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ANALYSIS OF THE TRENDS IN TEMPERATURE AND RAINFALL IN THIKA RIVER BASIN IN KENYA

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ABSTRACT

The Thika River catchment is of great importance to Kenya and holds Ndakaini Dam where about 84% of Nairobi's water supply comes from serving a population of over 3 million residents, whose contribution to Kenya's Gross Product is 60%. The evidenced climate variability and trends for Thika catchment were assessed for significance using the Man Kendall's trend test and discussed based on future climate variability scenarios. The results showed that the catchment has become relatively warmer over the past four decades. The annual precipitation and means of daily mean temperatures over the past 30 years has increased by about 7.8 mm (although not statistically significant), and 2.14°C respectively.

Contribution/Originality: This study is one of very few studies which have investigated the climate variability within the Thika catchment in Kenya. This analysis will be of great help to the water policy experts within the region in terms of future planning.

1. INTRODUCTION

1.1. Background Information

According to Turral, et al. [1] despite the role played by climate variability, and its impacts on different sectors of economy, society and the environment, there is low understanding on its extent in Kenya. This study was done with an aim at spearheading efforts towards such understanding. The Thika River catchment is highly important to Nairobi county in Kenya since it supplies the city 84% of water for over three million residents whose contribution to Kenya's Gross Domestic Product from Nairobi alone is over 60% [2]. This is a tributary to the Tana River which supplies the bulk of country's hydroelectricity power needs, irrigation needs and provision of clean drinking water to the millions of the country citizens. Ndakaini Dam which supplies 84% of Nairobi's water supply is also situated in this catchment. As indicated byNEMA [3] Kenya was characterized by dry conditions in the 1950s and the early 1970s, the wet conditions were evidenced in the early 1970s and the late 1980s. Recent extreme events include: droughts of 1984, 1990, 1994, and 1999 and El Nino floods in 1997/1998 [3].

Kenyan temperatures do not show large variations in its mean annually but the variations are seen geographically, seasonally and diurnally due to altitude. There is a wide spatial variation based on annual rainfall ranging from 200mm in the dry regions in the northwestern and the eastern regions of Kenya to the wetter areas were rainfall ranges from 1200-2000mm in regions bordering Lake Victoria and Central highlands locate on the east of rift valley. Kenyan climate has been subject to disasters, with floods and droughts occurring periodically based on rainfall anomalies. Over the past 50 years, there have been at least 13 serious droughts and six major floods affecting the Winam Gulf of the Lake Victoria and the lower Tana region [3].

1.1. Statement of the Problem

Determination of the climate variability impacts on the surface runoff both on local and regional assist in effective planning of the future water resources. Based on IPCC [4] temperature is expected to increase between 0.2ºC and 0.5ºC consequently triggering a rainfall increase of about 5 to 20% during the wet months and 5 to 10% during the dry months. Determination of these changes in runoff for both climate variability and climate change is not adequate without taking into account climate variability scenarios. Unfortunately, there is a major challenge in taking account of climate change scenarios making it hard to significantly determine climate variability effects. The outcome of wrong assumptions compromises future planning of water resources. This leads to adoption of assumptions on the climate change effects leading to wrong data when predicting surface runoff Arnell [5]. The outcome of wrong assumptions compromises future planning of water resources.

1.2. Study Justification

Currently, there have been increasing evidence that the earth's climate will become warmer in the 21st century which raises the essential question: What impacts will global warming have on the environment and human activities [6]. Global warming has the ability to lead to hydrological changes which have an impact on freshwater resources including surface runoff. These are among the most important potential effects of climate change and variability. As the climate warms, changes in global precipitation nature, evaporation, snowpack, stream flow and other factors that will have an impact on freshwater supply and quality will be evidenced. According to IPCC, et al. [6] Thika River provides water for hydroelectricity power as well as 84% of the Nairobi water needs which is the capital of the country. Nairobi has been periodically facing water shortages as water in Ndakaini Dam falls in unprecedented levels during the dry season. The country energy status is made worse by frequent low levels of water at Masinga Dam located in Tana River which leads to frequent shut downs. All this has come about due to the serious changes and variability in climate. Kenya was faced with the worst dry season in early 2015 which was followed by a season of extreme rainfall events.

1.3. Objectives

1.3.1. General Objective

The main objective of this study was to evaluate the trends in temperature and rainfall in Thika river basin in Kenya using Mann Kendall's trend.

1.4. Specific Objectives

The specific objectives are to:

i. Analysis of the trends in temperature and rainfall generated in the catchment based on the climatic data for the period starting 1976 to 2006.

1.5. Research Questions

Research questions were;

a) Are there any trends in temperature and rainfall generated in the catchment?

1.6. Scope and Limitations of the Study

The area that was under this study is Thika river catchment.

2. LITERATURE REVIEW

2.1. General Introduction

In a study by Lukeman [7] it asserts that the main causes of climate variability include precipitation, distribution, soil moisture, evaporation and temperature. Other causes of weather and climate variability includes the solar energy, earth's pressure systems, moisture sources, sea/ocean land interface, surface albedo, topography and relief Ndirangu, et al. [8]. Climate variability means variations in the mean state and other climate statistics including standard deviations, occurrence of extremes amongst others on all temporal and spatial scales beyond individual weather events. Universal climatic variability may be resulting from internal natural processes or perhaps even external processes. Global climate warming refers to the increase of earth's near-surface air and ocean temperatures which is usually caused by accumulation of greenhouse gases resulting from the anthropogenic activities such as burning of fossil fuels [3]. It is essential to note from the above definition that global climatic change, climatic variability and global climate warming are not quite the same though closely related.

2.2. Temperatures Variability

2.2.1. Global Variability

It is estimated that global temperature has risen by 0.6^{o}C since the 19th century [9]. In the recent decades (1950 – 1993), the rise in temperatures has involved a faster rise in daily minimum (0.2^{0}C / decade) than in daily maximum (0.1^{0}C / decade) in many continental regions. This has led to a decrease in diurnal temperature range (-0.1 ^{0}C / decade trend) in many parts of the world [10]. This is a rate higher than for the mean temperatures for the entire 20th century, indicating very strong warming in recent decades. The challenge with these ranges is that they were done for only 57% of the global surface and hence may not accurately reflect the global trend. However, with more GCM models in the market this is likely to change [11].

2.2.2. Regional Variability

According to Lins and Slack [12] temperatures have in rose in almost every location with the exception of Eastern Canada, small areas of Eastern Europe and the middle east. The diurnal temperature range has decreased in most regions except over Middle Canada, and parts of South Africa, south-west Asia, Europe and western tropical pacific islands. In New Zealand and central Europe, maximum and minimum temperatures have risen at similar pace and rates. Other regions like India have experienced increased diurnal temperature range due to decrease in minimum temperatures [12]. These different occurrences of variability across various regions make the assumption of a global value inadequate for evaluation of impacts and planning of mitigation measures at local scale. This leads to the need of assessing variability even at local scale i.e. sub regions of the continental regions are generally adopted in such studies [13].

2.2.3. Precipitation Variability

Over the 20th century, the annual precipitation increased by between 7% and 12% for the zones 30^{0}N to 85^{0}N and by about 2% between 0^{o} to 55^{o}S [6]. In the year 1998 the high latitudes (55°N and higher) of the Northern hemisphere had their wettest year ever recorded and the mid-latitudes recorded precipitation totals above the 1961 to 1990 mean every year since 1995 [14]. Studies indicate that precipitation in Canada has increased by about 10% during the 20th century. In china there has been a declining trend in total annual precipitation for the period 1950 to 2000 [8]. Studies have shown multi-decadal variation in the Indian monsoonal rainfall, from 1906 to 1960 the rainfall increased and then decreased through 1974 and has continued to increase since then, western Mexico has evidenced an increasingly erratic monsoonal rainfall since 1940s [13]. The driest period was witnessed in the 1980s. Southern Africa region has experienced observable decreases in precipitation since 1970s. Early 2000 have seen flood-producing rains in the eastern part of South Africa [7]. From all this consideration, it is seen generally that there is an increasing trend in precipitation.

2.3. Climate Variability Impacts

Climate variability has several impacts [15]. Bases on climate change projections made by IPCC, climate variability increases the occurrence of droughts, floods and extreme rainfall events Bernstein, et al. [16]. Recent studies show that cyclones intensity will increase with up to 10-20% due to climate variability. More El Niño like weather conditions are expected as a result of climate variability. All these will have an impact on crop agriculture, forestry, livestock and human life in general [15].

2.4. Assessment of Climate Variability Effects

As presented by Bernstein, et al. [16] a set of four future climate scenarios to project emission gases and temperatures are paramount to addressing these unforeseen challenges. These scenarios are used by researchers and policy makers to assess potential future conditions and compare them to baseline conditions in the absence of climate change. As an example rainfall variability in Kenya have an effect on agricultural production and the livelihoods of people, especially in the ASAL areas, like Makindu John, et al. [17]. These scenarios can also be used to analyze adaptation scenarios to mitigate the negative effects of climate change.

2.5. Trend Analysis

This method usually employs testing of trends of the times series of the climatic data over time. Trend detection can be done by both analytical and graphical methods [12]. The graphical methods involve the fitting of a trend line to a time series of the data. This method has the advantage of being visual, for instance, if a trend actually exists it can be seen visually and at times its magnitude can be appreciated from the slope of trend line. However, this method is limited in that if the trend is too slight it may not be easily discernible and also the actual magnitude of the change cannot be accurately determined [12]. Analytical methods have the advantage of revealing even the slightest changes and also the magnitude of the change. There are several methods used for trend detection depending on the nature of the data distribution. The broad categories of these methods are parametric and non-parametric [12].

2.6. Mann-Kendall's Trend Test's

The Mann-Kendall trend test is a non-parametric test used to detect trend in time series data. By the virtue of it being non-parametric, it does not require data to be of any particular distribution, it also has a high asymptotic efficiency [18]. The test statistic Z for a particular period will be estimated according to Fu, et al. [13] as follows:

$$\begin{cases} \frac{S-1}{(var(s))^{0.5}}, & \text{if } s > 0 \\ \frac{S+1}{(var(s))^{0.5}}, & \text{if } s=0 \\ & \text{if } s < 0 \end{cases} \quad (2.17)$$

$$Var(s) = (n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)j/18 \quad (2.18)$$

$$s = \sum_{k=1}^{n-1} . \sum_{j=k+1}^{n-1} sgn(Xj - Xk) \quad (2.19)$$

Where

X is the variable, a sample of n independent and identically distributed random variables (e.g. Monthly precipitation or temperature) it is the extent of any given tie.

For testing the null hypothesis, H_o, meaning no significance trend, against H_1 significant upward trend, H_o is rejected if $Z > Z_{1-\alpha}$. Testing for significant downward trend H_2, reject H_o if $Z < 0$ and the absolute value of $Z > Z_{1-\alpha}$ [13].

According to Casella and Berger [19] the choice used for a significant level (α) is completely arbitrary. Another way to carry out the test for hypothesis is through comparing the p-value of the sample test statistic with a significance level(α). In this case, the p-level of the sample test is the lowest level of significance where null hypothesis (H_0) can be rejected. The p-value is compared against actual significance level of the test and if it is smaller, results are taken as significant. If the null hypothesis is rejected at 5% significance level, it is reported as "$p<0.05$". Thus, when the value is smaller, it becomes more convincing to reject the null hypothesis. This is rejection of the null hypothesis based on strength of evidence rather than simply coming up with conclusions "Reject H_0" or "Do not reject H_0". The p-value is very important in evaluation and interpretation of the findings. This makes it possible for the researchers to set their own level of significance. It also makes it possible to reject or accept null hypothesis based on their criterion instead of using fixed level of significance.

2.7. The Sen's Slope for Trend Magnitude

The Mann Kendall trend test merely indicates the presence of trend but shows no indication of the magnitude of the trend. The Sen's slope is a formula that is used to measure the magnitude of the trend by estimating the slope of the assumed linear trend Gocic and Trajkovic [20]. When the data time series shows a linear trend, a true slope can be estimated using a simple nonparametric procedure given by Sen [21]. The Sen's slope estimator denoted by, b, is determined using Equation. 2.20.

$$b = \text{median}\left(\frac{x_j - x_i}{j-1}\right) \qquad \forall i < j \qquad 2.20$$

Where x_j and x_i are two generic sequential data values of a variable.

For a time series of annual values, b represents the annual increment under the hypothesis of a linear trend. The b estimator approximates the true slope of the trend, which can slightly vary from the slope of the trend line gained through linear regression. Hirsch and Slack [22] concluded that a lurking variable was unlikely to be affected by outliers since Sen's estimate is robust against these outliers.

3. METHODOLOGY

3.1. Study Area

3.1.1. Climate

The catchment is characterized by altitude dependent agro- climatic zones (humid to semi-arid). The rain distribution is bimodal with high peaks from March to May (long rains) and October to December (short rains). Annual rainfall varies from about 800mm at an altitude of about 1525m a.m.s.l to about 2200mm at an altitude of 2600m a.m.s.l [23]. The annual potential evapotranspiration increases from about 1250mm at an altitude of 2400 a.m.s.l to about 1800mm at 1100m a.m.s.l [24].The temperature is high at the lowest altitude ranging from 25^0 C to 30^0 C but reduces to between 18^0 C and 20^0C towards the higher altitudes of 3500m a.m.s.l. [23].

3.2. Trend Analysis

3.2.1. Mann Kendall's test

The non-parametric Mann Kendall's test was used to detect trends in precipitation and temperatures over the 30-year period. The data value was evaluated as part of an ordered time series. Each of the data value had to be compared with the subsequent data values. In instances where the data value obtained was higher than the later period value, an increment of 1 was added to statistic S. Also, when the data value from later period was lower than value which has been obtained earlier, a decrement of 1 to S was applied [18]. A significance level of 0.05 (5%) was used in this study as the level below which a significant trend can be observed. Effectively, in instances where Mann-Kendall test has a statistic above 1.96, the trend present in the data was said to be significant.

3.3. The Sen's Slope for Trend Magnitude

The Sen's slope formula was used to measure the magnitude of the trend in both temperature and precipitation by estimating the slope of the assumed linear trend. To get value of slope estimate (Q), the following formula as shown in Equation 3.1was used [18].

$$Q_i = \frac{x_j - x_k}{j - k}, i = 1, 2, \dots N, j > k \quad (3.1)$$

Where:

Q_i is the slope

X denotes the variable

J, K are the indices

N is the data size

4. RESULTS AND DISCUSSION

4.1. Trend Analysis

4.1.1. Rainfall Trends and Magnitude

Both Mann Kendell and Sen's slope estimate tests were carried on the 30-year rainfall data for the period between 1976 and 2006. The results illustrate that rainfall desiccation of the early 1980s established by New, et al. [25] in Sahelian region also affected the Great Horn of Africa. The results are presented in t Table 4.7.

Table-4.7. Mann Kendell and Sen's slope estimate tests results

Time series	First year	Last Year	n	Test Z	Significance	Q	Mean Monthly Rainfall	Min Monthly Rainfall - mm	Max Monthly Rainfall - mm
Jan	1976	2006	31	0.07		0.063	56.9	0.0	358.4
Feb	1976	2006	31	-0.17		-0.050	44.7	0.0	236.1
Mar	1976	2006	31	-0.82		-1.238	118.0	6.3	318.5
Apr	1976	2006	31	0.44		1.500	216.4	5.0	487.2
May	1976	2006	31	1.67	+	2.960	107.7	0.6	357.5
Jun	1976	2006	31	-1.67	+	-0.311	34.6	0.9	343.3
Jul	1976	2006	31	-1.17		-0.208	16.0	0.0	94.3
Aug	1976	2006	31	0.00		0.000	17.7	0.0	212.3
Sep	1976	2006	31	-1.05		-0.192	18.6	0.0	80.2
Oct	1976	2006	31	-0.03		-0.150	92.1	2.8	248.9
Nov	1976	2006	31	1.29		3.041	174.9	2.1	422.6
Dec	1976	2006	31	0.41		0.678	100.0	12.1	243.1
Annual	1976	2006	31	0.78		0.348	56.9	0.0	358.4

Source: Gocic and Trajkovic [26]

Overall, the Kendall's test results show a slightly increasing trend for annual precipitation, although it is not statistically significant as displayed on Figure 4.4.

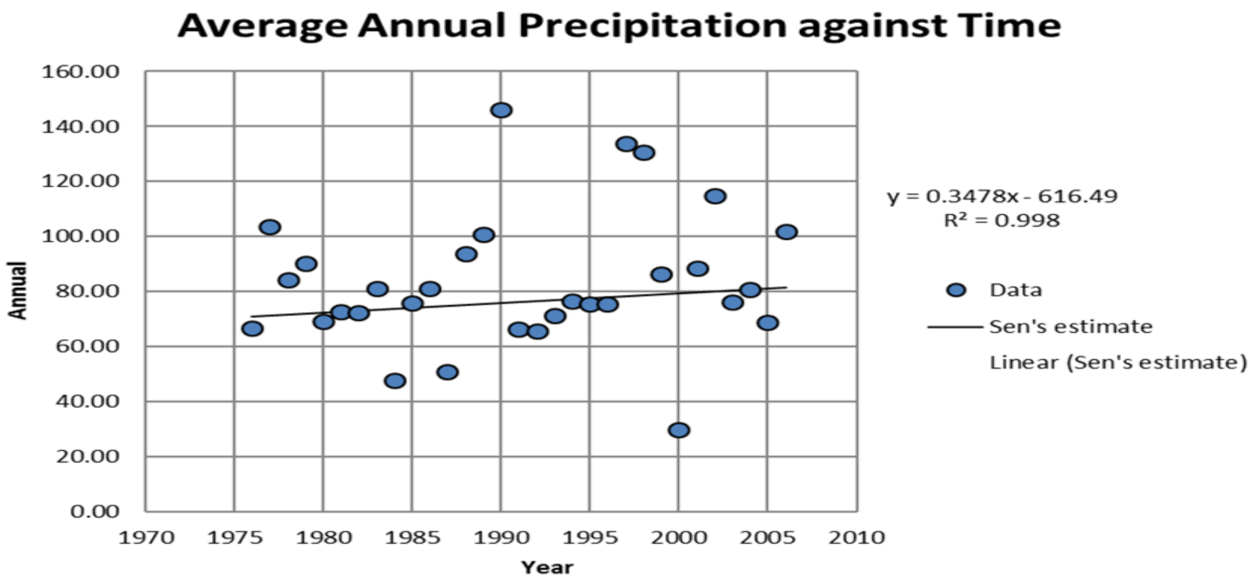

Figure-1.4. Average annual precipitation against time

Source: Gocic and Trajkovic [26]

This is in agreement with the findings by Yue, et al. [27]. The magnitude of the precipitation trend from Sen's slope indicates that overall the annual precipitation in the catchment has increased by 7.8mm in the last 30 yrs. A summary of the trend analysis results is as present on Table 4.8.

Table-4.8. Summary of statistical analysis on Rainfall trend

Years	1976 - 2006
No of years	31
Test Z	0.78
Significant	Not

Source: Gocic and Trajkovic [26]

4.2. Temperature Trends and Magnitude

Both Mann Kendell and Sen's slope estimate tests were carried on the 30-year temperature data as presented in table 4.8.

Table-4.8. Mann Kendell and Sen's slope estimate tests results

Time series	First year	Last Year	n	Test Z	Significance	Q	Mean Monthly Temp	Min Monthly Temp – °c	Max Monthly Temp – °c
January	1976	2006	30	0.35		0.004	19.7	18.0	20.8
February	1976	2006	30	0.09		0.000	20.4	17.6	21.5
March	1976	2006	30	0.93		0.020	21.2	19.8	22.5
April	1976	2006	30	1.44		0.028	20.9	19.8	22.1
May	1976	2006	30	1.15		0.017	20.2	18.3	22.1
June	1976	2006	30	0.31		0.005	18.8	17.8	20.6
July	1976	2006	30	0.02		0.000	17.8	16.8	19.3
August	1976	2006	30	1.19		0.021	18.1	17.0	19.3
September	1976	2006	30	1.39		0.019	19.5	18.2	20.5
October	1976	2006	30	1.22		0.023	20.5	19.6	21.7
November	1976	2006	30	0.60		0.010	20.1	19.3	23.4
December	1976	2006	30	1.96	*	0.031	19.7	18.8	20.9
Annual Mean	1976	2006	30	2.14	*	0.018			

Source: Gocic and Trajkovic [26]

The results of Kendall's test show that the climate of Thika Catchment has become warmer during the last three decades. From Figure 4.5 results show that the annual means of daily temperature have increased in the last three decades.

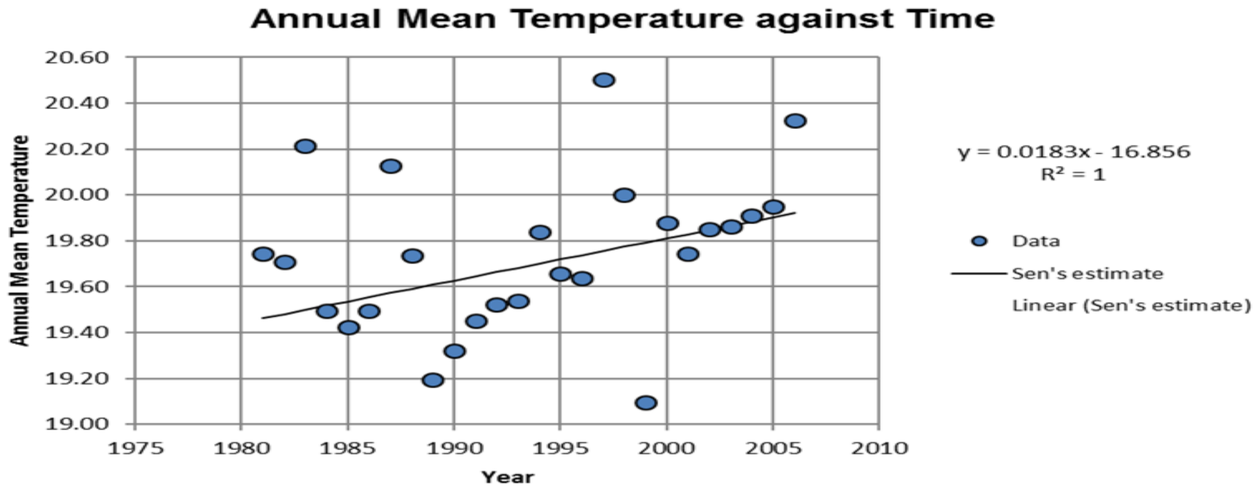

Figure-4.2. Annual mean temperatures against time

Source: Gocic and Trajkovic [26]

The Kendall analysis showed a statistically significant increasing trend during the last three decades (Fig. 4.5.) at α=0.05 level. A statistically significant trend in daily minimum temperature, or in the range of maximum and minimum daily temperature, is to be expected as an indicator of a global warming signal [28]. The magnitude of the temperature trend from Sen's slope indicates that overall, the mean temperature in the catchment has increased by 2.14°c in the last 30 yrs. A summary of the results is a shown-on Table 4.9.

Table-4.9. Summary of statistical analysis on Temperature trend

Years	1976 - 2006
No of years	30
Test Z	2.14
Significant	yes

Source: Gocic and Trajkovic [26]

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

i. Rainfall amounts and the mean annual temperatures were found to have increased in Thika catchment in the last four decades by about 7.8 mm (although not statistically significant), and 2.14°C respectively. This was a clear indication that climatic variability has been occurring in the catchment and affecting levels of runoff produced into the rivers. There is reasonable evidence that some of the warming in the catchment is a result of global warming.

5.2. Recommendations

i. Nairobi Water Company should build more water harnessing dams or alternatively expand the existing Ndakaini dam in the catchment. This will ensure that the excess runoff is captured and hence more water to the city residents.

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