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Research Article

Annual and Seasonal Rainfall Variability for the Kenyan Highlands from 1900-2012

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ABSTRACT

The study investigated the rainfall variability for Nairobi, Nyeri, Thika, Meru, and Embu which are agriculturally potential zones located in the Kenya Highlands region. The rainfall data were retrieved from the archival documentaries and instrumental rainfall records for 112 years. Using the non-parametric Mann Kendal and regression analysis tests, the coefficient of variance and long-term trend analysis, revealed an insignificant trend in the annual rainfall for all areas under investigation. The study found out a significant deterioration in the long rains (MAM), while the short rains (OND) trend continued significantly increasing over most of the highlands, particularly in Embu and Nairobi since the 1970s. A significant decrease in the long rains was observed in Thika and Meru, which portrays a likely deterioration of agricultural outputs in these areas during the season. The study findings conclude that there are no major observed changes in the annual rainfall amounts in the Highland zones, except a slight increase attributable to the increase of the short rains in some areas. This is a useful record disclosing localized long-term rainfall trends, which can be utilized in simulating the future rainfall events for these areas.

Keywords: Climate change; Rainfall variability; Kenya highlands; Annual; Seasonal; Rainfall trends; Decadal; Man-Kendall test

INTRODUCTION

The recently noted extremities in rainfall variability are proving to be a great challenge to the agricultural-based economies of the East African countries where irrigation systems are undeveloped and agriculture is entirely rain-fed [1]. An increase in the mean annual rainfall in eastern Africa is likely to occur, which is in contrast to the Mediterranean and northern Sahara regions that are likely to experience a decrease in rainfall or the West African region where it is uncertain how rainfall will change [2]. Although there are expectations of mean annual rainfall increasing in the East African region, this increase may not be uniform across space and time [3]. There is uncertainty about these changes due to the expected under-estimation of warming impacts of the Indian Ocean in most General Climate Models (GCMs), and thus there might be overestimation in rainfall increase in this region [1]. In connection to these views, despite the inconsistency of rainfall projections in Kenya and a range of models and scenarios suggesting both an increase and a decrease in total precipitation, some records indicate that there is an upward trend in rainfall in Kenya [2,4].

Several studies have established that the total rainfall projection for Kenya increases in the order of 0.2-0.4% per annum until the 2090s [4,5]. Heavy rainfall events have increased, and extreme events are projected to become more frequent, resulting in greater rainfall variability [6,7]. A slight decline in rainfall during the March-May season has been indicated, while the October-December season shows an increasing trend due to an extension of the rainfall seasons during January and February over some locations in recent years [4]. Due to these changes, it is expected that the coastal region of Kenya is likely to become drier, while the Kenyan highlands and some parts of the northern frontier will become wetter [2].

These changes and the seriousness of their threat to natural systems and human society draw the recognition and realization that, in addition to mitigation, society must consider how to adapt and build resilience to the changing climate effects. There is a need for long-term rainfall observations analysis to derive the relevant knowledge, which is very crucial for the development of the right drought adaptation and mitigation strategies for the arid and semi-arid zones [8]. This has been emphasized by some researchers who comments on the need to generate climate forecasts at a local level (downscaled) to improve the (ENSO) events prediction skills

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through the application of the knowledge derived from within-season rainfall characteristics such as onset, cessation, and length of the growing season for effective planning of agricultural decisions [9]. This is very important because apart from the seasonal rainfall amounts, the timing of the rains has a strong impact on agricultural activities and crop yields [10].

Due to the environmental changes being experienced locally, there is a need for accurate seasonal and interannual climate monitoring and forecasting which could be used to improve the planning and management of climate-sensitive activities involving agriculture, soil and water resources, and other development sectors [4]. Localized studies on rainfall variability in the East African region are limited [11]. The majority of the studies have a wide spatial coverage hence being more generalized and not able to give clear localized information on rainfall variability.

It is important to establish localized rainfall variability, which will greatly improve climate prediction and also positively affect agricultural output (both rain-fed and irrigated) together with water resources which are inextricably linked to the timing and amount of rainfall [12,13]. Kenya in particular suffers a scarcity of such records and therefore, there is a clear need to explore longer lead times, for predicting seasonal rainfall and continuously monitor prediction relationships. This can be achievable by using earlier records, which can give better spatial and temporal resolutions for the locally based rainfall variations [11,13]. On this backdrop, the current study establishes long-term annual and seasonal rainfall variability for the Kenyan Highlands by exploring monthly rainfall data dating from the year 1900-2012.

STUDY AREA

The highland regions

The highlands occupy the south western quarter of Kenya on a plateau raised at 4000 feet, with the highest altitude being the peak of Mount Kenya 5,199 m.a.s.l [2]. The Great Rift Valley dissects the region into east and west stretching from the central to the western region. Along with it are several rivers flowing into Lakes Turkana, Naivasha, Nakuru, and Victoria [14]. The rainfall amount in the highlands ranges from 1,016 mm-2540 mm per annum, and the region has fertile soils and cooler temperatures compared to other areas in the country, hence being one of the major agricultural zones in the country [15,16]. In this study, the gauged rainfall data for Thika, Nairobi, Nyeri, Meru, and Embu represented this region (Table 1 and Figure 1).

Table 1: List of the stations, their geographical locations, and the length of the rainfall records.

Region and stations	Latitude	Longitude	Altitude (m)	MAX (mm)	MIN (mm)	MEAN (mm)	SDE (mm)	Length of the data
Highlands								
Nairobi	1°18´S	36°42´E	1654	1687	320	958.4	288.6	1900-2012
Embu	0°32´S	37°27´E	1372	1965	229.4	1138	314.4	1908-2012
Meru	0°02´S	37°39´E	1565	2220	598.2	1331	316.3	1910-2012
Nyeri	0°26´S	36°57´E	1829	1622	284.1	935.8	235.2	1904-2012
Thika	1°03´S	37°04´E	1494	1702	357.3	889.4	260.3	1913-2012

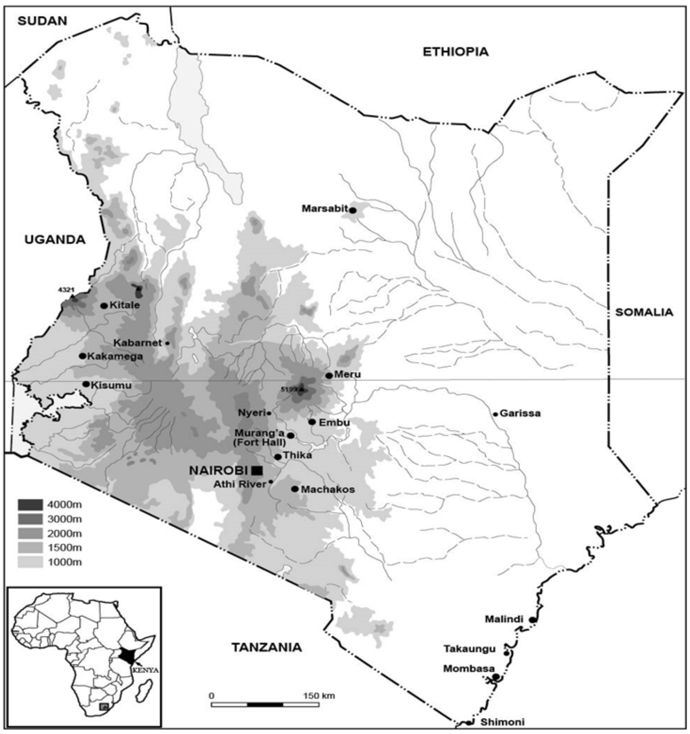

Figure 1: A map of Kenya showing the location of the meteorological stations identified for the study.

DATA SOURCES AND METHODS

The East African protectorate instrumental weather records dating from 1900-1955 in the annual and monthly bulletins, government official reports, and any unpublished records were retrieved from the archival records. The remaining instrumental records dating between 1956-2012 were sourced from the Kenya Meteorological Services Department. The locations selected for the study represented the central (Nyeri, Thika, Nairobi) and eastern (Meru and Embu) highlands of Kenya. Using non-parametric Mann-Kendall and the Linear regression tests the study analyzed the rainfall trends to establish long-term rainfall variations in the seasonal, annual, and inter-decadal scales in these areas.

Many different tests are used in detecting trends in hydro-climatology time series, which may be classified as either parametric or non-parametric [17]. Parametric trends are more powerful than non-parametric, but they require independent data which is normally distributed. On the other hand, the non-parametric tests only require the data to be independent and are tolerant to the presence of outliers in the data [14,18,19]. These are the commonly used methods in detecting statistically significant trends in environmental time series analysis. Mann-Kendall tau test is categorized as a non-parametric test and in this case, it was considered more suitable because of the outliers which may exist in the rainfall records. This test compares the relative magnitudes of data rather than data values themselves [19,20].

Another advantage of this method is that the data need not to conform to any distribution [20]. During the analysis, each data value in the time series is compared with all subsequent values. Mann-Kendall statistics (S) assumed to be zero. If the data value in subsequent periods increases than the data value in the previous period, S is increases by 1 and vice versa [19,20]. The net result of all such increase or decrease gives the final value of S. The equations for calculating the Mann-Kendall test (S) and the standardized z_{mk} are as follows:

$$s=\sum_{i=1}^{n}\sum_{j=i+1}^{n}\operatorname{sgn}(x_j-x_i) \quad \text{(Equation1)}$$

Where X_j and X_i are sequential data values of the time series in the years *i* and *j*. $sgn(x_j\text{-}x_i)$ is +1, 0 and -1 for $x_j\text{-}x_i$, greater than, equal to or less than respectively.

$$\operatorname{sgn}(x_j-x_k)=\begin{bmatrix}+1 \text{ if } (x_j-x_k)>0;\\ 0, \text{ if } (x_j-x_k)=0;\\ -1 \text{ if } (x_j-x_k)<0\end{bmatrix} \quad \text{(Equation 2)}$$

$$Var(\mathrm{S})=\frac{1}{18}\{n(n-1)(2n+5)-\sum_{p=1}^{n}t_p(t_p-1)(2t_p+5)\} \quad \text{(Equation3)}$$

Then *n* is the length of the time series t_p is the number of ties for the p^{th} value, and *q* is the number of tied values. Whenever the value of S is positive it is an indication of an increasing trend, while a negative value indicates a decreasing trend.

$$Z_{mk}=\begin{cases}\dfrac{s-1}{\sqrt{\operatorname{var}(s)}} \; if \; \mathrm{S}>0\\ 0 \; if \; S=0\\ \dfrac{s+1}{\sqrt{\operatorname{var}(s)}} \; if \; S<0\end{cases} \quad \text{(Equation 4)}$$

As shown in the equation above, the normal Z-statistics (Z_{mk}) was also established to show the significance of the trends. Positive values of Z_{mk} indicated increasing trends, while a negative Z_{mk} values indicated decreasing trend in the time series. When $|Z_{mk}|>Z_{1-a/2}$ the null hypothesis is rejected and a significant trend exists in the time series. $Z_{1-\frac{a}{2}}$, is the critical value of Z from the standard normal table, for 5% significance level the value of $Z_{1-a/2}$, is 1.96 [19-21].

To verify the Z score values the linear regression analysis was also applied which is a parametric test and the commonly used method for detecting a trend in data series. It is a model that develops a relationship between the dependent and independent variables by fitting a linear equation to the observed data [22]. The numerical measurement of the association is indicated by a correlation coefficient value which ranges between -1 to +1. A correlation coefficient value of ±1 indicates a perfect fit, while a value near zero means that there is a random, nonlinear relationship. This analysis follows the equation bellow;

Y=*m*X +C (Equation 5)

Where, Y is the independent variable, X is the dependent variable and *m* is the slope of the line and C. The coefficients (*m* and C) of linear regression are determined using the Least-Square method, which is the commonly used method with *t*-test being used to determine whether the linear trends are significantly different from zero at the 5% significance level.

In order to analyze different aspects of rainfall, monthly data was used to generate the annual rainfall time series, which were used to establish the rainfall trends for each area. The analysis of seasonal rainfall was defined into two periods, the long rain (MAM) and short rain (OND) seasons. For each station the seasonal data was divided into sub-datasets covering different periods, beginning from the starting year of rainfall data recording to 1940, 1941-1980, 1961-1990, and 1971-2012) from which trends were investigated. This is in line with the World Meteorological Organization (WMO) recommendations for determining the climatological 'Standard or normal' mean, for comparability of data collected from different stations. Using the Linear regression method the overall temporal evolution of the annual rainfall time series was analyzed. Then the overall trends for each series were determined using Mann-Kendall trend test method. Table 2 shows the temporal evolution of seasonal rainfall variability in the investigated stations over the study period.

The Kenyan highlands are comparatively wetter than other geographical zones in the country. For instance, the areas located near Mount Kenya such as Embu, Nyeri, and Meru receive a relatively higher amount of rainfall compared to other locations away from the mountains. For the evaluation of the rainfall changes in the Embu area, the Embu D.C meteorological station located at 0°32´S, 37°27´E, was considered useful due to the longevity of the data. The instrumental rainfall recording begun in Embu in 1908, the data was continuous with only a few gaps in 1918, 1952 and 1987, until the end of the study period. Although there were several years of high rainfall recordings such as 1988 (1884 mm) and 2006 (1780 mm), the highest annual rainfall (1965 mm) was registered in 1961. The study established that the long-term mean annual rainfall for Embu is 1138 mm with a standard deviation of 314.4 m.

Generally, the decadal annual trends analysis indicates that there

Table 2: Kendall tau trend analysis coefficients based on WMO climatological standard/normal mean.

	Scores	Nyeri		Meru		Thika		Nairobi		Embu	
		Long	Short	Long	Short	Long	Short	Long	Short	Long	Short
Start-1940	Kendall τ Coefficient	0.137	0.211	-0.212	0.13	-0.233	0.033	-0.148	-0.03	-0.044	0.722
	significant value	0.399	0.194	0.167	0.397	0.562	0.162	0.227	0.804	0.722	0.525
1941-1980	Kendall τ Coefficient	0.033	0.246	0.013	-0.013	0.126	0.069	0.118	0.139	-0.092	0.402
	significant value	0.774	0.032	0.91	0.91	0.262	0.67	0.32	0.248	0.402	0.376
1961-1990	Kendall τ Coefficient	0.103	-0.214	-0.129	-0.71	0.002	0.9	0.18	0.042	0.251	0.052
	significant value	0.422	0.097	0.309	0.58	0.452	0.54	0.164	0.75	0.052	0.556
1971-2012	Kendall τ Coefficient	-0.05	-0.022	-0.144	0.271	0.052	0.166	0.064	0.117	0.09	0.202
	significant value	0.641	0.837	0.183	0.043	0.284	0.35	0.551	0.281	0.406	0.132

Table 3: Percentage of increase/decrease in annual mean rainfall over the long-term normal mean.

		Nyeri	Meru	Thika	Nairobi	Embu
Long Term Mean (mm)		**935.8**	**1331**	**889.4**	**958.4**	**1138**
1900-1940	Mean	938	1295	866	924.82	1040
	%	0	3	3	3	8
1941-1950	Mean	740	1287	772	924	996
	%	21	3	13	3	12
1951-1960	Mean	945.41	1375	800	983	1031
	%	1	3	10	2.6	9
1961-1970	Mean	1126	1502	1039	971	1256
	%	20	13	17	1	10
1971-1980	Mean	992	1211	829	1001	999
	%	6	9	7	4	12
1981-1990	Mean	981	1180	976	957	1308
	%	5	11	10	0	15
1991-2000	Mean	940	1328	949	1037	1167
	%	0	0.2	7	8	3
2001-2012	Mean	926	1334	973	1129	1248
	%	1	0	9	18	10

is an increase in the annual rainfall in Embu (Table 3). The first six decades were marked by moderate variations, for most of the years, the trend cycles oscillated around the annual average and all decadal means were ~10% below the area long-term mean until the early 1960s. Since then for almost a decade, above-average rainfall was being experienced with 12% mean decadal increase of the rainfall above the long-term mean and then, a significant decline occurred in the early 70s with a 12% decline below the long-term mean. During this decade the lowest (229.40 mm) rainfall ever recorded in Embu was received in 1973, and this occurred again in the year 2000 (499.40 mm). Even though insignificant annual rainfall trends have been observed, the decadal averaging shows that the Embu total annual rainfall has been increasing since 1980, until the year 2012 the rainfall has been ~13% above the long term mean. This is evident in the linear regression trend analysis, which indicates that there is a continued significant rainfall increase in the area (Figure 2a-2c).

Generally, both long and short rain seasons in Embu have had increasing trends for most of the recording period. A significant decline for both seasons occurred from 1941-1980, specifically in the 1970s. Thereafter, both seasons improved and maintained that state until the end of the study period. The analysis shows there is an increase in the annual rainfall for Embu, and in most cases, a decrease in the annual rainfall amount coincided with poor long rainfall years. For instance, the lowest long rainfalls in Embu were recorded in 1973 (24 mm), and in 2000 (100.3 mm), as indicated earlier these coincided with the lowest annual recordings in Embu. Since1941, it is evident that the short rains maintained a significant positive trend until the year 2012, a trend anticipated to have continued after because the last two decades had shown tremendous short rainfall increase in most of the year. The decrease of the MAM rainfall and significant increase in the OND rainfall in Embu has been observed by several previous studies such as [8,9,12].

The study also considered the Meru D.C meteorological station located at 0°12´S and 37°40´E to represent Meru area. Meru is located on the northern side of Mt. Kenya and is one of the highlands, which receives high rainfall amount in Kenya. Instrumental rainfall recording in Meru started in 1910. Although there were some gaps in the 1970s, the rest of the records were adequately representative of the rainfall variability in the area. The long-term mean annual rainfall for Meru is 1331 mm. This area received the highest annual rainfalls in 1968 (2210 mm) and 1997 (2219 mm), while the year 2000 was the worst (598 mm) in records. Generally, the analysis reveals there is no significant trend for Meru annual rainfall, for most years over the study period the total annual rainfall remained within the average ranges, with exceptionally two decades (1960-1970) and (1980-1990), which registered 13% above long-term average rainfall and 11% below long-term mean respectively.

Even though the long rainfall amount seems insignificantly changed in Meru, the study establishes that there has been an unusual decline, especially in recent decades. The Mann-Kendall test analysis reveals that significant negative trends prevailed in three main epochs, during 1910-1940, 1961-1990, and in 1971-2012, while positive trends existed between the years1941-1980. The 1910-1940 and 1971-2012 trends were highly significant in comparison to the 1961-1990 trends. As the long rains decline in recent years in Meru, the short rains are on the other hand increasing. Despite the negative trends noticed in 1941-1980, 1961-1990, the short rains trend of the period between 1971-2012reveals a considerable increase of short rainfall in Meru. It can thus, be concluded that a slight decline in the long rains is being experienced in Meru, as short rains continue to increase, especially in recent years (Figure 3a-3c).

Unlike in Meru where the annual rainfall has not greatly changed, a significant increase has been noted in Nairobi in recent years. The data utilized in coming up with these conclusions were drawn from the Railway buildings meteorological station records located at 1°18´S, 36°50´E, representing the rainfall changes in the whole Nairobi ecological zone. Rainfall recording started at the Railway

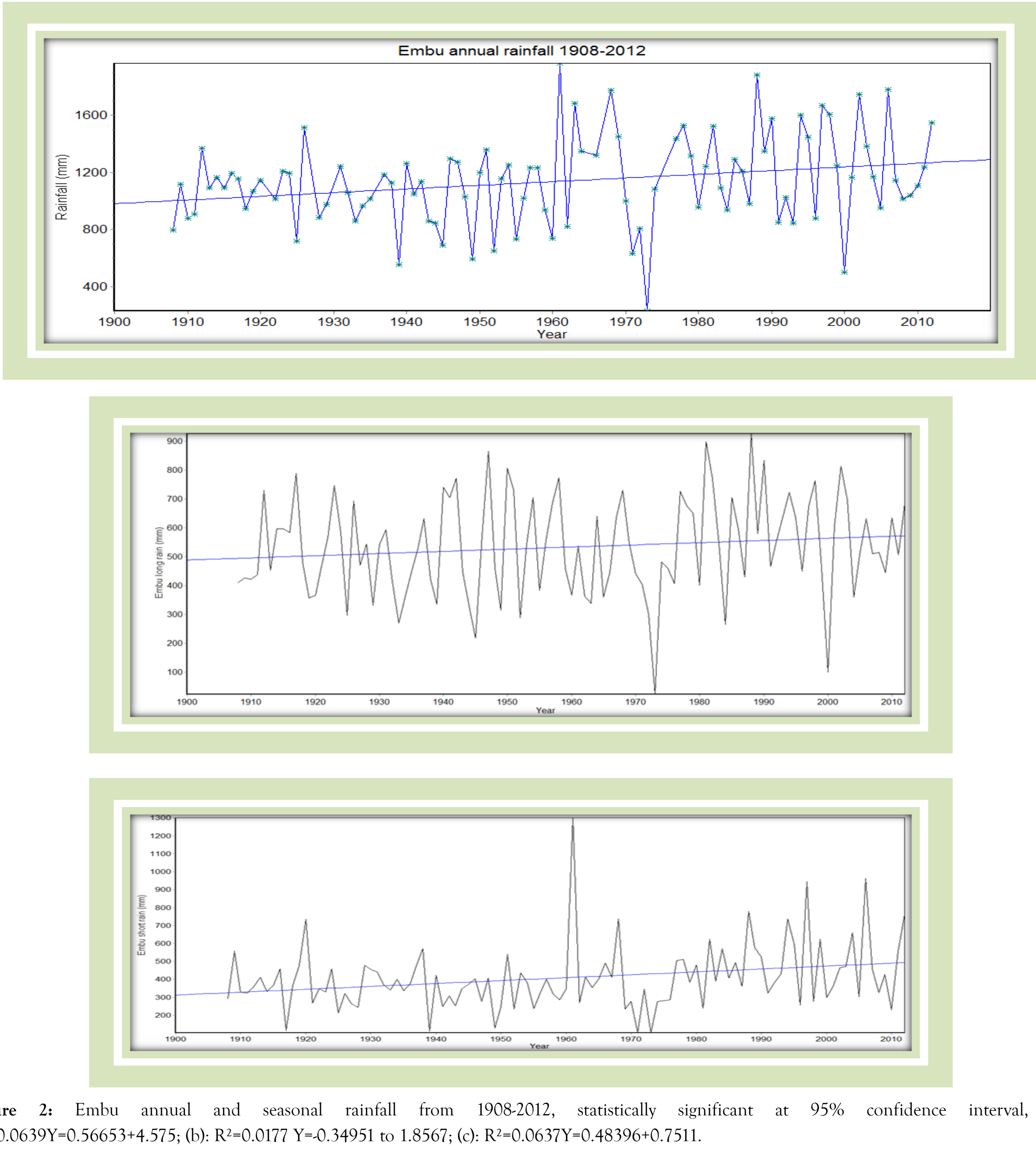

Figure 2: Embu annual and seasonal rainfall from 1908-2012, statistically significant at 95% confidence interval, (a): R^2=0.0639Y=0.56653+4.575; (b): R^2=0.0177 Y=-0.34951 to 1.8567; (c): R^2=0.0637Y=0.48396+0.7511.

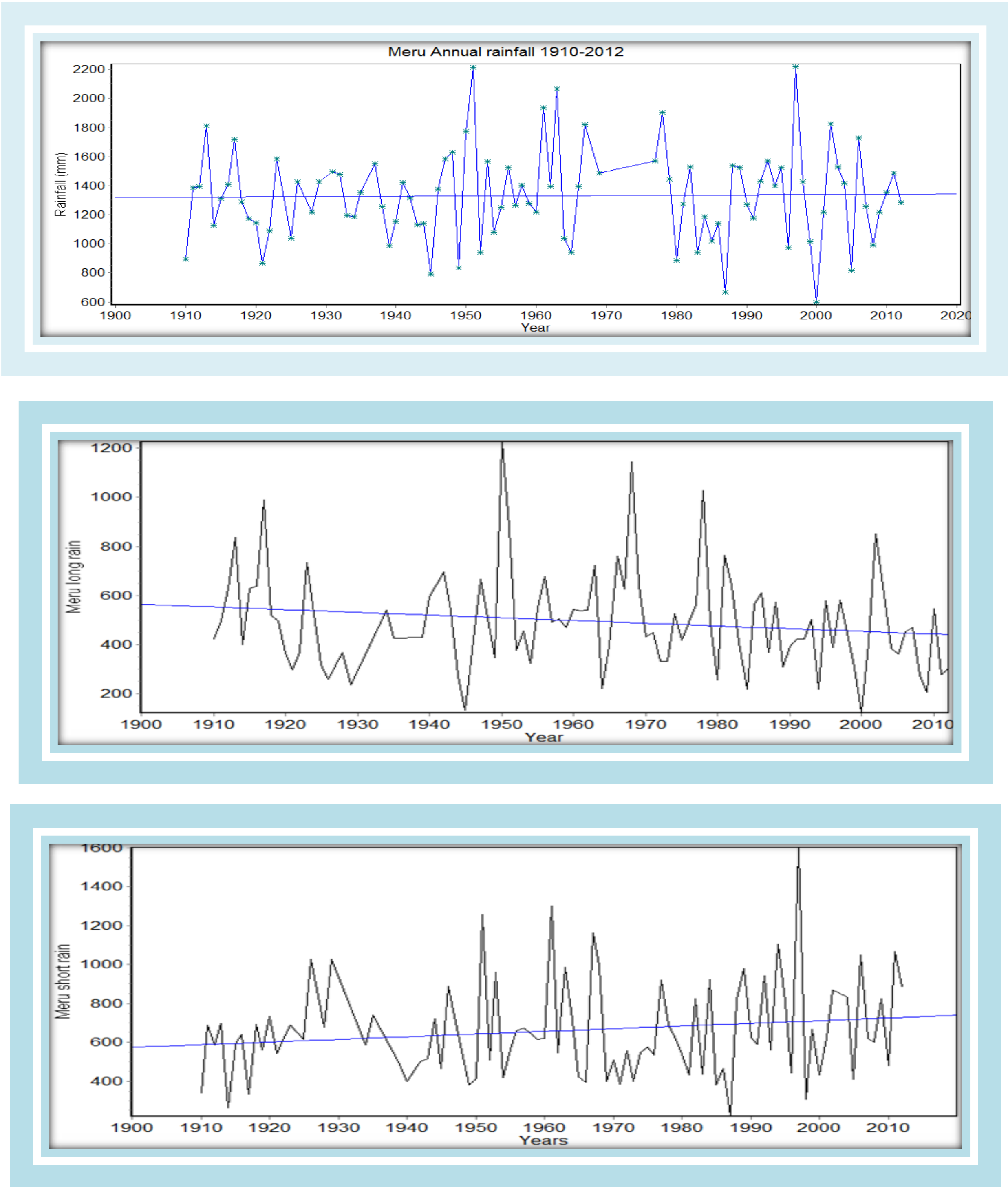

Figure 3: Meru annual and seasonal rainfall from 1910-2012, statistically significant at 95% confidence interval, (a): R^2=0.0003Y=-1.9692+2.3446; (b): R^2=0.0260 Y=-2.5236+0.31078; (c): R^2=0.0164 Y=-0.34553+3.0963.

buildings in 1900, these were the earliest rainfall recordings in Nairobi. The records for this station spanned for 65 years until 1964, after then the station became nonoperational. The study, therefore, concludes with the Dagoretti Corner rainfall entries dating from 1965-2012.

Although a lack of data was experienced in the early 40s,the available records show an increase of approximately 2% above the long-term annual rainfall mean over four decades in Nairobi from 1940-1980, after which there was about 8% increase in 1990s and 18% in the last decade of the study period. The highest ever recorded rainfall in this area occurred in 2007 (1687 mm), while the lowest amount was recorded in 1928 (320 mm). There was a decline in annual rainfall from the mid-1930s to mid-70s in Nairobi and then, thereafter in1977, heavy rainfall occurred, the favorable conditions lasted over five years before the onset of a long-term drought between 1983-1986. This concluded with another incidence of heavy rainfall in 1987and that positive trend prevailed until the end of the study period (Figure 4a-4c).

The long rains are not much changed in Nairobi as can be seen in the figure below. The analysis notes a significant negative trend in the earlier years from 1900-1940, but in the later years, an insignificant positive trend prevails until 2012. Compared to the long rains, the short rains are significantly increasing in Nairobi. As in the case of the long rains, a decline had also occurred on the

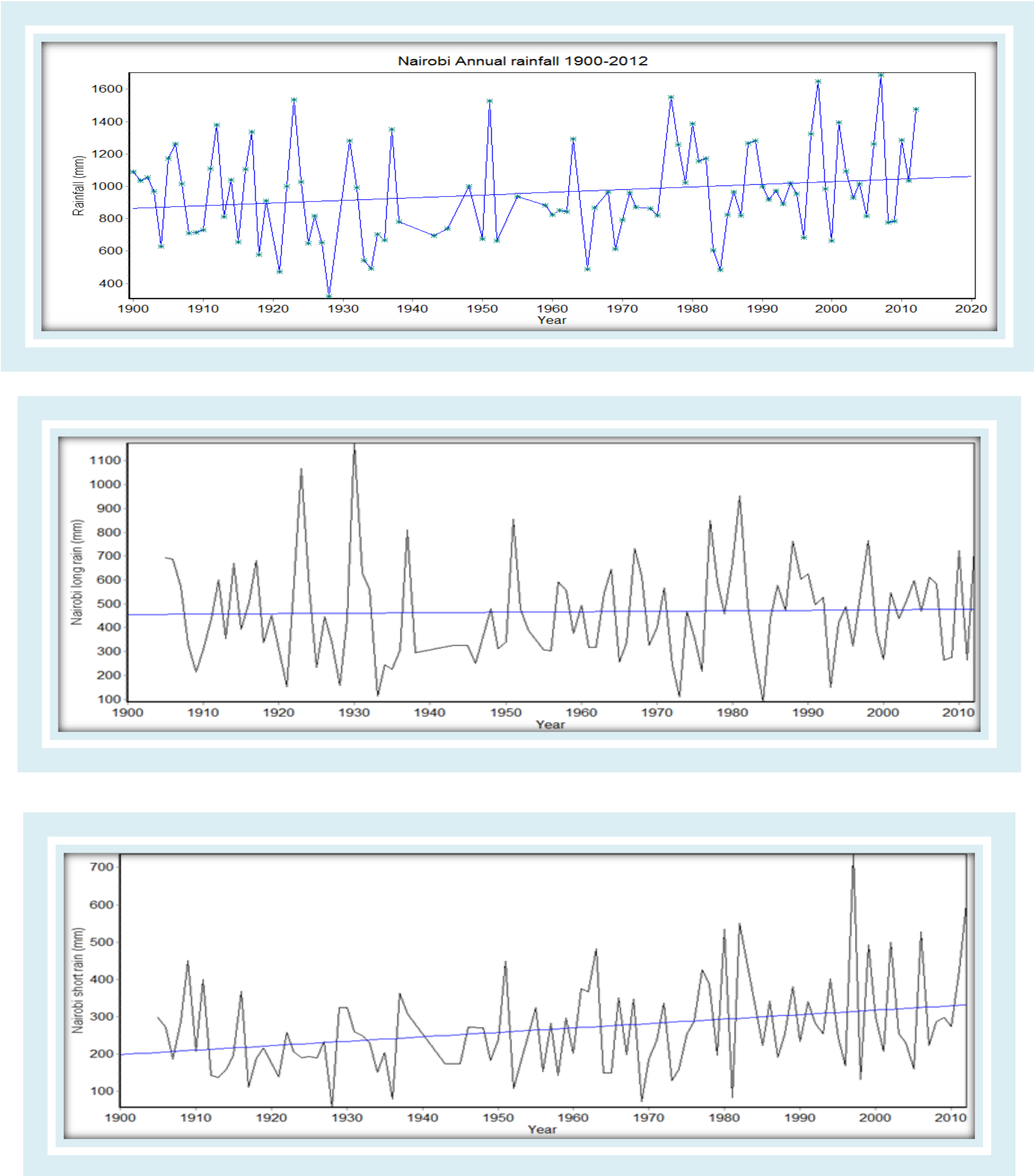

Figure 4: Nairobi annual and seasonal rainfall from 1900-2012, statistical significant at 95% confidence interval, (a): R^2=0.0407Y=-0.01903+3.3087; (b): R^2=0.001Y=-1.0878+1.4858; (c): R^2=0.0865Y=0.44931 to 1.9281

short rains in early 1900-1940, and then thereafter a significant increase occurred, which was sustained until the end of the study period. With these remarks, it is worth concluding that the total annual rainfall increase in Nairobi is attributable to the increase in the amount of short rainfall, which has been noted over the last four decades of this study period. Other than the 1981-1990 decade, which indicated no change at all in the annual records for this area, all other decades had moderate increases above the long-term mean. More importantly, the study reviews that, there has been an exceptionally high rainfall increase (18%) in Nairobi over the last 10 years (2001-2012) in comparison to all other areas investigated in this study.

The study also endeavored to establish the rainfall changes in Nyeri, which is located at 0°26´S, 36°57´Ein the southern end of Nyeri District, within the Kenyan highlands. Like in Meru, this area has not experienced great annual rainfall changes. The greatest annual rainfall decline (21%) below the long-term mean occurred in 1941-1950. Then, this decline was followed by an enormous increase (20%) in the 1960s, after which there has never been noted any other major rainfall decline in this area. The highest rainfall in Nyeri was recorded in 1961 (1619 mm) and 1997 (1622.20 mm), while the lowest record (284.1 mm) occurred in 1973. Since the year 1990, there has been no major change in the long-term annual mean for Nyeri until the end of the study period. Although, an insignificant declining trend is noticeable due to a slight decline in both rainfall seasons, in the last three decades of the study. More specifically, a significant decrease of the short rains occurred in 1961-1990, and then a significant decline for both rainfall seasons is seen occurring between 1971- to the mid-90s. Then thereafter both short and long rainfall assumes an insignificant decline trend until the year 2012 (Figure 5a-5c). In conclusion, there is a slight decline of rainfall in Nyeri.

As observed in Meru and Nairobi, the annual rainfall for Thika, which is geographically located near Nairobi at 1°03´S, 37°04´E has not also greatly changed. The highest total annual rainfall was experienced in 1968 (1702 mm) and the lowest occurred in 2000 (357.3 mm), the same years of occurrences noted in Meru and Embu. The analysis shows the long rains in Thika have not also greatly changed compared to the short rains. A negative trend prevailed in 1913-1940, although this may have been due to a lack of adequate data during this period as seen inthe figure below. There have been insignificant positive long rainfall trends all along until the year 2012. Unlike the long rains, the short rains are increasing in Thika. The study findings establish that the short rain has had positive trends until the year 2012, with the period 1971-2012 having a more significant positive trend. The highest amount of short rainfall in Thika was recorded in 1997 and 1961 respectively

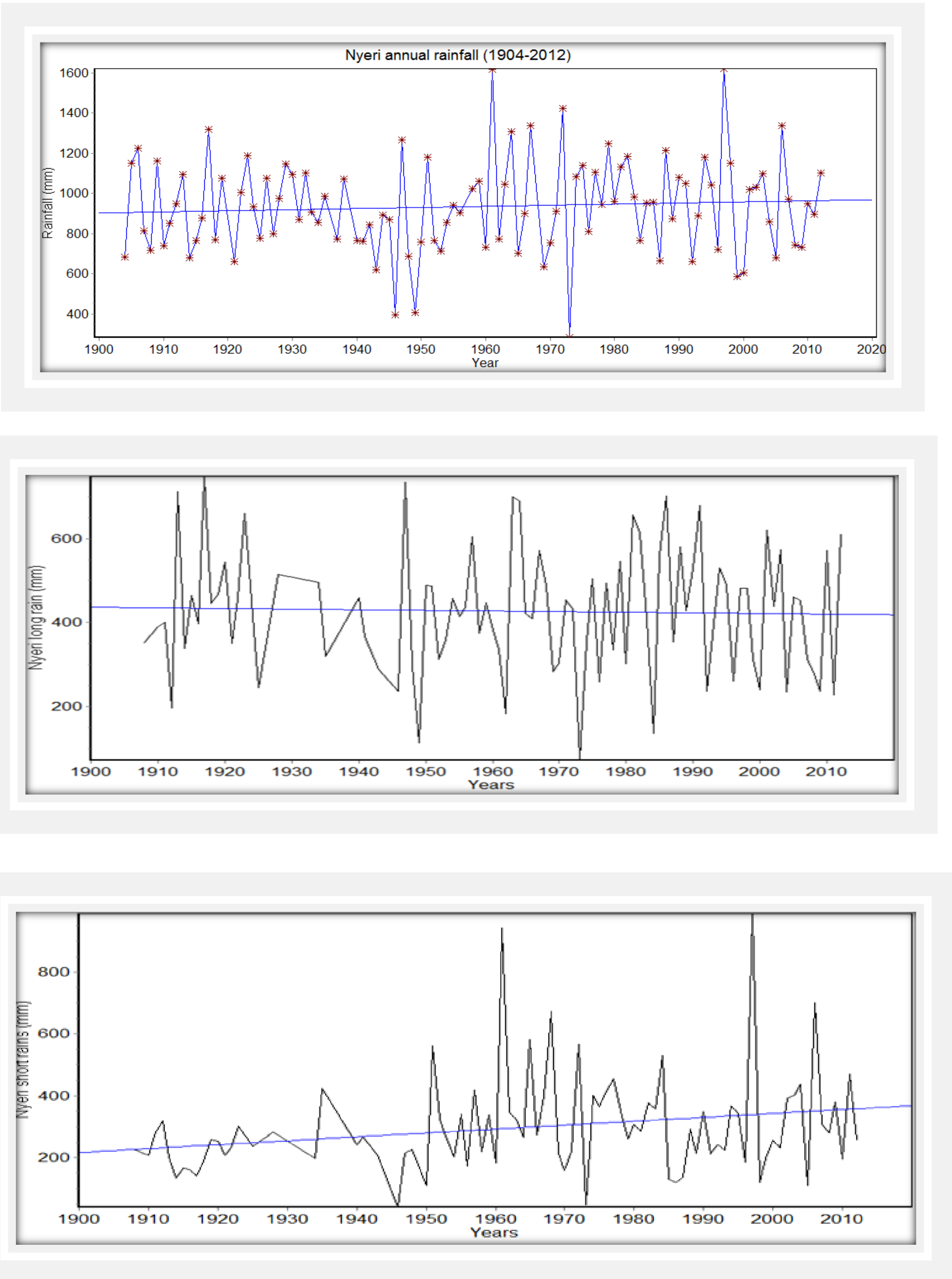

Figure 5: Nyeri annual and seasonal rainfall for from 1904-2012, statistically significant at 95% confidence interval, (a): R^2=0.0056Y=0.888+1.9902; (b): R^2=0.0009Y=-1.198+0.89921; (c): R^2=0.0446Y=0.15274 to 2.37

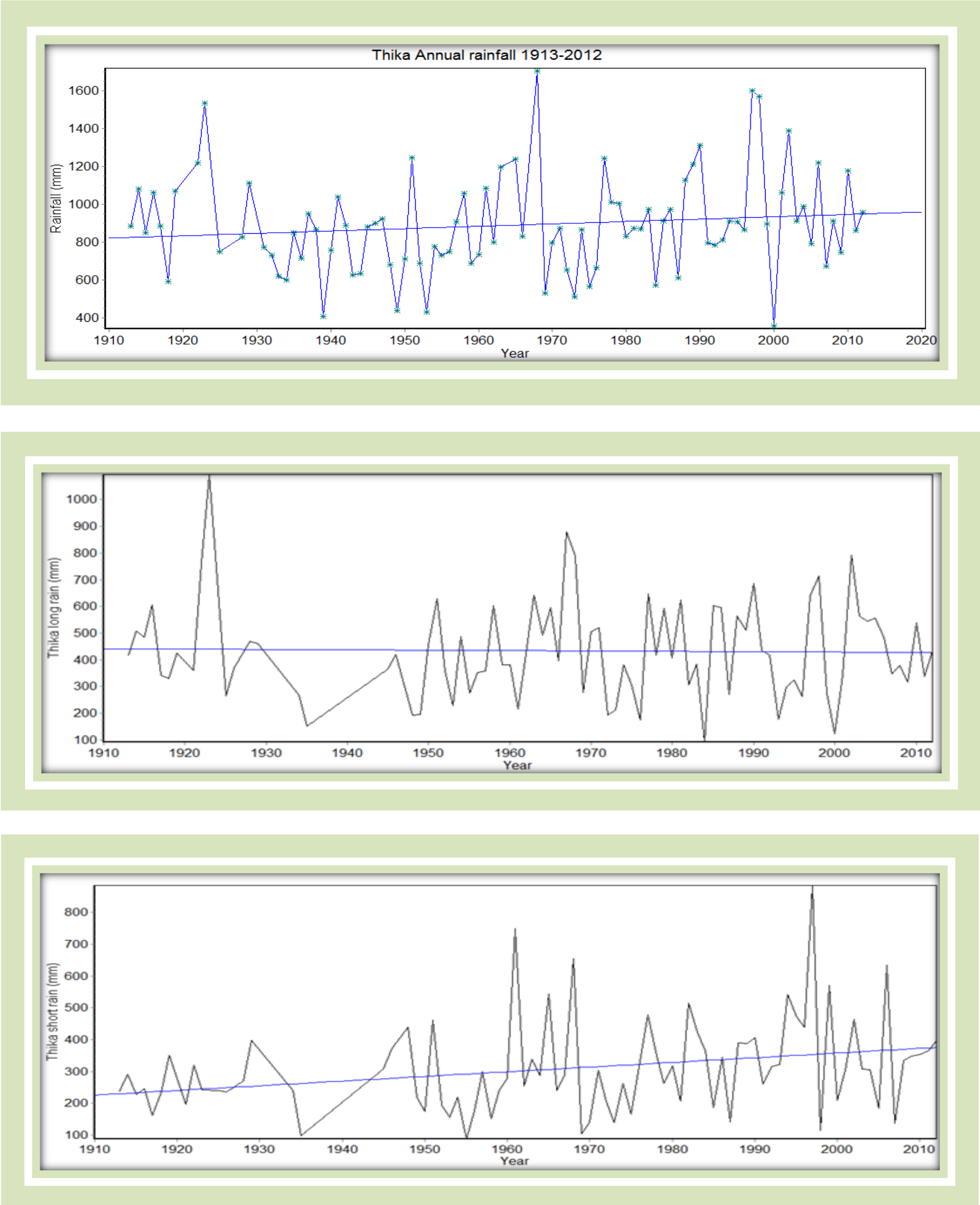

Figure 6: Thika annual and seasonal rainfall from 1913-2012, statistically significant at 95% confidence level, (a): R=0.0080Y=-0.6367+3.1476; (b): R^2=0.0005Y=1.5397+1.2597; (c): R=0.0713Y=0.38641+2.5469

(Figure 6a-6c). The current study findings, especially the seasonal variations concur with the previous studies in Kenyan Highlands and the East African region as a whole, which noted a significant decrease in the MAM rainfall and anticipated a significant increase in the OND rainfall [3,5,8,23]. This proves the robustness of the applied analysis tests and the accuracy of the rainfall data applied in this study.

CONCLUSION

The study concludes that the MAM rainfall pattern is much closer to that of the total annual rainfall than the OND rainfall pattern, in the highlands region. The study findings further indicate a significant increase in the annual rainfall in Nairobi and Embu since the 1970s, compared to the insignificant change found in Meru, Nyeri, and Thika. In these areas the annual rainfall has been greatly affected by the long rains deterioration especially in Nyeri, where a significant decline has been observed in both long and short rains from the year 1971-2012. Generally, a declining trend of the long rain has been observed in the highlands. Among the investigated stations, Meru receives the highest mean annual rainfall (1331 mm) followed by Embu (1138 mm), while Thika receive the least amount followed by Nyeri and then Nairobi. The long-term rainfall trend findings in this study are useful information that indicates the magnitude of climate variability and change at the local level and can help in formulating more informed mitigation and resilience-building policies for the local community development in the face of the globally changing climate risks.

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