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REGIONAL FLOOD FREQUENCY ANALYSIS OF CATCHMENTS IN UPPER BENUERIVER BASIN USING INDEX FLOOD PROCEDURE

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Abstract
Regional flood frequency analysis was conducted for catchments within Upper Benue river basin in Nigeria using the Index flood (IF) procedure utilizing discharge data collected from six gauging stations located within the region tested to be hydrologically homogeneous. The annual maximum discharges of the gauging stations were analyzed to develop: a regional frequency curve; regional regression equations to estimate peak annual flow for specified return periods (Q_T) and a regional regression equation to estimate the mean annual flood ($Q_{2.33}$) using catchment parameters. The regional regression equation developed for the mean annual flood ($Q_{2.33}$) has standard error (S_e) and coefficient of determination (R^2) values of 0.08175 and 0.9613 respectively. The equation can be applied to sites whether gauged or ungauged within the region to estimate the design flood (Q_T) needed for hydrologic modeling and engineering design of hydraulic structures. The IF procedure is particularly useful in developing countries where missing or inadequate data situation exist.

Keywords: Regional flood frequency analysis, homogeneity test, index flood, catchment, mean annual flood

1. Introduction

The planning and design of water resources projects and flood plain management depends on the frequency and magnitude of peak discharge or peak flood. Peak flood is an important hydrologic parameter in the determination of flood risk, management of water resources and design of hydraulic structures such as dams, spillways, bridges, culverts and irrigation ditches [1, 2], hence the design of these structures requires reliable design flood quantile (Q_T) of medium to high return period (T) which could be achieved through at-site or regional flood frequency analysis procedures. In at-site flood frequency analysis only flood records from the subject sites are utilized while a regional analysis is performed by utilizing flood records from a group of hydrologically similar catchments to compensate for the lack of temporal data [3]. In particular, if the length of the available data series is shorter than the return period (T) of interest or when the site of interest is ungauged, obtaining a satisfactory estimate of Q_T presents a challenge [4] and in such cases the regional approach is adopted by utilizing appropriate relationship of design floods and catchment characteristics.

For the inadequate data situation that commonly exist in developing countries [5, 6], where the length of records may be short, at-site flood frequency analysis is unable to provide reliable and consistent flood estimates; hence engineers resort to the regional flood frequency analysis to provide a reliable estimate for design flood [7, 8]. Many studies such as [9], [10] and [11] have shown that flood estimates based on regional information are more reliable, more accurate (have less absolute error) and are more stable (have less variance) than those based solely on at-site records.

In regional flood frequency analysis, regional flood frequency curves together with at-site mean flood is utilized to provide more reliable and consistent estimates of design flood and for the ungauged catchments, regional relationship between the mean annual peak flood and catchment characteristics is developed along with the regional flood frequency curves. In regional flood frequency analysis the data from gauged sites in a region is combined in such a way as to produce a single regional flood frequency curve applicable to all points within the region studied whether gauged or ungauged. The use of regional information to estimate design floods at sites with little or no observed data has become increasingly important in developing countries where many projects which require design flood estimates or information are located in areas where observed flood data are either missing or inadequate.

According to[7], the index flood method is the most popular method for regional flood frequency analysis and has been widely applied in many studies like [11], [12],[13], [14] and[15]. It is used to determine the magnitude and frequency of flood quantiles for basins of any size, gauged or ungauged as long as it is located within hydrologically homogeneous region [16] and these quantiles have proved to be more reliable than at-site estimates [4,10]. There are three main parts to index flood method of regional frequency analysis; first part being the delineation of catchments into homogeneous groups, the second is the development of basic dimensionless frequency curves representing the ratio of flood of any frequency to an index flood (mean annual flood) and the third is the development of regional prediction models (that is, the development of relations between hydrologic characteristics of drainage areas and mean annual flood ($Q_{2.33}$) for predicting the mean annual flood ($Q_{2.33}$) at any point within the region.

In this study, we undertake a regional flood frequency analysis of the Upper Benue River Basin utilizing annual peak flow data at gauging stations located at R.Donga at Manya, R.Donga at Donga, R.Bantaji at Suntai, R.Katsina Ala at serav, R.Taraba at Garsol and R.Mayokam at Mayokam within the region using the Index flood method. The specific objectives of the study were to:

(i) determine whether the catchments are within a hydrologically homogeneous region
(ii) develop the relation between the drainage basin characteristics (drainage area) and mean annual flood using flow data of the gauged catchment in the region; and hence develop the curve of mean annual flood peak vs. catchment area
(iii) develop the basic dimensionless ratio of specified frequency of flow to the index flow(mean annual flow) and hence develop the curve of peak flow ratio versus return period (The peak flow ratio being the ratio of peak flow for a given return period to mean annual flow)
(iv) develop regional prediction models for the index flood ($Q_{2.33}$) and other flood quantiles (Q_2, Q_5, Q_{10}, Q_{25}, Q_{50})

2. Study area and data

The study area consist of six catchments situated within the North Eastern geo-political region of Nigeria and located at River Donga at Manya, River Donga at Donga, River Bantaji at Suntai, River Katsina Ala at Serav, River Taraba at Garsol and River Mayokam at Mayokam. The catchments are gauged by the Upper Benue River Basin Development Authority. The catchments were checked for hydrological homogeneity using the approach presented in [17].

The particulars of the study catchments are presented in Table 1.

3. Methodology

The flood data consisting of annual peak discharges for the six catchments gauged by the Upper Benue River Basin Development Authority of Nigeria for the period 1955 to 1986 (32 years) were obtained from [18] and analyzed and utilized to develop two curves namely the mean annual peak flood versus catchment area and the regional frequency curve which is the peak flow ratio versus return period. i.e. (Q/Q_m versus T), where Q is the T year flood and Q_m is the mean annual flood.

3. 1 The procedure of the index flood method

The following sequential steps were followed for the index flood method of regional flood frequency analysis [19, 20, 21]:

(i) The annual flood peaks for the common time base for the gauged stations were tabulated.
(ii) For each station, the flood frequency curve was prepared with the ranked series; the corresponding plotting positions were estimated using Gringorten plotting position formula. The values were plotted on extreme value probability paper and a straight line fitted.
(iii) The mean annual flood ($Q_{2.33}$) for each station was determined using the EV-I defining equation applicable to the station.
(iv) The first curve is prepared by plotting the mean annual flood of each station against its catchment area.
(v) The data was tested for regional hydrologic homogeneity using the procedure of construction of confidence limits outlined in [17] and [18]. The return periods for upper and lower limits given in Table 2 were plotted against the corresponding sample size (n) on a semi- log paper as given in Figure 1.
(vi) For each station, the annual flood peak Q for different return periods (1.25, 2, 5, 10, 25, 50 years) were obtained from the frequency curves prepared in step 2. The values were converted into peak flow ratios by dividing them by the respective mean annual flood obtained in step 3.
(vii) For the six sites therefore, there were 6 values of such ratios for a given return period.
(viii) From the ratios obtained in step (vii), median flood ratios for each of the selected

return period were determined as recommended by [13].

(ix) The regional flood frequency curve was developed by plotting the median peak flow ratio against the return period on the extreme value probability paper and drawing a best fit line.

The data given in Table 3 utilized for plotting return period against effective period of record at each station for the homogeneity test presented in Figure 1 were obtained using procedures outlined in [18]. The effective length of record was determined as the number of recorded annual events plus one half the numbers of events computed for that station [18].

3.2 Construction of flood frequency curve for the ungauged catchment

The flood frequency curve for the ungauged catchment in the region can be constructed following these steps [21]:

i. The catchment area of the ungauged site is measured from the topographical maps.
ii. The mean annual flood is obtained from the graph of mean annual flood versus catchment area.
iii. The peak flow ratios for the selected return periods are obtained from the second curve.
iv. The peak flows are determined by multiplying peak flow ratios obtained in step (iii) by mean annual flood obtained in step (ii)
v. The flood frequency for the ungauged catchment is then prepared by plotting the flood peaks against their return periods on Extreme value paper.

4. Presentation and discussion of results

The Extreme value type 1 (EV-I) probability distribution defining equations and mean annual flood values ($Q_{2.33}$ or Q_m) obtained from the at-site flood frequency analysis for the respective stations are presented in Table 4.

In the defining equations Q_T is the flood discharge with return period T while X is the corresponding reduced variate for the EV-I distribution. Thus for T=2.33yrs,X =0.5785 and upon substitution of X =0.5785 in the respective EV-I defining equations, the $Q_{2.33}$ values are obtained for the respective stations and are presented in Table 2. From table 4, it can be seen that the mean annual flood (Q_m or $Q_{2.33}$) values ranges from 359.4m^3/s to 2626.63m^3/s within the region. The catchment characteristics and station statistics are summarized in Table 5.

Table 1: Particulars of the study catchment

S/N	Station Name	Drainage Area(km^2)	Position Latitude	Longitude	Length of record used (yrs)
1	R. Donga at Manya	9040	7^0 43'N	10^0 05E	32
2	R. Donga at Donga	11,909	7^0 19'N	10^{0}14E	32
3	R. Bantaji at Suntai	5818	7^0 55'N	10^{0}21E	32
4	R. Katsina Ala at Serav	22,000	7^0 47,'59" N	8^0 52, 13"E	32
5	R. Taraba at Garsol	20513	8^0 34'. 0"N	10^0 15. 0"E	32
6	R. Mayokam at Mayokam	2986	5^0 15' 0"N	11^0 05'E	32

Table 2: Upper and Lower Limit Coordinates of Envelope of Regional Homogeneity Test [18]

Sample size (n)	Return Period Lower limit	Upper limit
5	1.2	160
10	1.85	70
20	2.80	40
50	4.40	24
100	5.60	18
200	6.50	15
500	7.07	13
1000	8.30	12

Table 3: Data for homogeneity test

Station No.	Effective length of record (yrs)	Return period from individual frequency curve (yrs)
1	48	12
2	48	22.24
3	48	7.6
4	48	10.523
5	48	13.9
6	48	6.285

The results of the regional hydrologic homogeneity test is shown in Figure 1 and from which it is seen that the stations are within the same hydrologic homogeneous region indicating that the flood peak data for the stations can be combined and analyzed to produce a regional flood frequency distribution [16] as the regional approach is valid only if the data are collected from catchments which are within a region homogeneous with respect to climate, topography, land use, soil characteristics and hydrology [22,23].

Table 4: At-site flood frequency analysis for the stations

Station number	Station Name	EV-I defining equation	$Q_{2.33}$ (m³/s)
1	Donga at Manya	$Q_T = 150.5X+865.48$, $R^2 = 0.9348$	952.43
2	Donga at Donga	$Q_T = 205.7X+1639.1$, $R^2 = 0.9848$	1758.09
3	Bantaji at Suntai	$Q_T = 139.97X+581.7$, $R^2 = 0.9552$	662.67
4	K/Ala at Serav	$Q_T = 447X+2364.9$, $R^2 = 0.9782$	2626.63
5	Taraba at Garsol	$Q_T = 261.24X+1645$, $R^2 = 0.9500$	1796.82
6	Mayokamat Mayokam	$Q_T = 89.503X+307.63$, $R^2 = 0.9292$	359.40

Table 5: Catchment characteristics and statistics for the stations

	Station1	Station2	Station3	Station4	Station5	Station6
A(Km²)	9040	11909	5815	22000	20513	2986
L(Km)	196	257	185	291	291	120
$Q_{2.33}$ (m³/s)	952.43	1758.09	662.67	2626.63	1796.82	359.40
σ (m³/s)	191.12	254.37	161.81	555.25	302.8	104.91
C_S	0.01037	0.2068	-0.00423	-1.0036	-0.4551	-1.1326
C_V	0.2014	0.1450	0.2452	0.2124	0.1690	0.2934

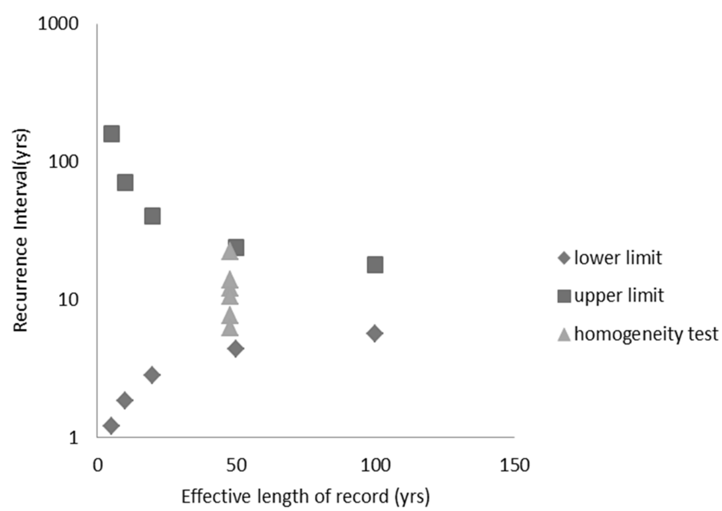

Fig. 1: Homogeneity test chart for upper Benue river basin, Nigeria

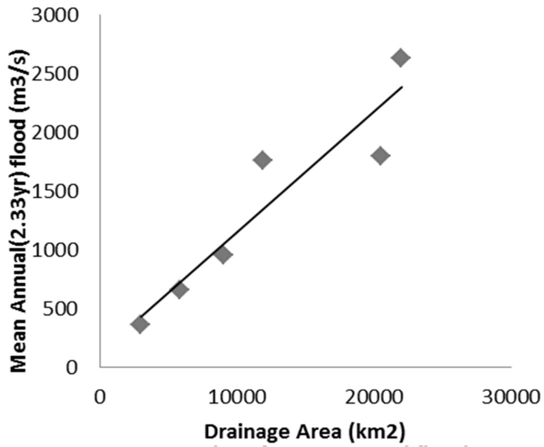

Fig. 2: Plot of Mean Annual flood vs drainage area

Table 6: Peak flood discharges (Q_T) obtained by flood frequency analysis.

STATION/ STATION NO	Q for a return period equal to						
	1.25	2	2.33	5	10	25	50
R.Donga at Manya [1]	793.96	920.56	952.43	1090.93	1203.72	1346.25	1451.97
R.Donga at Donga [2]	1541.23	1714.49	1758.09	1947.63	2101.98	2297.03	2441.72
R.Bantaji at Suntai [3]	515.10	632.99	662.67	791.64	896.67	1029.39	1127.85
R.K/Ala at Serav [4]	2151.76	2529.08	2626.63	3036.81	3372.97	3797.73	4112.83
R.Taraba at Garsol [5]	1521.40	1741.44	1796.82	2037.53	2233.57	2481.28	2665.03
R.Mayokam at M/kam [6]	265.04	340.43	359.40	441.87	509.038	593.91	656.86

Table 7: Stations peak flow ratios for different return periods.

STATION/STATION NO	Q/Qm for a return period equal to						
	1.25	2	2.33	5	10	25	50
[1]	0.8336	0.9665	1	1.145	1.264	1.413	1.524
[2]	0.8766	0.9752	1	1.107	1.195	1.306	1.388
[3]	0.7773	0.9552	1	1.194	1.353	1.5533	1.702
[4]	0.8192	0.9628	1	1.156	1.284	1.445	1.565
[5]	0.8467	0.9692	1	1.134	1.243	1.381	1.483
[6]	0.7374	0.9493	1	1.229	1.4163	1.652	1.827
Median	0.8264	0.9646	1	1.1505	1.274	1.429	1.5445

The plot of the mean annual flood ($Q_{2.33}$) of each station against its catchment area is presented in figure 2. The mean annual flood for a catchment is a graphical mean which is more stable than the arithmetic mean as its value is not affected as much by inclusion or exclusion of major floods.

The peak flood discharge for each return period obtained by flood frequency analysis is given in Table 6 while the corresponding peak flow ratios for the respective return periods are given in Table 7.

For each return period given in Table 7, the median value of the peak flow ratio for all the stations in the region is given in the last row of Table 7.

The plot of the median peak flow ratio against return period on the extreme value paper with a best line fit drawn is given in Figure 3 and it is the Regional flood frequency curve for the homogeneous region which can be readily used for flood frequency analysis in the region and applicable to both gauged and ungauged catchments.

The flood frequency curve for any stream site in the watershed can be determined as follows:

(a) Determine the drainage area above the site

(b) From figure 2, determine the value of ($Q_{2.33}$)

(c) For the selected return periods, multiply the median-flood ratio from figure 3

(Regional frequency curve) by the value of ($Q_{2.33}$) obtained from (b) above
(d) Plot the regional frequency curve.

For the six gauge stations (gauged sites) in the region under study, the return period peak discharge were obtained by multiplying the respective median values with the mean annual flood for each of the stations and the results are presented in Table 8.

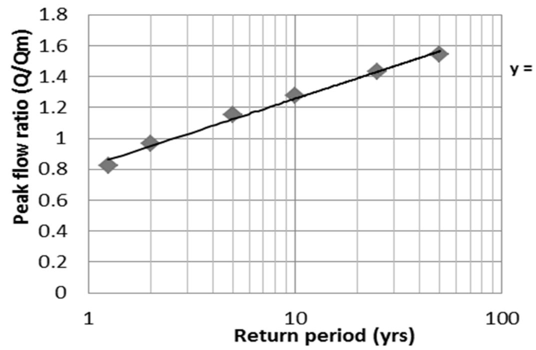

Fig. 3: Regional frequency curve

Table 8: Peak flow discharge obtained by regional flood frequency analysis

STATION NO	Mean Annual flood (Q_m) m3/s	Q_m(m^3/s) x median peak flow ratio for return periods (yrs) equal to:					
		1.25	2	5	10	25	50
1	952.43	787.08	918.71	1095.77	1213.39	1361.02	1471.03
2	1758.09	1452.87	1695.85	2022.68	2239.8	2512.31	2715.37
3	662.67	547.63	639.21	762.40	844.24	946.96	1023.49
4	2626.63	2170.65	2533.65	3021.94	3346.33	3753.45	4056.83
5	1796.82	1484.89	1733.21	2067.24	2289.15	2567.66	2775.18
6	359.40	297.00	346.68	413.48	457.87	513.58	555.09
Median values		0.8264	0.9646	1.1505	1.274	1.429	1.5445

Table 9: Peak discharge computations for stations obtained by Regional regression equations

STATION	Peak discharge(m3/s)				
	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}
[1]	939.62	1121.02	1239.64	1390.81	1504.78
[2]	1444.35	1723.22	1905.54	2137.93	2313.11
[3]	722.05	861.46	952.60	1068.77	1156.35
[4]	2189.41	2612.12	2888.51	3240.77	3506.32
[5]	2121.69	2531.32	2799.16	3140.52	3397.85
[6]	328.22	391.60	433.03	485.84	525.65

4.1: Development of Regional prediction models for Peak flow for given return period (Q_T)

Utilizing the flood data obtained in Table 8 and catchment characteristics in Table 5, regional regression model equations of the power model structure of multiple regression model utilized in regional flood studies [20] were developed using the SPSS version 16 software. The equations are of the form [20]:

$$Y_T = aX_1^{b1}X_2^{b2} \dots \dots \dots . X_p^{bp} \qquad (1)$$

Where, Y_T is the dependent variable, X_1, X_2, ..., X_p are independent variables, a is the intercept coefficient, and b_1, b_2, ..., b_p are regression coefficients.

The dependent variable is the peak flow for a given return period while the independent variables are selected to characterize the watershed and meteorological conditions.

The most important watershed characteristic is usually the drainage area hence most regression formulae include drainage above point of interest as an independent variable. Other watershed characteristics often considered are channel slope, length, geometry, watershed parameter, elevation and others. Meteorological characteristics like rainfall parameters, temperature, evaporation and wind may also be considered. For this study, channel length and drainage area were selected as independent variables.

The regression equations obtained using SPSS 16 Program are given in equations 2, 3, 4, 5, 6 and 7.

$$Q_2 = 0.0404L^{1.130}A^{0.449} \quad (2)$$
$$Q_5 = 0.0482L^{1.131}A^{0.449} \quad (3)$$
$$Q_{10} = 0.0533L^{1.130}A^{0.449} \quad (4)$$
$$Q_{25} = 0.0598L^{1.130}A^{0.449} \quad (5)$$
$$Q_{50} = 0.0647L^{1.130}A^{0.449} \quad (6)$$
$$Q_{2.33} = 0.042\, L^{1.130}A^{0.449} \quad (7)$$

Equation (7) is the regional regression equation to estimate the mean annual flood ($Q_{2.33}$) using catchment parameters. The equation can be applied to an ungauged site within the region to estimate ($Q_{2.33}$). Knowing ($Q_{2.33}$) the regional frequency curve can then be used to estimate (Q_T) for a specified return period (T). Thus the Index flood (IF) procedure is an approach based on indirect method of flood peak prediction.

The peak flows at various return periods (Q_T) for the different stations obtained using the regression equations are summarized in Table 9.

Comparison of the peak flows for return periods varying from 2 to 50 years determined by applying EV-I frequency analysis to observed gauge data at the stations and the corresponding peak discharge (Q_T) obtained from the developed regional regression equations as well as the regression residuals are presented in Tables 10, 11,12,13,14 and 15. The regression residuals are the differences between regression and station (observed) T- year estimates.

Table 10: Comparison of Peak flows from flood frequency analysis (EV-I distribution) and Regional regression equation for Station 1

Return Period	Peak discharge (m^3/s)		Regression Residual (m^3/s)
	EV-I	Regression Equation	
2	920.56	939.62	19.06
5	1090.93	1121.02	30.09
10	1203.72	1239.64	35.92
25	1346.25	1390.81	44.56
50	1451.97	1504.78	52.81

Table 11: Comparison of Peak flows from flood frequency analysis (EV-I distribution) and Regional regression equation for Station 2

Return Period	**Peak discharge (m^3/s)**		**Regression Residual (m^3/s)**
	EV-I	Regression Equation	
2	1714.49	1444.35	-270.14
5	1947.63	1723.22	-224.41
10	2101.98	1905.54	-196.44
25	2297.03	2137.93	-159.1
50	2441.72	2313.11	-128.61

Table 12: Comparison of Peak flows from flood frequency analysis (EV-I distribution) and Regional regression equation for Station 3

Return Period	**Peak discharge (m^3/s)**		**Regression Residual (m^3/s)**
	EV-I	Regression Equation	
2	632.99	722.05	89.06
5	791.64	861.46	69.82
10	896.67	952.60	55.93
25	1023.39	1068.77	45.38
50	1127.85	1156.35	28.50

Table 13: Comparison of Peak flows from flood frequency analysis (EV-I distribution) and Regional regression equation for Station 4

Return Period	**Peak discharge (m^3/s)**		**Regression Residual (m^3/s)**
	EV-I	Regression Equation	
2	2529	2189.41	-339.59
5	3036.8	2612.12	-424.68
10	3372.97	2888.51	-484.46
25	3797.73	3240.7	-557.03
50	4112.8	3506.33	-606.47

Table 14: Comparison of Peak flows from flood frequency analysis (EV-I distribution) and Regional regression equation for Station 5

Return Period	**Peak discharge (m^3/s)**		**Regression Residual (m^3/s)**
	EV-I	Regression Equation	
2	1741.4	2121.68	380.28
5	2037.53	2531.32	493.79
10	2233.57	2799.16	565.59
25	2481.28	3140.52	659.24
50	2665.03	3397.85	732.82

Table 15: Comparison of Peak flows from flood frequency analysis (EV-I distribution) and Regional regression equation for Station 6

Return Period	Peak discharge (m^3/s)		Regression Residual (m^3/s)
	EV-I	Regression Equation	
2	340.43	328.22	-12.21
5	441.87	391.60	-50.27
10	509.03	433.03	-76
25	593.91	485.84	-108.07
50	656.86	525.65	-131.21

From Tables 10,11,12,13,14 and 15 it can be seen that the peak discharges estimated from regression equations are higher than the comparable values determined from the EV-I analysis for stations 1,3 and 5 whereas for stations 3,4 and 6 the peak discharges determined by EV-I analysis are higher than the corresponding estimates obtained by the applicable regression equation. The regression residuals range from 19.06 to 52.81, 28.50 to 89.06 and 380.28 to 732.82 at stations 1, 3 and 5 respectively while for stations 2, 4 and 6 the regression residuals ranges from -128.61 to -270.14, -339 to –606.47 and -12.21 to -131.21 respectively. Though it has been canvassed by hydrologists that regression equations may give better estimates of peak flows of various frequencies than formal statistical frequency analysis [20], regional regression equations should not take precedence over frequency analysis especially when sufficient data are available. However, regression equations can serve as a basis of comparison of statistically determined peak flows of specified frequencies and for evaluation of results of a frequency analysis.

4.2 Assessment of Regression Equations' Prediction Accuracy

In order to assess the prediction accuracy of the regional regression equations developed, the associated standard errors (S_e), the coefficient of error variation (V_e) and the coefficient of determination (**R^2**) were computed. The standard errors of estimate are indicators of how accurately the regional regression equations predict the observed data used in their development while **R^2** is a standardized statistic which gives a measure of "goodness of fit" of the prediction equation [24].

The standard error of estimate is a measure of the deviation of the observed data from the corresponding predicted values and it is given by the basic equation [20]:

$$S_e = \left[\frac{\sum(\widehat{Q_i} - Q_i)}{n-q}\right]^{0.5} \qquad (8)$$

where Q_i = observed value of the dependent variable (discharge) and Q_i = corresponding value predicted by the regression equation

n = number of watersheds used in developing the regression equation

q = number of regression coefficients (i.e. a, b_1, b_2).

For regional regression equations S_e is computed using the logarithm of flows [20]. Thus $\widehat{Q_i}$ and Q_i of equation (8) were taken as logarithms of the corresponding flows.

According to [20], the error can also be expressed as a percentage by dividing the standard error (S_e) by the mean value ($\overline{Q_T}$) of the dependent variable as given in equation (9).

$$V_e = \frac{S_e}{Q_T}100\% \qquad (9)$$

Where V_e is the coefficient of error variation.

The regional regression equation coefficients for equations (2) to (7) and their corresponding prediction accuracy indicators (S_e, V_e (%) and R^2) are summarized in Table 16.

Table 16: Regression Equation Coefficients and Prediction accuracy indicators

Return period (yrs)	**Regression Coefficients**			**Standard error (S_e)**	**Coefficient of error variation V_e(%)**	**R^2**
	a	**b_1**	**b_2**			
2	0.0404	1.130	0.449	0.0825	2.72	0.9614
5	0.0482	1.131	0.449	0.0821	2.64	0.9575
10	0.0533	1.130	0.449	0.0852	2.71	0.9519
25	0.0598	1.130	0.449	0.0810	2.53	0.9434
50	0.0647	1.130	0.449	0.0934	2.89	0.9370
2.33	0.042	1.130	0.449	0.08175	2.68	0.9613

From Table 16, it can be seen that the values of standard error of regression (**S_e**) are in the range of 0.0810 to 0.0934; the values of the coefficient of error variation (V_e) are within the range of 2.53% to 2.89% while the values of the coefficient of determination (**R^2**) falls between 0.9370 and 0.9614.These range of values indicate that the regression equations reasonably fit the observed data and can thus be used to adequately predict peak flood discharge in the region. The smaller the standard error of regression, the better is the fit of the estimated regression to the scatter of data hence the closer the value of S_e to zero the better the distribution fits the data [24]

The 90% upper and lower confidence limits of the regression equations predicted peak discharge at the six stations were constructed using the expression [20]:

$$logQ_T \pm t_{(\frac{\alpha}{2},n-p)}S_e$$

Where log Q_T is the logarithm to base 10 of T- yr recurrence interval peak discharge, p is the number of independent variables in specific equation plus one for regression constant.

$t_{(\frac{\alpha}{2},n-p)}S_e$ is the critical value of t- distribution for selected confidence interval obtained from statistical tables; n = number of stations (6 for this study) and S_e is the standard error of estimate of regression equation.

The plots for the 90% confidence limits obtained for the stations are presented in figures 4 to 9.

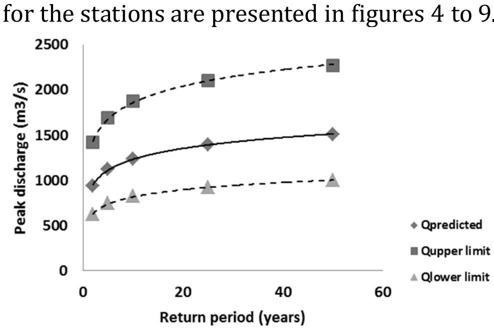

Fig. 4: Confidence limits of predicted peak discharge at Station 1

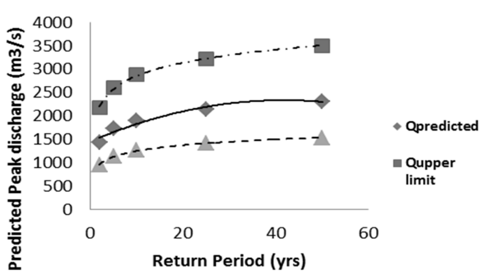

Fig 5: Confidence limits of predicted peak discharge at Station 2

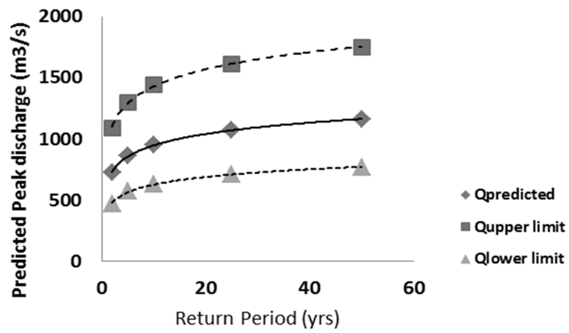

Fig 6: Confidence limits of predicted peak discharge at Station 3

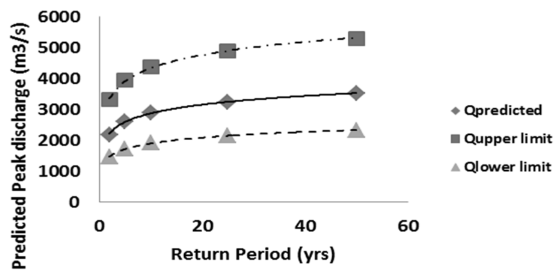

Fig 6: Confidence limits of predicted peak discharge at Station 4

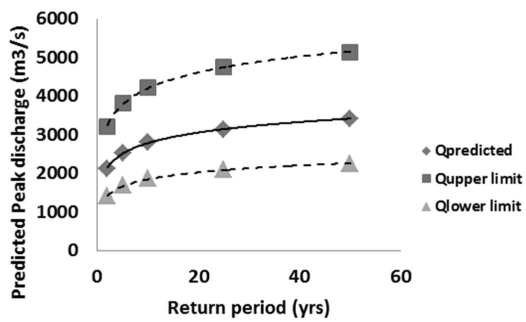

Fig 8: Confidence limits of predicted peak discharge at Station 5

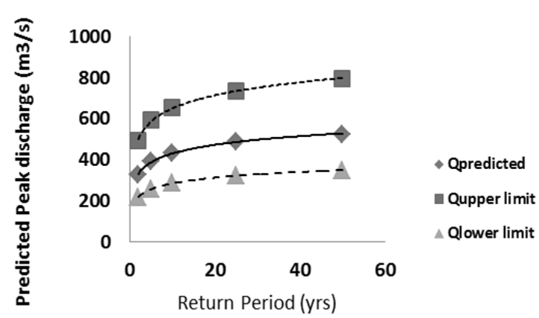

Fig 9: Confidence limits of predicted peak discharge at Station 6

5. Conclusions and recommendations

From the study, the following conclusions and recommendations are made:

(i) That the catchments studied are located within a hydrologically homogeneous region and hence could be analyzed by the Index flood procedure for regional flood frequency analysis
(ii) The flood frequency curve applicable to the homogeneous region is of the form:

$$\frac{Q}{Q_{2.33}} = 1.903 \ln(T) + 0.8188$$

(iii) Considering the values of model prediction accuracy indicators (S_e, V_e (%) and R^2) the regional regression models developed can adequately estimate the quantiles Q_2, Q_5, Q_{10}, Q_{25}, Q_{50} and Index flood quantile ($Q_{2.33}$) of catchments within the region whether gauged or ungauged.
(iv) The Regional flood frequency analysis technique is useful for water resources planning and management especially in developing countries where sufficient hydrological data are not readily available. Hence the results of this study will be useful to engineers involved in planning and design of water resources projects located in ungauged catchments or catchments with inadequate data in the region.
(v) It is however recommended that the regional equations and curve be reviewed from time to time as latest flood data become available so as not to obtain poor design flood estimates as the frequency and magnitudes of floods is expected to vary due to changing climate regime which has notable impacts on rainfall runoff processes.
(vi) It is further recommended that the density of stream gauging networks be increased and concerted efforts be made for the proper collection of hydrological data in view of its importance to national planning and development.

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