AN ANALYSIS OF MAXIMUM ONE HOUR RAINFALL INTENSITY

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H.Y. Temu

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ABSTRACT

Monthly and annual maximum one hour rainfall for thirty seven stations in East Africa for the last ten years is plotted and analysed.

Using Chow's version of the Gumbel method and probability paper developed by Powel for the function's linear plot, the two year, five, ten, twenty five, fifty and one hundred year recurrence periods are computed for each station and the ratio of the five, ten, twenty five, fifty, one hundred year recurrence periods to the two year recarrence period (The median) plotted and analysed.

Thus if the stations were well distributed over the whole of East Africa, it would be possible to obtain maximum one hour rainfall intensities even over some areas devoid of a recording raingauge. Nevertheless, physiographic influences and seasonal variations manifest themselves in the analyses made, so that it is still possible to approximate one hour maximum rainfall intensities and various recurrence periods over most parts of East Africa even where a recording rainguage is unavailable.

INTRODUCTION

Rainfall intensities of various durations are required for Hydrologic and Civil Engineering purposes. Design of structures subject to flooding such as bridges, factories, culverts, dams, warehouses, a city sewer system an airport drainage fascility and the like, must be based upon sizes of floods and therefore rainfall intensities which the structure will have to withstand during its economic life.

If the design flood for a particular project is to have a recurrence interval T much shorter than the period of record, its value may be easly determined by plotting peak flows V_s T as computed from Weibull plotting positions formula, $T = N+1 / m$

Where N is the period of record in years

m is the order number of the sample extreme value series

T is the recurrence interval in years.

and sketching the curve through the plotted points. Because of inaccuracies in the plotted positions of the larger floods, a line sketched to conform to these floods may depart substantially from the location of the true frequency curve. The principles of statistics must be employed to construct a frequency curve which conforms to the available data.

When a probability paper is chosen for use, the plotting of data on the paper requires the knowledge of plotting positions. Numerous methods have been proposed for the determination of plotting positions. Most of them are ampirical. As the extremal distribution was introduced to frequency analysis, the Weibull formula was soon found to be very satisfactory.

Chow has shown that this formula is theorectically suitable for plotting the annual maximum series. A comparative study of the Beard, Hazen, and Weibull methods by Benson has also revealed that, on the basis of theorectical sampling from extreme values and normal distributions, the Weibull formula provides the estimates that are consistent with experience. The Chegodayev formula is an empirical formula commonly used in U.S.S.R. but Weibull formula has been recommended as the All-Union Standard.

It may be noted that all methods of determining plotting positions give practically the same results in the middle of a distribution, but produce different positions near the "tails" of the distribution. Thus the choice of a plotting position formula becomes important. According to Benson, it is believed that only by use of a method that gives the mathematically expected value of a probability does the expected recurrence equal that experienced over a long period of time, and that commonly used methods may overestimate the benefit cost ratios or proposed projects if the method does not furnish the mathematically expected value. Therefore a refined choice of a method depends on the acceptance of certain statistical principles and on the aim of the analysis.

Frequency analysis techniques to draw maximum information from floods and rainfall records and evaluate the most probable distribution of the parent population exist.

Fisher and Tippett showed that if one selected the largest event from each of many large samples, the distribution of these extreme values was independent of the original distribution and conformed to a limiting function. Gumbel suggested that this distribution of extreme values was appropriate for flood analysis since the annual flood could be assumed the largest of a sample of 365 possible values each year. Based on the argument that the distribution of floods is unlimited (i.e. that there is no physical limit to the maximum flood, he proposed that the probability of the occurrence of a value equal to or greater than any value be expressed as $P = e^{-e^{-b}}$

where e is the naperian logarithms and b is given by $b = \frac{1}{0.77976\sigma}(x - \bar{x} + 0.45\sigma)$

where X is the flood magnitude with the probability P

$\bar{x}$ is the arithmetic average of all floods in the series and σ is the standard deviation of the series computed from.

$$\sigma = \sqrt{\frac{\Sigma(x-\bar{x})^2}{N-1}}$$

Where N is the number of items in the series (the number of years of record).

Probability P is related to the recurrence interval T by $T = 1/P$

Gumbel has therefore shown that for the assumed distribution, the value of a hydrologic event X which may be expected to be equalled or exceeded on the average once every T years is given by the formula.

$$X = \bar{X} + \frac{\sigma}{\sigma_n}(\log_e T - \bar{X}_n)$$

where $\bar{X}$ and σ are the mean and standard deviation of the observed annual maximum events and $\bar{X}_n$ and σ_n are the reduced mean and reduced standard deviation and depend only on sample size.

Chow proposed a general frequency formula by expressing the frequency of occurrence of the value X in terms of a frequency factor K which depends upon the distribution of the particular hydrologic event under consideration. The factor K is defined by the equation $\Delta X = \sigma K$

so that equation 4 becomes $X = \bar{X} + \sigma K$

note that from 4 and 6 $K = \frac{1}{\sigma_n}(\log_e T - \bar{X}_n)$

According to the definitions of the various terms in the equation, K is independent of the sample size and can be computed in advance. Therefore by computing the mean of the sample $\bar{X}$ and its standard deviation σ the value of x corresponding to a given return period T can be computed from equation 6. Values of K can be found in tables.

The theory of extreme values has been applied to many hydrological problems with satisfactory results. Certain assumptions must however be satisfied. That the population of the sample is normally distributed. Thus the observations are independent and that the series being analysed is a sample of an infinite population series. Therefore when theory is applied to the frequency distribution of annual maximum hourly rainfalls, we are assuming that the "population of 365 X 24 hourly values from which the annual maximum rainfall is drawn, is large enough to be considered infinite"

Linearization of probability plotting has been proposed by many hydrologists since Hazen first suggested graphical linearization of the normal distribution in 1914. By linearization Powel constructed the probability paper for type I extremal distribution proposed by Gumbel for the flood freqnency analysis. Such paper may be called Gumbel-Powel probability paper.

This paper makes use of the above Gumbel method, using Chow's frequency factor and the Gumbel-Powel probability paper to obtain the two year recurrence values.

In regions of strong topographic influences on precipitation short duration rainfall intensities for various return periods have been successfully related to topographic and general climatic parameters to observation stations for short duration rainfall. Analyses of this kind have also permitted the estimattion of rainfall intensities over some other areas where recording raingauges are not available. Evidenced from many publications, in United States of America for example, such analyses were performed over the entire country and for various project basins of the country. The two year values map and the recurrence period ratios

X_1/X_2 where $T = 5, 10, 25, 50$, and 100 years for each station therefore permit an estimation of one hour rainfall intensity over any part of East Africa.

METHOD

Monthly and annual distribution of maximum observed one hour rainfall amounts for selected thirty seven stations of East Africa with five to ten years records were plotted and analysed.

The five, ten, twenty five, fifty, and hundred year return period values were computed for each station's annual series using the Gumbel method.

The maximum observed annual series was plotted on the Powel-Gumbel probability paper for each station and a best straight line of fit drawn. The computed recurrence values, plotted as a straight line over the same Gumbel-Powel graph paper for each station and closely conformed with the fitted line by eye. The two year recurrence value X_2 was then determined for each station, plotted over the map of East Africa and analysed. Further; ratios of the recurrence period values to the two year recurrence period value for each station, namely X_5/X_2, X_{10}/X_2, X_{25}/X_2, X_{50}/X_2 and X_{100}/X_2 were separately plotted on maps of East Africa and analysed.

RESULTS

From the observed maximum hourly rainfall intensities' maps for each month, it is noted that there is a seasonal pattern closely related to the climate of East Africa. Thus Southern Tanzania experiences its highest fall per hour during the months of November to March. The two rainy season areas: the coast north of Dar es Salaam, the lake Victoria basin and central districts of Kenya are clearly manifested in the analyses. Regions of low seasonal and annual rainfall such as dry zones along the rift valley and Northern Kenya seems to experience low rainfall intensity as well. It is further noted that Northern Uganda seems to observe a long high rainfall intensity April to October with peaks in June and July months in conformity with the area's seasonal rainfall pattern.

From the annual maximum hourly rainfall intensity map, the highest intensities occur over the Rufiji basin, the north eastern highlands of Tanzania, the lake Victoria region, and northern Uganda. It is of interest that the same pattern is manifested over the two year recurrence values map.

Maps of the recurrence value ratios X_T/X_2 indicate a characteristic ratio for a given physiographic region. Thus the X_{10}/X_2 map shows a value of 1.2 for the lake, 1.6 for the central districts of Tanzania and central district of Uganda 1.7 central districts of Kenya, 1.6 over the coastal belt 1.9 on the foothills of mountainous areas.

DISCUSSION

For higher recurrence values we have low probabilities. Thus the errors in obtaining any values decreases with the frequency. The one year and two year recurrence values may therefore be resonably correct and hence the use of the X_2 map in evaluating any of the X_T values from the X_T/X_2 maps.

Due to the sparsity of stations it was not possible to examine more closely the variability of the one hour rainfall intensity in Elevation and Aspect.

Longer duration rainfall intensity 3 hours, 6 hours, 12 hours 24 to 72 hours analyses are necessary in designing large structures such as bridges and dams.

APPENDICES

(I) A stations map of East Africa

(II) Monthly maps and an annual map of maximum hourly rainfall of East Africa.

(III) Two year recurrence value map of East Africa.

(IV) X_T/X_2 recurrence period ratio maps of East Africa for $T = 5$, 10, 25, 50 and 100 years.

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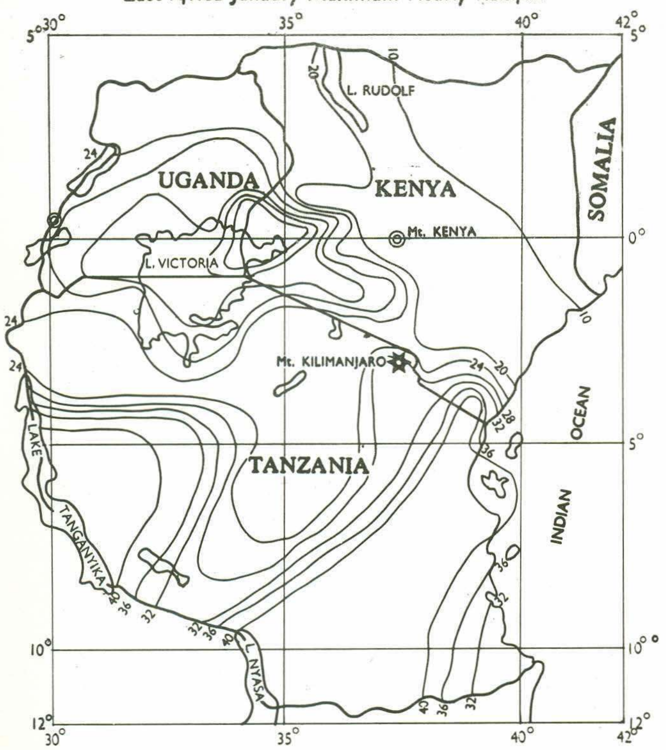
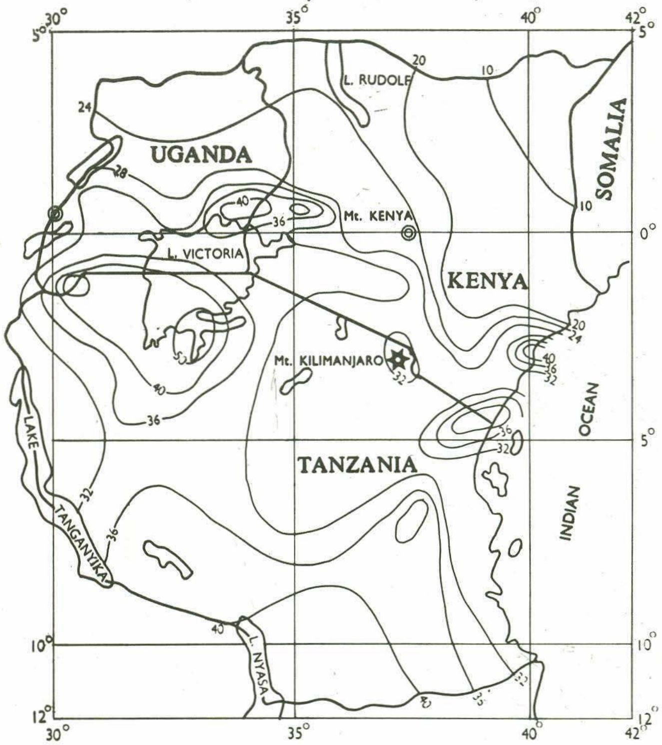
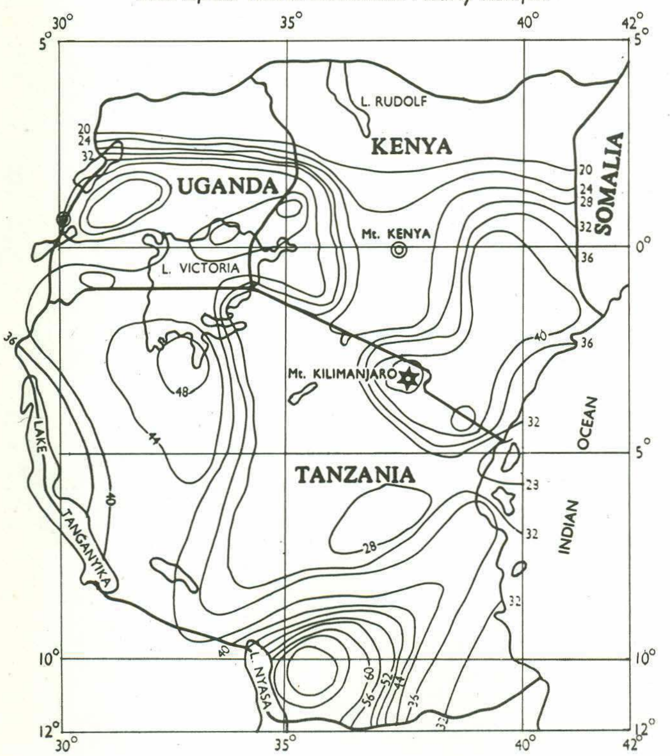
East Africa January Maximum Hourly Rainfall



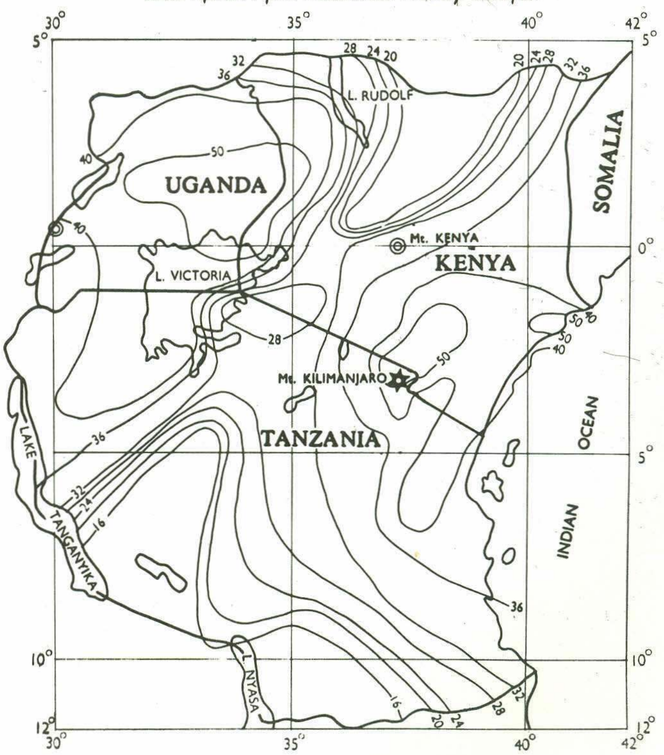
East Africa February Maximum Hourly Rainfall



East Africa March Maximum Hourly Rainfall



East Africa April Maximum Hourly Rainfall



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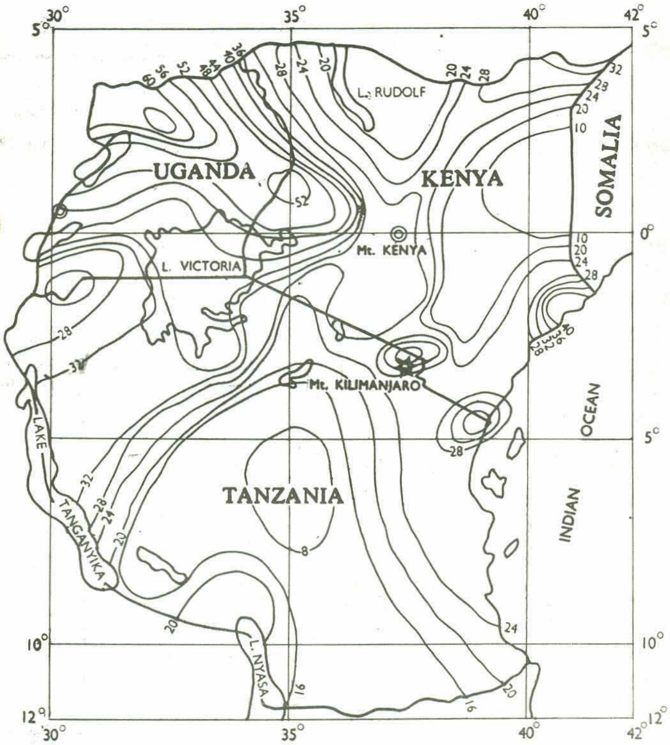
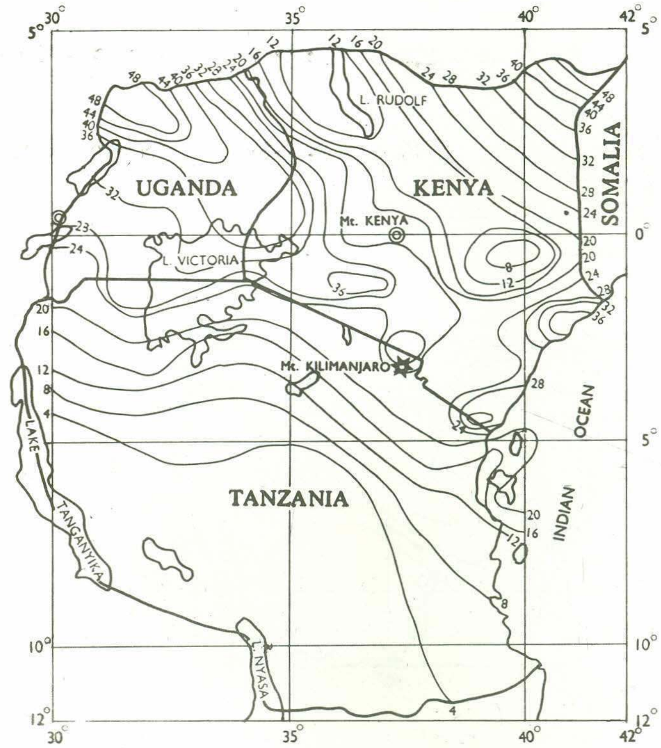
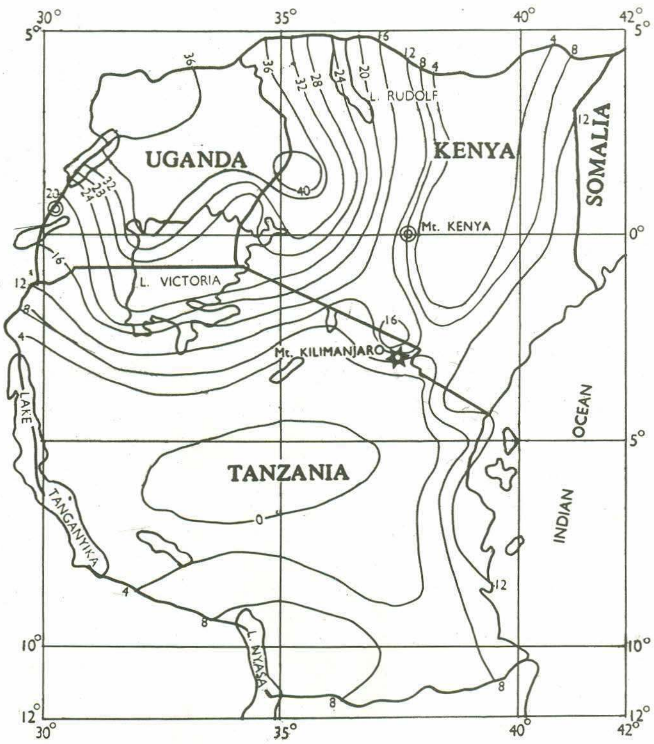


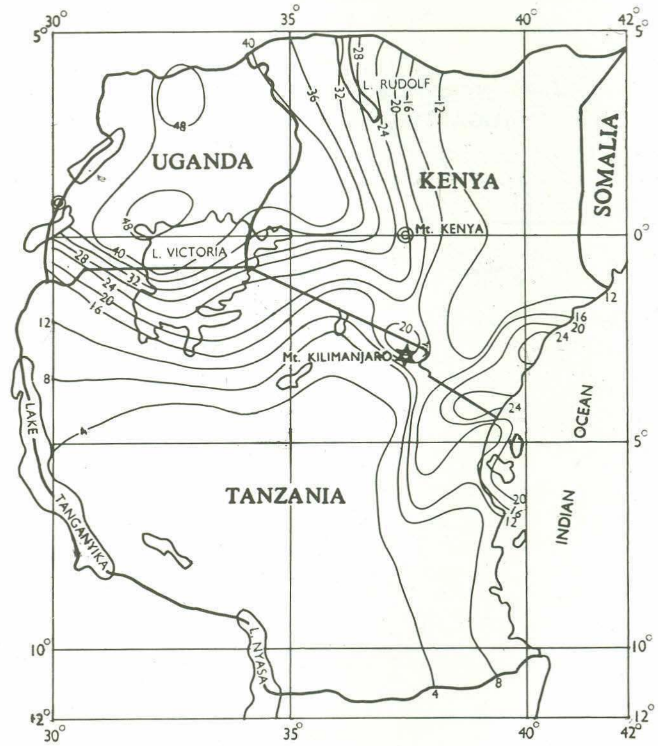
East Africa June Maximum Hourly Rainfall



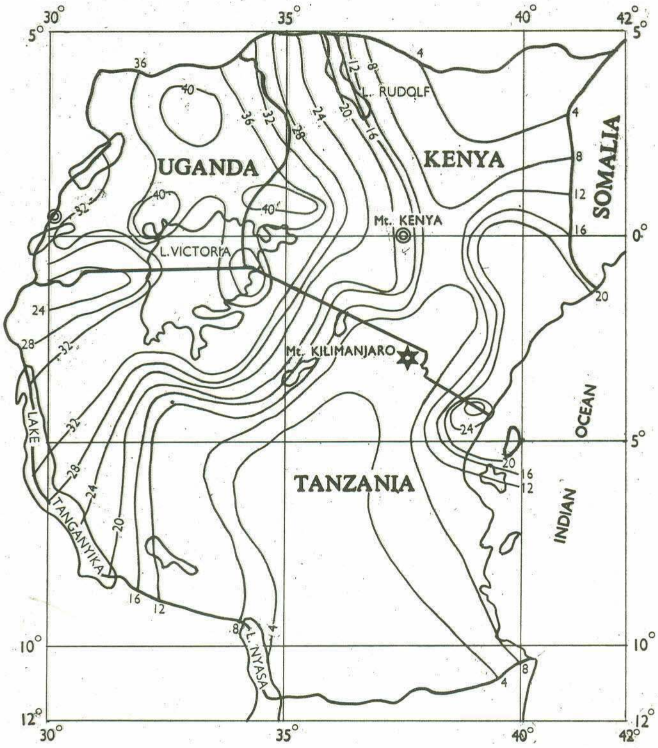
East Africa July Maximum Hourly Rainfall



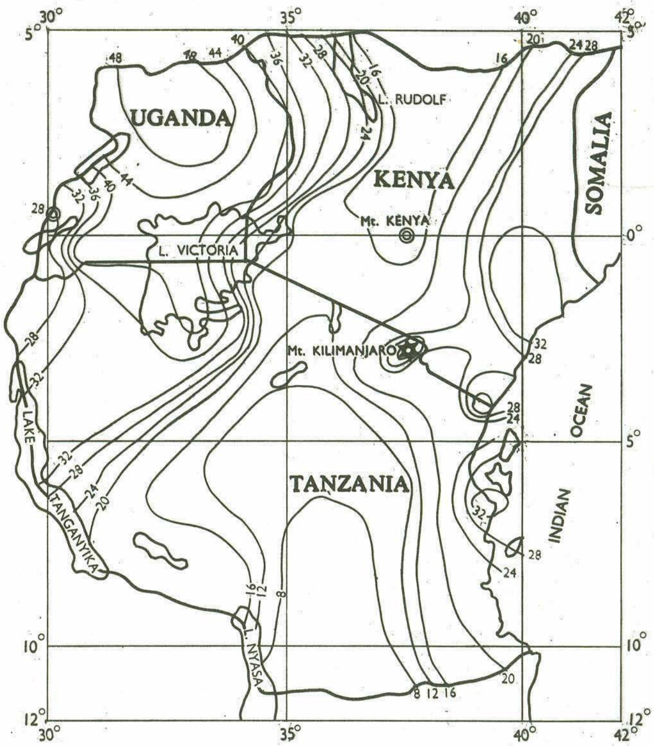
East Africa August Maximum Hourly Rainfall



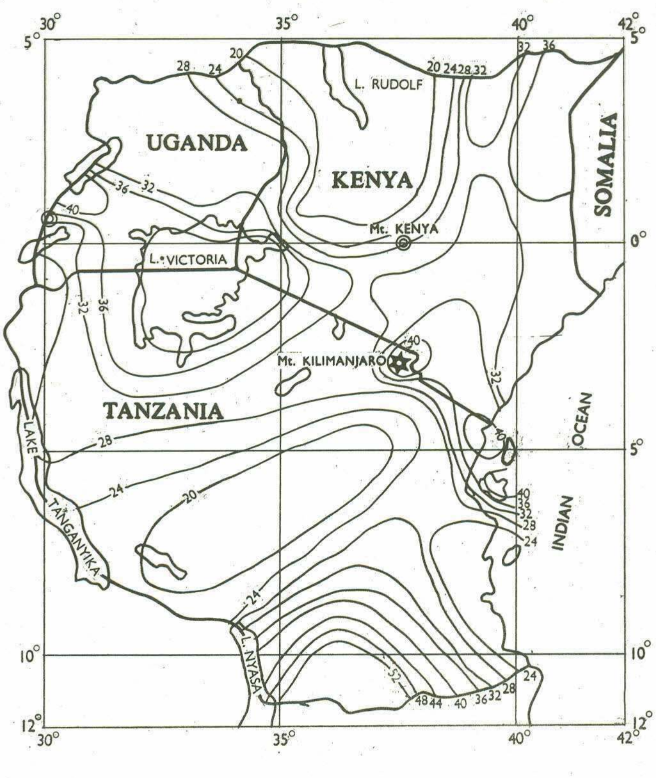
East Africa September Maximum Hourly Rainfall



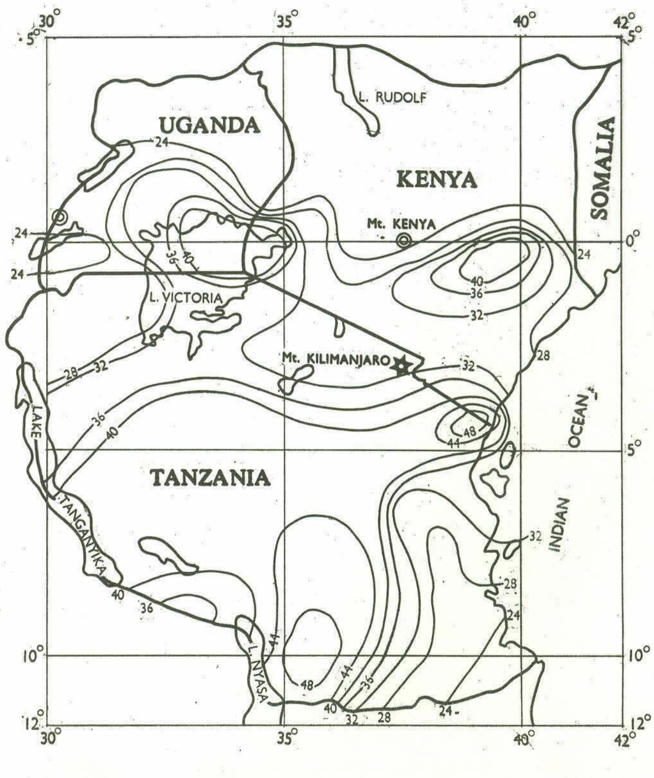
East Africa October Maximum Hourly Rainfall



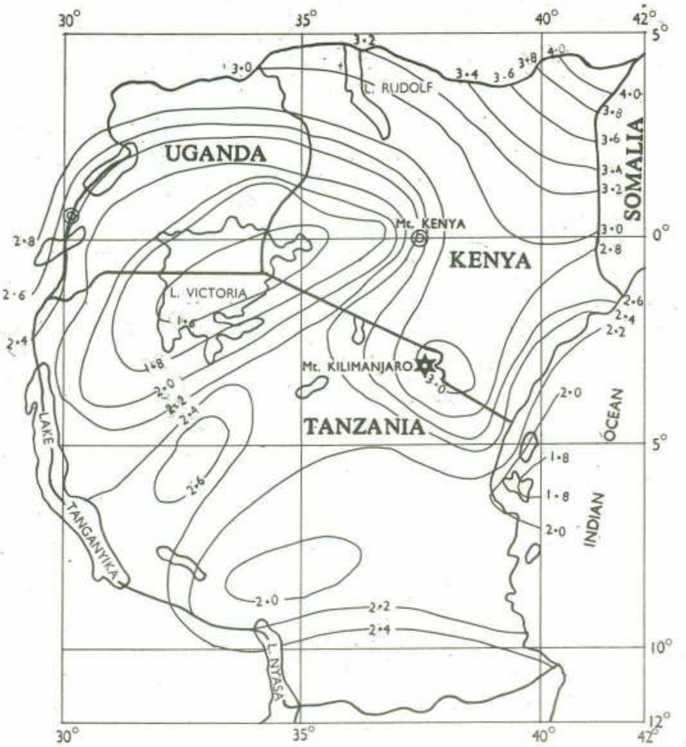
East Africa November Maximum Hourly Rainfall



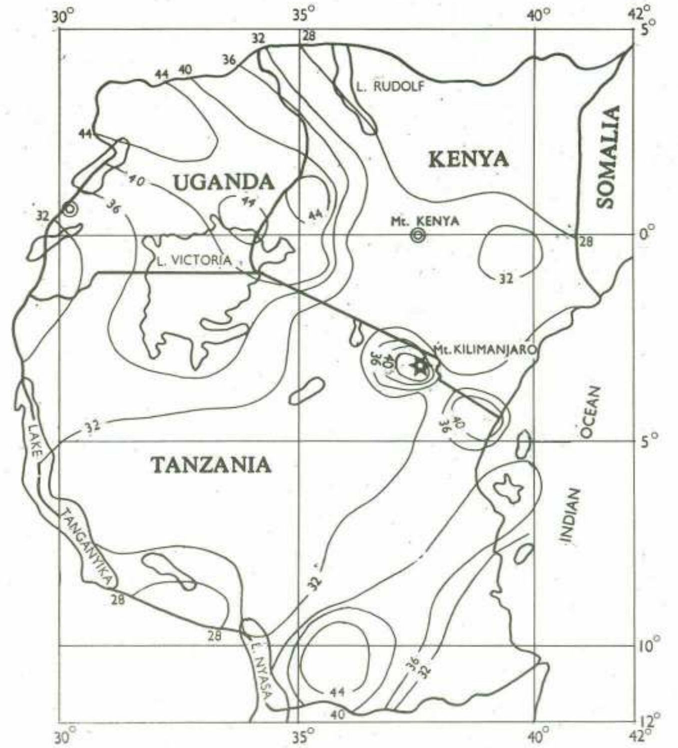
East Africa December Maximum Hourly Rainfall



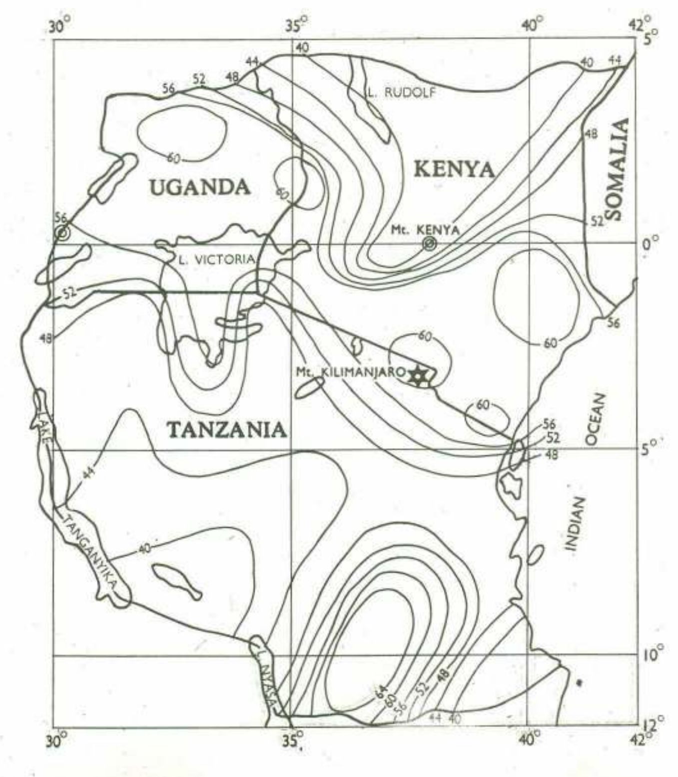
Maximum Hourly Rainfall for East Africa Recurrance Period T 100 / T 2



Maximum Hourly Rainfall for East Africa 2 Years Recurrance Values



Annual Maximum Hourly Rainfall for East Africa



East Africa Map for Station Names