PAPER 11

DOES RAINFALL TRENDS AND PATTERNS OF SOUTH AFRICA FOR THE PAST CENTURY DEMONSTRATE CLIMATE CHANGE?

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ABSTRACT

South Africa is a water-scarce country encountering increased climate variability. In the recent past, South Africa experienced the devastating Cape Town drought and most recently severe floods in Kwa-Zulu Natal. These extreme events expose the vulnerability of South Africa, a highly water resources-reliant country to the impacts of climate variability.

With climate change, the likelihood of extreme events occurring has increased, which requires a thorough analysis of rainfall trends and patterns for effective water resources planning and management. This research aimed to contribute to the existing contentious discourse on observable rainfall trends versus climate change rainfall projections, by employing non-parametric statistical analysis of rainfall station data spanning from 1900 to 2019, strategically distributed across the country.

The results demonstrated insignificant trends in daily rainfall. However, statistically significant increases were observed in monthly rainfall during November, December and January in Summer and 'All year' rainfall regions. Conversely, significant decreases were noted in March, May, June and September across Summer, Winter and 'All year' rainfall regions. Seasonal and annual trend analysis highlighted alternating short-term trends in the Summer rainfall region, while the Winter rainfall region experienced a shorter but wetter main rainfall season over short-term periods. The 'All year' rainfall region exhibited alternating dry and wet cycles with a slight decrease in mean annual rainfall.

Despite marginal long-term increases in annual rainfall, short-term periods showed increased variability. Although observed trends align with previous research outputs, change in annual rainfall remained relatively low, between 0.6 and 1.0 mm/year. This research hence recommends careful consideration of the observable rainfall trends when utilising climate change projected rainfall data in South Africa's planning processes and implementation of engineering projects.

1. INTRODUCTION

South Africa is a semi-arid country experiencing increased rainfall variability with a mean annual precipitation (MAP) of 450mm (Botai et al. 2018). The country is water-stressed with a high spatiotemporal variability in topography and climate making it vulnerable to the impacts of climate variability (Phakula et al. 2018). Researchers have acknowledged the impacts of climate change in South Africa while projecting a hot and drier future (Kruger & Nxumalo 2017, Almazrui et al. 2020, Du Plessis & Kalima 2021 and Kibii & Du Plessis 2024). This will impact the hydrological cycle with cascading effects on important sectors of the economy such as agriculture. Therefore, it is important for rainfall trends and patterns to be investigated for informed management and planning while also contributing to the topical discourse of climate change in South Africa. According to Chabalala et al. (2019), rainfall is an important variable of the hydrological cycle having a direct impact on water resources. Rainfall projections (using climate change data or observable trends) are therefore critical for researchers, policymakers and managers of water resources (Gajbhiye et al. 2015). Long-term (>100 years) observed time series is essential for the determination of statistics informing trends, cyclicity and variability of rainfall (Ndebele et al. 2020). This research obtained representative daily rainfall for South Africa for the period 1900-2019 and used it for the assessment of rainfall trends using a non-parametric approach.

Despite South Africa having a relatively good network of observation stations, Bailey and Pitman (2016) observe a worrying trend of declining number of observation stations further exacerbated by data deterioration and accessibility bottlenecks occasioned by policy challenges at the South African Weather Services (SAWS). This is complemented by Du Plessis and Kibii (2021) who observed a shortage of approximately 2700 rain gauge stations in South Africa measured against the WMO criteria of 1 rain gauge station per 100-250Km^2. However, the available observed rainfall data is still adequate to sufficiently investigate and characterise rainfall trends for South Africa over the past century.

To adequately characterise rainfall, it is important to appreciate that rainfall in South Africa is mostly influenced by the El Niño and La Niña Southern Oscillations. The El Niño Southern Oscillation phase (ENSO) leads to decreased rainfall with an increase in temperature while the La Niña results in the opposite (MacKellar et al. 2014). ENSO, often linked to extreme weather conditions, is defined as the interplay between the atmosphere and the ocean with a resultant cyclic variation of the sea surface temperatures (SST). This interplay is what influences the wetness or dryness within a given cycle (Lester 2019).

Previous research on rainfall trends in South Africa (Mason et al. 1999, Easterling et al. 2000, Misra 2003, Rouault et al. 2003, Groisman et al. 2005, Kruger 2006, New et al. 2006, Van Wageningen & Du Plessis 2007, MacKellar et al. 2014, Kruger & Nxumalo 2017 and Du Plessis & Schloms 2017) identify an inconsistent significant long-term trend in annual rainfall with a significant increase in extremes and interannual variability in rainfall over specific regions of South Africa. Most of these researchers apply parametric methods and global climatic models (GCMs) while emphasising the need for utilizing non-parametric approaches to better understand patterns of climatic variables and the interpretation of results. This research builds on previous research while utilising a non-parametric approach to investigate rainfall trends and patterns in South Africa for 1900-2019.

2. METHODOLOGY AND DATA

2.1 Study Area

This research was conducted in South Africa using 46 rainfall gauge stations strategically distributed as illustrated in Figure 1.

The climate of South Africa is characterised by four main seasons (Winter, Spring, Summer and Autumn). South Africa is further classified into eight (North-Eastern Interior, Central Interior, Western Interior, Southern Interior, South Coast, KwaZulu-Natal, North and South Western Cape) climatic zones

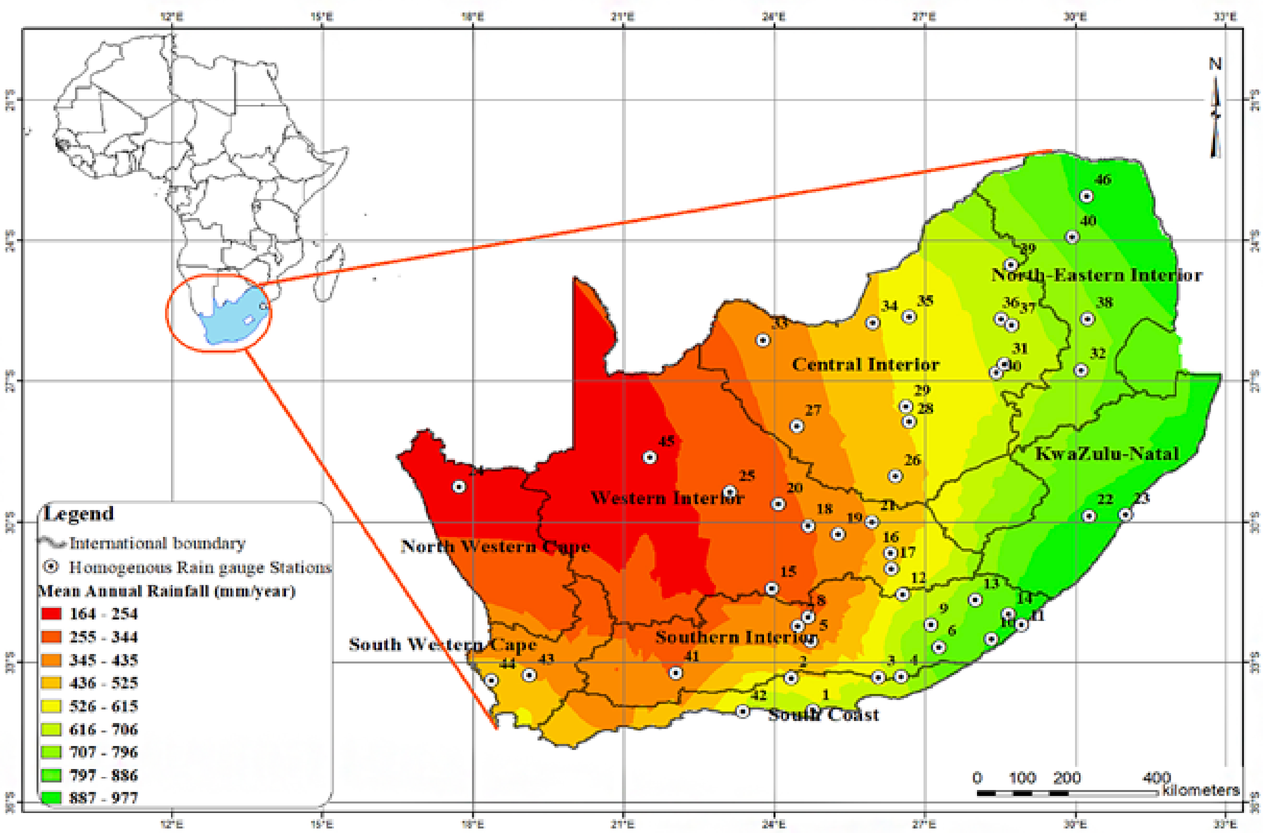

FIGURE 1: *Study Area – South Africa.*

(Rouault et al. 2003) receiving either winter, summer, or an 'All-year' rainfall depending on the rainfall formation mechanisms (Du Plessis & Schloms 2017). This research used the rainfall regions and climatic zones to characterise rainfall trends and discuss the results.

2.2 Data quality analysis

The obtained daily rainfall data from SAWS was subjected to quality analysis whereby outliers, negative and anomalous values were identified and removed. The long-term rainfall data was then subjected to gap analysis. Stations having more than 10% gaps were disregarded for quality control (Chabalala et al. 2019). Using the Normal Ratio (NR) method, stations with less than 10% gaps were gap-filled (Patra 2001).

2.3 Homogeneity analysis

This research applied four (Pettitt's, standard normal homogeneity, Buishand's and Von Neumann's) homogeneity tests (Alexandersson & Moberg 1997, Hirsch et al. 1982 and Peterson et al. 1998) to detect inhomogeneous data stations likely to results in artificial trends due to station relocation, change of measurement methods or environmental setting.

2.4 Definition of Rainfall Periods.

This research considered a long-term period of 1920-2019 (120 years) and short-term periods of 1900-1939, 1940-1979 & 1980-2019 (40 years each) for the characterisation of rainfall trends. The selection of the short-term 40-year periods was influenced by the World Meteorological Organisation (WMO) definition of climate to be the average climatic conditions for a period of between 21 and 30 years. Due to the staggered start and end years of the available data, the selected 40-year periods ensured that at least a climatic period was captured for each gauge station.

2.5 Trend Analysis.

A trend is a steady increase or decrease in the characteristic of a time series (Patra 2001). This research applied the Mann-Kendall (Mann 1945 and Kendall 1975) and Sens's slope (Sen 2012, Sen 2014 and Sen 2017) methods for trend analysis.

2.5.1 Mann-Kendall Test

The Mann-Kendall (MK) method was used to determine daily, monthly, seasonal and annual trends following the procedure as described by Gilbert (1987) and Hipel & McLeod (1994). The MK statistic is defined by Equation 1.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k) \quad \text{.................................Equation 1}$$

Where *n* denotes sample size, x_j and x_k are successive data where $j > k$; and

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k) \quad \text{..................................Equation 2}$$

A positive *S* illustrates an increasing trend while a negative *S* indicates a decreasing trend. This research adopted a two-tailed test with a null hypothesis, at 10% significance level (Hamed et al. 1998), that there is a significant decreasing/increasing trend (Che Ros et al. 2016, Shree & Kumar 2018, Kocsis et al. 2019 and Ndebele et al. 2020).

2.5.2 Sen's Slope

Sen's slope method was used to determine change per unit time after the detection of trends using the MK method. The slope (*Q*) for *N'* pairs of data is calculated as defined in Equation 3.

$$Q = \frac{x'_i - x_i}{i' - i} \quad \text{..Equation 3}$$

TABLE 1: *Summary of trend analysis results.*

Seasons	Periods	Climatic Zones Trends (mm/season)							
		North-Western Cape	South Western Cape	South Coast	Southern Interior	Western Interior	Central Interior	KwaZu-lu-Natal	North Eastern Interior
Summer	1900-1939			-2.34, 1.17	-1.6,3.4	2.92			
	1940-1979			-	0.99-2.05	2.77-4.33	3.19-3.73		7.0
	1980-2019		1.03	-1.5,1.83	3.5	1.65	-4.79,3.24	6.7	8.0
	1900-2019	**0.02**		**0.2**	**-0.29, 0.4**	**0.3-0.5**	**0.45-0.60**	-	**0.6**
Autumn	1900-1939	0.46	1.19			0.64	1.6	2.95	
	1940-1979	1.52	0.97	1.32		1.8	2.43		
	1980-2019					-1.39,1.5	3.95-2.13		
	1900-2019			**0.15**	**0.34-0.54**	**0.27**	**0.36**	**0.39**	**0.56**
Winter	1900-1939			0.48-1.04	1.42		0.01-0.18		0.37
	1940-1979		1.93	1.14-2.16	0.82-1.3	0.34	0.24		1.67
	1980-2019		2.8			0.52-1.59	0.22-0.69		0.54
	1900-2019		**0.39**		**0.24**	**0.03**	**0.03**		
Spring	1900-1939	0.63	0.94	1.17	-0.54,3.89	0.84-1.62			3.57
	1940-1979	0.61	1.04		0.5-1.1	0.57	3.03		3.20
	1980-2019		1.02	2.69	0.62-2.62	0.62-2.7	0.90-3.3	2.84	0.76-3.59
	1900-2019			**0.69**		**0.12**	**0.6**		
Annual	1900-1939	1.43	2.88	-5.32,3.75	-3,13.37	6.17	6.45	16.0	14.4
	1940-1979	2.23	4.6	4.32-6.79	9.17	3.89-6.38	5.78-6.60		11.13
	1980-2019					-8.40,3.47	3.78	9.37-9.64	
	1900-2019		**0.62**	**-1.02,0.89**	**0.41**	**-0.52,0.77**	**0.91-1.08**		
Legend									
+	Increasing trends								
-	Decreasing trends								
-,+	Fluctuating trends								
	No trends								

Where:

x'_i and x_i are series values for the period *i'* and *i*, respectively, and *i'>i*.

N' is the number of data pairs for which *i' >i*. The median of N' values of Q arranged from the largest to the smallest is then taken as the slope of the detected trend (Lakhraj-Govender & Grab 2019 and Ndebele et al. 2020).

3. RESULTS AND DISCUSSION

3.1 Rainfall characteristics

After data quality and homogeneity analysis, 46 (Figure 1) out of 71 stations obtained from SAWS were found suitable for trend analysis. The MAP of all the sites selected for analysis was 564mm with high spatial variability as illustrated in Figure 1. 43.5% of the stations had a greater site MAP than what was obtained from all the sites combined. The central parts of South Africa had an MAP of 450mm while the eastern and western regions had an MAP of 450mm and ≤ 250mm, respectively. The MAP of all stations for the short-term periods (1900-1939, 1940-1979 & 1980-2019) was calculated to be 559mm, 556mm and 562mm, respectively.

3.2 Rainfall Trends

Trend analysis was done for the long-term (120 years) and short-term (40 years) periods at all the stations. The daily trends were statistically insignificant due to the large sample size affecting the noise-to-signal ratio and were not investigated any further. Monthly trends demonstrated significant trends in November, December and January in the Summer and 'All year' rainfall regions. March, May, June, and September recorded decreasing trends in all three rainfall regions.

The results of seasonal and annual trends are summarised in Table 1.

3.3 Discussion

In performing the trend analysis, this research observed general fluctuations in short-term trends resulting in either small or insignificant long-term trends. The number of stations experiencing significant seasonal and annual trends varied in the short-term periods. The combined effect was shifting/changing short-term trends for the seasonal and annual rainfall. For example, during 1900-1939, the South Coast region had a fluctuating annual trend of between -5.32 and 3.75mm/year. In the succeeding period of 1940-1979, the same region had increasing annual trends of between 4.32 and 6.79mm/year. In the concluding period of 1980-2019, the region recorded no significant trend. A similar observation was noted for the Summer, Autumn, Winter and Spring seasons.

Comparatively, fewer stations (20%) recorded significant long-term seasonal and annual trends. The observed long-term trends were also marginal compared to the short-term trends. For example, the South Coast region recorded a long-term annual fluctuating trend of between -1.02 and 0.89mm/year, comparatively smaller than the short-term trends of between -5.3 and 6.79mm/year. Similarly, the South Western Cape, Southern Interior, Western Interior and Central Interior regions experience shifting annual (increasing/decreasing/fluctuating) trends in the short-term periods with only marginal long-term trends. For the North Western Cape, KZN and North Eastern Interior

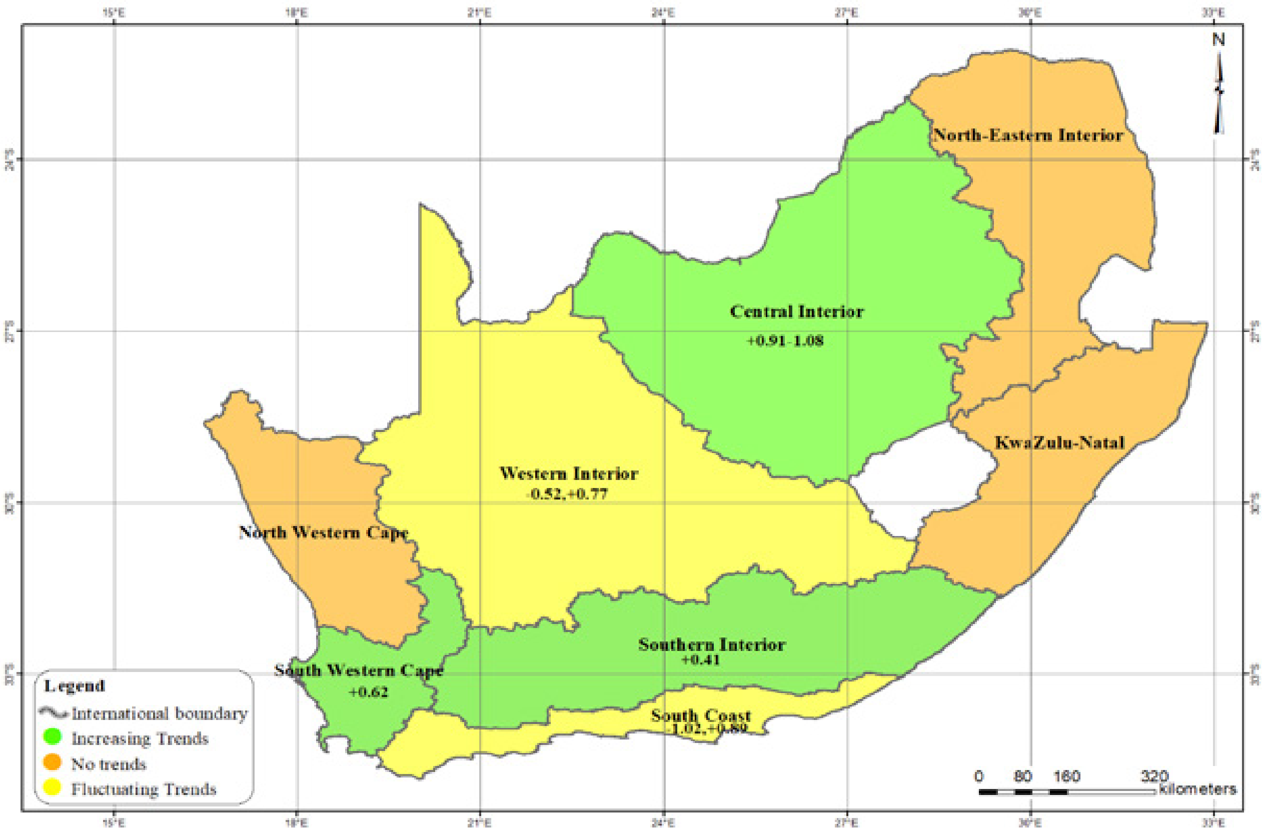

FIGURE 2: *Long-term trends of MAP for South Africa.*
NB: Figure 2 was developed from Table 1 and should be read in conjunction for a better understanding of the fluctuating rainfall trends in South Africa.

regions, shifting short-term annual trends result in long-term insignificant annual trends. The seasonal trend analysis was also observed to illustrate a similar picture for the short-term and long-term periods of analysis. Although researchers such as Kruger (2006) and Botai et al. (2018) observe insignificant long-term annual trends for South Africa, this research identified the presence of additional shifting short-term trends in the different climatic regions of South Africa.

The observations of this research corroborate with the already established consensus among researchers of a general global increase in rainfall variability, whereby a further focus on specific localities only highlights fluctuating short-term trends with marginal long-term trends. For example, Suhaila et al. (2008) demonstrated fluctuating rainfall trends for Malaysia which is complemented by Amirabadizadeh et al. (2015) and Che Ros et al. (2016). In Iran, Modarres & Da Silva (2007) and Kousari & Zarch (2011) also observe fluctuating rainfall trends with increased extreme events. A similar picture is painted for Italy by Liuzzo et al. (2016) who observed fluctuating rainfall trends with extreme events causing floods.

In South Africa, Easterling et al. (2000) and Groisman et al. (2005) observed increased extreme events in the Eastern Cape and are complemented by Richard et al. (2001) and Rouault et al. (2003). Although New et al. (2000) used the constructed gridded climate research unit (CRU) datasets, they observed insignificant annual rainfall trends for South Africa. Kruger & Nxumalo (2017) further complement Donat et al. (2013) in observing a general increase in the frequency and intensity of rainfall in South Africa. Contrastingly, Du Plessis & Burger (2015) using seven gauge stations observed no evidence of a changing trend in the short-term (sub-daily) rainfall intensity of South Africa. Further, Du Plessis & Schloms (2017) observe changing rainfall patterns and cyclicity of dry and wet periods in the Western Cape Region. After the 2015-2017 Cape Town drought, Seager et al. (2019) performed rainfall analysis for South Africa and observed a consistent but weak long-term drying signal while Gudmundsson et al. (2019) observed a strong signal for multidecadal rainfall variability.

The output of this research highlights the presence of shifting short-term trends resulting in long-term marginal trends complementing the findings of researchers such as Seager et al. (2019) and Gudmundsson et al. (2019). Although climate change studies have demonstrated intensified climatic conditions, for example, Kibii & Du Plessis (2024) in complementing Du Plessis & Kalima (2021) observe a possible future decrease in streamflow of more than 18% in the Western Cape region of South Africa, this research utilising 120 years of data (though may be considered a short period in light of climate change) observed only marginal (0.6 to 1.0mm/year) long-term changes in annual rainfall. If the past should inform the future, the observed marginal long-term trends hardly support the projected climate change rainfall at this stage.

4. CONCLUSIONS

This research was done to investigate observable rainfall trends in South Africa for the past 120 years and to also make an informed contribution to the ongoing topical debate of climate change. After successfully analysing the long-term and short-term trends for South Africa, this research made the following conclusions;

1. The climatic zones of the summer rainfall region (KZN, Southern, Western, Central and North-Eastern Interior regions) experience shifting trends in the short-term periods with marginal increases in the long-term period of analysis.
2. The North and South Western Cape climatic zones of the Winter rainfall region had mostly decreasing short-term trends. However, only the

South Western Cape recorded an insignificant annual long-term increasing trend.

3. The South Coast experiencing an 'All year' rainfall had fluctuating short-term trends with mixed signals in the long-term analysis.

Generally, the rainfall trends for South Africa demonstrated more pronounced trends in the short-term periods with marginal increases in the long-term periods of analysis. In conclusion, this research observed a marginal (0.6 - 1.0mm/year) long-term increase in annual rainfall for South Africa.

5. RECOMMENDATIONS

Having observed marginal long-term changes over a period of 120 years in South African rainfall, this research recommends the use of observed rainfall data and the trends as illustrated in Figure 2 to guide the application of projected climate change rainfall. Design and management decisions based on long-term rainfall projections should be adequately informed in consideration of observable long-term trends.

6. ACKNOWLEDGMENT

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