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Trend Detection in Precipitation and River Discharge to Assess Climate Change in the Upper Tana Basin

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Abstract:-*With Climate Change being a point of focus in modern times, this research study was done to detect the existence of a statistically significant trend in the hydro-meteorological characteristics of the upper Tana catchment to deduce whether Climate Change had occurred. The methodology involved subjecting mean monthly and mean annual precipitation and river discharge data to the Mann-Kendall trend detection tool from the XLSTAT software. Further, the one-tail trend tests (upper-bound test and lower-bound test) were done to confirm whether the trend detected was increasing or decreasing. In order for Climate Change to be reasonably implied, at least50% of the mean monthly data needed to exhibit a statistically significant trend and secondly, have mean annual data return a statistically significant trend as well. The results suggested that for mean monthly rainfall, there was a statistically significant decreasing (negative) trend detected in the months of August and September (16.67%). With regard to river discharge, a statistically significant positive trend was observed in the months of January, February, March and November (33.33%). However, for mean annual discharge, there was an overall positive statistically significant trend for the years spanning 1966-2006. These results for mean annual discharge were inclusive of data that had perceived outliers (2001-2003).When the same Mann-Kendalltrend test was done on mean annual discharge data between 1966-2000, no statistically significant trend was observed.*

Keywords: *Climate Change, Upper Tana Catchment, Mean-value time series,Mann Kendall, Trend Detection.*

1. INTRODUCTION

According to Morin,the existence of a statistically significant trend in either the annual minima, mean annualorannual maximariverdischarge may be a pointer to climate change. Results of such a studyhas an influence on the management and development of water as a resource [10]. Odhengo *et al* noted that other than changes in the stream flows, the existence of a statistically significant trend in rainfall patterns in a basin could also infer climate change [11]. With the Tana basin being identified as one of the four important basins in Africa for study by the *Green Water Credits*[3], an investigation to find out if climate change has affected the upper Tana basin was deemed an important area of study. The World Bank has categorized Kenya as a water-scarce country [15]. It has been projected that by the year 2025, Kenya's renewable water per capita will have dropped to 235 cubic metres down from the current per capita of approximately 650 cubic metres. This is against the internationally recommended benchmark per capita of 1000 cubic metres of renewable freshwater supplies Wafula [14]. From this realization, Kenya embarked on Water Sector Reforms by enacting the Water Act (2002). These reforms gave birth to the Water Resources Management Authority which was tasked with the management of water resources in the major catchment areas [12]. The Water Act (No. 43 of 2016) has since taken effect and was meant to align the Water Act (2002) to the Constitution of Kenya 2010. The water resources management authority (WRMA) has since been replaced by the water resources authority (WRA) [13].

According to Adebayo *et al,* by obtaining historical hydro-meteorological data, it is possible to evaluate the past, present and predict the future water resource status in a catchment basin [1]. It is only through the analysis of the precipitation and flow data that hydrological modeling, climate change assessment and urban environmental planning can be done effectively [4]. Several studies worldwide on trend-detection have been done on hydrological time series and research has suggested that statistically significant trends in extreme value time-series cannot be a reliable means of proving climate variability as compared with mean series according to Lindstrom *et al,*[7].

According to Maingi, some studies have suggested that time-series trend tests for precipitation data and discharge data are not necessarily correlated. This means that hydrological time-series may be found to be negative despite meteorological time series trend being positive [8]. This has been attributed to possible human activities, causing increased run-off despite decreasing trend in precipitation.

Prior to this study, there had never been a study to evaluate Climate Change through hydro-meteorological properties in the Upper Tana catchment, specifically on the two tributaries of the Tana river (river Kathita and Mutonga). Separate studies have been carried out in the middle and lower reaches of the Tana River for changes in the maximum and mean annual stream flows, but no study has been done to simultaneously examine rainfall and stream-flow data in the Upper Tana Catchment for statistically significant trend with a view to draw conclusions on Climate Change.

1.1 Objectives of the Study

The objective of this study was, therefore, to evaluate the existence of a statistically significant trend in mean monthly and mean annual precipitation and discharge in the Upper Tana catchment. The specific objectives were to evaluate the existence of statistically significant trend in the mean monthly rainfall for six rainfall stations (in the catchment area where Kathita and Mutonga rivers also found) over the period between 1980-1994 and secondly, to evaluate the existence of a statistically significant trend in the mean monthly and mean annual stream flows for Kathita and Mutonga rivers between 1966-2006.

For purposes ofthis study, only rainfall data from six stations was available and had data spanning between the years 1980 – 1994. The Kenya Meteorological Department had, under its custody, rainfall data from twenty-six (26) collaborating stations in the catchment. However, data from twenty (20) out of twenty-six (26) collaborating stations was found to have beeninconsistently collected and had missing data entries which were as high as 60% of the total dataset in each station. Only six rainfall stations were found to have collected consistent data between 1980 and 1994. No station in the entire catchment had data earlier than 1980 and likewise none had data beyond 1994. The proportion of missing data values in these six stations was less than 10% and therefore, it was relatively easy to use simulation techniques to impute the missing data entries. This study, therefore, focused on these six stations out of the network of twenty-six in the catchment. For stream flow data, however, data was available from the Water Resources Authority (WRA) for two tributaries of the Tana River (Mutonga and Kathita) at the "last" gauging station before they joined the River Tana between the years 1966 – 2006.

1.2 Assumptions of the Study

The main assumption in the study was that basin characteristics, including rainfall intensity is homogenous throughout the area under study. This was the reason behind picking as many rainfall stations as possible to give a fair and balanced picture of rainfall variability in the area under study over the period stated. The full extent and impact of human activity in the area and how this could have affected the runoff characteristics was not considered.

2. MATERIALS AND METHODS

2.1 Study Area

According to Knoop et. al., the Tana River basin stretches over an area of over 126,000 square kilometers. The upper Tana catchment is composed of a number of tributaries that come from the slopes of Mount Kenya and the Aberdares. Among these rivers are the Chania, Kathita, Thika, Thiba, Sagana and Mutonga. These tributaries converge to form the longest river in Kenya, covering a distance of over 1,000km to the Indian Ocean at Kipini [6]. Figures 1 show the study area.

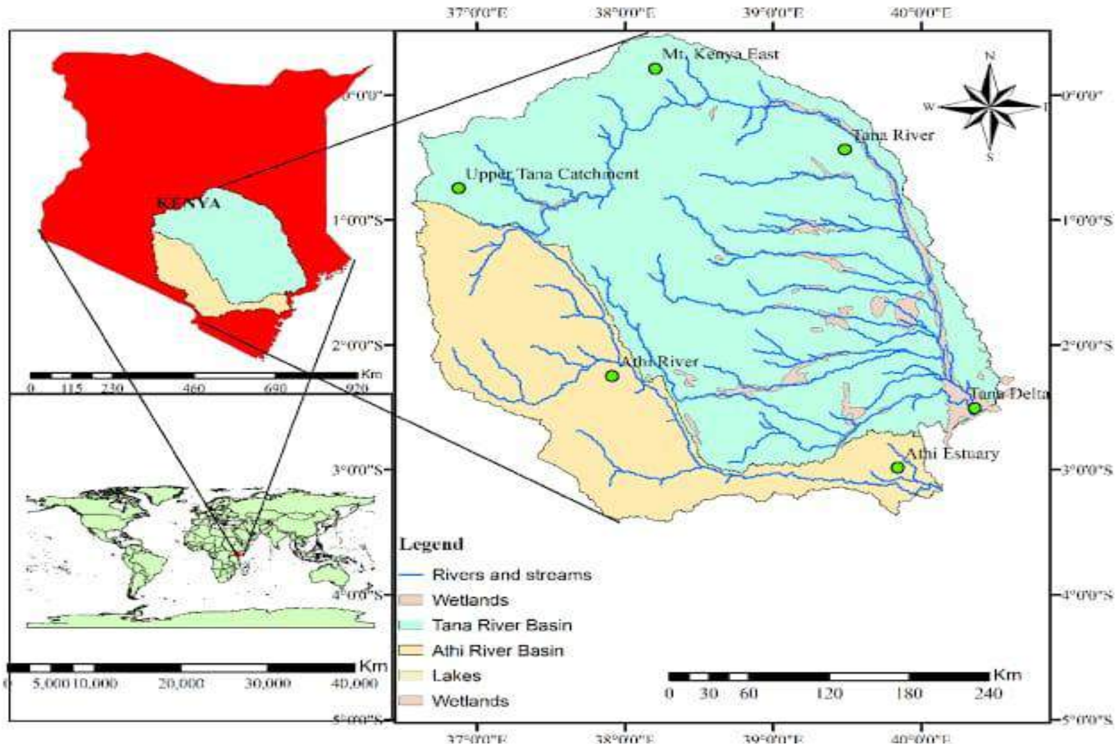

Figure 1: Geographical location of the Tana Catchment (Source: WRA, 2012)

2.2 Sampling Technique

As mentioned earlier, out oftwenty-six(26) collaborating stations,twenty (20) did not have reliable data; only six stations had quality data. As a result, all six stations were picked as the sample for the study. Data from these six stations also had missing entries but the proportion of missing values was less than ten percent (10%) of the total data values. With regard to the stream flow data for the Mutonga and Kathita rivers, data provided by the Water Resources Authority was complete and had no missing data whatsoever.

2.3 Data Analysis

For the purposes of analyzing data, the Mann-Kendall trend detection tool of the *XLSTAT* software was used. The test, categorized as *Non-Parametric*, is widely accepted in identifying statistically significant trends in time-series hydro-meteorological data values. The strength in this test comes from the fact that the dataset need not conform to any probability distribution and as a result, the outcome of such an analysis is normally very robust. In addition, the test allows for the existence of missing data as only ranks are assigned and used in the analysis. Data values reported as *non-detects* are assigned a common value smaller than the least reported value in the entire data set.

The Seasonal Mann-Kendall two-tail trend technique was employed to test the hypothesis at 5% significance level (H_0 – no statistically significant trend in time series and H_a – a statistically significant trend exists in time series) on mean monthly rainfall. The Mann Kendall test was also employedto evaluating the mean annual rainfall historical data for six rainfall gauging stations in the upper Tana catchment between 1980 and1994.

The same Seasonal Mann-Kendall two-tail trend tool was used to test the hypothesis at 5% significance level (H_0 – no statistically significant trend in time series and H_a – a statistically significant trend exists in time series) on mean monthly and mean annual discharge for the two key tributaries Mutonga and Kathita at the *"last"* gauging stationjust before these tributaries joined the River Tana over the period of 1966-2006.

Results from the Mann Kendall's two-tailed trend tests generated a plot of 'P-value" with a threshold line below which, variables are said to have a statistically significant trend. It is worth noting that in statistics, the p-value is what is employed for hypothesis testing.The results of the two-tailed tests, however,are not able to tell if the statistically significant trend was positive or negative. To further enhance the sensitivity of the test to determine if the trend detected was an increasing or a decreasing trend, an upper-tailed (upper bound) and a lower-tailed (lower bound) trend test were conducted at the same significance level to confirm the nature of trend. Any data variable falling below the p-value threshold line would act as a confirmation on whether the statistically significant trend is positive or negative. Interpretation of the analyzed data was done separately, bearing in mind the possibility that one variable such as rainfall data, may have a statistically significant decreasing trend, while the other variable (streamflow data) showing a statistically significant increasing trend and vice versa.

During data analysis, a peculiar pattern in the mean monthly discharge data was observed in the years 2001-2003. There was a near-steady discharge in the said years that did not conform to the seasonal variability in the previous years. Since rainfall records available only extended between 1980-1994, there was no independent means of verifying whether there had been any peculiar rainfall characteristics for those three consecutive years. Chart 1shows the plot of monthly discharge between the years 1998 – 2006.

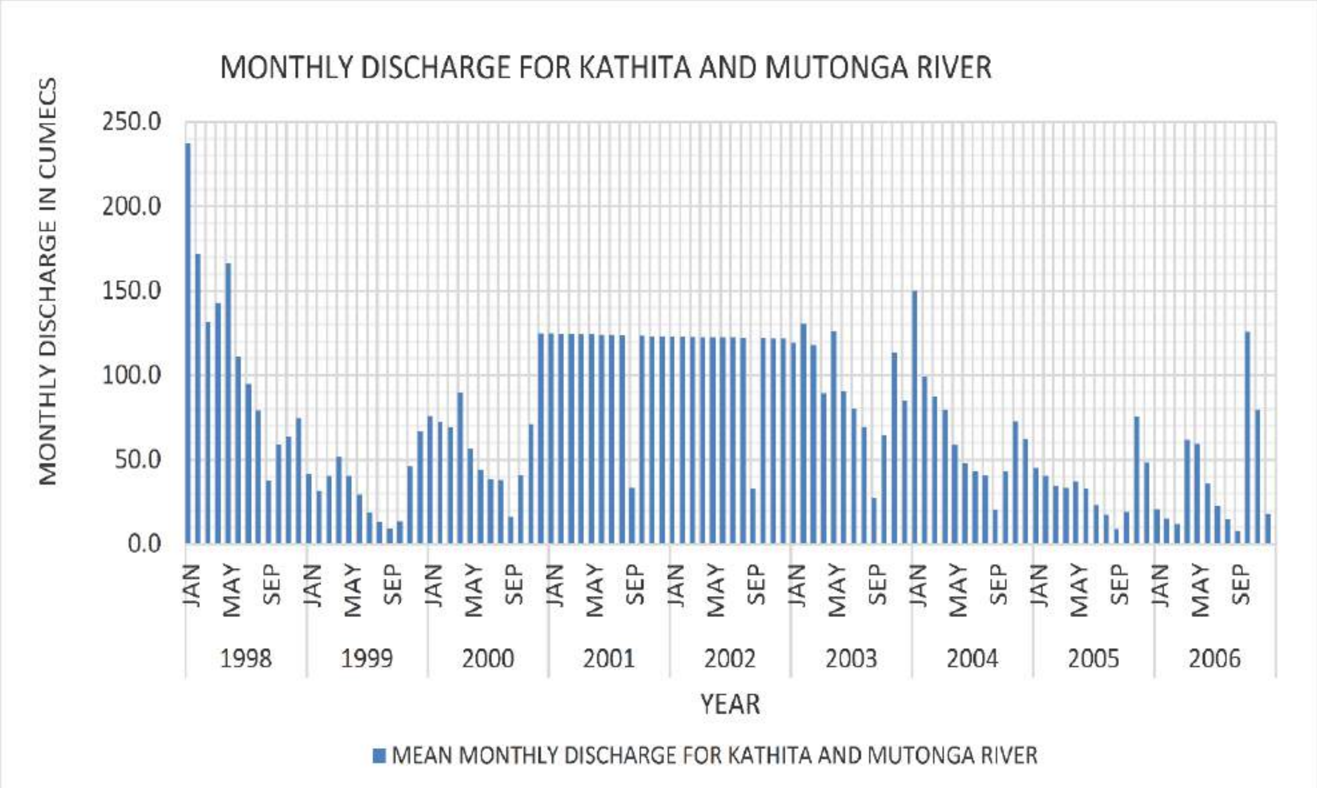

Chart 1: Mean Monthly Discharge for Kathita and Mutonga Rivers (1998 – 2006

The plot shows a near-uniform mean flow throughout the year with a sharp dip in the months of October (for all three years). This pattern ideally does not conform to the rest of the data set and could be viewed as an outlier. The cause of this behavior – whether due to human error in data collection, a systemic error in recording, errors in simulations to insert missing data or any other cause, may be confirmed in another study.

In view of this, the Mann-Kendall's trend test was run again on the data set between 1966-2000 to find out if a statistically significant trend still existed in the absence of data from the years 2001-2006. In order to reasonably imply that there is sufficient evidence of Climate Change, at least half (50%) of the mean monthly precipitation / discharge out of the twelve months in a year were to detect a statistically significant trend. This would almost automatically be supported by a statistically significant trend in mean annual precipitation / discharge.

3 RESULTS

3.1 Mean Monthly Rainfall

For mean monthly rainfall, the two-tailed trend test detected a statistically significant trend in the month of August. When the upper-bound and lower bound tests were done to determine if the trends were positive or negative, the lower bound test detected a statistically significant trend in the months of August and September.The results of the two-tailed, upper-tailed and lower-tailed tests for mean monthly tests are shown in charts2 to 5 respectively.

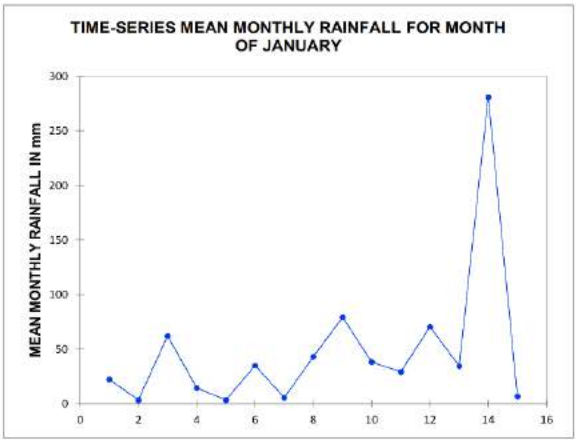

Chart 2: Sample Time-series mean monthly rainfall – January

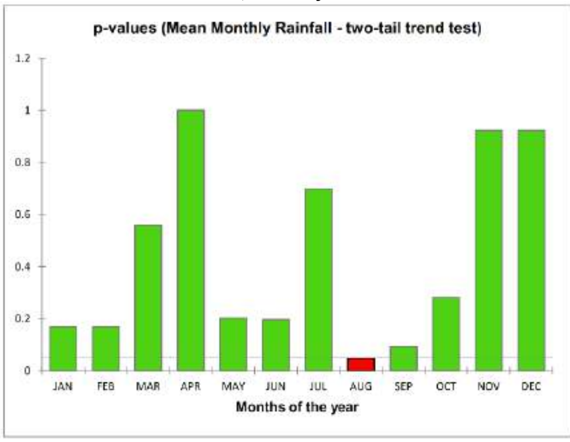

Chart 3: Plot of p-values (two-tail test)

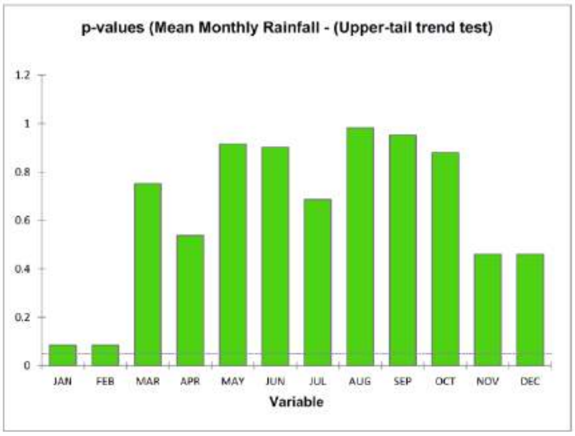

Chart 4: Plot of Mann-Kendall's Upper Bound p-values

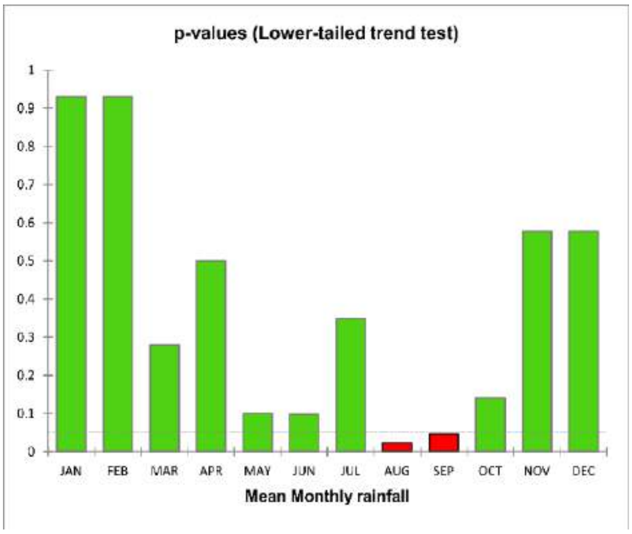

Chart 5: Plot of Mann-Kendall's Lower Bound p-values

3.2 Mean Annual Rainfall

The Mann-Kendall’s two-tailed trend test and the subsequent upper-tailed and lower-tailed trend test did not detect any statistically significant trend in mean annual rainfall. Charts 6-9 show the sample time series plot as well as p-value plots.

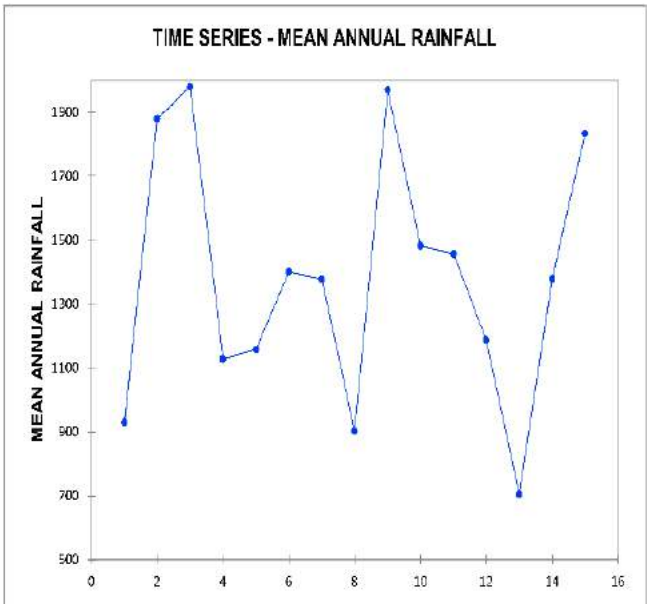

Chart 6: Sample plot of p-value for mean annual rainfall

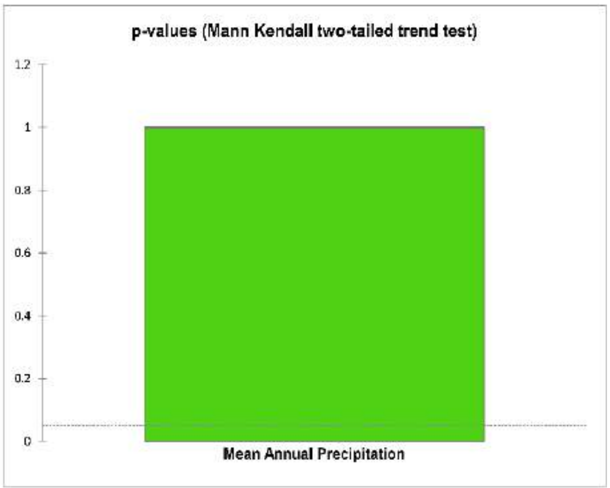

Chart 7: Plot of p-values (two-tail test)

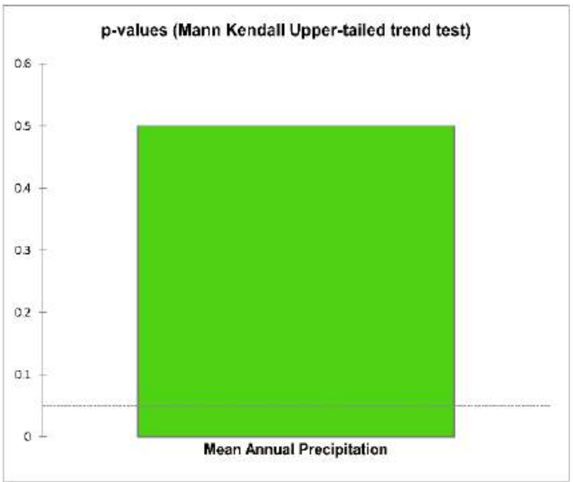

Chart 8: Plot of Mann-Kendall's Upper Bound p-values

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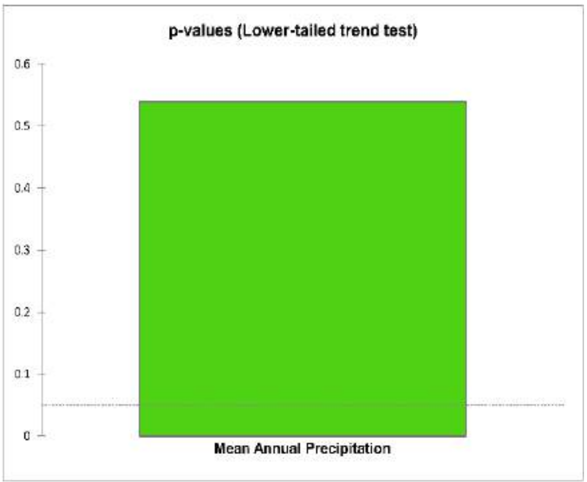

Chart 9: Plot of Mann-Kendall's Lower Bound p-values

3.3 Mean Monthly Discharge

The Mann-Kendall’s two-tailed trend test detected a statistically significant trend in the months of January, February and November.The subsequent upper-tailed detected a statistically significant trend in the months of January, February, March and November. The lower-tailed trend test did not detect any statistically significant trend. Charts 10-13 illustrate this.

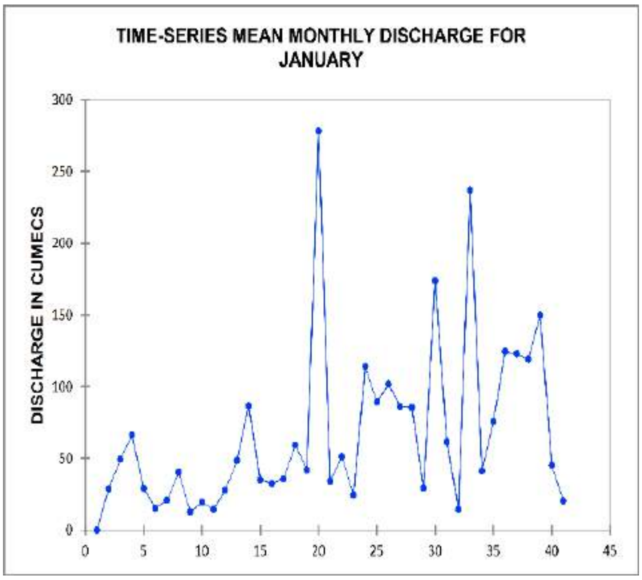

Chart 10: Sample Time-series mean monthly Discharge – January

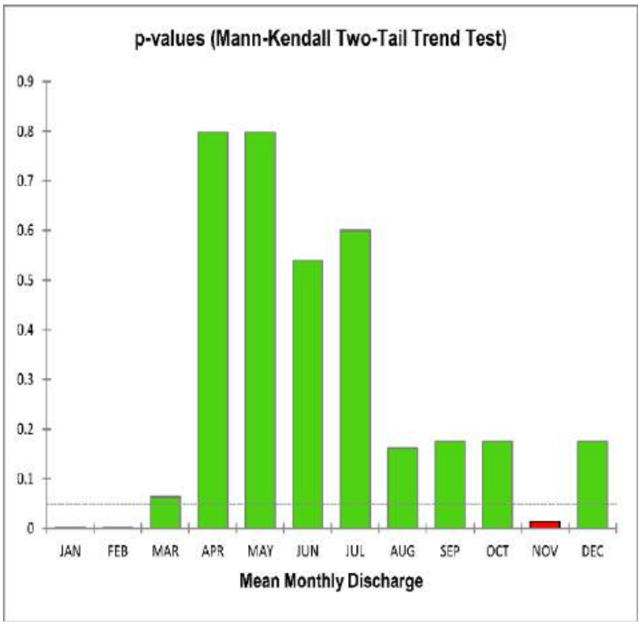

Chart 11: Plot of p-values (two-tail test)

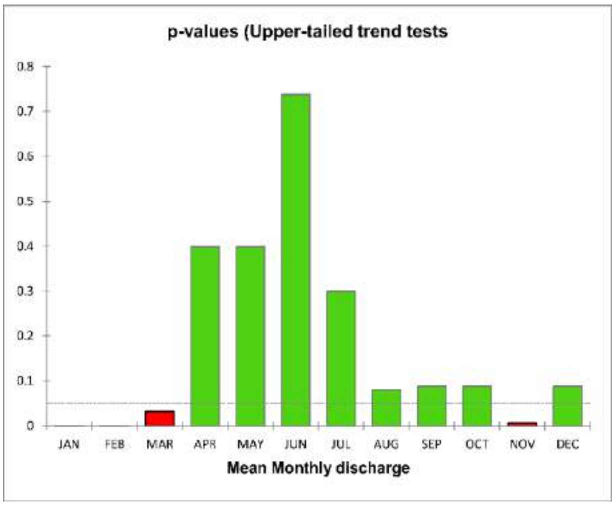

Chart 12: Plot of Mann-Kendall's Upper Bound p-values

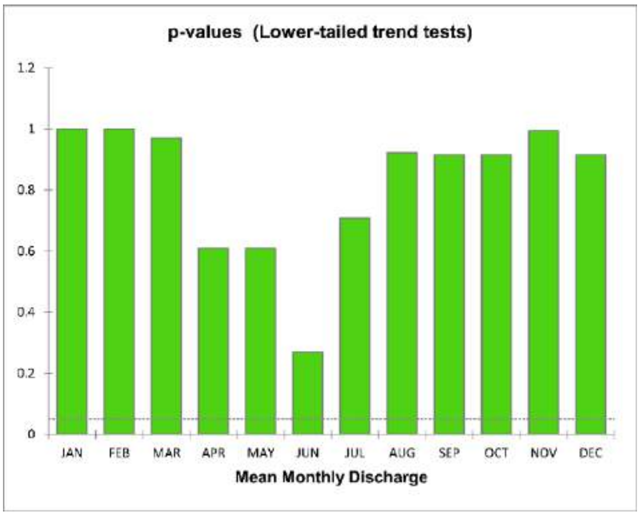

Chart 13: Plot of Mann-Kendall's Lower Bound p-values

3.4 Mean Annual Discharge (1966-2006)

The Mann-Kendall's two-tailed trend test on mean annual discharge between 1966-2006 did not detect any statistically significant trend. However, the subsequent upper-tailed detected a statistically significant positive trend. The lower-tailed trend test did not detect any statistically significant trend. It is worth noting that this data was inclusive of the perceived data outliers between the years 2001-2003. Charts 14 – 17 illustrate this.

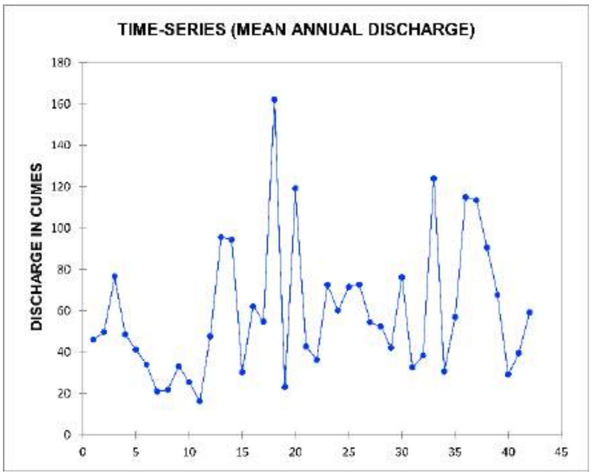

Chart 14: Sample plot of p-value for mean annual discharge (1966-2006)

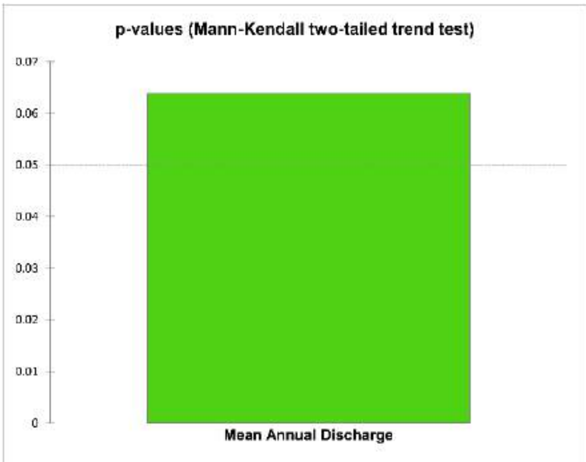

Chart 15: Plot of p-values (two-tail test)

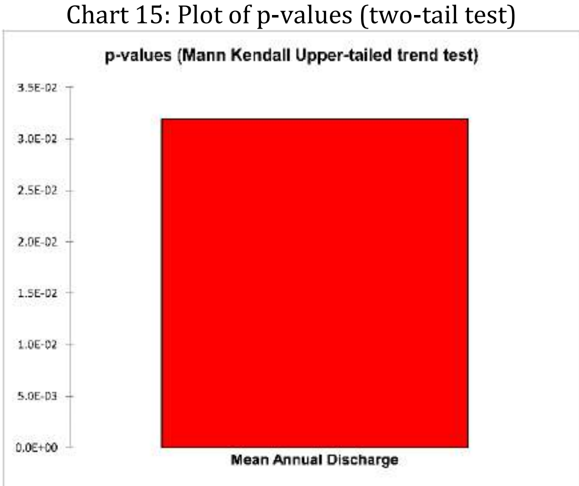

Chart 16: Plot of Mann-Kendall's Upper Bound p-values

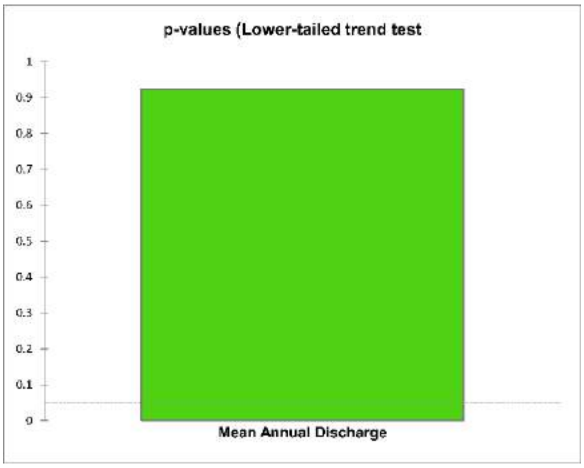

Chart 17: Plot of Mann-Kendall's Lower Bound p-values

3.5 Mean Annual Discharge (1966-2000)

Omitting the perceived data outliers and repeating the Mann-Kendall's two-tailed trend test and the subsequent upper-tailed and lower-tailed trend test, no statistically significant trend was detected. Charts 18-21 graphically represent this.

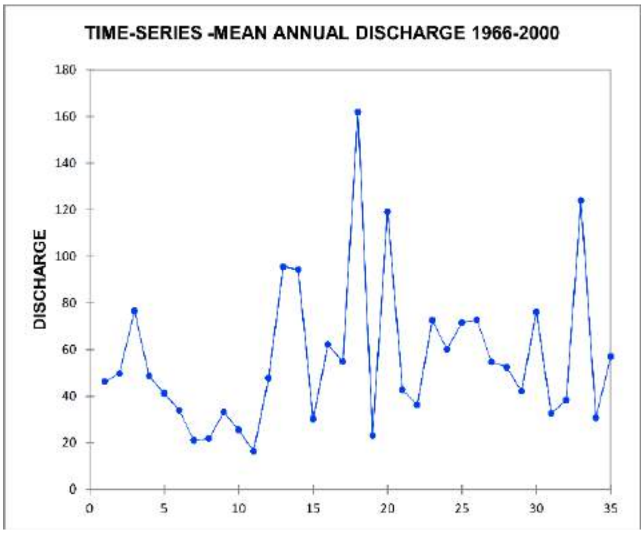

Chart 18: Sample plot of p-value for mean annual discharge (1966-2000)

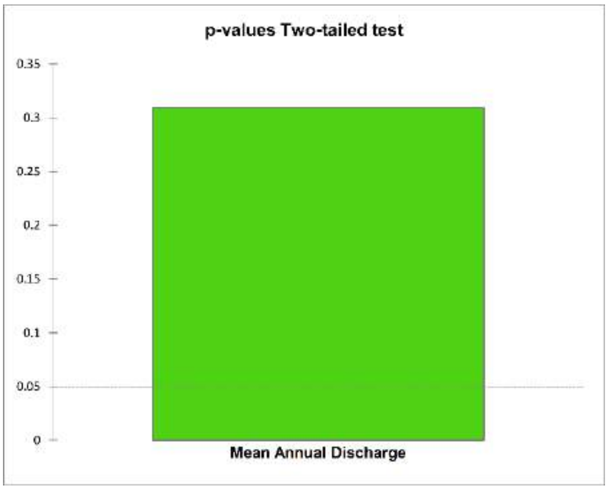

Chart 19: Plot of p-values (two-tail test)

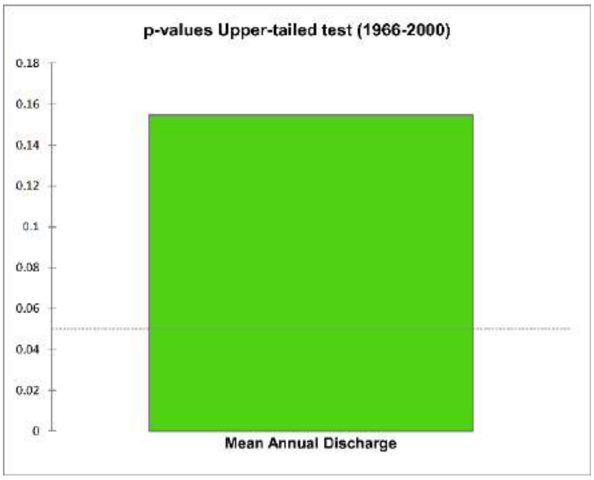

Chart 20: Plot of Mann-Kendall's Upper Bound p-values

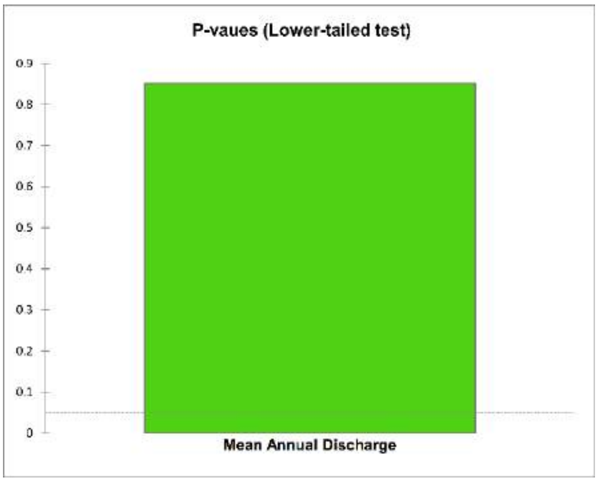

Chart 21: Plot of Mann-Kendall's Lower Bound p-values

3.6 Summary of Results

Table 1 summaries the results of the study.

Table 1: Summary of study results

Variable Tested	Two-Tailed Test	Upper-Tailed Test	Lower-Tailed Test
Mean monthly rainfall	Statistically significant trend detected in month of **August.**	No statistically significant trend detected.	Statistically significant trend detected in months of **August** and **September**.
Mean annual rainfall	No statistically significant trend detected.	No statistically significant trend detected.	No statistically significant trend detected.
Mean monthly discharge (1966-2006)	Statistically significant trend detected in months of **January, February** and **November.**	Statistically significant trend detected in months of **January, February, March** and **November.**	No statistically significant trend detected.
Mean annual discharge (1966-2006)	No statistically significant trend detected.	**statistically significant trend detected.**	No statistically significant trend detected.
Mean annual discharge (1966-2000)	No statistically significant trend detected.	No statistically significant trend detected.	No statistically significant trend detected.

4 DISCUSSIONS

With regard to the first objective that sought to evaluate the existence of a statistically significant trend in the mean monthly and mean annual rainfall, the results of the Mann Kendall's trend test showed that only two months (August and September) had a statistically significant negative trend, representing 16.67%. As a result, for those two months, the null hypothesis (H_0) was rejected and the alternative hypothesis (H_a) accepted. Trend tests on mean annual rainfall did not detect the presence of a statistically significant trend. This meant that the null hypothesis (H_0) could not be rejected.

The second objective sought to evaluate the existence of a statistically significant trend in the mean monthly and mean annual discharge. The results detected the presence of a statistically significant positive trend in the mean monthly discharge in the months of January, February, March and November (representing 33.33%). This meant that the null hypothesis (H_0) was rejected and the alternative hypothesis (H_a) accepted for those four months out of twelve. With regard to mean annual discharge for the years 1966-2006, an overall positive statistically significant trend was detected implying that the null hypothesis (H_0) was rejected and the alternative hypothesis (H_a) accepted. Ideally, the results of the mean annual discharge data would have been enough to draw conclusions that Climate Change has taken place. However, these results had taken into account the perceived data outliers between 2001-2003.When the Mann-Kendall's tool was run on data between 1996 – 2000 (excluding the perceived data outliers), no trend was detected in the mean annual discharge. As a result, it was reasonable to deduce that the data set between 2001-2003 had a significant effect on the results of the Mann-Kendall trend test for the period 1966-2006.

5 CONCLUSIONS

In conclusion, the results obtained from this study could not conclusively imply Climate Change for two reasons: first, only 16.67%and 33.33% of mean monthly rainfall and mean monthly discharge respectively detected a statistically significant trend; both results were belowthe (50%) threshold set in the objectives. The mean annual rainfall did not detect any statistically significant trend and although the mean annual discharge data for the period 1966-2006 detected a statistically significant positive trend, when the Mann Kendall tool was run on the mean annual discharge omitting the 2001-2003 data, no statistically significant trend was detected. The second reason why Climate Change could not be reasonably impliedis due to the fact thatthe rainfall data obtained had a relatively short span (1980-1994) and only six rainfall stations were analyzed in the vast upper Tana catchment. This sample dataset could be viewed as disproportionate to the size of the catchment and therefore relatively inadequate to give a proper representation of the catchment characteristics.

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