

Characterizing Rainfall of the Great Kei River Catchment, Eastern Cape Province, South Africa

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Abstract

This study seeks to understand long-term changes of rainfall for the Great Kei River catchment (GKRc) in South Africa for water resources management and planning. Monthly and annual rainfall time series data from 1950 to 2017 for 11 rainfall gauging stations are analyzed using various statistical methods. Data obtained from South African Weather Services (SAWS) was quality controlled to enable the use of Mann-Kendall (MK), Theil Sen's method, Precipitation Concentration Index (PCI), among others to characterise rainfall. Rainfall in the catchment is seasonal (particularly wet in spring and summer) and highly variable with a PCI of 17.2. Years which received rain above and below the mean inter-annually were 46% and 54%, respectively. Seasonality trends also confirm that the GKRc has been progressively receiving less rainfall since 1950, especially in the autumn. The methods are novel in understanding historical and existing trends, variability and characteristics that control freshwater availability in this catchment.

Keywords

Rainfall Concentration Index, Drought Potential, Rainfall Variability, Trend Analysis

1. Introduction

Comprehensive understanding of rainfall characteristics at a river catchment level has become important during these times of water uncertainties. The rapid growth of population, land use change and climate change are aspects rendering water availability to be uncertain in different localities and catchments (Okello et al.,

2015). Since, rainfall is the main source of water for this river catchment, it becomes important to study the rainfall patterns and characterise the hydro-climatology of catchments. Specifically, a shift in the climatic patterns can cause changes in hydro-climatic behavior and has a direct impact on the amount of water resources available in a region (Claussen, 2017). Hence, climate variables such as rainfall, temperature, and evaporation are crucial to understanding variability of water in any given region (Nunes & Lopes, 2016). Variability in rainfall is often reflected in flow variation (Banze et al., 2018) which impacts on water resources (Soro et al., 2016; Kisaka et al., 2015), basin characteristics (Molnár & Ramírez, 2001; Brunetti et al., 2004), streamflow dynamics (Nunes & Lopes, 2016) and runoff (UNECA, 2011). Hydro-climatic behavior can be studied using time series and trend analysis approach. A time series analysis approach provides direct evidence about hydrological deviations that require knowledge intensification of the water cycle parameters to evaluate their probable impact on water resources availability (He et al., 2016). Through trend studies, rainfall variability can be ascertained, identified, and quantified to support adaptation measures (Kampata et al., 2008). Furthermore, rainfall trends give an insight into the extent and magnitude of climate change and climate variability (U.S. Geological Survey, 2007; Owolabi et al., 2020; Banze et al., 2018; Kruger & Nxumalo, 2017; Soro et al., 2016; Mackellar et al., 2014; Kalumba et al., 2013; Philandras et al., 2011; Nel, 2009).

Recent literature provides some comparable but different work from the Eastern cape, like that of (Mahlalela et al., 2020) which uses coastal non-gauge stations; Zengeni et al. 2016 use data from stations not included here; while Botai et al. 2021 use a catchment based modelled data for stream flow in explaining variability. Like the approach in (Odiyo et al., 2015; Okello et al., 2015), this study will characterise the trends and variability of rainfall of Great Kei River catchment (GKRc) in South Africa. The river catchment is found in a country with an average annual rainfall of 500 mm and an evaporation rate three times the annual rainfall, which constrains the amount of water available for use (Zengeni et al., 2016; Mackellar et al., 2014). Specifically, the Eastern Cape (EC) Province receives more than 600 mm of rainfall annually (Dyson & Van Herdeen, 2002) and is expected in future to get wetter especially in December-February season (Hewitson & Crane, 2006). However, variability continues to occur, such as the 2018 drought event (Mahlalela et al., 2020) that made 234 rivers to be low or critically very low (DWS, 2018). Such rainfall variability, in a country which is already water scarce, requires understanding how the spatial and temporal distribution of rainfall can influence the hydrological cycle and alter the different processes that occur at a catchment scale like that of GKRc in Eastern Cape. Exploring this variation of rainfall facilitates decision-making in managing water resources. This study thus, aimed at analyzing rainfall characteristics over the GKRc in EC Province, for the 1950-2017 period, in particular, 1) determine trends in rainfall at monthly, seasonal, and annual scale; 2) characterise the nature and patterns of rainfall variability in the catchment; 3) explore the potential impacts such characteristics have on water

resources and adaptation strategies in the province. Achieving these objectives is a key step towards amplified understanding of local water distribution for human and environmental requirements. As well as providing important information for agricultural planning, flood hazard mapping, drought management, water supply and climate change impact modelling.

Study Area

The EC Province in South Africa shown in **Figure 1** is home to more than 6.5 million residents, in an area of around 168,966 km² (Stats SA, 2020), making it the second largest province in South Africa. According to (Gaulana et al., 2009), an escarpment divides the region into two water shed boundaries; the northern area is at higher altitude but receives below average rainfall, whereas the south, and eastern areas are wetter with a variety of rivers and wetlands that provide ample surface water (DWAf, 2009). Within the valleys lie the Great Kei River, with a catchment area of 20480 km² in size, fed by tributaries, like Tsomo, Gcuwa, Kubisi and Tyityaba rivers (Gaulana et al., 2009) and **Figure 1**. Weather systems from both the tropics and mid-latitudes influence rainfall over the EC region (Mahlalela et al., 2020) to produce a bi-modal rainfall distribution in winter and summer (Zengeni et al., 2016). Mean annual temperature for EC is 17.6°C, with a wide mean monthly range of 12.3°C - 22.4°C. EC is one of the least developed of the nine provinces of South Africa with a big rural population involved in agriculture (Mahlalela et al., 2020).

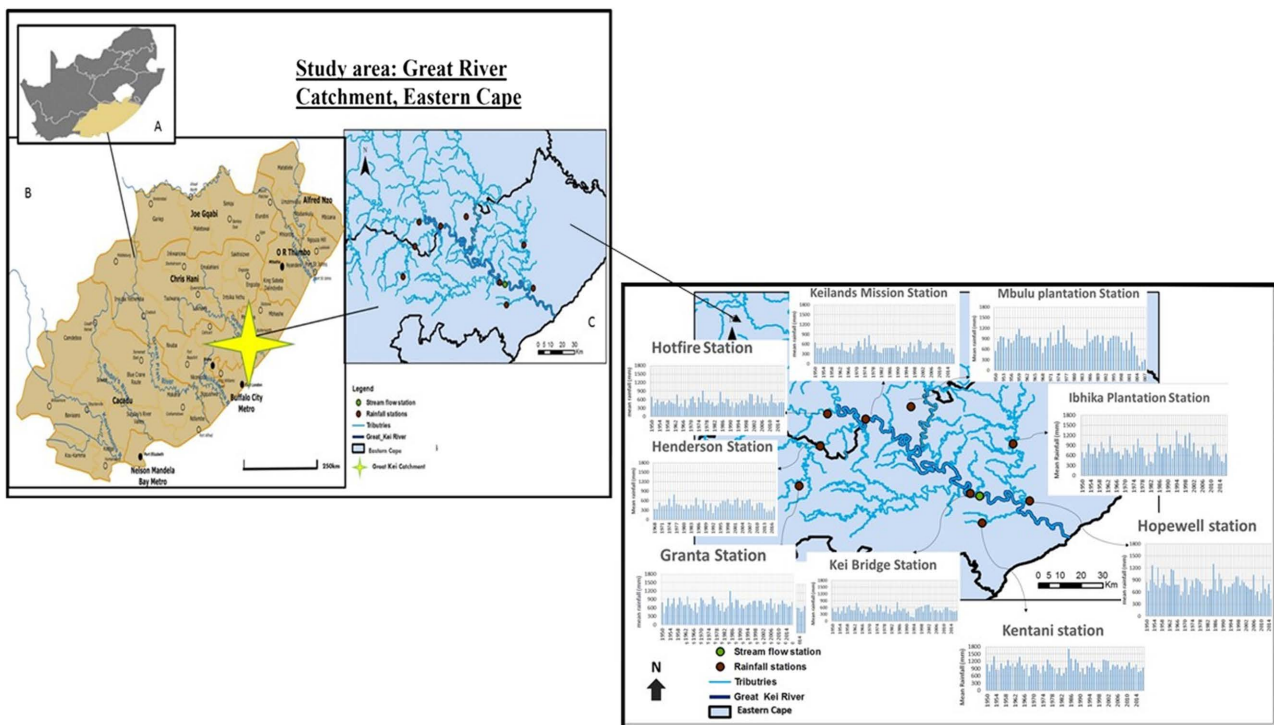


Figure 1. Locations of selected rainfall gauge stations around the Great Kei River catchment, with their respective mean rainfall distribution plots.

2. Data and Methodology

Monthly average rainfall data were obtained from 11 rainfall gauge stations provided by the South African weather services (SAWS) for years 1950 to 2017 (**Figure 1**). The choice of stations was guided by the span of time series and a threshold of 10% maximum missing data for each station (Stooksbury et al., 1999). Missing data were detected in all stations, with the Tygerhoek station missing most data. Above 10% of missing data can have considerable effects on the overall series (Ahokossi, 2019), especially if they occur early or late in the record (Kang, 2013; Weisent et al., 2014). Missing data was replaced using the long-term monthly mean values (see Nsubuga et al., 2014). Whereas four station annual series data gaps were completed using medians. Where surrounding stations had normal annual rainfall exceeding 10%, annual series were validated using the normal ratio method, advocated by (Singh, 1992) to overcome the effect of outliers. It was also important to determine the skewness and kurtosis of data series as justified in (Kisi et al., 2018) for the appropriateness of the intended statistical techniques (Machiwal & Jha, 2012).

Frequency analysis in climatology requires that time series be homogenous for in-depth studies of trends over time (Kisaka et al., 2015; Mahmood & Jia, 2016). For that matter, a test of randomness using Median Crossing tested for significant differences in mean/medians while a distribution free Cumulative Summation (CUSUM) tested for unknown change in time (CRCCH, 2005). The Median Crossing test revealed that, ten stations satisfied the null hypothesis “that data comes from a random process”, except for Mbulu plantation station, whose test statistic (z) was statistically significant.

A CUSUM analysis showed significant step jumps in the medians of annual rainfall to be positive at Tygerhoek and Hendersen, while Hopwell, Mbulu and Manubie had negative step jumps at 0.05. The rest of the stations experienced step jumps which were not statistically significant.

Statistical Methods

Monthly series were standardized like in (Nicholson et al., 2018) to establish the mean, and the extent of fluctuation in mean rainfall recorded using Coefficient of Variation (CV: see Kumaraswamy et al., 2015). The CV is also an index of climatic risk, that gives an insight into a likelihood of fluctuations in reservoir storage or crop yield annually (Suleiman & Ifabiyi, 2015). Rainfall anomaly series were constructed using annual total values for the 11 stations and later transformed into a regional series, here referred to as catchment climatology using a procedure described in (Nicholson, 1986). The validation of the catchment climatology was tested using correlation coefficients. The Henderson and Tygerhoek stations correlated at less than 0.4 to regional climatology. Like in (Nsubuga et al., 2014), the two stations were omitted for the catchment climatology series construction. Other stations reflected strong correlation to the regional climatology.

These monthly and annual rainfall time series were further analyzed using

descriptive statistics including finding the minimum, maximum, range, standard deviation, variance, standard error of the mean to provide a preliminary overview of data used for the study.

An interrogation of the series was also done using Rainfall Variability Index (RVI). This index is computed as the standardized rainfall departure to separate the available rainfall time series into different climatic regimes (Ogunrinde et al., 2019). In addition, a Standardized Precipitation Index (SPI) in this study is applied on a normalized time series and calculated on a 3 and 6-month time scale. Definition of the index, its computation and advantages can be followed in (McKee et al., 1995; WMO, 2012; Arkian et al., 2018).

To evaluate the varying weight of monthly rainfall to the total amount of rainfall we apply the Precipitation Concentration Index (PCI; see Viola et al., 2006). PCI values below 10 indicate a uniform monthly rainfall distribution in the year and values from 11 to 20 denote seasonality in rainfall distribution, whilst values above 20 denote climate with substantial monthly variability in rainfall amounts (de Luis et al., 2011).

Long-term trends in seasons were determined using the Mann-Kendall (MK) test statistic for summer (December-February), spring (September-November), autumn (March-May) and winter (June-August). The MK test is best suited for evaluating changes in hydrological characteristics and meteorological time series (Gedefaw et al., 2018). Its advantages are elaborated in (Zečňáková et al., 2018). This MK test statistic, Kendall's (Z) is calculated for annual, monthly, and seasonal rainfall data using the formula below.

The hypothesis, that there is no trend is rejected when the Z value is greater in absolute value than the critical value Z_α , at 0.01 and 0.05 level of significance α (Longobardi & Villani, 2010).

$$s = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sign}(y_j - y_i)$$

$$Z(S) = \begin{cases} \frac{S-1}{\sqrt{V(S)}}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \frac{S+1}{\sqrt{V(S)}}, & \text{if } S < 0 \end{cases}$$

When $Z > 0$, it indicates an increasing (positive) trend. When $Z < 0$, it represents a decreasing (negative) trend. To estimate the true slope of an existing trend (as change per year) the Theil-Sen's nonparametric method is used. The Sen's method can be used in cases where the trend is assumed to be linear (Gedefaw et al., 2018). This means that $f(t)$ in the model $x_i = f(t_i) + \varepsilon_i$, is equal to $f(t) = Qt + B$ where Q is the slope and B is a constant (see Kişi et al., 2018). The procedure in MAKESENS computes the confidence interval at two different confidence levels: $\alpha = 0.01$ and $\alpha = 0.05$. At first, we compute $C_\alpha = Z_{1-\alpha/2} \sqrt{\text{VAR}(s)}$, then $Z_{1-\alpha/2}$ is obtained from the standard normal distribution. Next $M_1 = (N - C_\alpha)/2$ and $M_2 = (N + C_\alpha)/2$ are computed (Salmi et al., 2002). The lower and upper limits

of the confidence interval, Q_{\min} and Q_{\max} are the M_1^{th} largest and the $(M_2 + 1)^{\text{th}}$ largest of the N ordered slope estimates Q_i . If M_1 is not a whole number, the lower limit is interpolated. Correspondingly, if M_2 is not a whole number the upper limit is interpolated. To obtain an estimate of B in equation the n values of differences $x_i - Qt_i$ are calculated. The median of these values gives an estimate of B (Drapela & Drapelova, 2011). The estimates for the constant B of lines of the 99% and 95% confidence intervals are calculated (see Salmi et al., 2002).

3. Results

Salient statistical properties derived from the long-term annual rainfall time series of 1950-2017 are relied on in this discussion (file can be provided on request).

3.1. Station Trends

Table 1 gives the minimum and maximum values (Q and B) for each 99% and 95% confidence intervals and the residuals (data minus trend) are shown. Nine of the stations exhibited decreasing trends in the annual rainfall and the trends in three of them were statistically significant. It is worth noting that these three stations (Hopwell, Hotfire and Ibhikha) were located far from each other (see **Figure 1**). Overall, rainfall is decreasing at most of the stations (**Table 1**). There are few incidences at Mbulu and Kei-Bridge stations where rainfall reflects a positive trend which is not significant. Trend for the GKRC is significantly decreasing, with a Z statistic of -2.12 at 95%. This trend with regards to Sen's slope estimator at stations is at $Q = -19.3$ mm/year.

Table 1. Trend test statistics of areal climatology of the Great Kei River Catchment for 1950-2017.

Great Kei catchment	Mann-Kendall trend			Sen's slope estimate										
	Areal climatology	n	Test Z	Signific.	Q	Qmin99	Qmax99	Qmin95	Qmax95	B	Bmin99	Bmax99	Bmin95	Bmax95
Monthly Time series														
January	68	-0.01			-0.052	-7.023	6.600	-5.188	5.038	932.43	1151.08	645.20	1100.83	725.65
February	68	-1.11			-1.973	-7.733	3.202	-6.193	1.849	906.45	1116.04	695.11	1089.94	751.27
March	68	-2.08	*		-5.166	-11.348	1.175	-9.530	-0.372	866.30	1094.91	660.61	1040.64	698.52
April	68	-0.28			-0.368	-4.610	4.106	-3.601	2.807	570.00	707.88	427.37	679.44	464.33
May	68	-1.85	+		-2.066	-5.915	0.890	-4.876	0.075	294.29	485.24	198.35	429.12	207.17
June	68	-0.12			-0.049	-1.964	1.389	-1.450	1.023	105.33	182.67	44.81	155.75	59.75
July	68	0.99			0.751	-1.271	3.122	-0.680	2.467	106.98	189.56	64.73	166.09	72.74
August	68	0.07			0.096	-3.403	3.163	-2.508	2.486	260.88	364.36	189.75	330.49	200.25
September	68	-2.25	*		-4.025	-9.449	0.639	-8.092	-0.435	561.67	751.17	392.20	698.62	449.47
October	68	-0.41			-1.097	-7.256	4.999	-5.466	3.596	761.71	897.49	502.216	865.15	571.092
November	68	-0.24			-0.540	-6.384	6.118	-4.651	4.441	850.48	1045.53	576.562	1004.5	658.824

Continued

<i>December</i>	68	-0.05		-0.177	-7.153	6.728	-5.192	4.991	742.58	1052.69	541.376	973.45	606.622
<i>Catchment_ANNUAL</i>	68	-2.12	*	-19.26	-44.479	3.835	-37.868	-1.286	7930.3	8990.1	7293.87	8704	7402.31
Seasonal Time series													
<i>AUTUMN_MAM</i>	68	-1.82	+	-8.068	-21.168	3.555	-17.370	0.743	1896.5	2308.11	1433.3	2241.4	1510.27
<i>WINTER_JJA</i>	68	0.06		0.116	-4.090	6.229	-2.999	4.890	578.56	755.323	456.83	717.76	474.988
<i>SPRING_SON</i>	68	-1.10		-4.670	-16.202	6.119	-13.056	3.384	2240	2634.11	1798.43	2496.5	1904.33
<i>SUMMER_DJF</i>	68	-0.77		-3.549	-18.456	8.928	-14.829	5.802	2770.2	3354.13	2318.55	3235.5	2447.39
Station Time Series													
<i>Tygerhoek</i>	68	-0.01		-0.052	-7.023	6.600	-5.188	5.038	932.43	1151.08	645.20	1100.83	725.65
<i>Granta</i>	68	-1.11		-1.973	-7.733	3.202	-6.193	1.849	906.45	1116.04	695.11	1089.94	751.27
<i>Hopwell</i>	68	-2.08	*	-5.166	-11.348	1.175	-9.530	-0.372	866.30	1094.91	660.61	1040.64	698.52
<i>Hendersen</i>	68	-0.28		-0.368	-4.610	4.106	-3.601	2.807	570.00	707.88	427.37	679.44	464.33
<i>Hotfire</i>	68	-1.85	+	-2.066	-5.915	0.890	-4.876	0.075	294.29	485.24	198.35	429.12	207.17
<i>Keilands</i>	68	-0.12		-0.049	-1.964	1.389	-1.450	1.023	105.33	182.67	44.81	155.75	59.75
<i>Mbulu</i>	68	0.99		0.751	-1.271	3.122	-0.680	2.467	106.98	189.56	64.73	166.09	72.74
<i>Kei-Bridge</i>	68	0.07		0.096	-3.403	3.163	-2.508	2.486	260.88	364.36	189.75	330.49	200.25
<i>Ibhikha</i>	68	-2.25	*	-4.025	-9.449	0.639	-8.092	-0.435	561.67	751.17	392.20	698.62	449.47
<i>Kentani</i>	68	-0.41		-1.097	-7.256	4.999	-5.466	3.596	761.71	897.49	502.216	865.15	571.092
<i>Manubie</i>	68	-0.24		-0.540	-6.384	6.118	-4.651	4.441	850.48	1045.53	576.562	1004.5	658.824

For the tested significance levels, the following symbols are used in the table: * if trend at $\alpha = 0.05$ level of significance; + if trend at $\alpha = 0.1$ level of significance; If the cell is blank, the significance level is greater than 0.1. Sen's slope estimate Q: the Sen's estimator for the true slope of linear trend; B: estimate of the constant B in model above; $f(\text{year}) = Q * (\text{year} - \text{first Year}) + B$ for a linear trend.

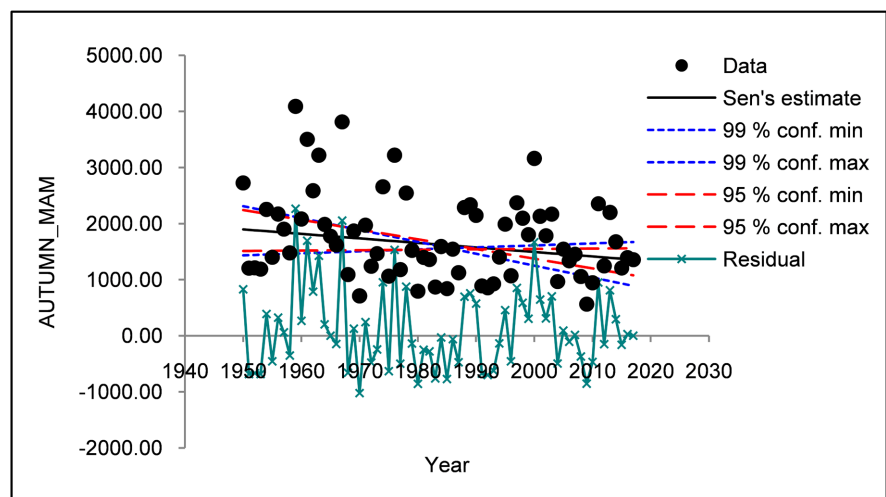
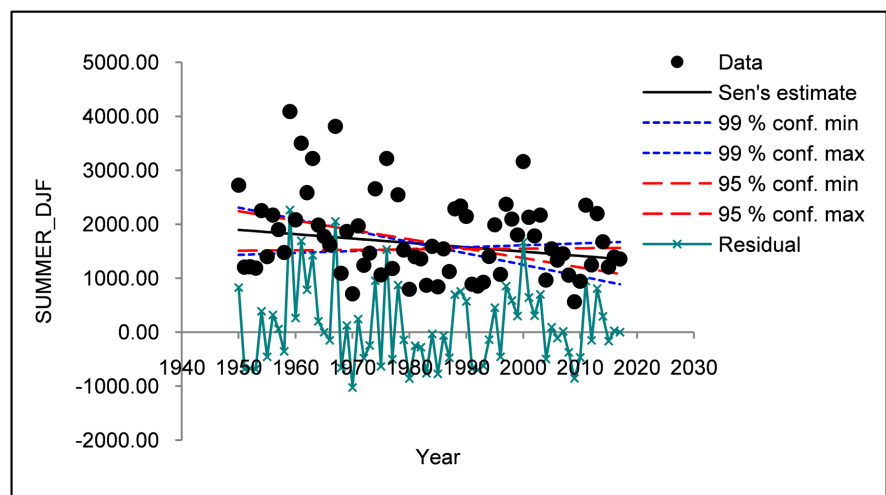
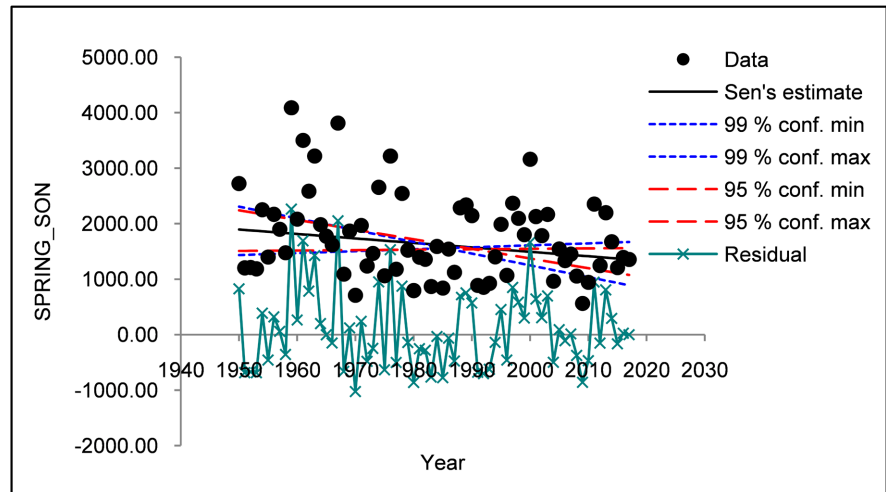
Intra rainfall trends

The results of the Mann-Kendall test Z on monthly rainfall trends for 1950-2017, show a non-significant increase in rainfall for the months of July and August, whilst the rest of the remaining months indicate a decrease in rainfall, with the most significant decrease ($\alpha = 0.05$) in March and September (see **Table 1**).

3.2. Seasonal Trends

Temporal trends for the entire study period show that, three of the seasons are experiencing a decrease in rainfall, especially in autumn where the decrease is significant at ($\alpha = 0.1$) with a $Q = -8$ mm per year (**Table 1; Figure 2**). Rainfall, however, increased in winter but not significant at a level greater than $\alpha = 0.1$.

Overall, the seasonality trends also confirm that the Great Kei River catchment has been progressively receiving less rainfall since 1950, especially in the autumn. Therefore, this should be put into consideration for agricultural planning and drought management.



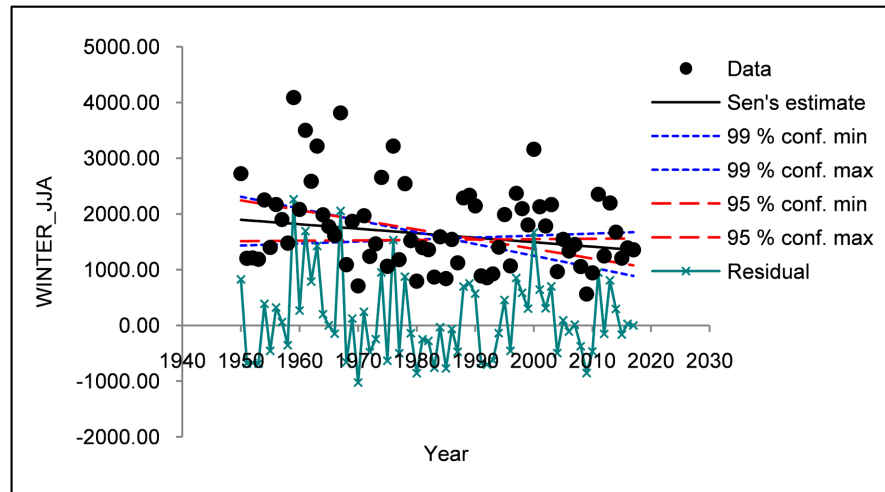


Figure 2. Precipitation trends (mm/year) within the catchment for summer, autumn, winter, and spring. Included is annual data, Sen's estimator for a linear trend, corresponding point values for the lines of 99% and 95% confidence intervals for the Sen's estimator, and the calculated residuals.

3.3. Rainfall Variability

Analysis revealed that total annual rainfall during the entire study period varied between 4988 mm to 11,574 mm (mean = 7641 ± 168 mm). Also see the distribution of annual rainfall at each station in **Figure 1**. The GKRC experiences a coefficient of variation (CV) of 18% indicating a less to moderate consistency of rainfall (results not shown). The higher the CV, the more variable the year-to-year rainfall of a locality is (Schulze, 2007). To attain a deeper understanding of long-term distribution for seasonal and temporal rainfall variability a PCI is computed for each station.

3.4. Rainfall Concentration Index (PCI)

Temporal variability in rainfall distribution at all stations had a PCI greater than 10 to +40%, suggesting a moderate to high concentrations in the distribution of rainfall (Figure not included). A higher PCI value also indicates that rainfall is more concentrated to a few rain years during the study period and vice versa (Zhao et al., 2011). Higher values for temporal concentration can be a result of seasonal concentration or a random deviation from the long-term mean (Nsubuga et al., 2014). This is evident at some stations (Kei-Bridge, Manubie, Mbulu, Keilands, which showed a PCI above 25%, after the 20th year.

Rainfall experienced in the catchment is not evenly spread out throughout the year but concentrated in certain seasons, particularly in spring and summer. Evidence of variability is demonstrated for the catchment area during 1950-2017 using RVI, (see **Figure 3**). The period 1950-1960 exhibits successive dry and wet periods, while the late years were either dry or very dry (**Figure 3**). Summarily, very wet years were 8.6%, very dry and dry periods were 34.3% and 22.8% respectively; while 34.3% were years that received normal rainfall.

A closer observation reveals a 20-year cycle, which raises interest in knowing which 20-year climatic age was wetter or drier than the other. Analysis reveals that, the years 1970-1990 were wet, while the 1990-2010 had more dry periods.

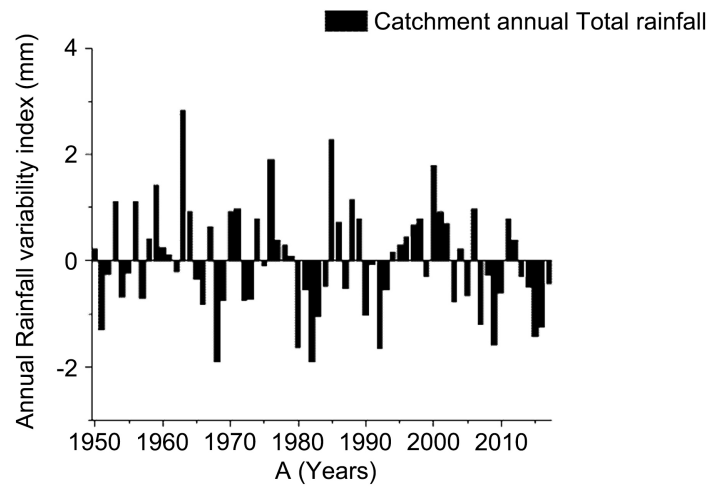


Figure 3. Rainfall variability index for the Great Kei catchment (1950-2017).

3.5. Inter-Annual Rainfall Variability

Analysis of annual total rainfall shows that 46% of the years received rain above the mean and 54% were below the mean for the catchment. It is also evident that rainfall for the catchment during 1968, 1980, 1982, 1992, was extremely very low, which was also revealed by the SPI analysis (see Figure 4).

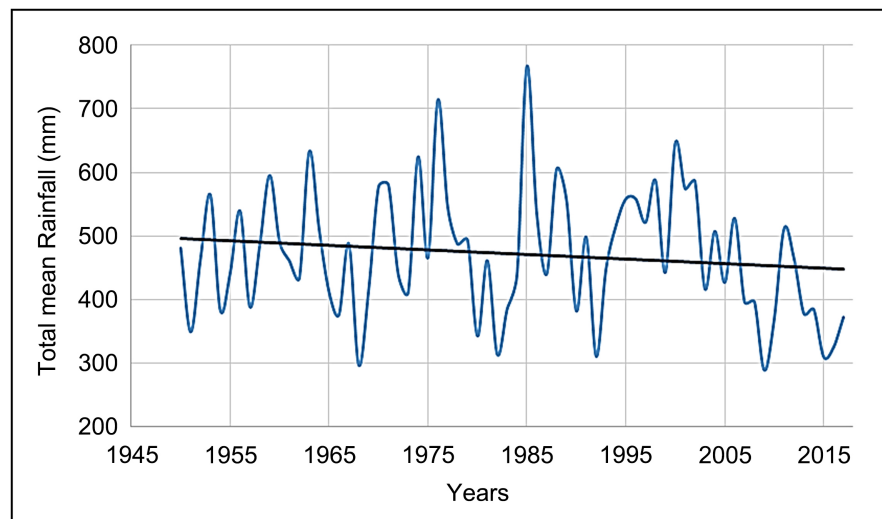


Figure 4. Variation in mean rainfall for the Great Kei catchment area for the period of 1950-2017.

To quantify the changes in seasonal rainfall at each station for the period 1950-2017, analysis for summer (Dec.-Feb.), winter (Jun.-Aug.), spring (Sep.-Nov.), autumn (Mar.-May) is derived and plotted as anomalies. Analysis shows that 36.6%

of the rainfall fell in summer, 29.3% in spring, 23.4% in autumn and 10.7% in winter seasons during the study period. It indicates that the mean rainfall of the wet season (summer and spring) was twice to that of the dry season. There was desiccation of the winter rains of 1985-1995 and autumn rains of 1990-1995. The SON season has shown the highest variability associated with below average rainfall during the late 1960's and early 1970's. A progressive decrease in rainfall is evident especially in the autumn season.

This study establishes that rainfall during January-February contributed 25%, whilst June contributed the lowest at 2.2% to the total annual rainfall received for the catchment (Figure not shown). The ENSO effect as well as the Madden-Julian Oscillation (MJO) have a noticeable impact on the intra-annual rainfall variability along with other factors (see Fauchereau et al., 2003; Mackellar et al., 2014; Mahlalela et al., 2020).

A closer look into the monthly rainfall anomalies gives further insight into the distribution of rainfall. Monthly rainfall series reveal December as the month with the most above normal rainfall in the catchment. For all months, the frequency of above mean rainfall reduces from the year 2000 in the entire study period.

3.6. Drought Potential and Occurrence in the Great Kei Catchment

As observed by (Nsubuga et al., 2014) areas with coefficients > 20% are also likely to have more frequent and severe droughts. Stations like Tygerhoek, Ibhikha and Mbulu had a coefficient above 20%, which necessitated an investigation about the potential occurrence of droughts in the catchment, which can affect reservoir storage and crop yield. Droughts are apparent after a long period with a shortage or without any rainfall (Guenang & Kamga, 2014). To give a better representation of abnormal wetness and dryness an SPI is used. In this work, SPI is used to quantify rainfall deficits on seasonal time scales, i.e. SPI time scale of 3 and 6 months' is shown in Figure 5 and Figure 6.

Figure 5 shows some consistency in SPI values between seasons in 1960-1980 and 1985-1995. Spring and summer show more years of positive SPI, while winter and autumn have more years of negative SPI for the period of analysis. In the last five years of the study period, all seasons tend towards negative SPI. The winters have experienced severe to extreme drought between 1987 and 1991 in the catchment and these droughts are still consistent with a few interruptions of wetness every ten years. Droughts are apparent, specifically in summer, which is the main rainfall season for the catchment, (Figure 5(B)).

For water resources management and agriculture, World Meteorological Authority (WMO) recommends a longer time scale e.g., 6 months for effective indication of rainfall over distinct seasons. For example, a 6-month SPI at the end of February would give a very good indication of the amount of rainfall that has fallen during the wet season from December through February for South Africa (Figure 6(C)). The same SPI can inform about stream flows and reservoir levels for the region in a particular year, which is vital for water management. Figure 6

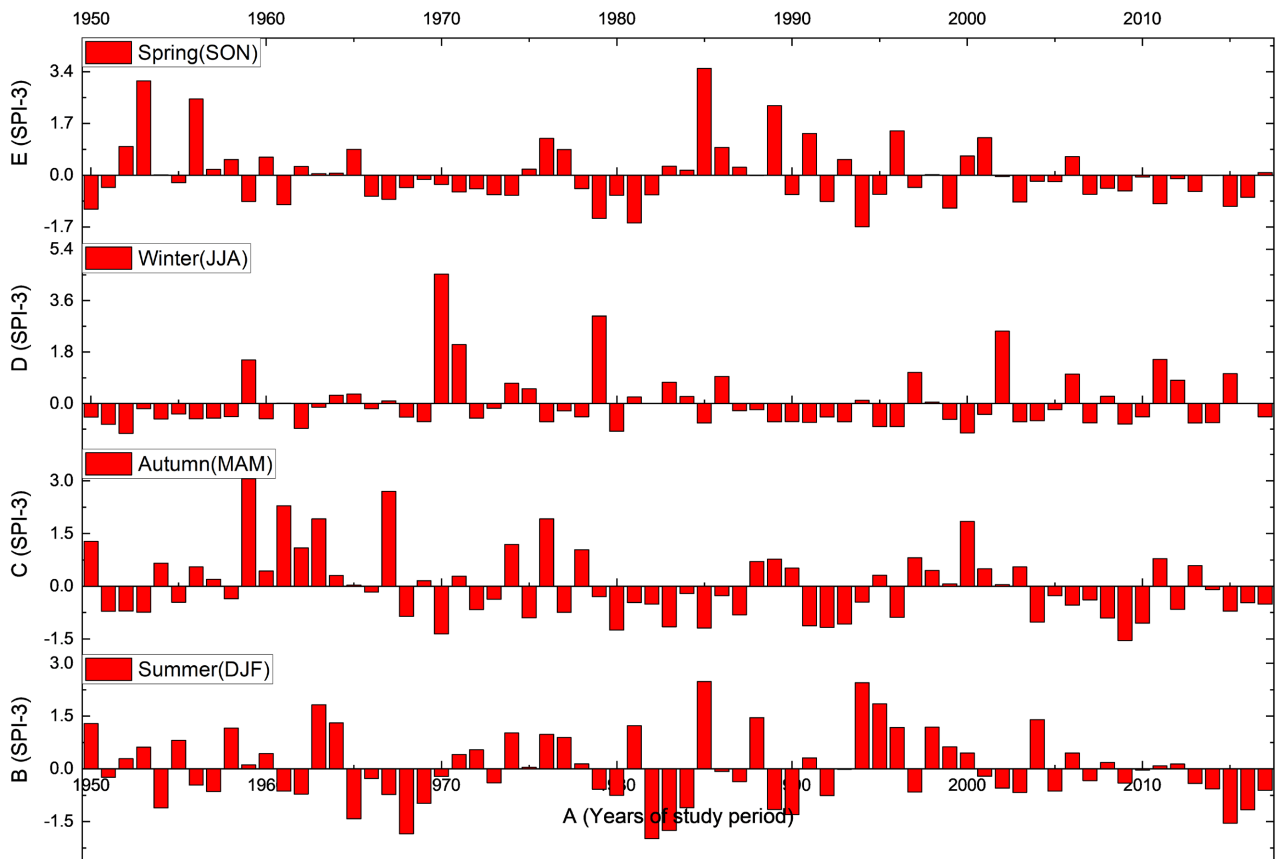


Figure 5. Time series of SPI-3 of the Great Kei River catchment.

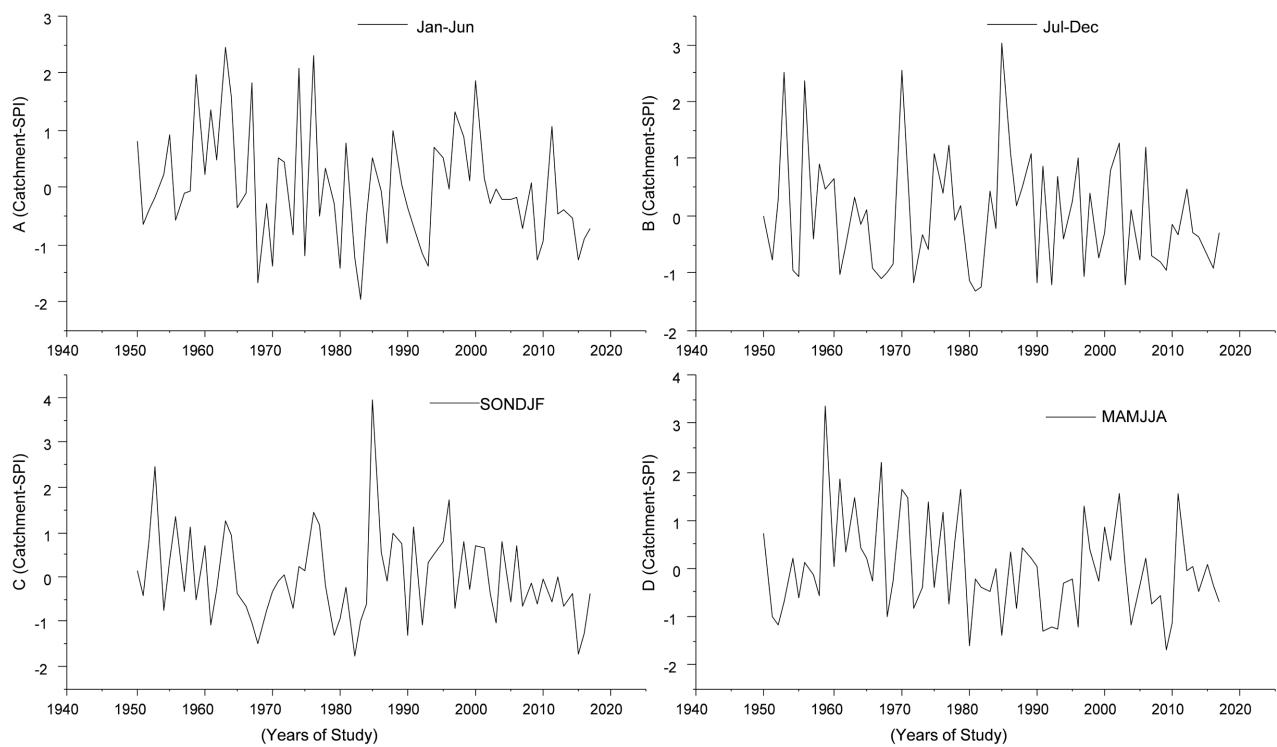


Figure 6. Time series of SPI-6 at the Great Kei River catchment.

shows the time series of SPI-6 for the catchment. The catchment recorded a classified type of drought at one or more times in the 50s, 60s, 80s, 90s and 2010s. Droughts were mild in 1968 and 2016; moderate in 1952, 1955, 1966-7, 1972, 1980, 1985, 1990-93, 2001, and 2017; severe in 1981-82, and 2015 (**Figure 6**) based on (Mckee et al., 1995) drought categorization.

4. Discussion

These results, have implications of utmost importance to the GKRC in EC. Eastern Cape according to Mdoda et al. (2020) is experiencing on average, low rainfall, high temperatures and frequent droughts that lead to both ground and surface water scarcity. The decreasing trend in rainfall often intensifies ground water resource abstraction in the catchment, something also noted by (Hossain et al., 2014). A change in rainfall amount results in fluctuations in run off. This distresses the ground water recharge rates which in turn have a bearing on water supply (Nunes & Lopes, 2016). It is evident that winters have experienced severe to extreme drought every ten years. ENSO events have been linked to drought and floods events in southern Africa like the 2005/2006 drought (Mosase & Ahiablame, 2018). Warm ENSO events (El Niño) are commonly associated with below average summer rainfalls, whilst La Niña events typically bring about above-average rainfall in South Africa (Mackellar et al., 2014). So, to plan for adaptation strategies, it is important to have in mind the inter-annual variability and atmospheric systems that influence rainfall distribution for annual activities in the catchment.

Spring season also noted by Mahlalela et al. (2020) offers an opportunity for surface and ground water resources to start replenishing, particularly if the preceding summer has been drier than normal. Since summer and spring are also seasons that bring the most rainfall to the GKRC, a decrease in rainfall in both these seasons without a significant increase in the other seasons has led to an overall decrease in rainfall for the entire catchment at a magnitude of -19.3 mm per year.

It is also essential to note that on a monthly or seasonal basis, rainfall variability is higher than on an annual basis (Schulze, 2007). Trends for the entire study period (1950-2017) indicate that autumn is the only season that has a significant decreasing trend at 90% significance level. It is evident that rainfall has been at a decrease since 1950, and more drastically from the 1980's, which correlates to a similar study done by (Blignauta et al., 2009). Spring and summer show a significant decrease in rainfall at a rate of -4.6 and 3.5 , respectively. A decrease in rainfall in these seasons that bring the most rainfall causes significant dryness to the catchment and impacts on human activities. However, historical trends indicate that, this is not a new phenomenon.

Thus, water managers ought to watch over rainfall variability and control the water resource availability as they monitor water levels. A report by Department of Environmental Affairs (DEA), observes that annual average temperatures will increase for Eastern Cape in the near future (2015-2035) to more than 2°C .

Projections for the mid future (2040-2060) are between 1°C - 3.5°C beyond the range of present-day climatology. But (Jury, 2018, 2019) found significant warming of $>0.02^{\circ}\text{C}\cdot\text{yr}^{-1}$ during the 1980-2014 for South Africa. A corresponding study done in the East London area, with the same climatic patterns as GKRC, revealed non-significant decreasing trends for 1975-2011 period (Kalumba et al. 2013). A year later, Mackellar et al. (2014) reported that no significant decrease in rainfall is indicated over the Eastern Cape for the period of 1960-2014, besides an increase in rain days along the southern coast. This study finds an overall mean rainfall of the catchment area to have experienced extreme variability from 1950 to 2017 (Figure 4) which was also noted by (Hosu et al., 2016). Subsequently, rainfall variability has been more frequent in the last twenty years within the catchment, which calls for adaptation interventions such as timely growing of food crops and constructing water dams in the catchment.

A combination of changes in temperatures and rainfall, has a bearing on planting dates and scheduling of other vital activities that have consequences on household incomes and livelihoods for farmers and rural communities. For instance, Mdoda et al. (2020) has established that climate variability has substantial effects on net returns for small holder farmers in Eastern Cape.

Knowing that rainfall significantly influences streamflow dynamics (Nunes & Lopes, 2016) like of that of GKRC, understanding hydrological responses to climate variables such as rainfall is critical to understanding the variability of water in this catchment. In so doing, one can develop sustainable catchment management strategies that will cope with increasing demand. Such strategies should offer robust solutions that can work in an array of probable climate change scenarios that balance immediate and long-term needs.

Prioritizing adaptation actions of improving soil, water, and land management by engaging actors is an aspect that should not be ignored. Efforts to strategize for adaptation in a changing climate while planning, designing and management of water resources projects is another aspect, also appreciated by (Jhajharia et al. 2014). Adaptation opportunities will require increasing awareness of climate change, its magnitude and impending costs and benefits in relation to dominant activities that exist in the area. Sustainable economic development in the catchment should be associated with the available opportunities for research, training and education, access to expertise and technology which are available in the country. Relying on the current stability of rainfall distribution, one can design adaptive measures like water harvesting that will sustain livelihoods around the catchment.

5. Conclusion

This study has attempted to analyse rainfall characteristics for the Great Kei catchment in the Eastern Cape at both annual, monthly and seasonal scales. In addition, this study fills a real gap in hydro-climatic studies in EC region as a whole. The analysis was conducted using quality controlled data from eleven ground stations

which are well distributed in the catchment covering a period of 68 years. This topic has not been fully explored its paramount for the ECs' climate change, development, agricultural and hydrological endeavors. The Great Kei River catchment has experienced rainfall variability since 1950 to 2017, with several drought and wet years, due to influences from the ENSO, sea surface temperatures and Madden-Julian (Washington & Preston, 2006). Mean rainfall of 472.1 mm received in the GKRC is only sufficient, but still lower than the provincial mean of 600 mm. Furthermore, this catchment receives rainfall of moderate consistency all year, with the least in June and highest in February. The PCI indicated that rainfall is seasonally distributed, more specifically around the summer, spring, and the beginning of the autumn season. This offers an opportunity to plan for water requirements to support livelihoods. Knowing the seasonal concentration of rainfall in a year is an important aspect of climate related activities and water availability. When rainfall distribution is not stable, it makes water resources forecasting, plant and crop growth problematic. The study recommends that human activities such as farming ought to adapt to rainfall variability, since higher inter-annual variability is experienced. Therefore, municipalities can respond by gathering water during peak times to make provisions during drought years. Water extraction for human consumption, land use practices, such as agriculture, should be monitored and in certain instances, restricted to ensure sufficient water availability. A study of this kind at a catchment scale helps in fighting the hostile impacts if any, on rain fed agriculture and community-based activities. To fully understand the influences on hydrological processes, future studies should take into consideration land use/land cover changes that may affect water discharges of the Great Kei River.

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No potential conflict of interest can be reported. This is part of student work submitted for an award of honors degree. The student is the second author. And this work is held by University of Pretoria.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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