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Analysis of Rainfall Trends and Periodicity in Ruiru Location, Kenya

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Abstract- Climate change is a serious issue in the world today with extreme weather conditions being experienced globally as characterised by devastating floods and prolonged droughts. This has often led to destruction of property and loss of life. These conditions are viewed as disasters requiring mitigation. Ruiru location being a peri-urban area has a lot of farming taking place and increased population due to settlement. This has increased the demand for water as stream flow is decreasing and boreholes are drying, with water scarcity prominent during droughts. Moreover during floods there is high surface runoff in the paved areas. The study sought to determine rainfall trends across the year for 31 years if any in Ruiru location. Monthly rainfall data for 31 years (1984-2014) obtained from four stations located within the location; Ting'ang'a, Ruiru mills, coffee research foundation and Doondu were used. Graphs were constructed to show trends within months and years and statistical significance of the observed trends tested using a linear regression model. Statistical analysis using Mann- Kendall, Spearman's Rho, Linear Regression and Student's t was employed to determine the significant difference among the four stations. High annual mean rainfall of 170mm and low annual mean rainfall of 37 mm were observed. Mann- Kendall, Spearman's Rho, Linear Regression and Student's t showed no significant difference of rainfall means between Ting'ang'a and Ruiru Mills stations, while the other stations were statistically insignificant. Linear regression models showed an upward trend which was statistically insignificant in all the four stations. There was no significant trend across the year for the past 31 years. The research findings will help in prediction of the occurrence of high and low rainfall amounts for proper planning and water resources management.

Index Terms- climate change, linear regression, periodicity, rainfall, trends, water resources

1. INTRODUCTION

There are about 40 million people living in Kenya (Kenya population census, 2009), of which about 17 million do not have access to clean water (Municipal Council of Ruiru, 2006). For decades, water scarcity has been a major issue in Kenya, caused mainly by years of recurrent droughts, poor management of water supply, contamination of the available water resources, and a sharp increase in water demand resulting from a high population growth rate and industrial development. Lack of sufficient rainfall affects ability to acquire food and has led to eruptions of violence in Kenya (Marshall, 2011).

In many areas of Kenya, shortage of water has been amplified by government's lack of investment in water, especially in rural areas. Most of the urban poor in Kenya also only have access to polluted water, which causes cholera epidemics and multiple other diseases that affect health and livelihoods. Despite this critical shortage of clean water in Kenya's urban slums, there is also a large rural to urban discrepancy in access to clean water in Kenya (Marshall, 2011).

Slightly less than half of the rural population has access to water, as opposed urban population where 85 percent have access to safe water including a small portion of the urban poor in slums. Due to continued population growth, it has been estimated that by the year 2025, Kenya's per capita water availability will be 235 cubic meters per year, about two thirds less than the current 650 cubic meters (World Bank, 2010). Groundwater plays a major role in Kenya's development as it contributes to water for irrigation, domestic and industrial use and helps in offsetting supply deficit.

In Ruiru location, the contribution of groundwater to total supply is about 70% the remaining percentage being contributed by Ruiru-Juja Water and Sanitation Company, rainfall, rivers and Nairobi Water and Sewerage Company (RUJWASCO, 2008). There is thus pressure to increase available water resources especially groundwater resources which is a major contributor of water supply in Ruiru location. The study of groundwater levels variability will help in determining sustainability of groundwater water resources

Water scarcity is a critical problem that causes a major challenge to socio-economic development in the world today. Ruiru location is one of such area affected by water scarcity due to its high population density as a significant population working in Nairobi and Thika towns reside in the location. High population has increased water demand leading to water scarcity. Recent studies have confirmed that Ruiru location has rapid population growth without a corresponding increase in water sources (SIPA, 2006). According to Ruiru-Juja Water and Sewerage Company (RUJWASCO), demand for water in Ruiru location is 33,161m^3 per day while the company can only supply 7000m^3 per day which is about 21% of the demand. The remaining 79% is obtained from other sources such as Community Based Organization's mains, boreholes, dug wells, Nairobi Water and Sewerage Company (NWSC) mains, rainfall and directly from rivers.

Analysis show that even after completion of Jacaranda dam, RUJWASCO's water supply cannot meet the water demand in the location. In addition, drying up of wells and decline in borehole water level during the dry season has become a major issue in recent times (Municipal Council of Ruiru, 2006). Because borehole water makes a major contribution to water supply in Ruiru location, there is need to assess its status for proper conservation and management. Rainfall is a major contributor of groundwater recharge, due to climate change there has been prolonged drought and floods which greatly impact of groundwater recharge. The study looked at variability of groundwater levels within the location and their relationship with rainfall amount and distribution.

A study on trend and periodicity in India using Seasonal and annual rainfall data of the stations: Akluj, Baramati, Bhor and Malsiras stations located in Nira Basin, Central India, were analyzed. The analysis was carried out by using Mann-Kendall (MK), Modified Mann- Kendall (MMK) and Theil and Sen's slope estimator tests describing rising trend at all the stations. Study showed that it was statistically significant at Akluj and Bhor stations at 10% significance level. Bhor station showed the maximum increase in percentage change i.e. 0.28% in annual rainfall. Monsoon and post-monsoon seasonal rainfall showed a rising trend while the summer and winter seasonal rainfall showed a falling trend. Wavelet analysis showed prominent annual rainfall periods ranging from 2 to 8 years at all the stations after 1960s resulting in describing more changes in the rainfall patterns after 1960s. (Murumkar, 2013)

A study of Trends and periodicities of annual rainfall for 29 sub-locations of India was done using the rainfall series for a period of 124 years (1871–1994). The trends were evaluated using a linear regression technique. To identify the climatic changes, the rainfall series were subjected to 11-year moving averages. It was found that in some sub-locations the trend in one direction reverses its direction after some years. The significance of the trend values were tested. The periodicity was attributed to the quasi-biennial oscillation. Rainfall series of the most of the sub- locations and all India indicate a triennial cycle. Significant periods in the range from 3.0 to 8.0 years and 8.0 to 12.0 years were also identified (Naidu *et al*., 1999).

A study to analyse rainfall time series over a wide time interval was done in Campania region, southern Italy. 211 gauged stations, mainly located within the Campania region, southern Italy, was analysed for the period 1918–1999. An accurate database was set up through a data quality and time series homogeneity process. Statistical analysis of the database highlighted that the trend appeared predominantly negative, both at the annual and seasonal scale, except for the summer period when it appears to be positive. The study also showed that over the whole reference period, positive and negative trends were significant respectively for 9 and 27% of total stations and (3) over the last 30 years (Longobardi and Villani, 2009).

Rainfall and temperature trends study at Namulonge parish, in Wakiso district of Uganda used temperature and rainfall records aggregated into monthly means over a period of more than 55 years. These records were analyzed in an effort to identify both seasonal trends and shifts in climate. This was achieved by using non- parametric (Mann-Kendall) and parametric (linear regression) techniques. The analysis showed that total rainfall during the March-May season decreased, while maximum temperatures were increasing during the months between April and September, with both trends statistically significant at 5% confidence level. The Mann-Kendall test revealed that the number of wet days reduced significantly. Temperatures were found to be warmer and rainfall higher in the first climate normal compared to the recent 30 years. Results revealed that April was the only month with a statistically significant rainfall trend (Nsubuga, et al., 2011).

The objective of the study is to determine rainfall trends and periodicity in Ruiru location.Impacts of climate change have led to extreme conditions in the world such as prolonged drought and floods. These changes cause variability in rainfall, a major contributor to groundwater resources. Ruiru location depends on groundwater as a source of its water supply. Any shortcoming in groundwater levels due to prolonged drought is therefore likely to affect water supply in the location. It is therefore necessary to assess groundwater levels variability and the impact of rainfall on groundwater levels for better planning and management of groundwater resources. Provision of safe and clean water to all citizens is one of the objectives of the social pillar of Vision 2030 to which this research hopes to contribute by providing information on the sustainability of groundwater resources. With country's new constitution, establishment of devolved government has localized many activities which are likely to increase dependence on groundwater especially in areas without sufficient surface water sources. The study will provide data and information on groundwater resources necessary for planning and development.

2.0 Materials and Methods

2.1 Description of study area

2.1.1 Geographical Settings

Ruiru location is located at an altitude of 1564m, latitude of between 1.08333^{o} S and 1.15°S and longitude of 36.96667°E and 37.16667 ^{o} E in Kiambu County, Kenya. The construction of Thika Super Highway and Northern Bypass has put Ruiru at a strategic point as it now takes less than 30 minutes to reach Nairobi the capital city and about 15 minutes to reach Thika Town the County headquarters. The location borders Juja location to the north, machakos to the East, Githunguri to the West and Nairobi to the South. The location covers approximately 179.90 square kilometers.

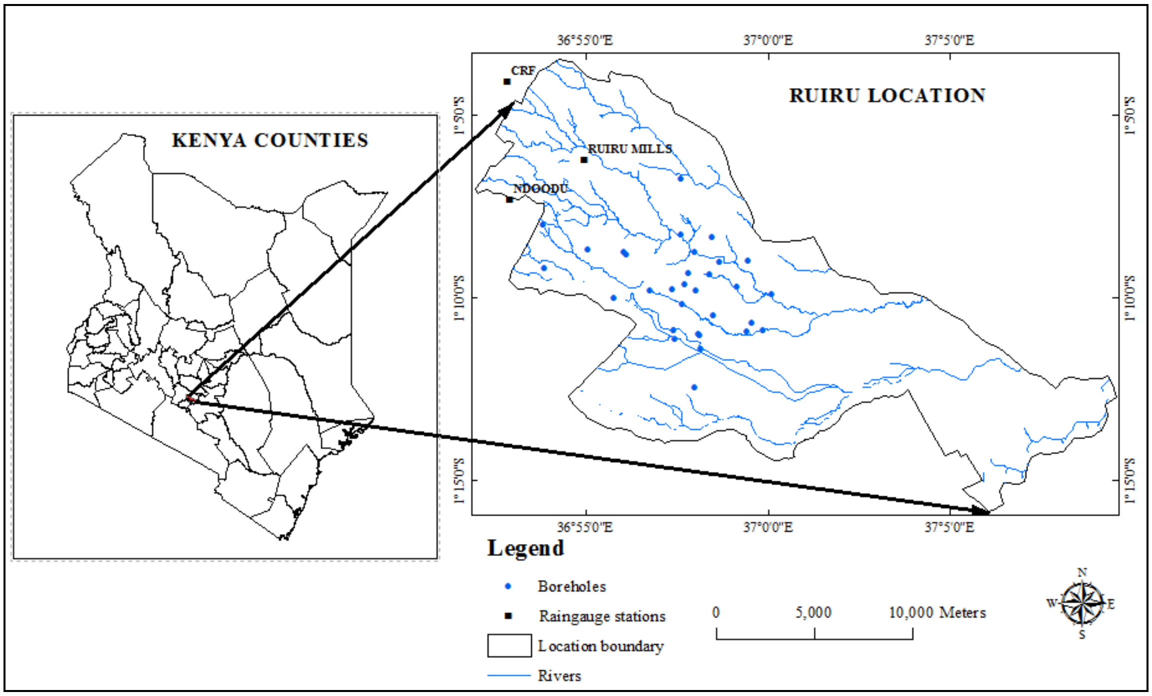

Figure 1: Map of Ruiru location

2.1.2 Topographic Features

Ruiru location lies between 1,300-1,500 metres above sea level. The landscape comprises of volcanic middle level uplands.

2.1.3 Administrative and Political Units

The location lies within Ruiru sub-county and is divided into seven wards that is Mwiki, Mwihoko, Kiuu, Kahawa wendani, kahawa sukai, Gatongora and Biashara.

2.1.4 Climate

Climate is humid highland sub-tropical in character with seasonal dry and wet periods. Ruiru receives 1065 mm of rainfall annually which is bi-modal with long rains between March and May and short rains between October and December. A monthly average temperature of 18.9°C, maximum temperature of 24.9°C and a minimum temperature of 13.0°C. Temperatures are highest in the months of January to mid-March before the long rainy season and lowest in the months of July and August.

2.1.5 Soils

The soils are sandy or clay and can support drought resistant crops such as soya beans and sunflower as well as ranching. Most parts of the location are covered by soils from volcanic footbridges. These are well drained with moderate fertility. They are red to dark brown friable clays, which are suited for cash crops like coffee, tea and pyrethrum. However, parts are covered by shallow soils, which are poorly drained, and these areas are characterized by low rainfall, which severely limits agricultural development.

2.1.6 Hydrogeology

The hydrogeology of an area is the interplay of several factors of the site. These include: the nature of the parent rock; structural features of the primary and of the secondary origin; weathering processes and the resultant products; the mechanism of recharge; the recharge medium of water; quantity and its frequency; the morphology; disposition and gradient of the subsurface as well as the hydrological and topographical environment. The overall permeability of the subsurface is a result of the grain size, sorting, cementing material and the secondary feature present of joints, faults, fissures and the presence of impending layers such as aquiclude beds, often of clay or consolidated material. The aquifer complex of Nairobi which covers Ruiru reaches 400 m. The poorly defined drainage pattern points to an internal drainage model in a closed basin.

2.1.7 Socio-economic activities in Ruiru

Ruiru is well-covered with industries and coffee growing that provides employment opportunities and contributes to economic growth in the town. These industries have been instrumental in renovation, construction and expansion of schools and general infrastructure such as roads within the location. It is covered by two major hospitals Nazareth hospital and Ruiru hospital and also houses Kenyatta University Ruiru Campus. It also has many registered middle-level colleges such as Nairobi Institute of Business Studies (NIBS) and Zetech.

2.1.8 Environment, Water and Sanitation.

Ruiru location's water resources comprises of both Surface and Ground water. There are two rivers that traverse the location; River Ruiru where Ruiru Water and Sewarage Company gets its water from and River Kamiti. Some parts of the location are also supply water by Nairobi City Water and Sewarage Company and areas outside the jurisdiction of these Companies either have no water infrastructure or are served by community water projects and boreholes. There is no sewer line in some parts of the location and majority of the communities including the major trading centres utilize septic tanks and pit latrines for human waste disposal.

2.2 Methodology

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Historical monthly rainfall data for the past thirty one years was obtained from rainfall stations located within the study area. The stations included Coffee Research Foundation, Ruiru Mills and Doondu.Monthly rainfall for 31 years (1984-2014) was obtained from four stations i.e Ting'ang'a, Ruiru mills, Doondu and Coffee Reseach Foundation located within Ruiru contituency. Statistical analysis was carried out to assess any rainfall significant difference among the four stations using Mann- Kendall, Spearman's Rho, Linear Regression and Student's t. Graphs were constructed to show any trend in the monthly and annual rainfall. Statistical analysis was done to indetify any significant trend using Linear regression model. Linear regression model is explained in the form of

$y = a + bx$

$$y = rainfall$$

$x = year$

$b = slope$

$a = intercept$

The slope explains the trend , if the slope is negative the the trend is decreasing or downward trend and if the slope is positive the the trend is increasing or increasing. The null hypothesis is that the slope of the line is zero i.e there is no trend in the data. The sisgnificance of the data is shown by the p-values with the significance level of 0.05.If the p-value is less than the significance level then the null hypothesis in rejected and if its more the null hypothesis is not rejected.The R- square is the correlation coefficient which is used to show how strong is the correlation between x and y. R^2 range between 0 and 1. 1 means there is a strong correlation while 0 means there is no correlation. The correlation strength increases from 0 to 1.

The Periodicity test was performed using Wavelet analysis because it shows the rainfall amounts and frequency of occurrence. Recent periodic analysis approaches have however been based on wavelet analysis (Daubechies, 1992). In this study wavelet analysis was used to study periodicity in rainfall in Ruiru location. Wavelet analysis is a tool for analyzing non-stationary variance at many different frequencies (Daubechies, 1992) within a geophysical time series (Torrence and Compo, 1998; Smith, *et al*, 1998; Labat, *et al*., 2005). Wavelets are a set of limited duration waves, also called daughter wavelets, because they are formed by dilations and translations of a single prototype wavelet function $\psi(t)$, where t is real valued, called the basic or mother wavelet. The mother wavelet designed to oscillate like a wave, is required to span an area that sums to zero and die out rapidly to zero as t tends to infinity to satisfy the so-called admissibility condition i.e.

$$\int \Psi(t)dt = 0 \qquad (3.1)$$

In this study to compute the wavelet power, the Morlet wavelet $(k = 6)$, was used because its structure resembles that of a rainfall time series, given by

$$\Psi(t) = \pi^{-1/4} e^{6it} e^{-t2/2} \qquad (3.2)$$

Examples of other wavelet functions include the Paul, Mexican hat and derivative of Gaussian (DOG), details are given in Torrence and Compo (1998).

The continuous wavelet transform W_n of a discrete sequence of observations x_n is defined as the convolution of x_n with a scaled and translated wavelet $\psi(\eta)$ that depends on a non-dimensional time parameter η

$$W_n(s) = \sum_{n'=0}^{N-1} x_{n'} \psi * \left[\frac{(n' - n)\delta t}{s} \right] \qquad (3.3)$$

Where n is the localized time index, s is the wavelet scale, δt is the sampling period, N is the number of points in the time series and the asterisk indicates the complex conjugate. Since complex wavelets lead to complex continuous wavelet transform, the wavelet power spectrum, defined as, $|W_n(s)|^2$ is a convenient description of the fluctuation of the variance at different frequencies. Further, when normalized by σ^{-2} (where σ^2 is the variance) it gives a measure of the power relative to white noise, since the expectation value for a white noise process is σ^{-2} at all n and s.

To determine significance levels for wavelet spectrum an appropriate background spectrum was be chosen. The many geophysical phenomena, an appropriate background spectrum is either while noise (with a flat Fourier spectrum) or red noise (increasing power with decreasing frequency) (Torrence and Compo, 1998). It has been shown on average that the local wavelet power spectrum is identical to the Fourier power spectrum given by

$$P_k = \frac{1-\alpha^2}{1+\alpha^2 - 2\alpha\cos\left(\frac{2\pi k}{N}\right)} \qquad (3.4)$$

where $k = 0 .... N/2$ is the frequency index. By choosing an appropriate lag-1 autocorrelation equation (14) can be used to model a red-noise spectrum. If $\alpha = 0$ in equation (14) then it models a white noise spectrum.

If x_n is a normally distributed random variable, then both the real and imaginary parts of $\hat{x}_k$ are normally distributed (Chatfield, 1989). Hence $|\hat{x}_k|^2$ is chi-square distributed with two degrees of freedom, denoted by X_2^2. In order to determine the 95% confidence level, the background spectrum in equation (14) is multiplied by the 95th percentile value of X_2^2 (Murumkar, 2013)
The confidence interval at each scale can be used to construct confidence contours. In this study the 95% confidence limit was used to study the periodicity seasonal rainfall in Ruiru location.

3.0 Results and Discussion

3.1Rainfall Trend and periodicity
3.1.1Coffee Research Foundation (CRF) Station

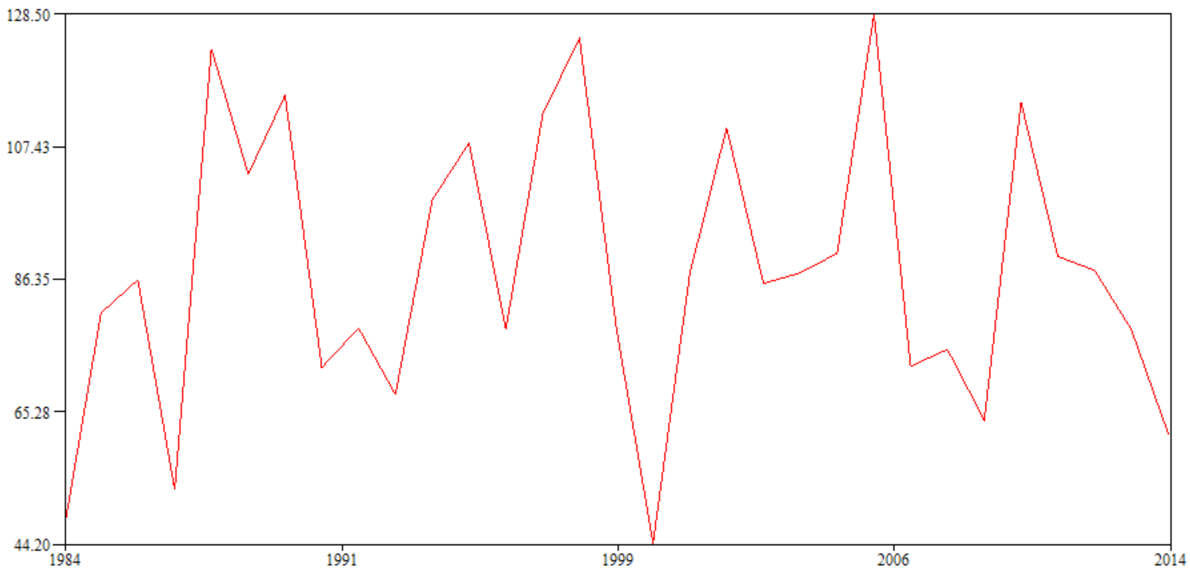

Figure 2: rainfall trends in CRF

High total annual rainfall of 1541.8mm was recorded in the year 2006 and low amounts of 529.9mm in the year 2000. There was an increasing trend from 1984 to 2014 though not significant.

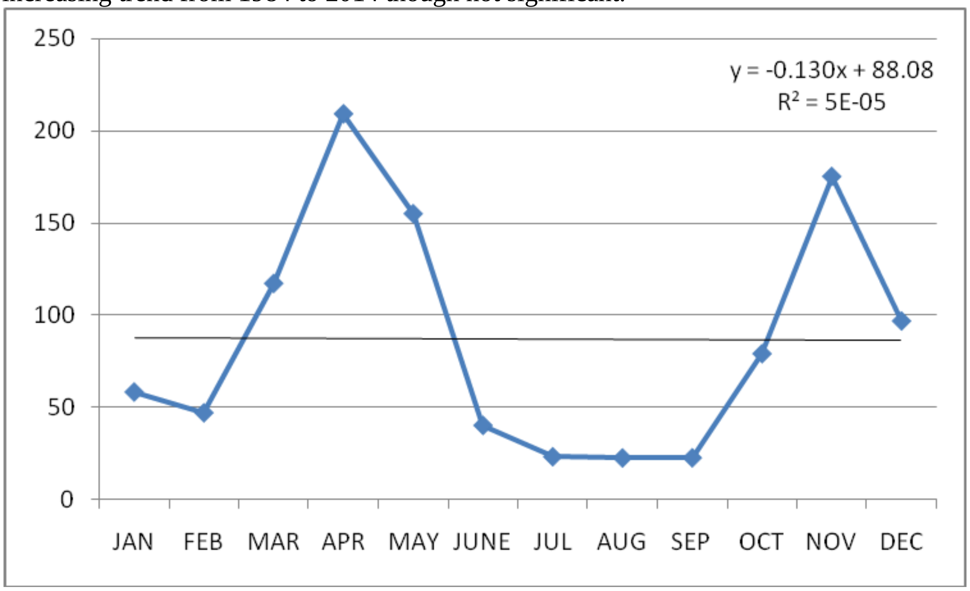

Figure 3: Mean monthly rainfall trend in CRF

High mean monthly rainfall of 209.3mm in the month of April followed by 175.3mm in the month of November was experienced with the monthly mean of 22.5mm in the month of August. There was an insignificant decreasing trend with double maxima in April and November.

Table 1: summary statistic of trend for CRF

Data file : crf tr.csv: RAINFALL					
	Test statistic	Critical values			Result
		(Statistical table)			
		a=0.1	a=0.05	a=0.01	
Mann-Kendall	0.017	1.645	1.96	2.576	NS
Spearman's Rho	0.031	1.645	1.96	2.576	NS
Linear regression	0.094	1.699	2.045	2.756	NS
Student's t	0.66	1.697	2.042	2.75	NS

H_{null} : there is no trend in the rainfall trend analysis for 31 years in coffee research foundation
H_{Alter} : there is a trend in the rainfall trend analysis for 31 years in coffee research foundation.
The p-value calculated using winks software was 0.42 which is greater than the significant vaue of 0.05. Therefore the null hypothesis was not rejected meaning there is no trend in the rainfall analysis for 31 years in Coffee research foundation station.

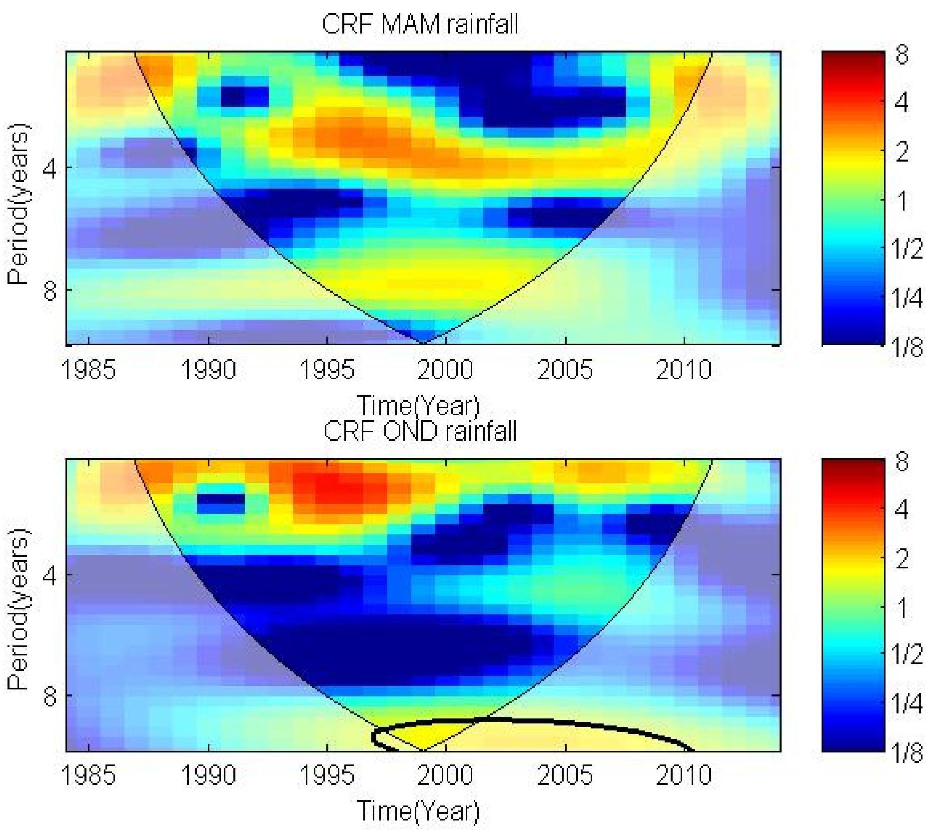

Figure 4: Wavelet power spectrum MAM and OND for CRF

Relatively higher power wavelet spectrum was observed within the band of approximately 2-5 years between 1993 and 2004 which was significant using the March April and May(MAM) wet season. In the October , November and December (OND) higher power spectrum was observed within the band of approximately 0-2 years between the year1992 and 2000.

High total annual rainfall of 1541.8mm was recorded in the year 2006 and low amounts of 529.9mm in the year 2000. There was an increasing trend from 1984 to 2014 though not significant.

3.1.2 Ndoondu Station

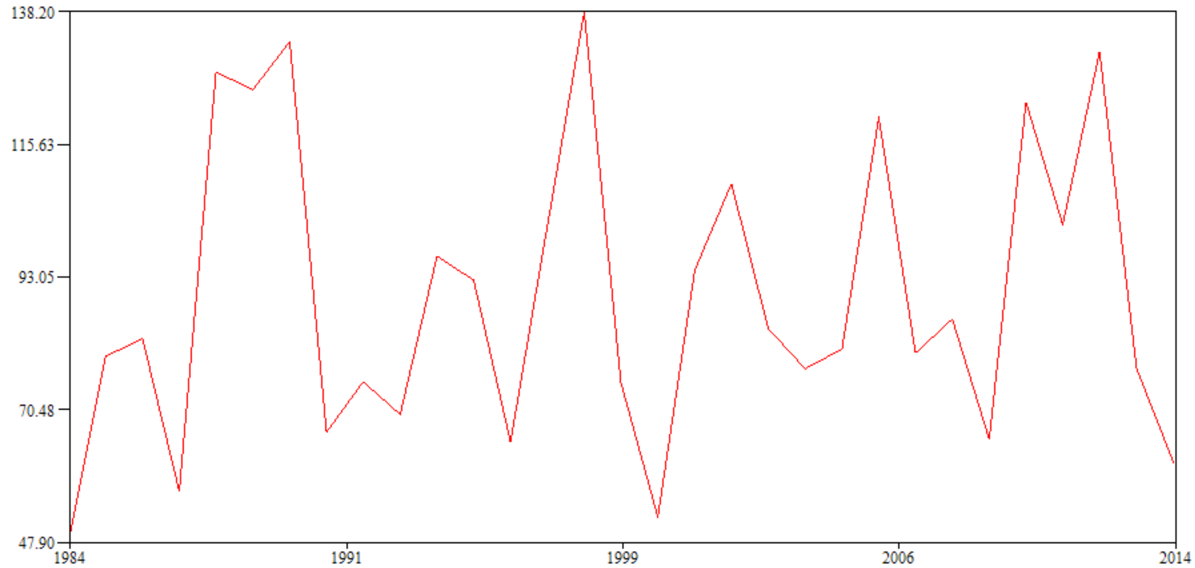

Figure 5: rainfall trend in Ndoondu

High total annual rainfall of 1658.5mm was recorded in the year 1998 and low amounts of 574.7mm in the year 1984. There was an increasing trend from 1984 to 2014 though not significant.

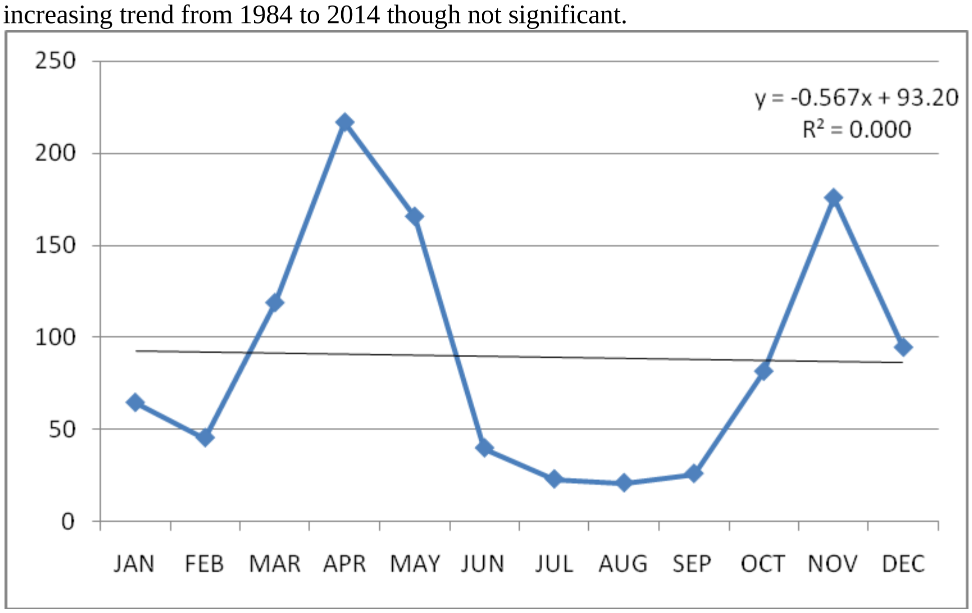

Figure 6: Mean monthly rainfall trend in Ndoondu

High mean monthly rainfall of 216.9mm followed by 175.9mm in the month of April and November respectively was experienced with the monthly mean of 21.0mm in the month of August. There was an insignificant decreasing trend with double maxima in April and November.

Table 2: summary statistic of trend for Ndoondu

Data file : Ndoondu.csv: MEAN ANNUAL RAINFALL					
	Test statistic	Critical values (Statistical table)			Result
		a=0.1	a=0.05	a=0.01	
Mann-Kendall	0.646	1.645	1.96	2.576	NS
Spearman's Rho	0.594	1.645	1.96	2.576	NS
Linear regression	0.518	1.699	2.045	2.756	NS
Student's t	0.194	1.697	2.042	2.75	NS

H_{null} : there is no trend in the rainfall trend analysis for 31 years
H_{Alter} : there is a trend in the rainfall trend analysis for 31 years.
The p-value calculated using winks software was 0.667 which is greater than the significant vaue of 0.05. thus the null hypothesis was not rejected meaning there is no trend in the rainfall analysis for 31 years in Doondu station.

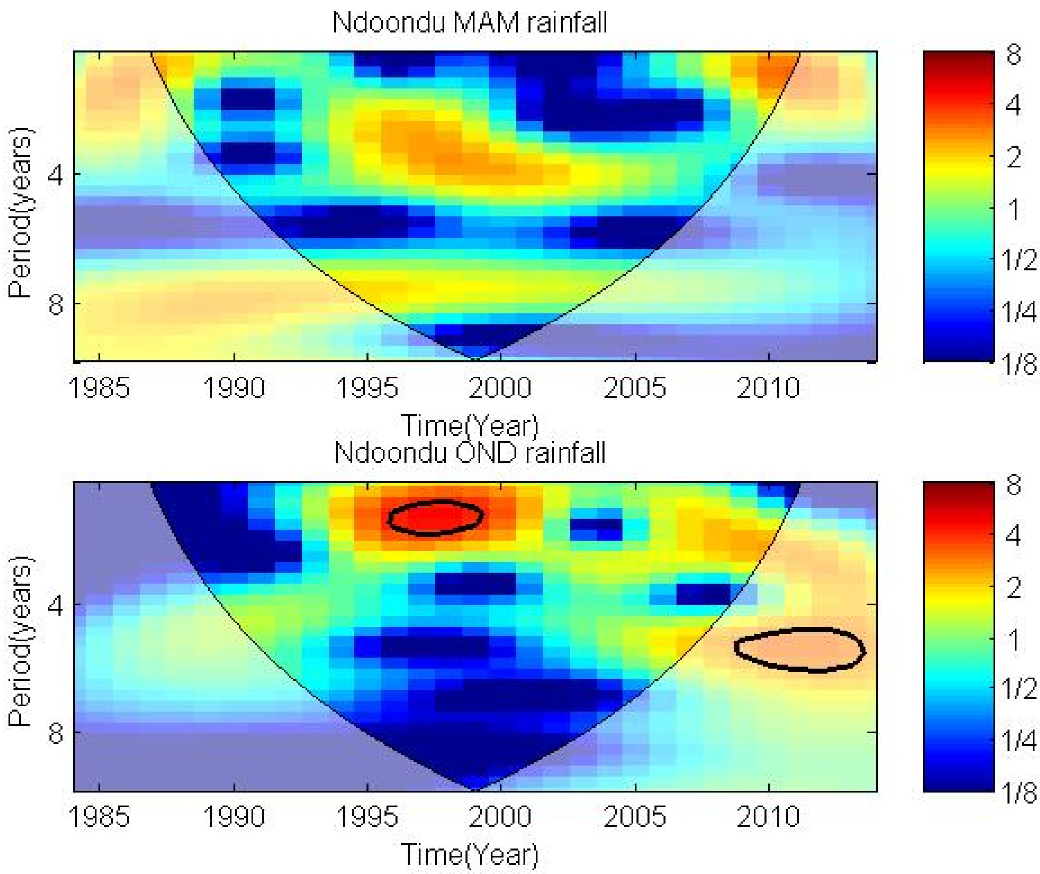

Figure 7: wavelet power spectrum OND and MAM for Ndoondu

High power spectrum was observed within the band of 0-4 years in the year 1995 and 2000 which was sigfinificant. Relatively higher power spectrum was observed within the band of 4-8 years between 2009 and 2014 though it was not significant in the OND season. During the MAM season relatively higher power spectrum was observed within 2- 5 years bad in the years of 1994 to 2000.

High total annual rainfall of 1658.5mm was recorded in the year 1998 and low amounts of 574.7mm in the year 1984. There was an increasing trend from 1984 to 2014 though not significant.

3.1.3 Ruiru mills station

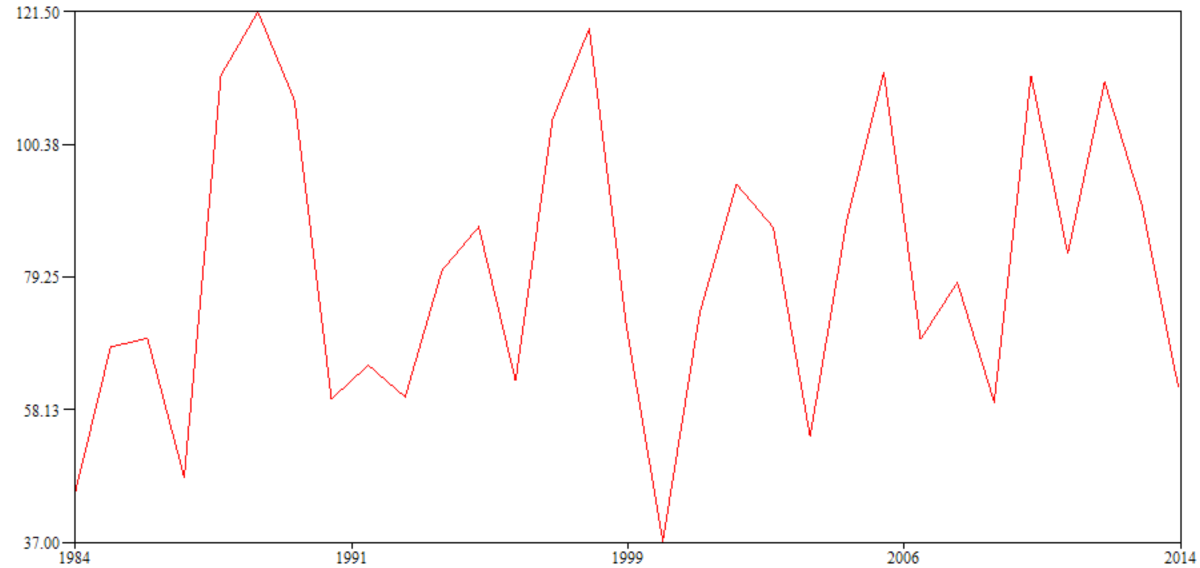

Figure 8: Rainfall trend in Ruiru Mills

High total annual rainfall of 1459.95 mm was recorded in the year 1989 and low amounts of 444mm in the year 2000. There was an increasing trend from 1984 to 2014 though not significant.

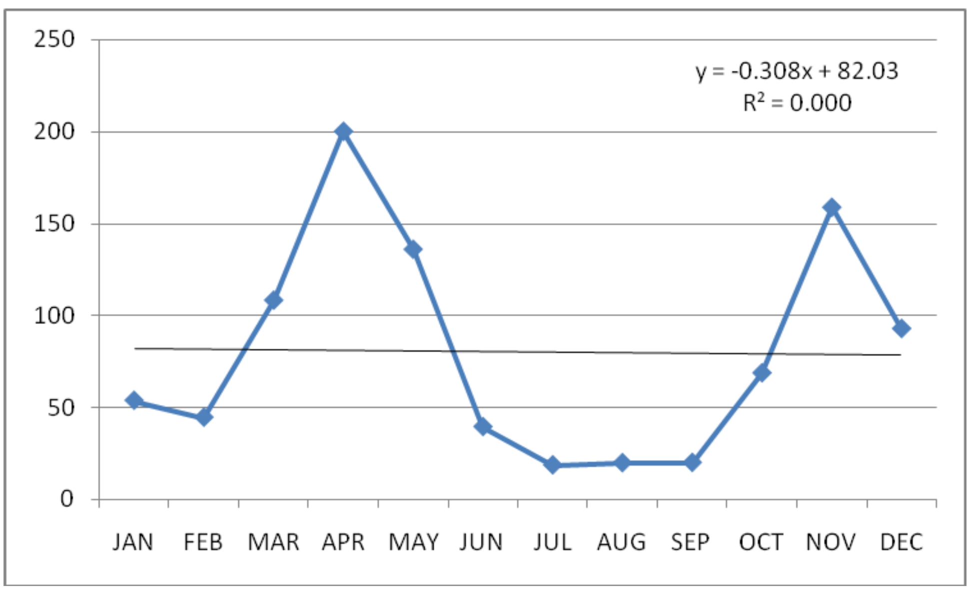

Figure 9: Mean monthly rainfall trend in Ruiru mills

High mean monthly rainfall of 199.9mm followed by 158.6mm in the month of April and November respectively was experienced with the monthly mean of 18.6mm in the month of July. There was an insignificant decreasing trend with double maxima in April and November.

Table 3: summary statistic of trend for Ruiru Mills

Data file : Ruiru mills.csv: MEAN ANNUAL RAINFALL					
	Test statistic	Critical values			Result
		(Statistical table)			
		a=0.1	a=0.05	a=0.01	
Mann-Kendall	0.986	1.645	1.96	2.576	NS

Spearman's Rho	0.954	1.645	1.96	2.576	NS
Linear regression	0.9	1.699	2.045	2.756	NS
Student's t	0.046	1.697	2.042	2.75	NS

H_{null} : there is no trend in the rainfall trend analysis for 31 years in Ruiru Mills
H_{Alter} : there is a trend in the rainfall trend analysis for 31 years in Ruiru Mills.
The p-value calculated using winks software was 0.401 which is greater than the significant vaue of 0.05. thus the null hypothesis was not rejected meaning there is no trend in the rainfall analysis for 31 years in Ruiru Mills station.

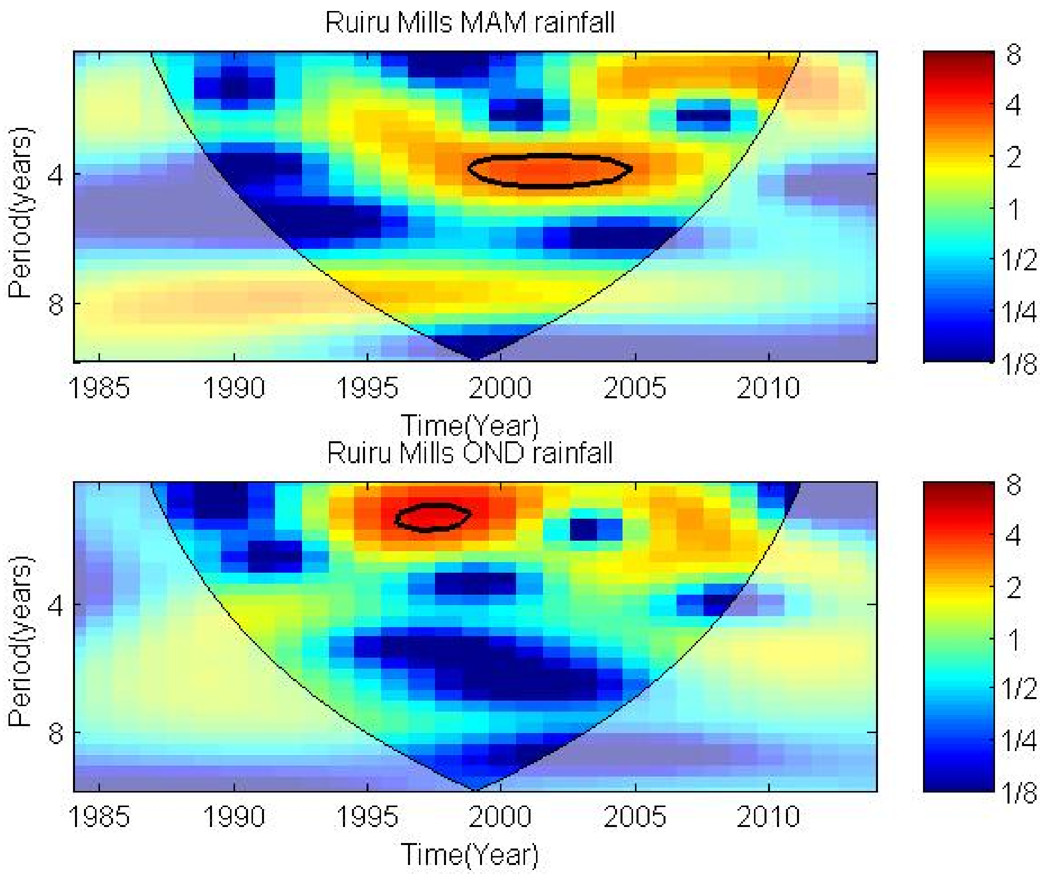

Figure 10: Wavelet power spectrum MAM and OND for Ruiru Mills

During the MAM wet season high power spectrum was observed within the band of 3-5 years in the year of 1999 to 2005 which is significant. In the OND season, high power spectrum was observed within the band of 0-3 years between the year 1995 and 2001 and its signicant.

High total annual rainfall of 1459.95 mm was recorded in the year 1989 and low amounts of 444mm in the year 2000. There was an increasing trend from 1984 to 2014 though not significant.

3.1.4 Rainfall Trends for the Three Stations

H_{null} – No significant difference in the mean annual rainfall among the stations
H_{Alter} – There is a significant difference in the mean annual rainfall among the four stations
The calculated p-value according to winks software was 0.006 comparing Ting'ang'a and Ruiru mills. The null hypothesis was rejected meaning there was significant difference between the two. The p-vaue between Ting'ang'a and Coffee research Foundation, Ting'ang'a and Doondu, Doondu and Ruiru mills, Doondu and Coffee Research Foundation, Coffee Research Foundation and Ruiru mills were 0.149, 0.342, 0.934, 1.00 and 1.00 respectively which are greater than 0.05. The null hypothesis was not rejected therefore there was no significant difference between the stations.

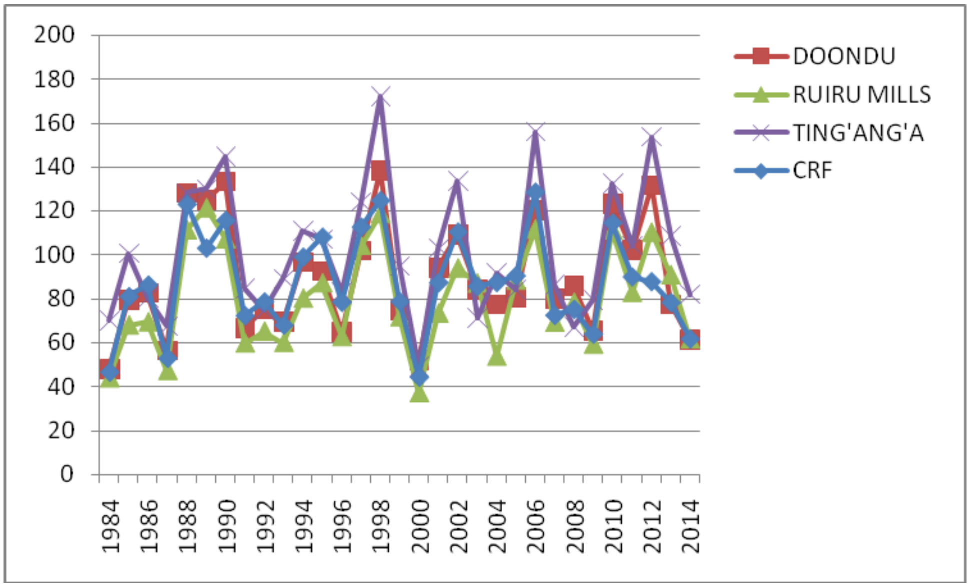

Figure 11: Rainfall trends in three stations

There was an increasing rainfall trend for the years 1984 to 2014 which was not significant in all the stations

CONCLUSION

There was an increasing rainfall trend across the four rainfall stations i.e Ndoondu, Ting'ang'a, Ruiru mills and Coffee Research Foundation for the years 1984 to 2014. The trend was not significant as the p-value was greater than 0.05 and hence the null hypothesis was not rejected. The null hypothesis was adopted meaning there was no significant trend. It was recommended that more research on the impact of climate change on water resources and determination of net recharge should be done. Water conservation measures should be adopted to avoid wastage

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