PREDICTION OF RAINFALL MAGNITUDES AND VARIATIONS IN NIGERIA

BY

Nnaji, Chidozie Charles
Department of Civil Engineering, University of Nigeria, Nsukka.
Email: chidozie.nnaji@unn.edu.ng; **Mobile No**.: +23408038948808

ABSTRACT

Rainfall data from 14 locations in Nigeria (six in the north and eight in the south) were collected for the period spanning 1980 to 2002. The data were subjected to analysis using five different methods of hydrologic forecasting namely: Fuller, Gumbel, Powell, Ven Te Chow and stochastic methods. It was found that Fuller's method overestimated rainfall magnitude in all locations by a large margin. Powell's method underestimated rainfall magnitude in all locations studied. Ven Te Chow's method gave the best prediction in all cases except for Enugu in which case Gumbel's method was found to be more appropriate. Gumbel's method closely follows Chow's method in accuracy for all locations. The analyses show that the maximum 1000 years rainfall is 1100mm and will probably occur in around Calabar. Variations in monthly rainfall magnitude were found to be more in the north and less in the south. It is therefore recommended that the Chow's method and the Gumbel's method be adopted for rainfall forecasting in Nigeria.

Keywords: return period, rainfall, forecasting,

INTRODUCTION

Rainfall is a random hydrologic event whose occurrence cannot be predicted with certainty. The distribution of the precipitation over time, as well as over the distance is very complex and irregular. Such irregularity is especially pronounced with respect to the occurrence of the exceptionally heavy storm events [1]. However, it is possible, by the use of rainfall data spanning a long period of time, to estimate the likelihood of the rainfall of a particular magnitude or more occurring within a specified period of time referred to as return period or recurrence interval. The ability to predict the possibility of occurrence of rainfall of a particular magnitude or more can help individuals, authorities and engineers to plan for such extreme eventualities as flood, drought, landslides [2], thunderstorms [3], etc.

For instance, if it is determined that a rainfall causing severe flooding occurs once in 100 years, it confers a degree of certainty on an otherwise elusive event. It will therefore, be wise to expect such flood one hundred years from the last one. A cursory review of rainfall data over time will reveal that both drought and flooding are two opposite hydrologic extremes that need to be guarded against. Of course, it goes without mentioning that flood and drought combined together have caused inestimable havoc on mankind. The best that can be done is to foresee these events and do whatever is possible to reduce their impact.

STUDY AREA

Nigeria covers approximately latitudes 4E – 14EN north of the equator and longitudes 3E - 15E east of the Greenwich meridian with about 923,300 km^2 of land mass [4]. Nigeria borders the Atlantic Ocean on the south and approaches the Sahara Desert on the north. The climate of Nigeria is more varied than those of any other country in West Africa [4] due to the fact that the distance from the south to the north of the country is very great (1,100km) and thus covers many (virtually, all) of the climatic belts of West Africa [5].

Rainfall commences at the beginning of the rainy season from the coast (in the south), spreads through the middle belt and eventually reaches the northern part very much later. The converse of the situation also holds for the rainfall retreat period [5, 6]. In addition, rainfall magnitude generally decreases from the south (near the ocean) to the north (hinterland).

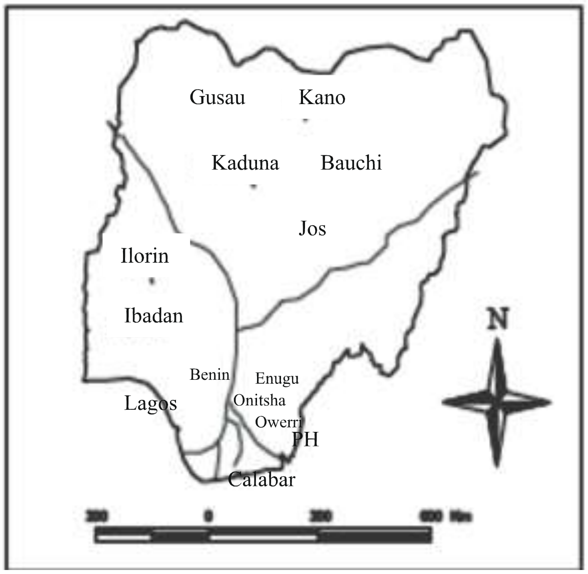

Fig 1: Study Locations

Because Nigeria has such variable rainfall pattern, it is necessary to ascertain which forecasting method suits a particular location most.

METHODOLOGY

Rainfall data spanning a period of twenty two years (1980-2001) were collected for different states. Since the long-term rainfall data required for planning and design of water resources are not available [7], extending the study period beyond this length would have probably resulted in the elimination of some locations. Not all states are represented partly because of the difficulty in sourcing those data and partly because even when the data are available, they are grossly inadequate for any useful analysis because of the predominance of missing data.

The maximum rainfall for every year within the study period was selected for each location and then ranked in descending order. The return period was then calculated as follows:

$$T = \frac{n+1}{m} \tag{1}$$

Where T is the return period, n is the number of data points and m is the rank.

After the ranking, each location was subjected to analysis using the methods of Fuller, Gumbel, Powell, Ven Te Chow and the stochastic method. The Fuller's, Gumbel's and the Powell's methods were derived from the general equation of hydrologic frequency analysis which is of the general form:

$$X_T = \overline{X} + K\sigma \tag{2}$$

Where X_T is the value of the variate X of a random hydrologic series of return period T.

K = a frequency factor which depends on the return period.

σ = standard deviation of the variate.

The random hydrologic series in question could be flood, rainfall, earthquake, landslide, thunderstorm, etc. In this study, X_T is the maximum annual rainfall depth of return period T.

The **Fuller's** method is given by

$$X_T = \overline{X} + 0.8\overline{X}\log T \tag{3}$$

Equation (3) can be rewritten to conform to Equation (2)

$$X_T = \overline{X} + \frac{(0.8\log T)}{C_v}\sigma \tag{4}$$

Where C_v = coefficient of variation while all other parameters are as previously defined.

The **Gumbel's** method is given by

$$X_T = \overline{X} + \left(\frac{y - \overline{y}_n}{\sigma_n}\right)\sigma \tag{5}$$

Where $\overline{y}_n$ and σ_n are the reduced mean and the reduced standard deviation, respectively which depend on the sample size n. y is the reduced variate obtained from Gumbel's extreme value distribution given by

$$P = 1 - e^{-e^{-y}} \tag{6}$$

P is the probability of occurrence or exceedence of a rainfall peak X_T.

Powell's formula is given by

$$X_T = \bar{X}_T - \frac{\sqrt{6}}{\pi}\left[0.5772 + \ln\ln\frac{T}{T-1}\right]\sigma \qquad (7)$$

All terms retain their usual meaning.

Table 1: Summary of K's for different methods

S/N	Method	K
1	Fuller	$\frac{(0.8\log T)}{C_v}$
2	Gumbel	$\frac{y-\bar{y}_n}{\sigma_n}$
3	Powell	$-\frac{\sqrt{6}}{\pi}\left[0.5772+\ln\ln\frac{T}{T-1}\right]$

The **Ven Te Chow's** method uses the least square method to find a regression line for X_T and $\log\log\frac{T}{T-1}$. Hence,

$$X_T = a + b\log\log\frac{T}{T-1} \qquad (8)$$

Where a and b are parameters obtained from regression analysis.

The **stochastic** method which is based on Poisson probability law and theory of sums of random number of random variable is expressed as

$$X_T = X_{\min} + 2.3(Q - Q_{\min})\log\left(\frac{n_f}{n}T\right) \qquad (9)$$

$X_{\min}$ = the least of the maximum annual rainfall depth within the period of record.

n_f = number of recorded rainfall, counting only one for same maximum annual rainfall depth occurring in different years.

$T = \frac{n}{m}$, while all other parameters retain their usual meaning as previously defined.

After the computations, graphs of rainfall depth (mm) versus return period were plotted on a semi logarithmic paper. The results obtained for all the five methods were plotted on the same paper for each location. In order to assess the suitability of the methods for predicting rainfall in these locations, the standard errors for all the five methods were computed for each location using the expression:

$$S_{X_T,T} = \sqrt{\frac{\sum(X_T - X_{T(est)})^2}{n-2}} \qquad (10)$$

Where $S_{X_T,T}$ = standard error of the estimate of X_T (annual maximum rainfall depth) with respect to T (return period). Also, in order to determine the degree of variability of rainfall for the locations under study, a plot of $\frac{Q_{\max}}{Q_{mean}}$ versus return period (T) was done as shown in figure 16.

RESULTS AND DISCUSSION

Figures 2 to 14 show that these methods forecast rainfall better at larger return periods. The reason for this is that, at lower return periods the plot of observed rainfall versus return period is not perfectly linear even when plotted on a semi logarithmic paper; whereas at higher return period, the plot is almost linear. In all cases examined, Fuller's method grossly overestimated rainfall and, in some cases, even gave rainfall values twice the value of that observed. The reason for this is the large safety margin built into the Fuller's method which presupposes that predicted rainfall value cannot fall below the mean value. However, Fuller's method gives safer prediction in all cases and will even yield better results when used on an area whose rainfall pattern is uniform. In such a case, the mean will be close to both the maximum and the minimum values thus giving a more realistic result.

A closer look at the graphs will reveal that Powell's method always underestimated rainfall values and is therefore the most unsafe for rainfall forecasting in the areas of study. Because the areas of study cover a substantial portion of the country, it will be appropriate to infer that Powell's method should not be used in Nigeria. It is pertinent to note from figure 15 that Kano exhibits a higher amount of rainfall than all the other locations at a return period of 1,550 years. This pattern is almost consistent with all the prediction methods. Because this behavior cannot be backed up by any scientific explanation based on the geographic or climatic characteristics of the location, it will be regarded as arising from error inherent in the data used for analysis.

A mere look at the graphs will not be able to determine which method is the overall best for rainfall forecasting in the areas examined, but table 2 shows that Chow's method has the lowest standard errors for eleven out of the fourteen locations, Powell's has the lowest standard errors for two while Gumbel's has the lowest standard error for one location and second lowest standard errors for ten locations. However, as stated earlier Powell's method underestimated rainfall values in almost all cases examined, it will therefore be discarded and replaced by the method which gives the second lowest standard errors in those cases and that is Chows method for those locations.

Table 2: STANDARD ERROR OF PREDICTED RAINFALL VALUES

STATE	FULLER	GUMBEL	POWELL	VEN TE CHOW	STOCHASTIC	SHORT TERM RAINFALL PREDICTION
SOKOTO	85.9328	21.90996	22.91308	20.67010838	32.62413599	*VEN TE CHOW
GUSAU	99.77876	14.04445	7.608529	11.54049777	17.85377904	*POWELL
KADUNA	116.7774	14.22217	10.92609	12.60587393	30.34926341	*POWELL
KANO	126.7055	20.57689	27.78157	20.14946374	44.46069891	*VEN TE CHOW & **GUMBEL
ILORIN	99.04722	11.88249	12.82772	11.60212233	40.4281367	*VEN TE CHOW & **GUMBEL
JOS	111.3647	10.48534	12.11155	10.24046346	33.03526653	*VEN TE CHOW & **GUMBEL
LAGOS	156.7195	17.43655	21.66572	17.00412022	51.93763062	*VEN TE CHOW & **GUMBEL
IBADAN	98.42627	35.54664	35.49655	34.49837807	45.80371672	VEN TE CHOW, **GUMBEL & **POWELL
BENIN	195.3104	25.27626	28.22278	24.87214249	123.5570843	*VEN TE CHOW & **GUMBEL
ONITSHA	137.482	9.79216	14.5834	9.56211315	26.44418989	*VEN TE CHOW & **GUMBEL
PH	161.79	35.17222	35.76575	34.29925434	39.0871918	VEN TE CHOW, **GUMBEL & **POWELL
OWERRI	177.2114	20.01277	22.6441	19.62612817	87.06555871	*VEN TE CHOW & **GUMBEL
ENUGU	129.3448	12.70683	16.46877	119.8800369	25.47955237	*GUMBEL
CALABAR	206.1177	19.00608	22.14018	18.56035629	23.60559128	*VEN TE CHOW & **GUMBEL
sum	1902.009	268.0708	291.1558	365.1110592	621.7317963	
***** Estimator with lowest standard error						
****** Estimator whose standard error does not varry from the estimator with the lowest standard error by more than 5%						

Table 3 shows that Chow's method is more appropriate for most locations within Nigeria. This conclusion can also be arrived at independently by looking at the sum of standard errors. Enugu has an inexplicably erratic standard error for Chow's method. So if Enugu is skipped, Chow's method will have the lowest sum of standard errors (see Table 2), followed by Powell's and then Gumbel's. If we discard Powell's method for reasons stated earlier, we have Chow's method first and then Gumbel's method. Because Chow's method appears to be the best predictor, a plot of rainfall depth versus return period for all the locations under study is shown on Figure 15. The graph shows that the maximum 1000 years flood in Nigeria is about 1100mm around Calabar.

Table 3: Summary of Suitable Forecasting Methods

Location	Method	Location	Method
SOKOTO	VEN TE CHOW	**IBADAN**	VEN TE CHOW & GUMBEL
GUSAU	VEN TE CHOW	**BENIN**	VEN TE CHOW & GUMBEL
KADUNA	VEN TE CHOW	**ONITSHA**	VEN TE CHOW & GUMBEL
KANO	VEN TE CHOW & GUMBEL	**PH**	VEN TE CHOW & GUMBEL
ILORIN	VEN TE CHOW & GUMBEL	**OWERRI**	VEN TE CHOW & GUMBEL
JOS	VEN TE CHOW & GUMBEL	**ENUGU**	GUMBEL
LAGOS	VEN TE CHOW & GUMBEL	**CALABAR**	VEN TE CHOW & GUMBEL

Figure 16 shows the behaviour of the locations with respect to rainfall variability. A general pattern was revealed though there are some exceptions. The locations with higher slopes of the plot of Q_{max}/Q_{mean} versus return period are areas with high variations in rainfall over the years(eg. Nguru, Sokoto and Kano) while the areas with lower slopes show a fairly uniform rainfall pattern (eg. Calabar, Owerri and Benin). Locations higher on the plot are those that exhibit large variation in rainfall from month to month while those lower on the plot exhibit little variation in rainfall from month to month. The plot has three belts which can be classified as follows: upper belt or belt of acute variation (eg Nguru, Sokoto and Kano), middle belt or belt of moderate variation (eg Kaduna and Bauchi) and lower belt or belt of moderate to little variation (eg. Calabar, Owerri, Benin and Port Harcourt)

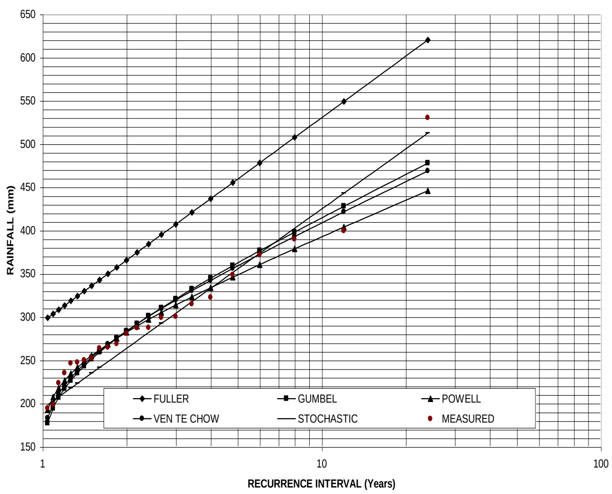

Fig 2: Rainfall frequency plot for Gusau

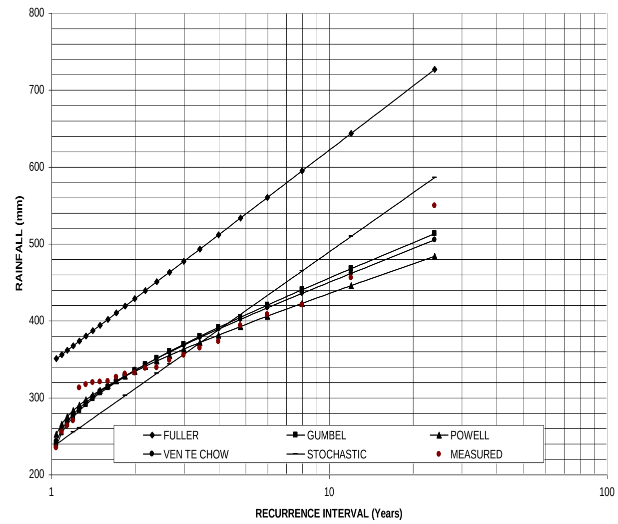

Fig 3: Rainfall frequency plot for Kaduna

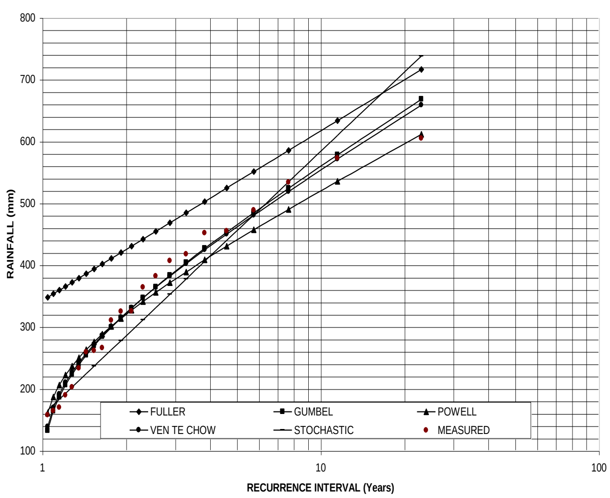

Fig 4: Rainfall frequency plot for Kano

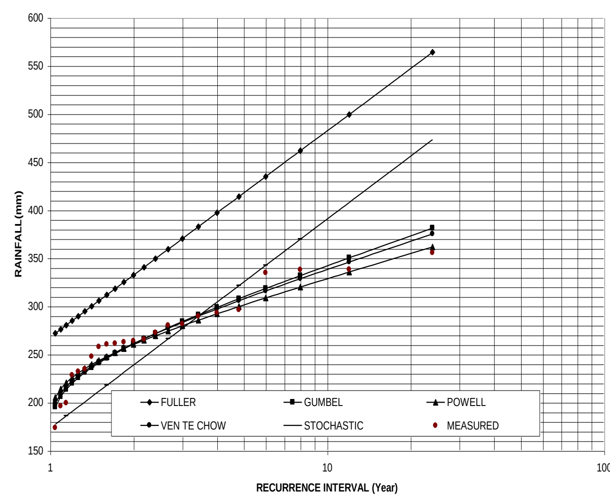

Fig 5: Rainfall frequency plot for Ilorin

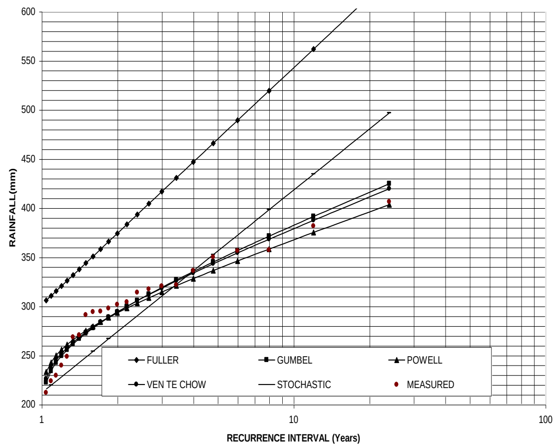

Fig 6: Rainfall frequency plot for Jos

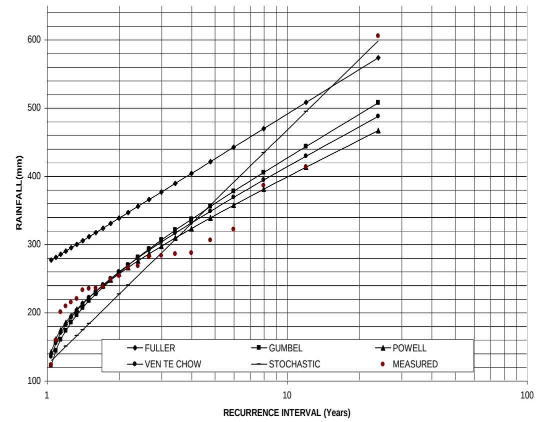

Fig 7: Rainfall frequency plot for Ibadan

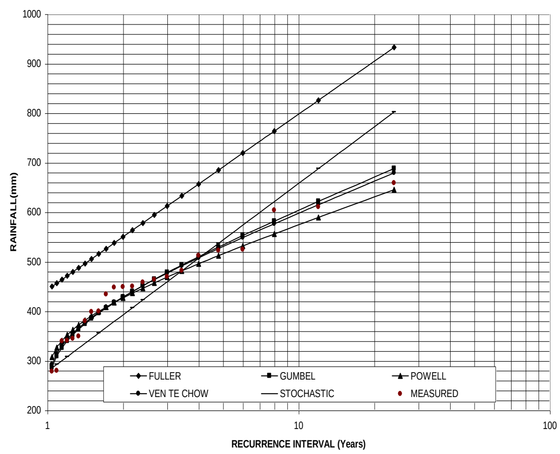

Fig 8: Rainfall frequency plot for Lagos

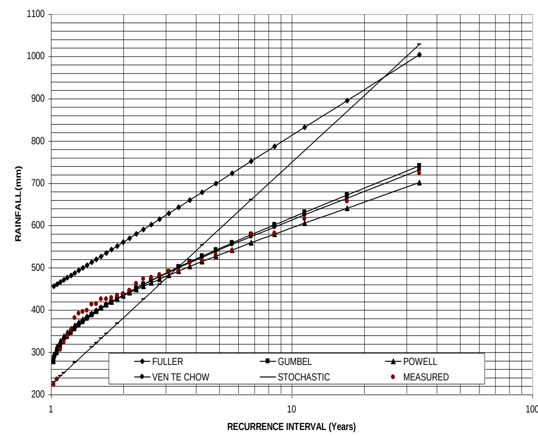

Fig 9: Rainfall frequency plot for Benin

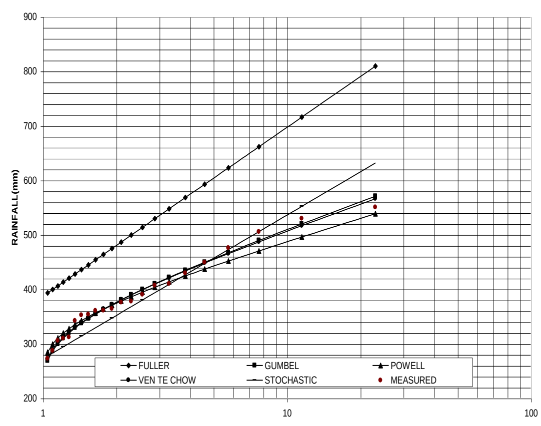

Fig 10: Rainfall frequency plot for Onitsha

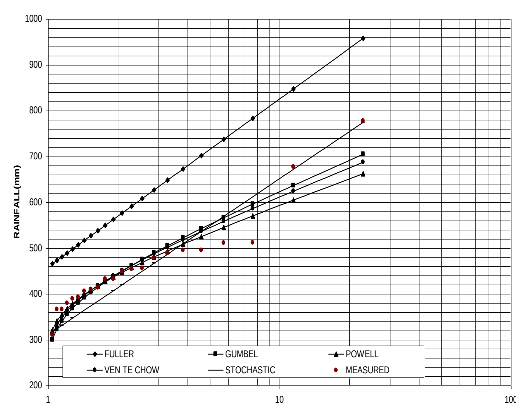

Fig 11: Rainfall frequency plot for Port Harcourt

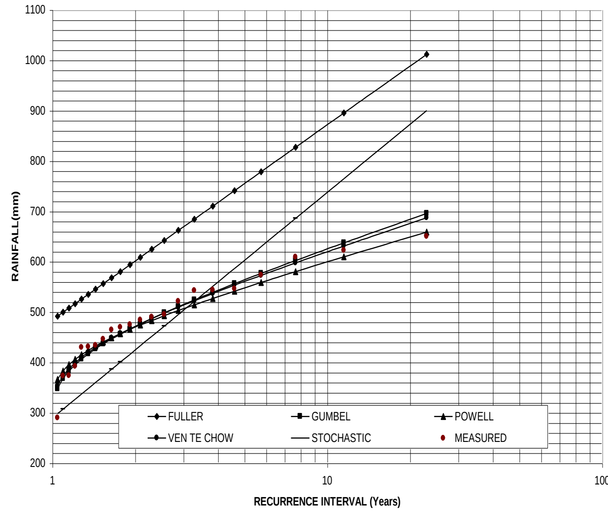

Fig 12: Rainfall frequency plot for Owerri

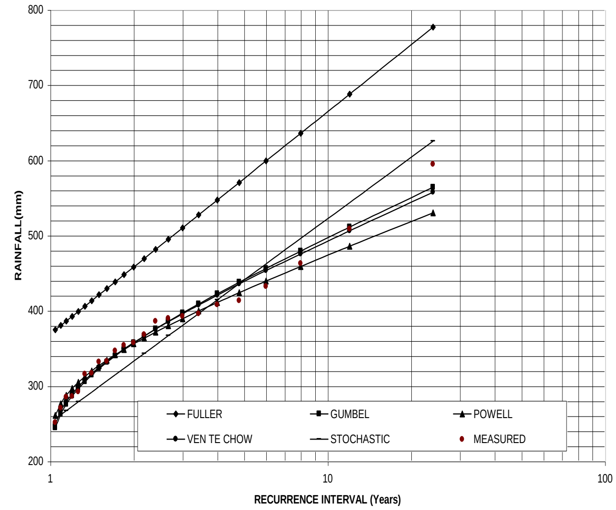

Fig 13: Rainfall frequency plot for Enugu

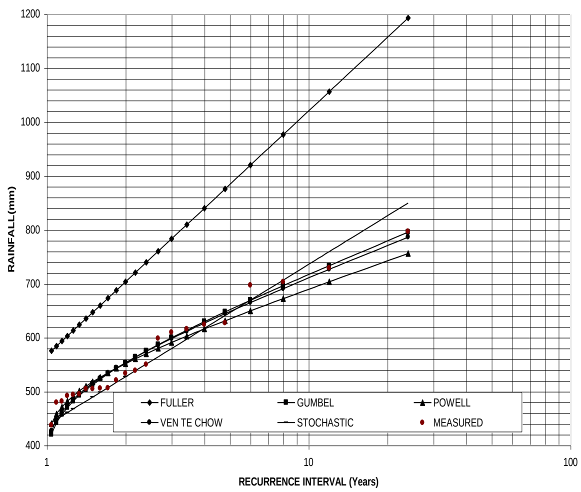

Fig 14: Rainfall frequency plot for Calabar

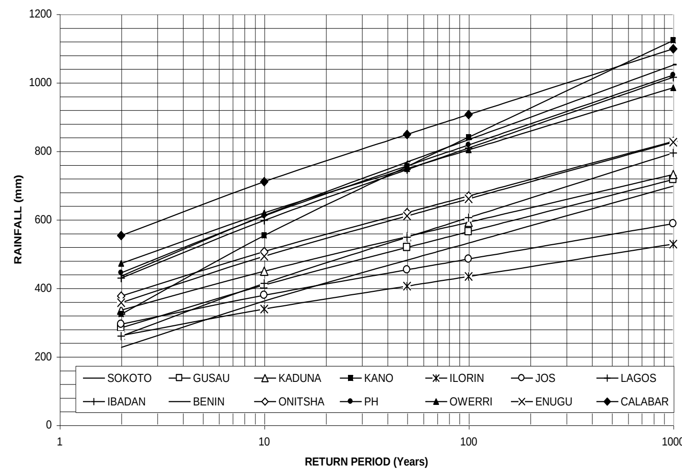

Fig 15: Predicted Maximum Annual Rainfall using Chow's Method

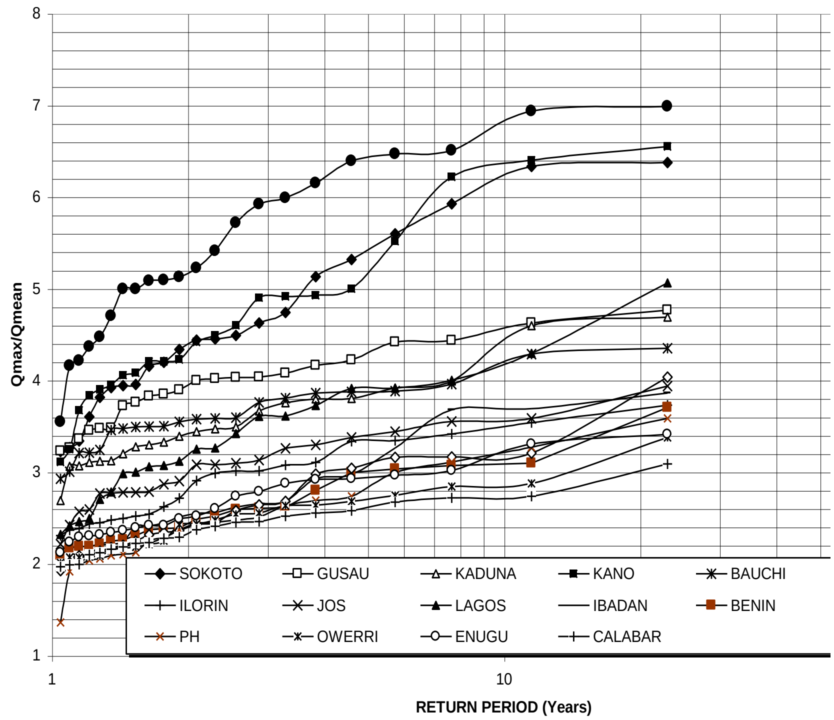

Fig16: Rainfall Pattern for Different Locations

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