Kenya Journal of Science and Technology (A) (1981) 2: 83–90

Trend of rainfall in East Africa

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ABSTRACT

Trends of rainfall in East Africa during the period 1922–1975 are examined using two independent approaches, namely the graphical and statistical methods. Under the graphical method the original and smoothed rainfall series were displayed visually on a graph, while the Spearman rank correlation test and the analysis of variance approach were employed in the statistical approach. The data used included the monthly, seasonal and annual rainfall records of about 100 stations during the period 1922–1975.

The results of the study indicate significant trends of annual rainfall at nine stations when the Spearman rank correlation test was used. The smoothed graphs indicated similar tendencies at these stations during the period of study. The use of analysis of variance technique, however, indicated no significant difference between long-term averages and the averages of some standard periods at six of the nine stations. The only three stations where significant rainfall trends were indicated with both methods were Lodwar, Wajir and Magadi. All methods indicated an increasing annual rainfall tendency at these stations during the period of study. The results from the monthly, seasonal and regional rainfall records revealed no significant trends on the regionally averaged annual rainfall records, or on the monthly and dry season records. The wet seasons had characteristics close to those of the annual series.

INTRODUCTION

The economy of the East African countries depends largely on agricultural and pastoral products. The major factor which limits these products is water from rainfall. This water source also limits the water supply for domestic and industrial use and for hydro-electric production.

It is evident from both historical and instrumental records that the global general circulation and climate have experienced certain fluctuations. These fluctuations have ranged from long-term changes of great magnitude to short-term regional anomalies. Such fluctuations have been observed in all weather elements including rainfall.

Short-term variations of the meteorological parameters are referred to as weather changes while their long-term fluctuations constitute climatic variations. The trend describes long-term movement of any time series. Such movements can be described by the use of graphical or statistical methods.

In East Africa Rodhe and Virji (1976) used a graphical technique in examining the nature of trend of annual rainfall of 35 stations concentrated mainly in Kenya and northern Tanzania. Their graphical technique indicated no significant rainfall trend except in the northeastern region of Kenya where an increasing annual rainfall tendency was displayed. In this study both graphical and statistical methods are employed to examine the nature of trend of the East African monthly, seasonal, annual and regionally averaged rainfall records during the period 1922–1975. The distribution of the stations used are given in table 1 and figure 1.

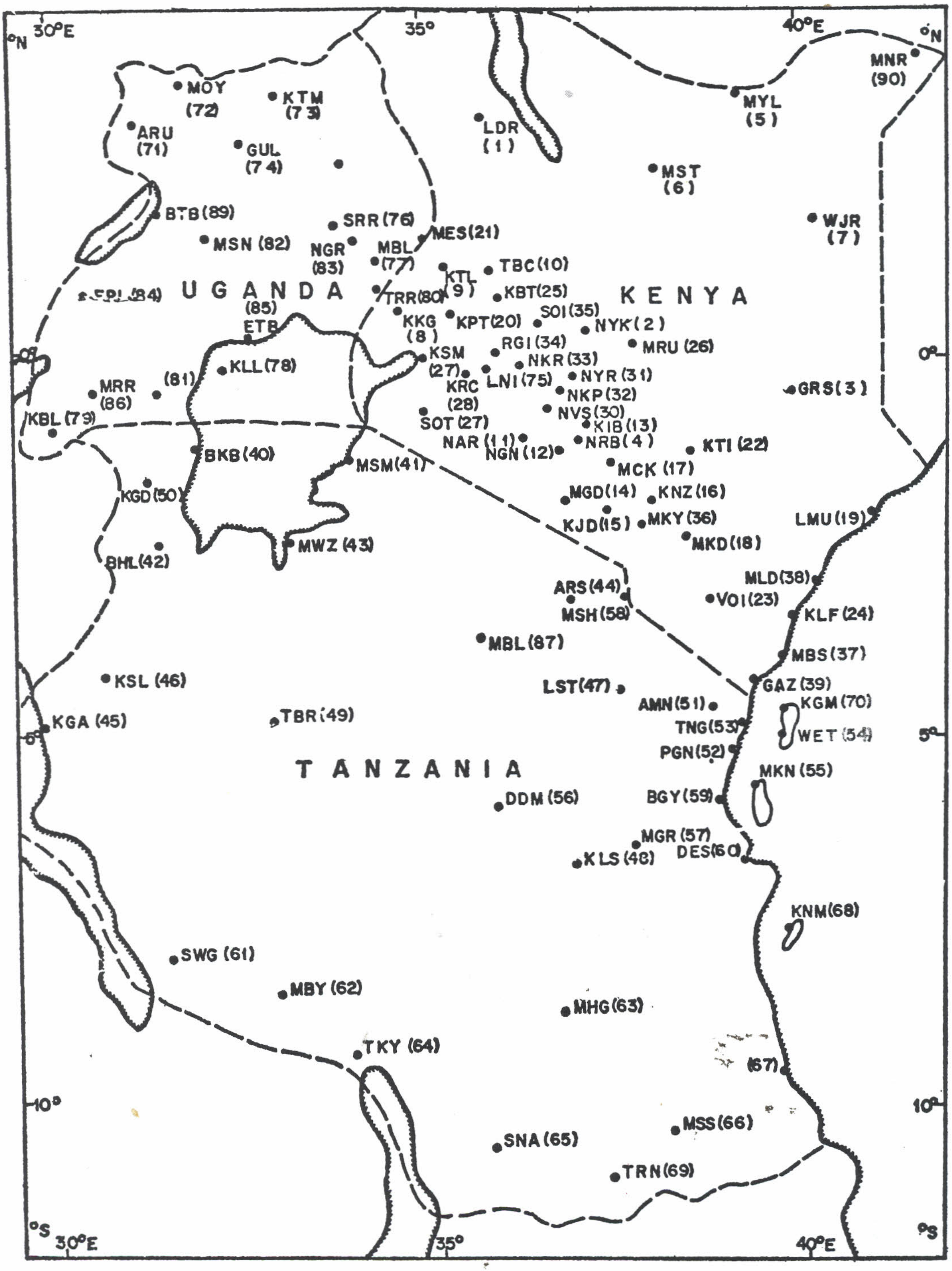


Figure 1. Network of the rainfall stations (code name and number are given for each station)

GRAPHICAL METHODS

In graphical methods, the trend is visualised from the graphical representation of the smoothed and unsmoothed time series. In the smoothed time series the trend at any given point in time is represented by a weighted average of the observed values near that point. Several weighting functions have been used in the smoothing of time series (WMO 1966; Shapiro 1975; Herrman 1971; Rabiner et al. 1975; Julian and Stephens 1977; and many others). In this study five-term binomial coefficients (WMO 1966) have been used to smooth the rainfall series. The corresponding smoothed and unsmoothed rainfall series were then displayed graphically. Some of these graphs are presented in figures 2–5.

STATISTICAL METHODS

The examination of trend by graphical methods has several disadvantages which may derive from the facts that:

1. The methods are based on visual techniques which depend highly on individual judgement;
2. Some data set are lost by some smoothing techniques;
3. Some smoothing techniques generate fluctuations which are not present in the original data a good example is the Slutzky-Yule effect where systematic oscillations may appear in the filtered series (WMO 1966; Kendall 1976);
4. Some smoothing techniques may have the effect of altering the amplitude (and often the phase as well) of the fluctuations of the time series.

An objective approach towards determining the trend of any time series is to include some statistical tests to examine the significance of any trend observed in the time series. The most commonly used methods are the analysis of variance techniques, the use of polynomial functions and methods based on rank statistics.

In the analysis of variance techniques the study period may be divided into some standard subperiods, generally of at least 30 years' records (WMO 1967). The averages of these standard periods may then be compared by using statistical tests (WMO 1966; Parthasarathy and Dhar 1974; Jones 1975; Granger 1976).

Under the polynomial approach, the trend of the time series may be approximated by fitting to the time series a polynomial which is a function of time. The weakness of this method is that, quite often the observed trends in the climatic data are unknown functions of time which generally move with time making it difficult to represent them well with polynomial functions.

In the rank statistical methods, the application of the rank correlation tests are more common. The rank correlation tests use a nonparametric (distribution-free) measure of correlation based on ranks. The most common of these methods are the Mann-Kendall and the Spearman rank tests (Kendall 1938, 1945, 1948; Kendall and Stuart 1961; Siegel 1956; WMO 1966). The Spearman rank correlation test has been used in this study. The Spearman rank correlation r_s is defined from the equation,

$$r_s = 1 - \left(6 \sum_{i=1}^{N} d_i^2 \right) / N(N^2 - 1) \qquad (1)$$

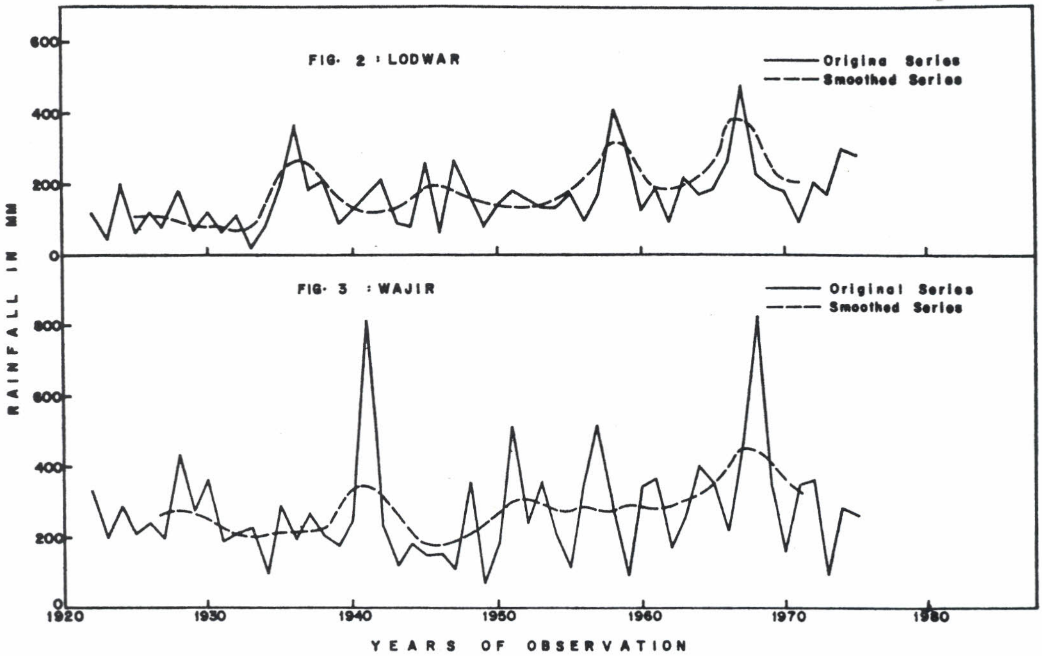
where $d_i = k_i - i$, k_i is the rank of the time series X_i with N number of observations.

The significance of the calculated r_s are tested by computing the statistic t given by,

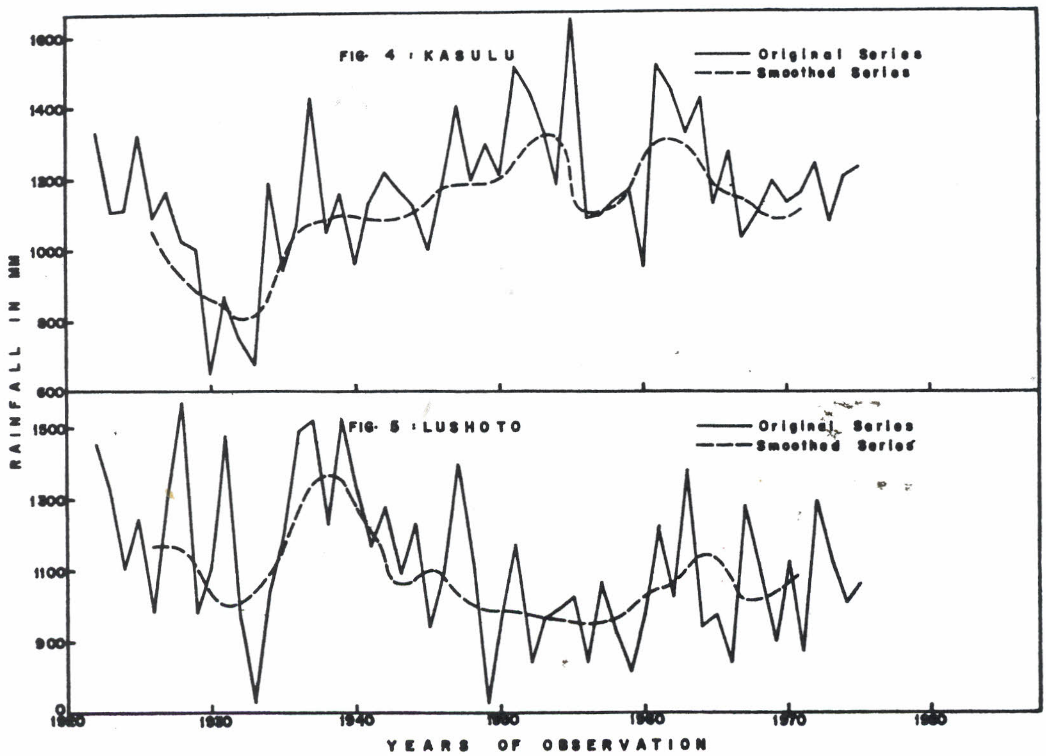
$$t = r_s \, [(N-2)/(1-r_s^2)]^{\frac{1}{2}} \qquad (2)$$

The computed t values are compared with those of the theoretical t-distribution with $N-2$ degrees of freedom. The results of this test is presented in table 1 for the annual rainfall.

The nature of rainfall trend in East Africa was further examined using the t-test. Under this method arithmetic averages for the common periods 1922–1951 and 1931–1960 were compared with the long-term averages (averages for the period 1922–1975). The results are presented in the next section.



Figures 2 and 3. Observed rainfall trends at Lodwar and Wajir



Figures 4 and 5. Observed rainfall trends at Kasulu and Lushoto

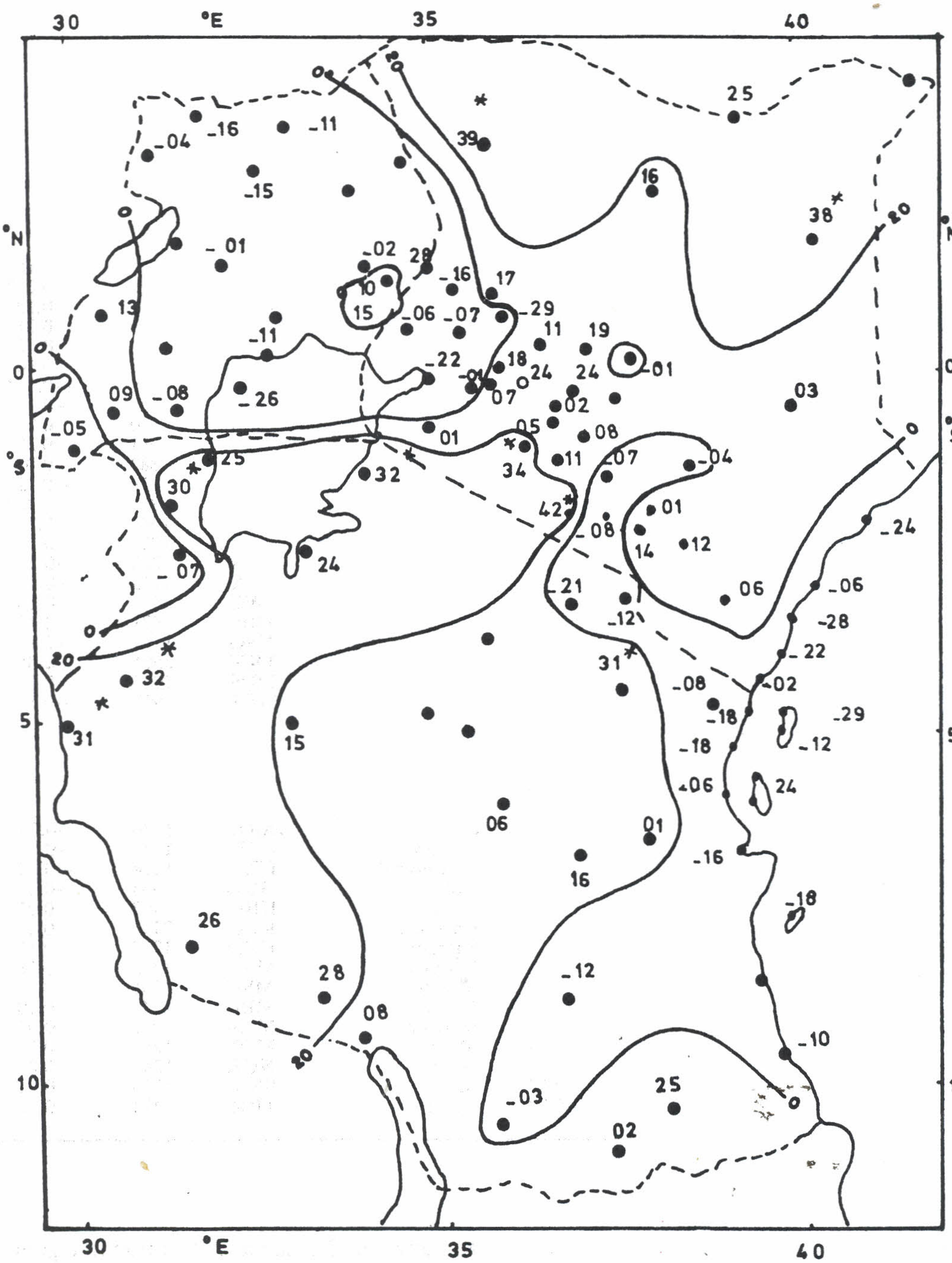
Table 1. Statistical parameters

Country and stations	Code	Mean (mm)	r_s
Kenya			
Garissa	GRS	317	0.03
Gazi	GAZ	1315	−0.02
Karbanet	KBT	1060	−0.29
Kabete	NRB	970	0.11
Kajiado	KJD	472	−0.08
Kakamega	KKG	1829	−0.06
Kapsabet	KPT	1435	−0.07
Kericho	KRC	1779	−0.01
Kiambu	KIB	1290	0.08
Kilifi	KLF	962	−0.28
Kisumu	KSM	1056	−0.22
Kitale	KTL	1018	−0.16
Kitui	KTI	1026	−0.04
Konza	KNZ	495	0.01
Lamu	LMU	1023	−0.24
Lodwar	LDR	174	0.39*
Londiani	LNI	1134	−0.08
Machakos	MCK	869	−0.07
Magadi	MGD	411	0.42*
Makindu	MKD	521	0.12
Makuyu	MKY	927	0.14
Malindi	MLI	1049	−0.06
Marsabit	MST	843	0.16
Meru	MRU	1349	−0.01
Mombasa	MBS	1184	−0.22
Mt. Elgon	MES	1061	0.28
Moyale	MYL	693	0.25
Naivasha	NVS	618	0.05
Nakuru	NKR	1040	0.24
Nanyuki	NYK	692	0.19
Narok	NAR	732	0.34*
Ngong	NGN	779	0.09
N. Kinangop	NKP	1086	0.02
Nyeri	NYN	866	0.24
Rongai	RGI	982	0.23
Solai	SOI	987	0.11
Sotik	SOT	1339	0.01
Tambach	TBC	1196	0.17
Voi	VOI	525	0.06
Wajir	WJR	277	0.38*
Tanzania			
Amani	AMN	1947	−0.08
Arusha	ARS	1238	−0.29
Bagamoyo	BGY	1051	−0.06
Biharamulo	BHL	974	−0.07
Bukoba	BKB	2044	0.25
Dar es Salaam	DES	1027	−0.16
Dodoma	DDM	562	0.06
Kigoma	KGM	971	0.32*
Kilosa	KLS	1009	0.18
Kagondo	KGD	1690	0.30*
Kilindoni	KNM	1890	−0.19
Kigomasha	KGM	1602	0.21
Kasulu	KSL	1066	0.32*
Lindi	LND	896	−0.10
Lushoto	LST	1124	−0.31*
Mahenge	MHG	1906	−0.12
Masasi	MSS	900	0.25
Mbeya	MBY	911	0.28
Morogoro	MGR	883	−0.01
Moshi	MSH	871	−0.12
Musoma	MSM	812	0.32*
Mwanza	MWZ	1049	0.24
Mkokotoni	MKN	1721	0.24
Pangani	PGN	1262	−0.18
Songea	SNA	1123	−0.03
Sumbawanga	SWG	817	0.26
Tabora	TBR	921	0.15
Tanga	TNG	1299	−0.18
Tukuyu	TKY	2505	0.08
Tunduru	TRN	1035	0.02
Wete	WET	1907	−0.12
Uganda			
Arua	ARU	1376	−0.04
Entebbe	ETB	1537	−0.11
Port Fortal	FPL	1474	−0.12
Gulu	GUL	1505	−0.15
Kabale	KBL	993	−0.05
Kalagala	KLL	2121	−0.26
Kitgum	KTM	1228	−0.11
Masaka	MSK	1112	−0.08
Masindi	MSN	1298	−0.01
Mbale	MBL	1140	0.10
Mbarara	MRR	925	0.09
Moyo	MOY	1265	−0.16
Ngora	NGR	1348	−0.02
Serere	SRR	1330	0.01
Tororo	TRR	1424	0.15

* Significant trend

RESULTS AND DISCUSSION

Table 1 gives some results of the Spearman rank test. It can be observed from these results that nine annual rainfall series indicated significant trends. These stations were Lodwar, Wajir, Narok and Magadi in Kenya, and Musoma, Kasulu, Kigoma, Lushoto and Kagondo in Tanzania. No station in Uganda indicated any significant trends. The results also indicate that the significant values of the rank correlation coefficients were positive during years of study except at Lushoto. This indicates a general increasing rainfall tendency at the eight stations with a decreasing tendency at Lushoto. These



* INDICATE SIGNIFICANT TREND AT 5 % LEVEL.

Figure 6. The spatial distribution of the spearman rank correlation coefficient (r_s)

patterns could be confirmed from the graphical approach. Figures 2–5 present graphs of some of the smoothed and unsmoothed rainfall time series. The smoothed graphs indicate tendencies close to those observed from the Spearman rank statistics.

Figure 6 presents the spatial distribution of the rank correlations. It can be observed from this map that the spatial distribution of the nine stations with significant rainfall trends forms no organized pattern. Although eight of the stations are located in the dry regions of East Africa which have high year to year rainfall variability, the rainfall stations adjacent to the nine stations showed no significant trends.

When the arithmetic averages of the standards periods are compared, no significant differences can be detected between the averages of the standard subperiods and the long-term average, except at Lodwar, Wajir and Magadi. Two of these stations (Lodwar and Wajir) are located in the dry northern region of Kenya.

The results from the monthly, seasonal and regional annual rainfall records indicate:

1. no statistically significant trend on the regionally averaged rainfall series;

2. no significant trend in the monthly and dry season records;

3. that the records of wet seasons had results close to those of the annual rainfall records. This is due to the strong seasonality of rainfall in East Africa (Trewartha 1961; EAMD 1962; Potts 1971; Griffiths 1972; Brown and Cochemé 1973).

Many authors have observed no established patterns of rainfall trends over various parts of Africa (Landsberg 1975; Bunting et al. 1975; Tyson et al. 1975; Ogallo 1979). The regional annual rainfall graphs presented by Rodhe and Virji (1976) indicated some increasing rainfall tendency in the north-eastern region of Kenya during the period 1922–72. Their regional series was defined using the yearly averages of Lodwar, Marsabit and Wajir. The results of the present study indicate some significant increasing rainfall tendency at two of these three stations (Lodwar and Wajir) during the period 1922–75. Hence any rainfall series defined using the yearly rainfall averages of Lodwar, Wajir and Marsabit will show some increasing rainfall tendency. The regional series used here were defined from empirical orthogonal analysis (Ogallo 1980).

CONCLUSIONS

Fluctuations in rainfall are manifestations of certain characteristics of the general circulation over the globe. The results of this study indicate that of the about 100 rainfall stations examined, only nine show some significant annual rainfall trend during the period 1922–75. Comparison of the averages of some standard periods using the *t*–test, however, declared only three rainfall series significant. These were the annual rainfall series at Lodwar, Wajir and Magadi.

Much effort has been made to study the causes of the fluctuations which are observed in the climatic elements, but the major drawback has been that the role of the physical factors that govern climate are not fully understood, making it difficult to understand fully the actual causes of the observed climatic fluctuations.

The results of this study also indicate that the spatial distribution formed by the nine stations with some significant rainfall trends formed no organized pattern. This make it difficult for any climatological explanations to be given for the observed significant rainfall trends. Considering the limited data used (54 years), it may be that these observed significant trends could form part of large period fluctuations which could not be detected with the available records. The fluctuations in the microclimate around the stations showing significant trends have not been examined here, but the results from homogeneity analysis indicate that the rainfall records from the nine stations with significant trends were not heterogeneous (Ogallo 1981).

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Acceptance date: 11 November 1981.