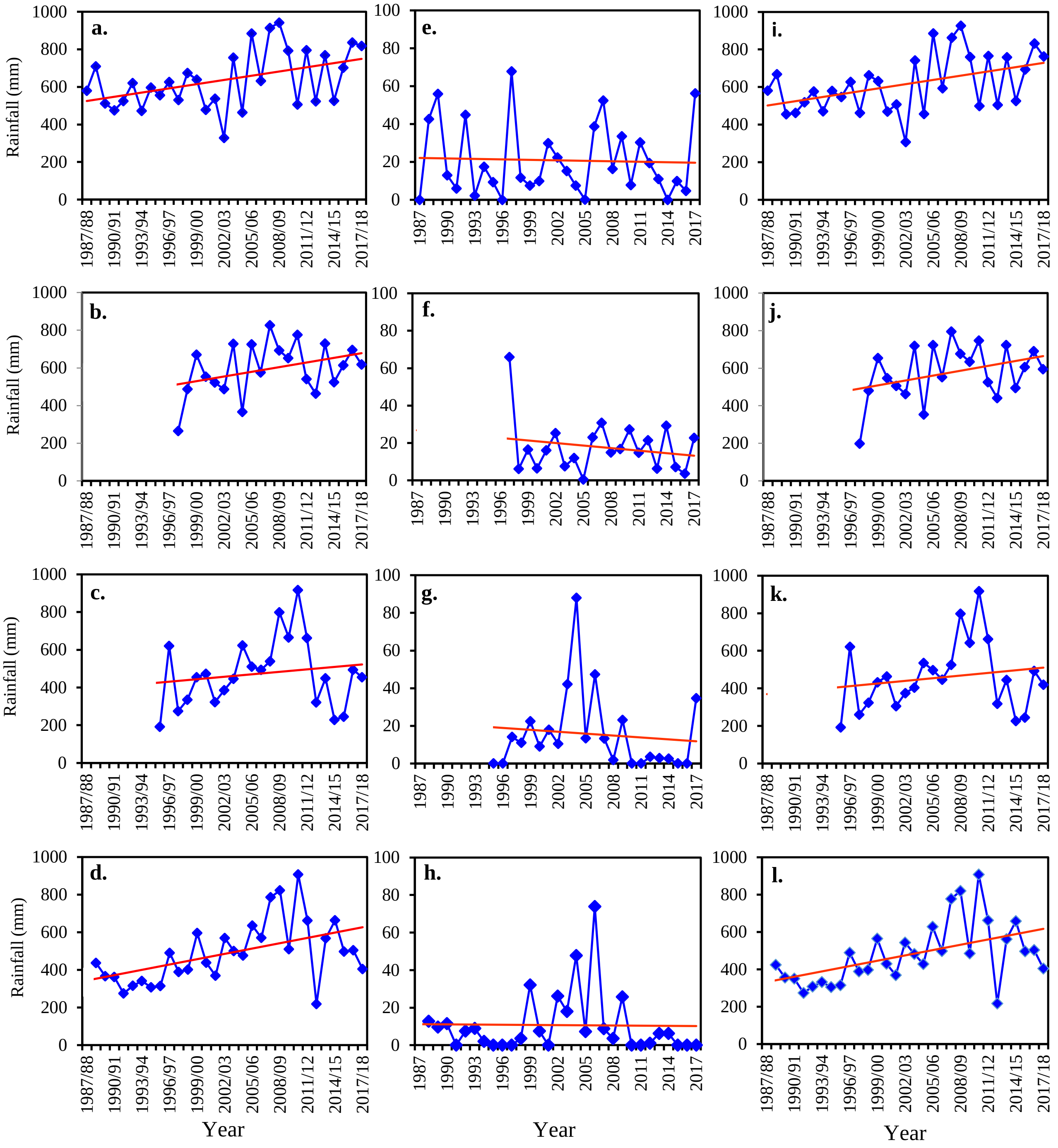

Figure 5. Spatial-temporal variations and linear trends of annual rainfall (left): **a**. Katima Mulilo, **b**. Rundu, **c**. Okashana and **d**. Omahenene; dry season rainfall (middle): **e**. Katima Mulilo, **f**. Rundu, **g**. Okashana and **h**. Omahenene; and rainy season rainfall (right): **i**. Katima Mulilo, **j**. Rundu, **k**. Okashana and **l**. Omahenene in northern Namibia during the years 1987–2018.

4.4.2 Trends in monthly rainfall

Based on the results of MK-trend test and Sen's estimator test, monthly rainfall in northern Namibia displayed high spatial and temporal variability in both magnitude and direction (Table 4). Among the stations, dry-season months were generally characterised by the lack of rainfall trends due to the absence of rainfall except for October, which showed nonsignificant negative rainfall trends for Rundu, Okashana and Omahenene. As for the rainy season months (November–April), rainfall trends were generally increasing, the

Z and Sen's slope values were predominantly positive for all the month across the stations. The results showed statistically significant increases at Rundu in December (3.7 mm year^{-1}, $P = 0.023$), March (4.3 mm year^{-1}, $P = 0.086$), and at Omahenene in March (3.8 mm year^{-1}, $P = 0.006$). January and February presented statistically nonsignificant heterogeneous rainfall trends, with decreasing trends observed for January rainfall at Okashana and for February rainfall at Katima Mulilo. During the study periods, all stations had considerable increases in monthly rainfall in March, except Katima Mulilo, which experienced a substantial rainfall increase in January. The reduction in October rainfall amounts may signify a prolonged dry season, while the increasing trends in March rainfall denoted a seasonal movement towards concentrated rainfall at the end of the rainy season across northern Namibia.

Table 4. Mann-Kendall statistic (Z_{MK}) and Sen's slope estimator (mm year^{-1}) for the mean monthly rainfall for four stations northern Namibia during the years 1987–2018

Station/	Dry						Rainy					
Statistic	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Katima Mulilo												
Z_{MK}	0.022	0.000	0.000	0.000	-0.097	0.004	0.135	0.105	0.196	-0.062	0.148	0.108
P-value	0.901	0.000	0.000	1.000	0.509	0.986	0.295	0.418	0.127	0.637	0.251	0.418
Sen's slope	0.000	0.000	0.000	0.000	0.000	0.000	0.880	1.233	2.392	-0.705	1.343	0.070
Rundu												
Z_{MK}	-0.006	0.210	0.000	0.210	-0.039	-0.019	0.171	0.362	0.095	0.067	0.276	0.154
P-value	1.000	0.271	0.000	0.271	0.844	0.929	0.296	0.023*	0.572	0.699	0.086$^{\#}$	0.348
Sen's slope	0.000	0.000	0.000	0.000	0.000	-0.024	1.016	3.699	1.368	0.744	4.310	0.442
Okashana												
Z_{MK}	-0.125	0.000	0.000	0.000	-0.139	-0.110	0.036	0.170	-0.123	0.075	0.170	0.132
P-value	0.513	0.000	0.000	0.000	0.444	0.488	0.835	0.272	0.434	0.639	0.272	0.397
Sen's slope	0.000	0.000	0.000	0.000	0.000	-0.150	0.367	1.467	-1.321	1.000	2.870	0.357
Omahenene												
Z_{MK}	0.009	0.000	0.000	0.000	0.205	-0.192	0.067	0.117	0.113	0.080	0.352	0.168
P-value	0.976	0.000	0.000	0.000	0.204	0.155	0.621	0.376	0.396	0.548	0.006**	0.203
Sen's slope	0.000	0.000	0.000	0.000	0.000	-0.125	0.300	1.180	1.492	1.067	3.777	0.472

**,*, #, significant at $P < 0.01$, < 0.05, and 0.10.

4. Discussion

4.1 Rainfall variability and distribution patterns

The results showed spatial rainfall gradient decreasing from far northeast towards the north-western zone of Namibia (Table 2; Fig. 2). These results corroborate with those of previous local studies (Mendelsohn et al., 2009; Eckardt et al., 2012; Mendelsohn et al., 2013) and other studies in Southern Africa (Mphale et al., 2013; Mupangwa et al., 2016), which were related to the effects of the patterns of movements of the climatic systems that bring rain to Southern Africa. Mendelsohn et al. (2009) particularly described the patterns of rainfall across different ecological zones of Namibia, while Mendelsohn et al. (2013) specifically focused on weather systems in north-central Namibia. They cited that mean annual rainfall varies in a smooth gradient from the wettest and tropical areas in the northeast to the extremely arid Namib Desert in the west, attributing this spatial trend to the effects of the ITCZ and STHPZ climatic systems that dominate over northern Namibia. Fig. 1 illustrates the rainfall gradient over the country's northern areas, decreasing gradually from more than 600 mm in the northeast to less than 100 mm in the Namib Desert and Atlantic Ocean Coastline in the northwest. Therefore, the risk of low rainfall increases from the northeast towards the northwest, and also from the northern parts towards the southern parts of the country.

Besides the effects of climatic systems, human activities such as land clearing and other development activities also have the potential to influence local weather systems over the long term, and so the rainfall patterns. Mendelsohn (2006) noted a general gradient on the extent of cultivated area across northern Namibia, with the smallest cultivated areas found in the north-eastern regions (Zambezi, Kavango East and Kavango West), averaging about half the size of those in the north-central regions (Ohangwena, Oshikoto and Oshana) and towards the northwest zone (Omusati) (also see Fig. 2 for the regions). Mendelsohn (2006) ascribed this discrepancy to several factors, including population density, availability of labour and rainfall risk aversion, elucidating that the farmers in the more densely populated north-central regions tend to have larger families—thus affording family labour to cultivate all available fertile land areas. He further stated that the larger farm fields towards northwest are perhaps intended to compensate for the lower rainfall prevailing in the area. Furthermore, Roder et al. (2015) noted that the area around Rundu has continuously been evolving into a large township, causing widespread conversion of forests to arable land, although such conversion remains limited to rainfed agriculture. Nonetheless, there are even more, larger townships in the north-central parts of the country, such as Eenhana, Oshikango, Ondangwa, Ongwediva and Oshakati towns, and towards the north-western zones, e.g. Outapi and Ruacana towns (Mendelsohn et al., 2009). More than 40% of Namibia's population lives in north-central areas (NSA, 2015), which also encompass the barren, or poorly vegetated Etosha Salt Pan (Mendelsohn, Jarvis, & Robertson, 2013; Fig. 2). These characteristics are, however, in sharp contrast with those of the eastern parts of the country that have sparse populations, perennial rivers and more forested areas (Mendelsohn et al., 2009), seemingly causing variations in rainfall amounts across the study area.

Table 2 showed temporal variations in annual and seasonal rainfall amounts among the stations (illustrated further by Figs. 5a–l), with the lowest variations observed at Rundu and Katima and the highest variations at Okashana and Omahenene. Mendelsohn et al. (2013) and Hooli (2015) reported the recent occurrences of extreme weather phenomena in north-central Namibia, including the seasonal floods of 2008–2012 and the severe drought of 2013, which caused grain deficit and the massive livestock losses in the area. High rainfall variation is a natural characteristic of semi-arid regions attributed to the erratic and unpredictable nature of the weather conditions (Lu et al., 2016), so Okashana and Omahenene stations are located in the lower rainfall zone. However, variations in rainfall within the stations should be associated with fluctuations in local weather events rather than with the movements of the regional climatic systems, which generally affect large areas. Therefore, the higher temporal rainfall variations at Okashana and Omahenene should be related to differences in topographies (Mendelsohn et al., 2009; Mendelsohn et al., 2013) and the modification of the ecosystems through human activities (Mendelsohn, 2006; Roder et al., 2015), as has previously been explained in this section.

At Katima Mulilo and Rundu, rainfall peaks occurred in January, while at Okashana and Omahenene, the highest rainfalls spread almost evenly between January and March (Figs. 4a–d). These results concur with those of Mendelsohn et al. (2009), who demonstrated that in the eastern regions of Namibia, the peak rainfalls occur in January; whereas in the north-central and towards north-western zones of the country, the highest rain somewhat evenly spread between January and March. Results also revealed that during the rainy season, the north-eastern stations had more rainfall in the first half of the season (November–January), while the north-central or north-western stations received slightly more rainfall in the second half (February–April). Higher rainfall during the period February–April has previously been observed in several parts of Southern Africa, for example in the Cuvelai-Etosha Basin of Angola-Namibia (Mendelsohn et al., 2013), in Central Namibia (Lu et al., 2016) and the Limpopo Basin of Southern Africa (Mupangwa et al., 2016). The researchers ascribed this phenomenon to the effects of the movements of ITCZ and STHPZ climatic systems and air masses over Southern Africa, as described by Mendelsohn et al. (2009). According to Mendelsohn et al. (2009), the eastern parts of Namibia receive their summer rainfall much earlier, but this rainfall also tends to cease earlier, which contrast the observations in the north-central and north-western parts of the country. Therefore, this situation possibly explains the differences in intra-seasonal rainfall characteristics between the north-eastern regions and north-central or north-western regions of Namibia.

4.2 Rainfall trends

The spatial patterns of trends in mean rainy-season rainfall were similar to those of annual rainfall trend patterns, depicting increasing rainfall amounts; while the trends in mean rainfall of the dry season showed a decreasing rainfall amount across the study area during the period 1987–2018 (Table 3; Figs. 5a–l). The results also showed decreasing trends in October rainfall amounts, but increasing trends in March rainfall across the study area (Table 4). Varying spatial-temporal rainfall trends have previously been reported; for example, by Batisani, and Yarnal (2010) in their rainfall study across Botswana. Temporally, the dry-season rainfall exhibited a statistically insignificant downward trend, whereas the rainy-season rainfall trends displayed an upward movement, which was statistically significant for Katima Mulilo and Omahenene, but insignificant for Rundu and Okashana. The presence of insignificant trends in the dry-season rainfall at all the stations may be ascribed to high intra-seasonal rainfall variations as manifested in higher CV values ranging between 78–152% (Table 2). The insignificant trends in the rainy season rainfall at Rundu and Okashana, despite numerically higher Sen's slope values, maybe due to the shorter data periods of these two stations compared with Katima Mulilo and Omahenene, which had longer data durations (Table 1). These results suggest the probability of drought intensification during the dry season and flood risks during the rainy season in the study area. According to Cheo (2016), when rainfall presents a decreasing tendency, then there is a high probability of drought risks and vice-versa.

The results also showed increasing annual rainfall trends across the study area during the period under review. Increasing rainfall trends may be due to the effect of higher rainfall experienced in northern Namibia during the years 2008–2012 (Figs. 5a–d). These results are similar to those reported by Diop et al. (2016) on spatiotemporal trends of mean annual rainfall in Senegal, during the period 1984–2013. They consider the increasing trends as a sign towards a progressive return on favourable rainfall conditions. However, using data for the period 1940–2013 across the country, the same study found significant downward trends. Nonetheless, in his study of changes over time of annual rainfall in Zimbabwe, Mazvimavi (2010) argued that the general perception about declining rainfall is likely due to the presence of multi-decadal variability associated with alternating rainfall regimes of successive years with above and below-average rainfall. Mendelsohn et al. (2009) illustrate this somewhat cyclical nature of longer-term rainfall changes using data for the period 1900–2000 from a few stations across Namibia. The results of the present study seem to support this observation, as the study area experienced a higher rainfall regime between 2008 and 2012, noticeably preceded and followed by years of lower rainfall (Figs. 5a–d & i–l). Therefore, it seems that rainfall trends of medium-term data, as the case with the current study, may not show climate change but would instead reflect the cyclic effect of decadal variability in rainfall regimes.

4.3 Implications of rainfall trends and variability

In northern Namibia, the climate is exceedingly divided between the dry and rainy seasons, but local communities have lived with these varying weather extremes for centuries (Hooli, 2015). This area is the most densely populated and has the poorest people in the country (NSA, 2015), with the majority of the people being the smallholder farmers whose livelihoods depend mainly on natural resources, livestock farming and rainfed agriculture (Mendelsohn, 2006; Mendelsohn et al., 2009). The results of the present study have significant implications for agricultural production, rangeland productivity, biodiversity dynamics and socio-economic conditions in the area.

The rainy-season upward and dry-season downward trends in the time series data of rainfall for the last two to three decades across the study area (Table 3; Figs. 5e–l) have implications for floods and droughts, respectively. Gornall et al. (2010) stated that the nature of agriculture and farming practices in any given location is influenced by the long-term mean climate state because local farming communities adapt both their experience and infrastructure to particular types of farming and crops thriving under the prevailing climate. Floods result in diseases, destroy infrastructure, disrupt agricultural systems, aggravate food insecurity and diminish biodiversity, eventually causing food deficit and poverty to local communities (Hooli, 2015); the same is also true for drought. Jiménez et al. (2011) stated that an event of 15 mm of monthly precipitation was biologically crucial for their study system. For northern Namibia, whose climate is arid to semi-arid, any reduction in rainfall amount would tend to intensify drought in the area, thus negatively affecting biodiversity and community livelihoods. In this area, the dry-season rainfall stimulates sprouting and regrowth of rangeland vegetation, which supports local wildlife and livestock during the dry period. The reduction in the dry-season rainfall would, therefore, have adverse effects on these moisture-dependent ecological systems.

Furthermore, the rainfall received towards the end of the dry season (September–October) determines the time for commencing preparing for the new planting season. Generally, the local subsistence farmers use oxen and donkeys for ploughing their crop fields, which in turn rely on natural rangelands for grazing. Therefore, any prolongation in the dry season length would have detrimental effects on local flora and fauna and the local farming communities. Besides the impact of drought or low rainfall, Addisu et al. (2015) and Mukherjee (2017) highlighted that under semi-arid conditions there is a negative relationship between rainfall and ambient temperature, meaning that as rainfall increases, the temperature would decrease and vice-versa. The rising temperature, on the other hand, augments other weather variables such as evapotranspiration rate, thus exacerbating the degradation of ecological systems and reduction of agricultural productivity (Huang, Guan, & Ji, 2012), which undermine food security and debilitate community livelihood systems in arid and semi-arid regions of SSA.

The spatial-temporal discrepancies in rainfall risks across the study area (Table 2) suggest for location-specific water management strategies in the study area. In this regard, planning for agricultural activities for north-central and north-western zones of the country would be complex due to the higher uncertainty of rainfall timing and amounts. Hooli (2015) highlighted that recent changes in socio-environmental dynamics associated with urbanisation, inappropriate spatial planning, and population growth had aggravated flooding incidences in the area. Population growth and urbanisation have resulted in the inhabitants destroying vegetation, and establishing informal settlements and constructing homesteads in floodplains and natural waterways, interfering with natural flows of water and eventually causing inundation of the farmlands and settlements in years of high summer rainfall. Former studies (Tsheko, 2003; Tschakert et al., 2010) have acknowledged that drought is the primary constraint to crop production in semi-arid regions. However, the irregular occurrences of seasonal floods also cause crop damage and food insecurity to these regions (Tschakert et al., 2010; Mendelsohn, Jarvis, & Robertson, 2013; Anthonj et al., 2015). The higher risk of rainfall uncertainty in flood-affected semi-arid areas of north-central and north-western Namibia requires a water management strategy that would simultaneously mitigate both flood and drought effects, and improve local water productivity. Therefore, agricultural sustainability in these areas may be achieved by harmonising existing farming methods with local water resource and climatic conditions.

Generally, any strategy to improve agricultural productivity among small-scale farmers in semi-arid regions should encourage the adoption of climate-change adaptive farming systems. Previous studies carried out in Southern Africa have proposed various farming techniques buffering subsistence agriculture against the vagaries of climate variability and change. As for crop production, these methods include cultivation of drought-resistant crops and irrigation (Bola et al., 2013), crop diversification and mix-cropping of dryland cereals with rice to reduce the risk of total crop losses by flood or drought (Awala et al., 2016). The techniques also entail the adoption of *ex-situ* rainwater harvesting techniques and *in-situ* or in-field rainwater harvesting by basin or ripper tillage systems to mitigate the effects of intra-seasonal dry spells on crops (Mupangwa et al., 2016). Additionally, Iijima et al. (2018) have proposed a flood- and drought-adaptive cropping system involving the planting of crops on alternating ridges and furrows to minimise the risk of crop losses by flood or drought. The subsistence farmers should also be encouraged to adopt the application of both organic and inorganic fertilisers for improved soil fertility and increased crop growth and yield.

Interventions for livestock rearing, on the other hand, should strive for the promotion of drought-hardy indigenous breeds, maintenance of optimum herd size to curtail and possibly reverse the rate and extent of rangeland degradation by overgrazing, and introduction of cultivated pasture to enable sustainable supplemental feeding during the dry period. The new strategy should, therefore, integrate the farming system components with appropriate technologies, and exploit their synergistic effects for improved livelihoods of the local subsistence communities. Currently, small-scale farmers in northern Namibia rarely practise critical technologies such as rainwater harvesting, small-scale irrigation and fodder production, which ought to be the prerequisites for agro-pastoral sustainability in drought-prone regions. We prepared this paper at the time when Namibia was experiencing one of the most severe droughts in its recent history. Most parts of the country received little rainfall or nothing at all during the 2018/2019 rainy season, and the resultant drought has caused huge livestock losses and widespread crop failure, particularly in the study area—the northern communal areas of Namibia.

5. Conclusion

Accurate information on rainfall variability and trends is especially crucial for improving water productivity in semi-arid regions where livelihoods of the majority of the inhabitants—the resource-poor smallholder farmers—depend mainly on natural resources, livestock farming, and rainfed agriculture. This study demonstrated that over the past two to three decades, there were spatial variations in rainfall across northern Namibia. Both mean annual and mean seasonal rainfall gradually declined from the extreme northeast towards the north-western zone of the country, with concomitant spatial and temporal variability simultaneously increasing north-westward. Moreover, rainfall distribution patterns across the study area had two distinct seasons, the dry-winter season covering the May–October period and the rainy-summer season spanning the November–April period, which also accounted for 97% of the annual rainfall mainly concentrating in December–March months. The stations in the northeast received more rainfall during the first half of the season, but those located in the north-central area or towards the north-western zone of the country showed an inverse rainfall pattern. Also, all stations had homogenous upward trends for annual rainfall and rainy-season rainfall, on average increasing by 7.74 mm year^{-1}, which have implications for floods. The dry-season rainfall predominantly had downward trends due to the decrease in November rainfall amounts, with an average reduction of -0.14 mm year^{-1}, signifying the risk of drought intensification in the region. However, the stations exhibited increasing trends for March rainfall, denoting a seasonal movement towards a concentrated rainfall at the end of the rainy season. Affirmation of climate change in the study area requires analysis of much longer-term rainfall data in conjunction with other variables such as temperature. These results should be useful in planning for rainwater management, designing flood and drought-risk management measures and promoting sustainable agriculture among smallholder farmers in semi-arid regions.

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References

Addisu, S., Selassie, Y., Fissha, G., & Gedif, B. (2015). Time series trend analysis of temperature and rainfall in lake Tana Sub-basin, Ethiopia. *Environ Systems Research, 4*(25), 1–12. doi:10.1186/s40068-015-0051-0

Akinyemi, F. O. (2017). Climate change and variability in semiarid Palapye, Eastern Botswana: An assessment from smallholder farmers' perspective. *Weather, Climate, and Society*, *9*(3), 349–365. doi:10.1175/wcas-d-16-0040.1

Anthonj, C., Nkongolo, O., Schmitz, P., Hango, J., & Kistemann, T. (2015). The impact of flooding on people living with HIV: A case study from the Ohangwena Region, Namibia. *Glob Health Action*, 8. dio:10.3402/gha.v8.26441

Awala, S. K., Yamane, K., Izumi, Y., Fujioka, Y., Watanabe, Y., Wada, K. C., . . . Iijima, M. (2016). Field evaluation of mixed-seedlings with rice to alleviate flood stress for semi-arid cereals. *European Journal of Agronomy*, *80*, 105–112. doi:10.1016/j.eja2016.07003

Batisani, N., & Yarnal, B. (2010). Rainfall variability and trends in semi-arid Botswana: Implications for climate change adaptation policy. *Applied Geography*, *30*(4), 483–489. doi:10.1016/j.apgeog.2009.10.007

Bhuyan, M. D. I., Islam, M. M., & Bhuiyan, M. E. K. (2018). A trend analysis of temperature and rainfall to predict climate change for Northwestern Region of Bangladesh. *American Journal of Climate Change*, *07*(02), 115–134. doi:10.4236/ajcc.2018.72009

Bola, G., Mabiza, C., Goldin, J., Kujinga, K., Nhap, I., Makurira, H., & Mashauri, D. (2013). Coping with droughts and floods: A Case study of Kanyemba, Mbire District, Zimbabwe. *Journal. Physics and Chemistry of the Earth*, 7. doi:10.1016/j.pce.2013.09.019

Box, G., & Jenkins, G. (1970). Time Series Analysis. *Forecasting and Control*.

Brown. (1998). *Coefficient of variation: Applied Multivariate Statistics in Geohydrology & Related Science*. Berlin: Springer. doi:10.1007/978-3-642-80328-4-13

Cheo, A. (2016). Understanding seasonal trend of rainfall for the better planning of water harvesting facilities in the Far-North region, Cameroon. *Water Utility Journal*, *13*, 3–11.

Chikodzi, D., Murwendo, T., & Simba, F. M. (2013). Climate change and variability in Southeast Zimbabwe: Scenarios and societal opportunities. *American Journal of Climate Change*, *02*(03), 36–46. doi:10.4236/ajcc.2013.23a004

Diop, L., Bodian, A., & Diallo, D. (2016). Spatiotemporal trend analysis of the mean annual Rainfall in Senegal. *European Scientific Journal*, *12*(12), 231. doi:10.19044/esj.2016.v12n12p231

Djaman, K., Tabari, H., Balde, A. B., Diop, L., Futakuchi, K., & Irmak, S. (2016). Analyses, calibration, and validation of evapotranspiration models to predict grass-reference evapotranspiration in the Senegal river delta. *Journal of Hydrology: Regional Studies*, *8*, 82–94. doi:10.1016/j.ejrh.2016.06.003

Dube, T., & Phiri, K. (2013). Rural livelihoods under stress : The impact of climate change on livelihoods in South Western Zimbabwe. *American International Journal of Contemporary Research*, *3*(5), 11–25. www.aijcrnet.com

Eckardt, F. D., Soderberg, K., Coop, L. J., Muller, A. A., Vickery, K. J., Grandin, R. D., … Henschel, J. (2013). The nature of moisture at Gobabeb, in the central Namib Desert. *Journal of Arid Environments*, *93*, 7–19. doi:10.1016/j.jaridenv.2012.01.011

El-Beltagy, A., & Madkour, M. (2012). Impact of climate change on arid lands agriculture. *Agriculture and Food Security*, *1*(1), 1–12. doi:10.1186/2048-7010-1-3

Feng, G., Cobb, S., Abdo, Z., Fisher, D. K., Ouyang, Y., Adeli, A., & Jenkins, J. N. (2016). Trend analysis and forecast of precipitation, reference evapotranspiration, and rainfall deficit in the blackland prairie of eastern Mississippi. *Journal of Applied Meteorology and Climatology*, *55*(7), 1425–1439. doi:10.1175/JAMC-D-15-0265.1

Fensholt, R., Langanke, T., Rasmussen, K., Reenberg, A., Prince, S. D., Tucker, C., … Wessels, K. (2012). Greenness in semi-arid areas across the globe 1981-2007: An Earth Observing Satellite-based analysis of trends and drivers. *Remote Sensing of Environment*, *121*, 144–158. doi:10.1016/j.rse.2012.01.017

Gabriel, C. (2013). The Mann Kendall test: the need to consider the interaction between serial correlation and trend. *Journal Scientiarujm Agronomy*, *35*(4), 393-402. doi:10.4025/actasciagron.v35i4\6006

Gornall, J., Betts, R., Burke, E., Clark, R., Camp, J., Willett, K., & Wiltshire, A. (2010). Review: Implications of climate change for agricultural productivity in the early twenty-first century. *Philosophical Transactions of the Royal Society B*, *365*, 2973–2989. doi:10.1098/rstb.2010.0158

Hadgu, G., Tesfay, K., Mamo, G., & Kasse, B. (2013). Trend and variability of rainfall in Tigray, Northern Ethiopia: Analysis of meteorological data and farmers' perception. *Academic Journal of Agricultural Research*, *1*(6), 88–100. doi:10.15413/ajar.2013.0117

Hare, W. (2003). Assessment of knowledge on impacts of climate change - contribution to the specification of the Art.2 of the UNFCCC. In *Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen*.

Hirsch, R., Slack, J. R., & Smith, R. (1982). Techniques of trend analysis for monthly water quality data. *Water Resources Research*, *13*(1), 107–121.

Hoffman, T., & Vogel, C. (2008). Climate change impacts on African rangelands. *Rangelands*, *30*(3), 12–17. doi:10.2111/1551-501x(2008)30[12:ccioar]2.0.co;2

Hooli, L. (2015). The resilience of the poorest: coping strategies and indigenous knowledge of living with the floods in Northern Namibia. *Regional Environmental Change*, 13. doi:10.1007/s10113-015-0782-5

Huang, J., Guan, X., & Ji, F. (2012). Enhanced cold-season warming in semi-arid regions. *Atmospheric Chemistry and Physics*, *12*, 5391–5398. doi:10.5194/acp-12-5391-2012

Huang, J., Ji, M., Xie, Y., Wang, S., He, Y., & Ran, J. (2016). Global semi-arid climate change over the last 60 years. *Climate Dynamics*, *46*(3–4), 1131–1150. doi:10.1007/s00382-015-2636-8

Iijima, M., Awala, S., Nanhapo, P., Wanga, A., & Mwandemele, O. (2018). Development of flood- and drought-adaptive cropping systems in Namibia. In K. Kokubun, & S. Asanuma, *Crop production under stressful conditions: Application of cutting edge science and technology in developing countries* (pp. 49-70). Singapore: Springer Nature Singapore Pte Ltd.

Jiménez, M. A., Jaksic, F. M., Armesto, J. J., Gaxiola, A., Meserve, P. L., Kelt, D. A., & Gutiérrez, J. R. (2011). Extreme climatic events change the dynamics and invasibility of semi-arid annual plant communities. *Ecology Letters*, *14*(12), 1227–1235. doi:10.1111/j.1461-0248.2011.01693.x

Kendall, M. G., & Stuart, A. (1967). *The Advanced Theory of Statistics: Inference and Relationship* (Vol. 2). Charles Griffin.

Kiros, G., Shetty, A., & Nandagiri, L. (2017). Extreme rainfall signatures under changing climate in semi-arid northern highlands of Ethiopia. *Cogent Geoscience*, *3*(1), 1–20. doi:10.1080/23312041.2017.1353719

Lema, M. A., & Majule, A. E. (2009). Impacts of climate change, variability and adaptation strategies on Agriculture in semi arid areas of Tanzania: The case of Manyoni District in Singida Region, Tanzania. *African Journal of Environmental Science and Technology*, *3*(8), 206–218. doi:10.5897/AJEST09.099

Lu, X., Wang, L., Pan, M., Kaseke, K. F., & Li, B. (2016). A multi-scale analysis of Namibian rainfall over the recent decade – comparing TMPA satellite estimates and ground observations. *Journal of Hydrology: Regional Studies*, *8*, 59–68. doi:10.1016/j.ejrh.2016.07.003

Mann, H. B. (1945, July). Non-parametric Test against Trend. *Econometric*, *13*(3), 245-259. Retrieved from https://www.jstor.org/stable/1907187

Mati, B. M. (2000). The influence of climate change on maize production in the semi-humid-semi-arid areas of Kenya. *Journal of Arid Environments*, *46*(4), 333–344. doi:10.1006/jare.2000.0699

Mavhura, E., Manatsa, D., & Mushore, T. (2015). Adaptation to drought in arid and semi-arid environments: Case of the Zambezi Valley, Zimbabwe. *Jàmbá: Journal of Disaster Risk Studies*, *7*(1), 1–7. doi:10.4102/jamba.v7i1.144

Mazvimavi, D. (2010). Investigating changes over time of annual rainfall in Zimbabwe. *Hydrology and Earth System Sciences*, *14*(12), 2671–2679. doi:10.5194/hess-14-2671-2010

Mendelsohn. (2006). *Farming Systems in Namibia.* Windhoek: RAISON.

Mendelsohn, J., Jarvis, A., & Robertson, T. (2013). *A profile and atlas of the Cuvelai–Etosha Basin.* Windhoek: Gondwana Collection.

Mendelsohn, Jarvis, A., Roberts, C., & Robertson, T. (2009). *Atlas of Namibia: A Portrait of the Land and its People* (3 ed.). Cape Town: Sunbird Publishers.

Modarres, R., & de Paulo Rodrigues da Silva, V. (2007). Rainfall trends in arid and semi-arid regions of Iran. *Journal of Arid Environments*, *70*(2), 344–355. doi:10.1016/j.jaridenv.2006.12.024

Montenegro, S., & Ragab, R. (2012). Impact of possible climate and land use changes in the semi-arid regions: A case study from North-Eastern Brazil. *Journal of Hydrology*, *434–435*, 55–68. doi:10.1016/j.jhydrol.2012.02.036

Mphale, K. M., Dash, S. K., Adedoyin, A., & Panda, S. K. (2013). Rainfall regime changes and trends in Botswana Kalahari transect’s late summer precipitation. *Theoretical and Applied Climatology*, *116*(1–2), 75–91.doi:10.1007/s00704-013-0907-z

Mukherjee, K. (2017). Trend analysis of rainfall in the Districts of West Bengal, India, a study for the last century. *Journal of Engineering Computers & Applied Sciences (JECAS)*, *6*(1), 1-12. Retrieved from www.borjournals.com

Mupangwa, W., Walker, S., Masvaya, E., Magombeyi, M., & Munguambe, P. (2016). Rainfall risk and the potential of reduced tillage systems to conserve soil water in semi-arid cropping systems of southern Africa. *AIMS Agriculture and Food*, *1*(1), 85–101. doi:10.3934/agrfood.2016.1.85

Namibia Statistics Agency. (2015). Namibia Census of Agriculture 2013/2014: Communal Sector Report. Windhoek: Namibia Statistics Agency.

National Planning Commission. (2012). *Namibia 2011 Population and Housing Census Preliminary Results.* Windhoek: National Planning Commission.

Nema, M. K., Khare, D., Adamowski, J., & Chandniha, S. K. (2018). Spatio-temporal analysis of rainfall trends in Chhattisgarh State, Central India over the last 115 years. *Journal of Water and Land Development*, *36*(1), 117–128. doi:10.2478/jwld-2018-0012

Pearson, K. (1905). "Skew Variation, a rejoinder". Biometrika. *Biometrika*, *4*, 169-212.

Persendt, F. C., Gomez, C., & Zawar-Reza, P. (2015). Identifying hydro-meteorological events from precipitation extremes indices and other sources over northern Namibia, Cuvelai Basin. *Jàmbá: Journal of Disaster Risk Studies*, *7*(1). doi:10.4102/jamba.v7i1.177

Roder, A., Pröpper, M., Stellmes, M., Schneibel, A., & Hill, J. (2015). Assessing urban growth and rural land use transformations in a cross-border situation in Northern Namibia and Southern Angola. *Land Use Policy*, *42*, 340–354. doi:10.1016/j.landusepol.2014.08.008

Rohde, R. F., & Hoffman, M. T. (2012). The historical ecology of Namibian rangelands: Vegetation change since 1876 in response to local and global drivers. *Science of the Total Environment*, *416*, 276–288. doi:10.1016/j.scitotenv.2011.10.067

Sarr, B. (2012). Present and future climate change in the semi-arid region of West Africa: A crucial input for practical adaptation in agriculture. *Atmospheric Science Letters*, *13*(2), 108–112. doi:10.1002/asl.368

Sen, P. K. (1968). Estimates of the Regression Coefficient Based on Kendall's Tau. *Journal of the American Statistical Association*, *63*(324), 1379-1389. Retrieved from http://links.jstor.org/sici?sici=0162-1459%28196812%2963%3A324%3C1379%3AEOTRCB%3E2.0.CO%3B2-A

Serdeczny, O., Adams, S., Baarsch, F., Coumou, D., Robinson, A., Hare, W., … Reinhardt, J. (2017). Climate change impacts in Sub-Saharan Africa: from physical changes to their social repercussions. *Regional Environmental Change*, *17*(6), 1585–1600. doi:10.1007/s10113-015-0910-2

Tschakert, P., Sagoe, R., Ofori-Darko, G., & Codjoe, S. (2010). Floods in the Sahel: an analysis of anomalies, memory, and anticipatory learning. *Climate Change*, 471–502. doi:10.1007/s10584-009-9776-y

Tsheko, R. (2003). Rainfall reliability, drought and flood vulnerability in Botswana. *Water SA*, *29*(4), 389–392. http://www.wrc.org.za

Patle, G., & Libang, A. (2014). Trend analysis of annual and seasonal rainfall to climate variability North-East region of India. *Journal of Applied & Natural Science 6*(2), 480-483.

Vicente-Serrano, S. M., Cabello, D., Tomás-Burguera, M., Martín-Hernández, N., Beguería, S., Azorin-Molina, C., & Kenawy, A. El. (2015). Drought variability and land degradation in semiarid regions: Assessment using remote sensing data and drought indices (1982-2011). *Remote Sensing*, *7*(4), 4391–4423. doi:10.3390/rs70404391

Wuensch, K. (2016). *Introduction to Descriptive Statistics.* Retrieved May 01, 2019, from http://core.ecu.edu: http://core.ecu.edu/psyc/wuenschk/docs30/Descript.pdf

Yamusa, A. M., Abubakar, I. U., & Falaki, A. M. (2015). Rainfall variability and crop production in the North-western semi-arid zone of Nigeria. *Journal of Soil Science and Environmental Management*, *6*(5), 125–131. doi:10.5897/JSSEM14.0444

Zika, M., & Erb, K. H. (2009). The global loss of net primary production resulting from human-induced soil degradation in drylands. *Ecological Economics*, *69*(2), 310–318. doi:10.1016/j.ecolecon.2009.06.014