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Spatial and Temporal Variability in Hydro-Meteorological Selected Variable in the Southern Highlands, Tanzania

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ABSTRACT

Continuous decline of natural vegetation cover has been claimed to adversely affect trends of rainfall and streamflow in Kilolo District. This study analyzed the extent of rainfall characteristics, streamflow and runoff for the period 1972-2019 at Kilolo District. Data were collected from various sources and collated. Linear regression, descriptive statistics and trend analyses techniques were used to analyze rainfall variability. Non-parametric rank-based Mann-Kendall test employed to detect trends in annual and seasonal rainfall. Rainfall patterns in Iringa Airport, Maji, Mtera and Msembe stations closely resembled each other. Rainfall characteristics follow unimodal pattern with rainfall starting in November through May. Analyses of long-term annual rainfall records from the four stations show that rainfall in the Kilolo District is highly variable. It received an average of 706 mm yr^{-1} with years of high rainfall above the mean, and years of low rainfall below the mean. There is a significant declining trend of streamflow recorded in rivers draining the district. Decline of natural forest, bushland and wetland converted into cropland and plantation has played a great role to reverse this negative trend. This study recommends that efforts should be geared towards land cover conservation in order to enhance rainfall availability and improved streamflow.

Key words: Trend analysis - forest plantations - crop farming - water resources - hydro-meteorological variables.

INTRODUCTION

Continuous decline of natural vegetation cover into cropland, forest plantations and settlements have been claimed to adversely affect trends of rainfall and streamflow in Kilolo District, Tanzania. Natural vegetation in the district has greatly diminished because of human activities, resulting in a change in rainfall–runoff response. Apart from land use and land cover changes, climate variability has also impacted the water resources of the region. Recent global climatic change has resulted into an increased variability of the hydrological cycle and weather extremes, creating the need to study subsequent changes in hydro meteorological variables (Houghton *et al.* 1995, Easterling *et al.* 2000). Hydro meteorological variables are those variables, which influences hydrological process. These includes precipitation (rainfall), temperature, evapotranspiration, streamflow quantity, streamflow yield, baseflow quantity and baseflow index (Hawtree *et al.* 2015). This study focused much on rainfall and streamflow as parts of the hydro meteorological variables. Several studies have assessed trends and variability in hydro-meteorological datasets, mainly rainfall and temperature at regional levels (Manton *et al.* 2001, Zhang *et al.* 2005, Donat 2013) as well as country levels (Hamisi 2013). Rainfall variability in amount and their distribution has significant short and long-term effects on natural resources system, such as lake and rivers. A study by Nicholson (2017) noted that although shortage of rainfall causes stress, most significant problem is often

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caused by inter and intra seasonal rainfall variability.

Kilolo District is one of the four districts in Iringa Region, which is part of Southern Highlands of Tanzania. Agriculture is the main economic activity whereby farming of food and cash crops including maize, paddy rice, beans and vegetables are practiced. The districts also host number of small and large-scale forest plantations. The district has plantation area of 19,443 ha of which 18,754 ha (almost 96%) are owned by private owners (PFP 2017).

Several rivers, permanent and seasonal streams either originate or drain within the Kilolo District landscapes. Streamflow in the rivers is characterized with variability at temporal and spatial scales as a result of the variability in rainfall and interaction of groundwater and surface water. Detecting variability and trends in river flows is vital for planning, developing, and managing water resources to ensure adequate, and sustainable supplies and qualities of water for both humans and natural ecosystems and for appropriate management and planning of these water resources, as it diminishes the risks and detrimental effects associated with wrongfully assumption of stationarity in hydrologic designs (Mbungu and Kashaigili 2017). Therefore, this study was conducted to analyze the spatial and temporal variability and trends in rainfall and streamflow for the period from 1972 to 2019. The study provides information that will be useful for appropriate water resources management systems.

METHODOLOGY

Study area

Kilolo District is located at the North Eastern end of Iringa Region, about 37 kilometers from the regional headquarters (Figure 1). The district lies between 7^0 - $8^0 30''$ S and 34^0 - 37^0 E with a total area of 7,874.6 sq. kms and a population of 218,130 people (URT 2012). The district lies at an altitude ranging from 900 to 2,700 m.a.s.l. covered by alluvial soil. The district experiences mean annual rainfall ranging from 500 to 1600 mm and temperatures 15 to 27°C. It already hosts a number of small and large-scale agriculture and forest plantations (PFP 2017). Major crops been grown include; maize, legumes, fruits, and vegetables. The region is among the big four regions described as the breadbasket of the country (URT 2012).

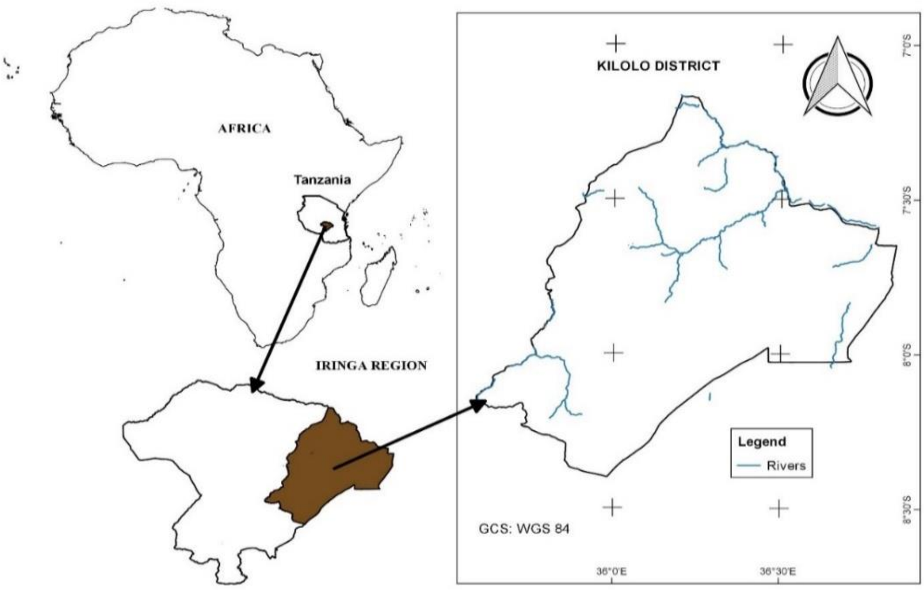

Figure 1: Map of Kilolo District.

Research Design

This research was carried out using a combination of techniques involving temporal and spatial analysis of data for detection of trends in rainfall and stream flow data. Hydro-meteorological data were collected from the Rufiji Basin Water Office, Little Ruaha and the Great Ruaha Catchments, Mtera Reservoir and other small discharges. The collected data were collated and checked for consistency and accuracy. Then analyzed using a combination of techniques to examine variability and trends in the time series.

Methods

Rainfall data for the period from 1972 to 2019

Daily rainfall data were collected from several rain gauge stations located within and adjacent Kilolo District. Based on the quality check, it was revealed that many of the stations lack consistency in rainfall data capturing. A criterion was set to exclude stations with missing data longer than six months, especially when no neighbouring stations were found to be used in data filling. This study required a station to have at least 30 years of data, but only four of the stations were within the criteria. Data from other stations were therefore used for filling missing data in the selected stations utilizing rainfall stations located in the same area. The selected stations used in this study are shown in Figure 2.

Spatial location of the stations in the Kilolo District are as shown in Figure 2. Lukosi, Msembe, Boma la Ng'ombe and Usokami are located within the Kilolo District, with Iringa Maji and Iringa Airport located just adjacent the boundary of the district on the western side. Uhafiwa station is located in the southern part of the district while Mtera is situated in the northern part of the district but all within 30 kilometers as recommended by the World Meteorological Organization (WMO 1994)

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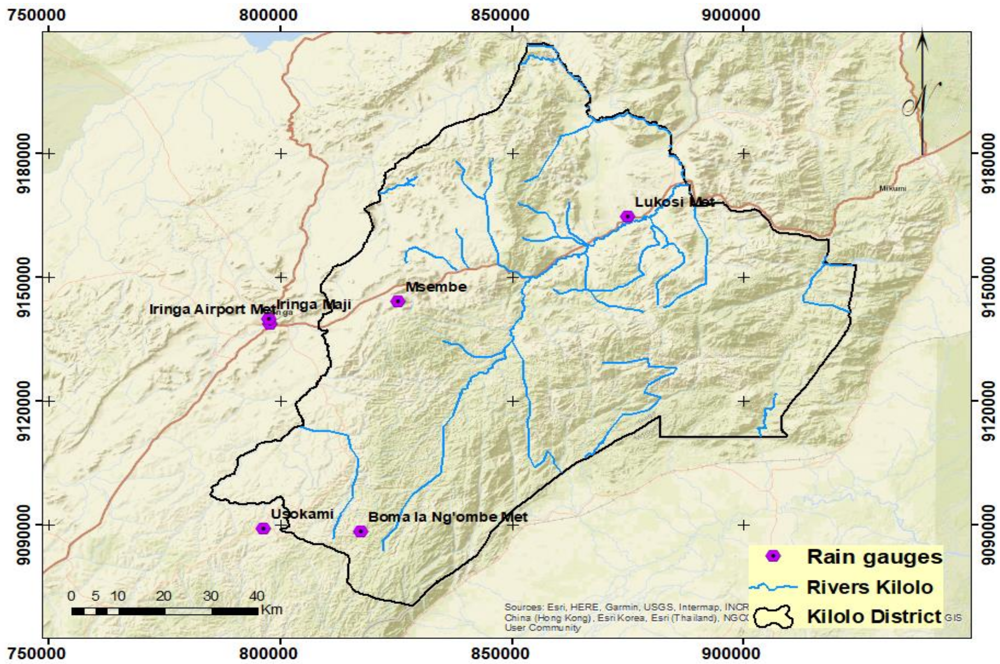

Figure 2: Location of rainfall stations in Kilolo District.

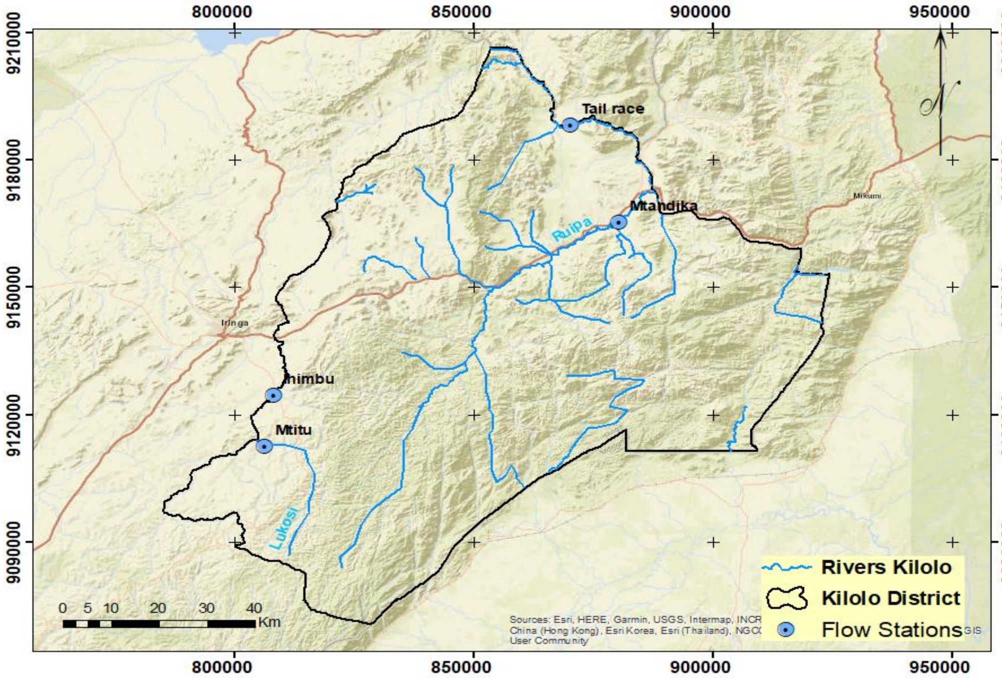

Figure 3: Locations of rainfall and flow gauging stations within Kilolo District.

Runoff data for the period from 1957 to 2019

Kilolo District is drained by several rivers including the Great Ruaha River, Little Ruaha, Lukosi and Mtitu rivers. Water quantity is measured in several stations within the Rufiji Basin and there are four flow gauging stations located within the district Figure 3.

Trend analysis of Rainfall and Runoff data

Seasonal, inter-annual and annual variation in rainfall and runoff at Kilolo District was characterized using linear regression, and descriptive statistics. The analysis based on three stations shown in Figure 2 include Iringa Maji which had data from 1972 to 2019, Iringa Airport with data from 1961 to 1990, Mtera with data from 1972 to 2019 and Msembe with data from 1979 to 2019.

Therefore, the study used the non-parametric rank-based Mann-Kendall test widely used for studying trends in hydro-meteorological time series around the world (Mann 1945, Garbrecht *et al.* 2004, Malley *et al.* 2009, Mbungu *et al.* 2012, Tabari *et al.* 2012, Mbungu and Kashaigili 2017) to detect trends in runoff, annual and seasonal rainfall The Mann–Kendall test is a non-parametric test, which does not require the data to be distributed normally. The second advantage of the test is its low sensitivity to abrupt breaks due to inhomogeneous time series (Tabari *et al.* 2015). According to this test, the null hypothesis H0 states that the de-seasonalized data (x1, ..., xn) is a sample of n independent and identically distributed random variables. The alternative hypothesis H1 of a two-sided test is that the distributions of x_k and x_j are not identical for all k, j, and n with k – j. The test statistic S, which has mean zero and a variance computed by Eq. (3), is calculated using Eqn. (1) and (2), and is asymptotically normal:

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

$$sgn(x_j - x_k) = \begin{cases} +1 \ if \ (x_j - x_k) > 0 \\ 0 \ if \ (x_j - x_k) = \ 0 \\ -1 \ if \ (x_j - x_k) < \ 0 \end{cases} \quad (2)$$

$$Var(S) = \frac{[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)]}{18} \quad (3)$$

where n is the number of data points, m is the number of tied groups (a tied group is a set of sample data having the same value), and t_i is the number of data points in the i_{th} group. In cases where the sample size n > 10, the standard normal variable Z is computed by using Eq. (4)

$$.\begin{cases} \frac{S-1}{\sqrt{var(s)}} \ if \ S > 0 \\ 0 \ if \ S = 0 \\ \frac{S+1}{var(S)} \ if \ S < 0 \end{cases} \quad (4)$$

Positive values of Z indicate increasing trends while negative Z show decreasing trends. When testing either increasing or decreasing monotonic trends at a significance level, the null hypothesis was rejected for an absolute value of Z greater than Z1α/2, obtained from the standard normal cumulative distribution tables (Partal and Kahya 2006). In this research, significance levels of α = 0.01 and 0.05 were applied.

Sen's Slope Estimator

If a linear trend is present in a time series, then the true slope (change per unit time) can be estimated by using a simple nonparametric procedure developed by Sen (1968). The slope estimates of N pairs of data are first computed by:

$$Q_i = \frac{x_{j-}x_k}{j-k} \text{ for i = 1, ….., N} \quad (5)$$

Where x_j and x_k are data values at times j and k(j > k), respectively. The median of these N values of Q_i is Sen's estimator of slope. If N is odd, then Sen's estimator is computed by

$$Q_{med} = Q_{\left[\frac{(N+1)}{2}\right]} \quad (6)$$

if N is even, then Sen's estimator is computed by

$$Q_{med} = \frac{1}{2}\left(Q_{\left[\frac{N}{2}\right]} + Q_{\left[\left(\frac{N+2}{2}\right)\right]}\right). \quad (7)$$

Finally, Qmed is tested with a two-sided test at the 100(1- α)% confidence interval and the true slope may be obtained with the non-parametric test (Partal and Kahya 2006).

RESULTS

Monthly and Seasonal Rainfall Variation

Results showed that there is no different between rainfall pattern in the four rainfall stations and that the wet season consists of almost six months followed by dry seasons. Results further indicated that rainfall characteristics in the study area follow a unimodal pattern with rainfall starting in November to May (Figure 4). Out of the four stations with long-term data shown in Figure 4, Iringa Maji stations consistently recorded higher amounts of rain, followed by Lukosi, Msembe and Mtera stations. Mtera station consistently recording the lowest amount of rainfall. Long-term monthly average of rainfall recorded at Iringa Maji for the month of January (159.1 mm) is almost 17% higher compared to the average rainfall recorded at Mtera station (136.2 mm). This implied that there is high correlation of rainfall with altitude, which is depicted by the higher amounts of rainfall in high altitude areas and low amount of rainfall in the low altitude areas.

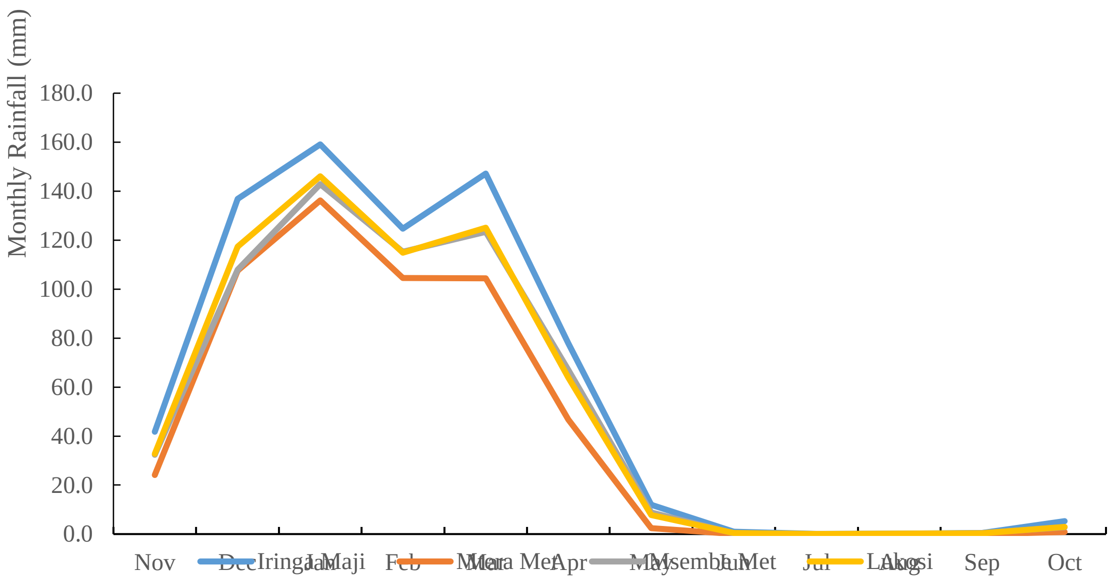

Figure 4: Average monthly rainfall for selected stations in Kilolo District.

Figure 5 shows the long-term average (1972-2019) monthly variation of rainfall at Iringa Maji station. The results indicated that, on average January receives the highest amount of rainfall (159.1 mm) followed by March (144.2 mm). June, July, August and September are the driest months. The same rainfall pattern for monthly variation is observed at Msembe station, which is located at the altitude of 793 m above mean sea level. Results show that rainfall starts in November with a peak in January, declining in April to reach cessation in May (Figure 6).

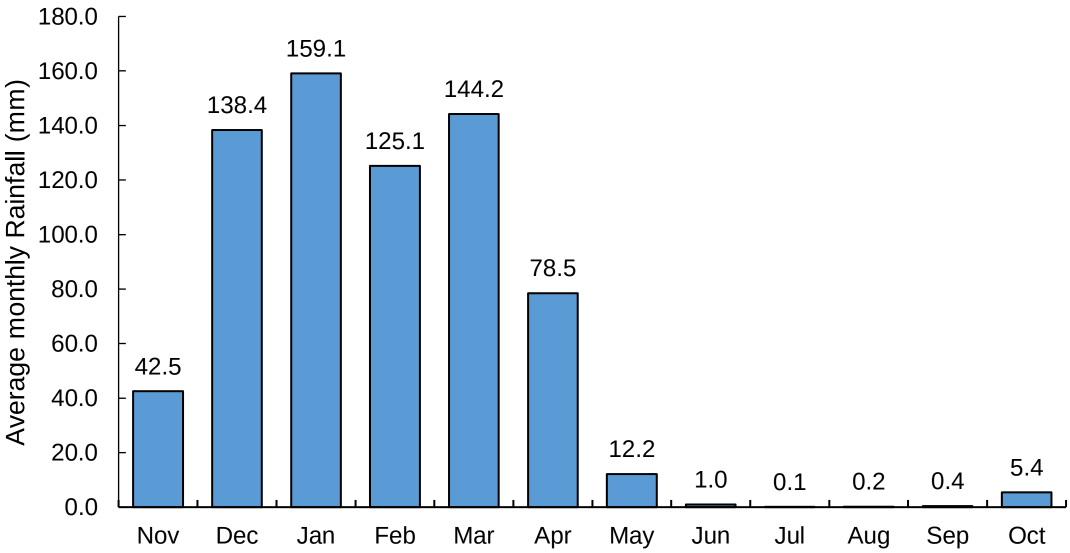

Figure 5: Average monthly rainfall variation at Iringa Maji Station (1972 – 2019).

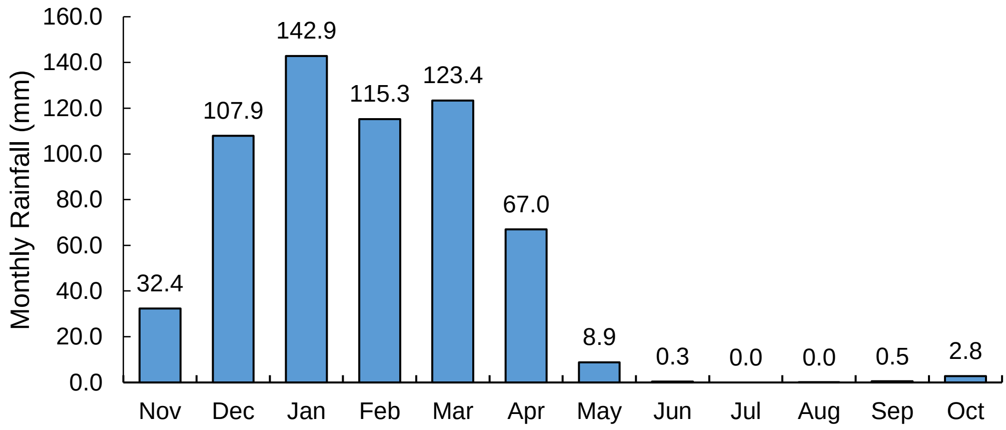

Figure 6: Average monthly rainfall variation at Msembe station (1972 – 2019).

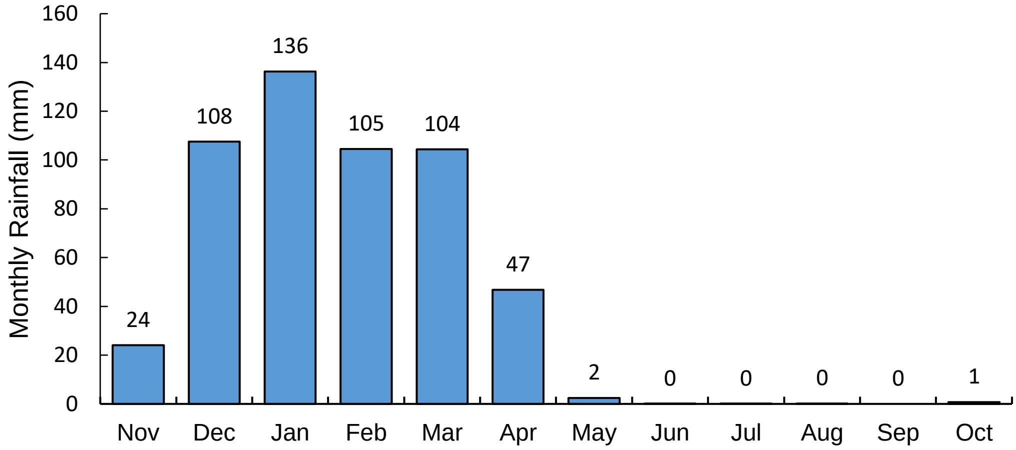

Figure 7: Average monthly rainfall variation at Mtera station (1971 – 2019).

Figure 7 shows monthly variation of rainfall at Mtera station from 1971 to 2019. Like other stations in the district, rainfall starts in November and peaks in January and cessation is experienced in May. The dry period receives almost no rain for the entire period indicating that the area remains completely dry.

Annual Rainfall Variation

Figure 8 shows annual rainfall variation at Iringa Maji Station between 1972 and 2019. The results show that on average the area received around 706 mm per annum with years of high rainfall above the long-term mean, and years of low rainfall below the long-term mean. Results further show that years of high rainfall include 1974 (847.9 mm), 1978 (994.7 mm), 1981(822 mm), 1989 (921 mm), 1992 (915 mm), 1997 (1010 mm), 2014 (830 mm) and 2017 (865 mm). Years of low rainfall include 1976, 1980, 1983, 1986, 1990, 1993, 1995, 2000, 2003, 2005, 2007, 2010, 2012 and 2015.

A declining trend in rainfall amount received in a year was also observed for rainfall recorded at Mtera station (Figure 9). The standard deviation of rainfall was 138.44 mm and coefficient of variation was 0.27. Analyses further show that Msembe station showed an increasing trend with a standard deviation of 192.82 mm and a coefficient of variation 0.33 (Figure 10).

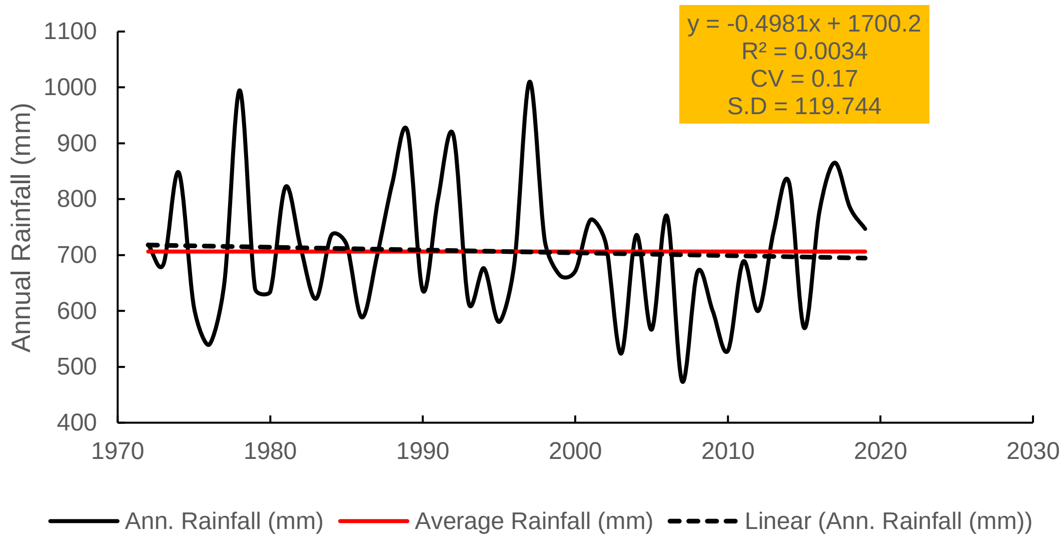

Figure 8: Annual rainfall at Iringa Maji Station (1972 – 2019).

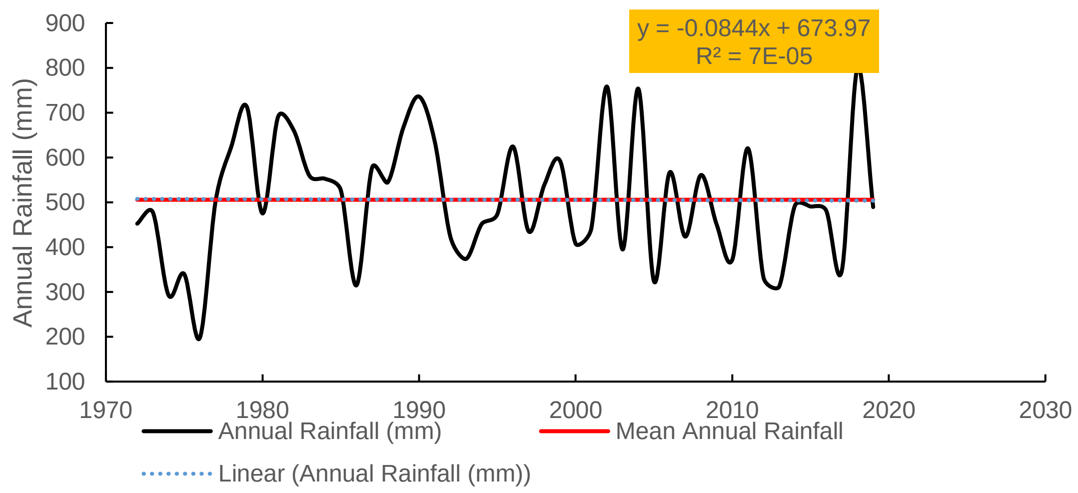

Figure 9: Annual rainfall at Mtera Station (1971 – 2019).

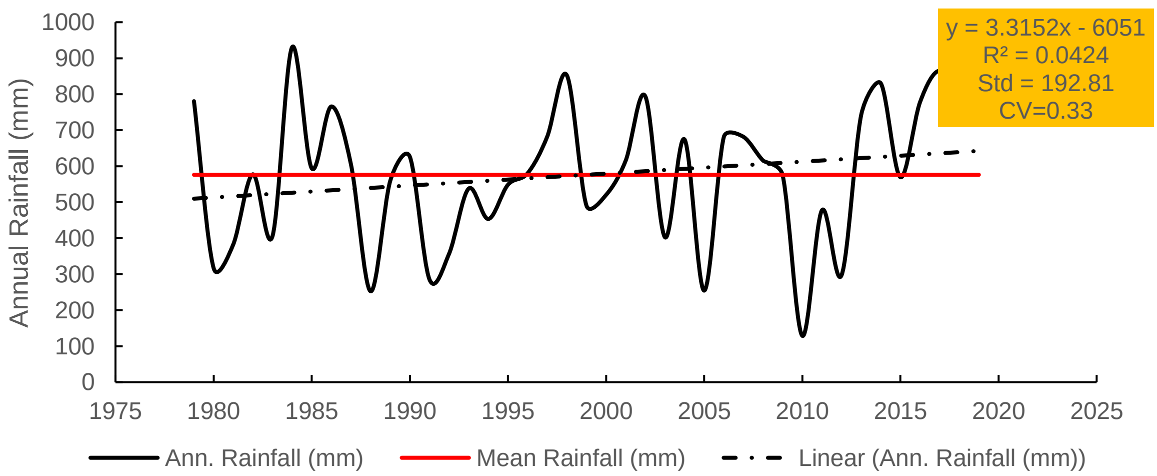

Figure 10: Annual Rainfall at Msembe Station (1972 – 2019).

Annual Trends of Rainfall Data

Annual trends of rainfall and their magnitude (in mm/ year) obtained by the Mann–Kendall test, the Sen's slope estimator and the linear regression are given in Table 1. The annual trends found by the linear regression were almost similar to the precipitation trends found by the Mann–Kendall test and the Sen's slope estimator. Both positive and negative trends were identified by the statistical tests in annual precipitation data. However, although a declining trend was observed in the linear regression in the Iringa Maji and Mtera stations records, Mann-Kendall test show that the trends were not significant at the 95% and 99% levels of significance. On the contrary, results for the Msembe station showed an increasing trend that was significant at the 95% level of significance. Results further show that the Sen's slope for the Mtera station is negative and is about -0.903, for Iringa Maji is positive and is about 0.750, and for Msembe station is positive and is about 5.894.

Table 1: Annual rainfall trends in Kilolo District.

Rainfall Station	Test Statistic	Significance	Sen's Slope
Mtera	-0.49	ns	-0.903
Iringa Maji	0.10	ns	0.750
Msembe	2.04	*	5.894

Runoff trends and variation

Analyses of long-term annual flow records from the four gauging stations located in rivers in and around the Kilolo District show that like rainfall, streamflow is highly variable at annual scales. Figure 11 shows streamflow variation in the Mtitu River between 1971 and 2020. The results show that on average the river recorded annual flow of about 3.5 m^3/s with years of high flows above the long-term mean, and years of low streamflow below the long-term mean. The standard deviation for the Mtitu River was 0.672 m^3/s. The coefficient of variation of the station was 0.18, which shows that there was less variation from year to year. The results in Figure 11 show a declining trend in streamflow over the 50 years. Several years with extreme low flows can be observed from Figure 11 and these includes 1971, 1977, 1982, 1988, 1992, 1995, 2000, 2003, 2006, and 2013.

Figure 12 shows long-term variation of stream flow in the Lukosi River between 1957 and 2020. The results shown on average the river recorded around 10.6 m^3/s with 1958 (63.83 m^3/s), 1971 (65.8 m^3/s), 1973 (35.5 m^3/s), 1979 (30.69 m^3/s), 1985 (28.85 m^3/s),1989 (30.97 m^3/s), 1997 (28.22 m^3/s), 2008 (23.58 m^3/s) having extreme high flow values, while 1961, 1966, 1970, 1982, 1988, 1991, 2000, 2003, 2012 showing extreme low values. This station recorded a high coefficient of variation of 0.45 showing that there was a high variation in stream flow from year to year.

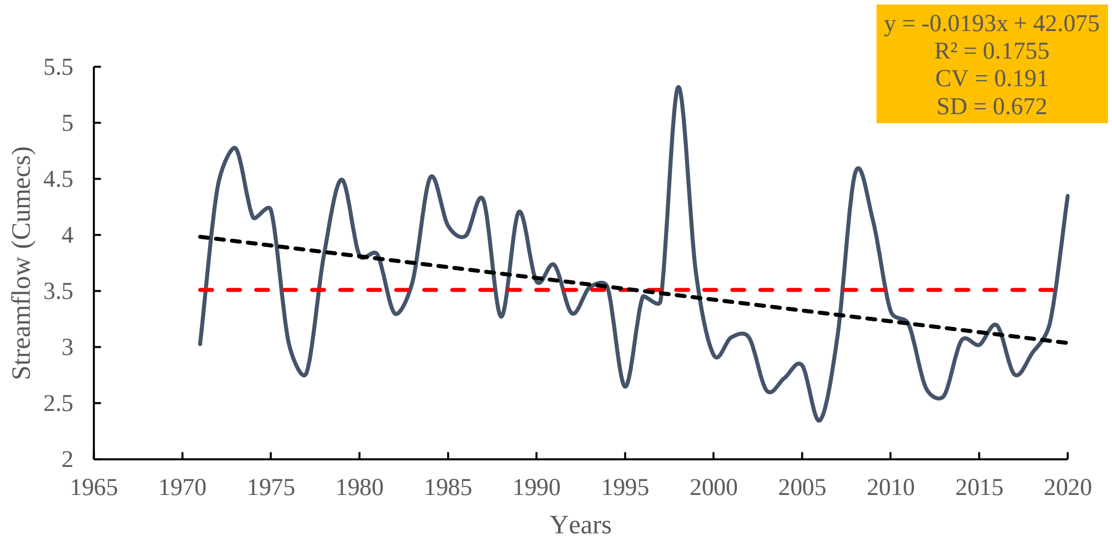

Figure 11: Annual streamflow variations in Mtitu River (1971 – 2020).

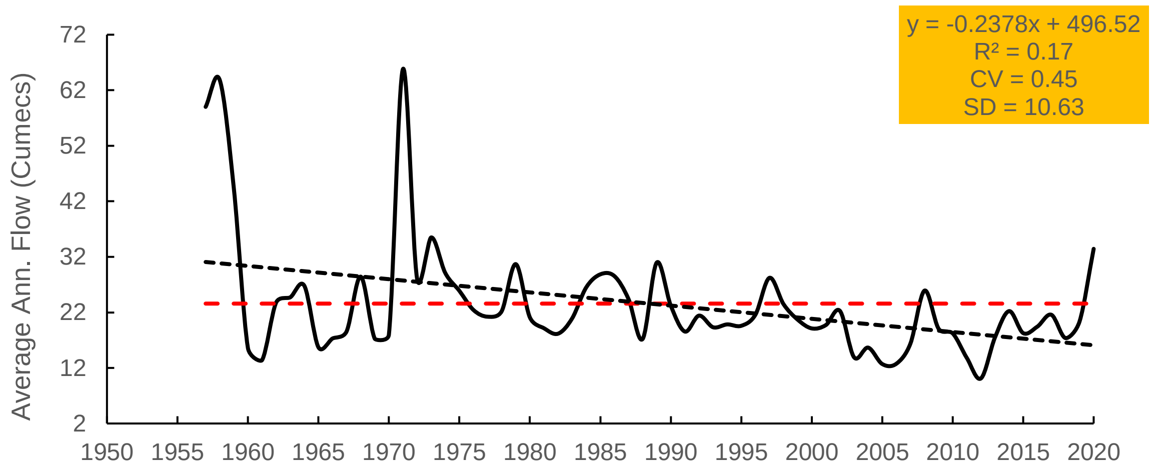

Figure 12: Annual stream flow variations in Lukosi River (1957 – 2020).

Annual trends in streamflow data

Annual trends of stream flow and their magnitude obtained by the Mann–Kendall test, the Sen's slope estimator and the linear regression are given in Table 2. The annual trends found by the linear regression were almost similar to the streamflow trends found by the Mann–Kendall test and the Sen's slope estimator. All four stations showed a negative declining in stream flows with three of the stations showing significant trends and one with no significant trend (Great Ruaha at Tail Race).

Table 2: Annual flow trends at stations located in the Kilolo District.

Station	Test Statistic	Significance	Sen's Slope
Mtitu	-3.40	***	-0.024
Lukosi	-2.81	**	-0.126
GR (Tail Race)	-2.18	*	-1.033
Little Ruaha (Ihimbu)	-0.88	Ns	-0.0289

DISCUSSION

Monthly and Seasonal Rainfall Variation

There is decreasing trends of rainfall in some months of the year. The drop in rainfall was mainly driven by the unimodal pattern of rainfall trends observed to continuously occur over the successive periods. Merabtene *et al.* (2016) reported negative trends in rainfall in some months of the year. Hamisi (2013) and Mwinuka *et al.* (2021) displayed the existence of decreasing trends in seasonal rainfall in most part of Tanzania. Rainfall in the district starts in November and peaks in January and cessation is experienced in May. These findings are in line with Mwinuka *et al.* (2021) reported the same trend in Southern highlands of Tanzania. The dry period receives almost no rain for the entire period indicating that the area remains completely dry. There seems to be a good correlation of rainfall with altitude, which is depicted by the higher amounts of rainfall in high altitude areas and low amount of rainfall in the low altitude areas. Tanko (2011) reported that the distribution of rainfall is highly influenced by locations, the geological differences and the topographical peculiarities between the areas.

Annual Rainfall Variation

Analyses of long-term annual rainfall records from the four stations show that rainfall in Kilolo District is highly variable and understanding of the variability is crucial for proper planning of different activities including socio-economic activities such as tree planting and food crop farming. Variations are not uniform across the district, but differ from station to station and from one area to another.

Annual rainfall in the Kilolo District displays both spatial and temporal variations. During the period analysed (1961–2019), a general decreasing pattern of annual rainfall was observed. These findings are in line with Merabtene *et al.* (2016) who reported annual rainfalls exhibit high deviations from the annual mean and that rainfall variability is visibly marked by periodic intermittence between successive wet years and successive dry years. The declining trend is observed from 1998 and this could be a result of the decline of natural forest, bushland, open-land and wetland attributed by the increase of cropland, settlement and forest plantation. The decline in rainfall has resulted into increased temperature which are similar to observations by Adewole and Serifat (2015), Olagunju (2015), Balogun *et al.* (2016), Umar *et al.* (2018). The implication of the findings to the water-related programs and activities in the area is that the downstream areas may perpetually suffer from reduced flow even in the future. Thus, water supply and irrigation will be affected tremendously. Currently, this decline trend has caused some of the areas that were used to produce food crops are now not doing so especially the eastern part of the Kilolo District (lower side) has been facing challenges of reduced rains and increased temperatures. Ngetich *et al.* (2014) reported that, the amount of soil-water available to crops depends on rainfall onset, length, and cessation which influence the success/failure of a cropping season.

Runoff trends and variation

The detection of runoff irregularities via trends and variations from the historical river discharge data noted in Kilolo District is crucial for the proper planning and management of surface water resources as well as for the future river discharge prediction. Detecting fluctuations in river discharge is the most suitable way to discern trends (decreasing or increasing) in the river discharge series (Afzal *et al.* 2011). Study findings are in line with Mbungu and Kashaigili (2017) observed a decline in magnitude of annual flows over time for the Little Ruaha River at Makalala and Mawande. Some years showed extreme declining trends of streamflow over the 50 years. This decline trend plays a significant role in shaping the choice of cultivars for crops and tree species. As farmers continue to face uncertainties in the amount and distribution of rainfall in their area, they tend to choose crop cultivars that do well under the perceived condition such as short maturing varieties, high yield but long duration if the season is perceived to be good. Several factors contributing to changes in water flow in the studied districts including change of climatic condition and increased anthropogenic activities. These findings are in line with Dettinger *et al.* (2004). Morison *et al.* (2007) reported that, human activities commonly affect the distribution, quantity, and chemical quality of water resources by increasing sedimentation and the use of pesticides and chemicals. Agricultural activity accounts 70% of all fresh water withdrawals globally (FAO, 2017). Such large abstraction of water has led to large reductions in river flow, indeed, to long and repeated periods of zero flow for several major river systems. The declining trend of water flowing in the rivers could have devastating effects not only on domestic usage, but could also curtail important socio-economic activities such as irrigation, manufacturing industries and the environment including water for supporting biodiversity and ecosystems.

Streamflow Trends and Variation

Table 2 shows that there is a declining trend in streamflow in almost all the stations in around the Kilolo District. This goes out to show that over there has been a movement towards less water flow from year to year. Although trends could be a result of natural randomness, but the persistence shown through the levels of significance refutes that claim. It remains a fact that records of streamflow show that there is a significant decline of streamflow in rivers in and around Kilolo District. The main drivers as seen from the analysis could be rainfall. Although rainfall has shown a declining trend, but only few stations had shown a significant decline. The significance of the declining trends in the streamflow depicts a correlation, but shows that there is a high possibility that some other factors or changes are associated with what is happening in the streamflow in the area. One hypothesis is the increase in human activities that play significant role in changing the landscapes. It is clear that land clearing to pave way for some human activities such as crop production, plantation establishment and irrigation play a role in the changes witnessed in the area. As more nature is continually being converted into other activities such as irrigation, manufacturing industries and the environment including water for supporting biodiversity and ecosystems. It is important that proper conservation techniques applied to increase infiltration and allow for more water taken into the subsurface that can later be used to sustain base flow in the rivers.

CONCLUSIONS

The study has revealed high variability in temporal and spatial levels of rainfall in Kilolo District. High temporal variability is described by the coefficient of variation which was less at Iringa Maji (0.17) and was higher at Msembe (0.33) and Mtera stations (0.27). This signifies that the rainfall at Iringa Maji is more reliable than rainfall at Msembe station. Two rainfall stations (Mtera and Iringa Maji) have high variability and display a declining trend, albeit not significant. On the other hand, Msembe station shows a significant increasing trend, displaying spatial differences.

Observed rainfall and streamflow variability play a significant role in shaping the choice of cultivars for crops and species in trees. However, there is a need for research to identify the water use by different tree species. Further, the study recommends more that efforts to be taken towards land cover conservation in order to enhance rainfall availability and improved streamflow.

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