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Regional Flood Frequency Analysis using Dimensionless Index Flood Method

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Abstract

Hydrologic designs require accurate estimation of quartiles of extreme floods. But in many developing regions, records of flood data are seldom available. A model framework using the dimensionless index flood for the transfer of Flood Frequency Curve (FFC) among stream gauging sites in a hydrologically homogeneous region is proposed. Key elements of the model framework include: (1) confirmation of the homogeneity of the region; (2) estimation of index flood-basin area relation; (3) derivation of the regional flood frequency curve (RFFC) and deduction of FFC of an ungauged catchment as a product of index flood and dimensionless RFFC. As an application, 1983 to 2004 annual extreme flood from six selected gauging sites located in Anambra-Imo River basin of southeast Nigeria, were used to demonstrate that the developed index flood model: $Q_m = 0.495A^{0.6676}$, overestimated flood quartiles in an ungauged site of the basin. It is recommended that, for wider application, the model results can be improved by the availability and use of over 100 years length of flood data spatially distributed at critical locations of the watershed.

Keywords: Analysis; Estimates; Index Flood; Regional; Southeast Nigeria.

1. Introduction

The estimation of extreme flood probabilities has been a long-standing problem in hydrology because of insufficiently long flood records needed to estimate the annual exceedence probabilities (AEPs) at the site of interest [1]. Yet estimates of extreme floods and AEPs are needed for hydrologic engineering designs. Robson and Reed [2] recognized the practical value of this problem and suggested the analysis of flood frequency. According to Robson and Reed [2], the fitting of a defined probability distribution to historical annual maximum or partial discharge time series in order to determine the magnitude of a flood event at set AEP or return period is called flood frequency analysis (FFA).

Historical discharge time series required to estimate AEPs and peak floods are furnished from installed stream gauging stations [3]. However, in developing countries like Nigeria, spatial coverage of stream gauges is limited by logistics and functional challenges [3]. Even where gauging stations exists, intense flooding, poor planning and technological limitations lead to insufficient length of flood data due to faulty and dysfunctional gauging equipment [4]. The estimated flood quartiles of these sites are therefore based on large degree of extrapolation by simulation with associated high level of uncertainties [5]. In such cases, the widely used at-site flood frequency analysis is most preferred as historical flood records are drawn from a single site of interest. In at-site flood frequency analysis,

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probability distributions fitting flood data vary from site to site [6]. Sahoo et al. [7] studied bivariate low flow FFA of Mahanadi basin, India. In another study, Bhat et al. [8] estimated AEPs of River Jhelum, India, using Gumbel and LP III distributions. Using HEC-RAS and Gumbel's distributions, Parhi [9] estimated peak floods with up to 100years return period in the same Mahanadi River at Hirakud and Naraj dams.

Often times, there are still sites with no flood records at all. Thus, this makes quantification of the maximum floods at desired AEPs neither possible nor reliable [10]. However, for a hydrologically homogeneous region, it is possible to overcome this challenge by conducting regional flood frequency analysis (RFFA). In contrast to at-site FFA, RFFA refers to the pooling together of flood data from other similar sites in order to quantify the magnitudes of peak floods by FFA [10]. These similar sites are called homogeneous regions [6]. Also the term regionalization in RFFA was defined by Kamal et al. [6] as the process of transferring flood information from gauged to ungauged sites. Few published studies provide approaches to estimate extreme floods using RFFA. Malekinezhad et al. [11] applied Ward's cluster and L-moments approach to several sites in the Namak-Lake basin in central Iran to delineate homogeneous regions based on site characteristics. Also a study was conducted by Nathan and Macmahon [12] to test the homogeneity of 184 basins in Southeast Australia using cluster analysis, multiple regression and principal component. In another study by Haddad and Rahman [13], Bayesian generalized least squares regression was used in a region-of-influence framework for RFFA to calculate the flood quartiles using the data from 399 catchments in eastern Australia. Also Leclerc and Ouarda [14] used logical correlation and multiple regression method for FFA of 29 basins in Canada, South East and North East America. The results showed serious under- or overestimation of the quartile estimates.

While these studies recorded different degrees of accuracy, the index flood method as applied by Dubey [15] recorded greater accuracy. Dubey [15] fitted generalized extreme value distribution to flood data pooled from a homogeneous region after estimating the index flood correlated with the 16 different catchment areas in the region. The results revealed that all the maximum discharges, with different return periods matched accurately with their counterparts estimated using at-site FFA. It is to this end that this study presents the dimensionless index flood model for RFFA. The framework for the dimensionless index flood model consists: (1) use of spatial flood pattern to confirm the existence of a hydrological homogeneous region; (2) derivation of dimensionless Regional Flood Frequency Curve (RFFC) by averaging individual at-site dimensionless FFC and (3) to develop the regional index flood-catchment area relation.

To demonstrate this approach, flood data of six selected gauged catchments in Anambra-Imo River basin located in the southeast region of Nigeria, were used to calibrate the flood model and estimates of extreme flood quartiles at AEPs for Orammiriukwa River, an assumed ungauged catchment in the basin, were made. As far as the authors are aware, no scientific studies have addressed this topic in the southeast region of Nigeria. This paper continues with a presentation of the study area and source of data collection. Then follows the methodology used for detail calibration and validation of the flood model as well as derivation of RFFC. Results are thereafter presented and discussed before conclusions are finally drawn**.**

2. Materials and Methods

The discharge data were obtained from the Anambra-Imo River Basin Development Authority (AIRBDA) (Table 2). The maximum monthly runoffs of the selected basins were collated from the available discharge records to form a time series of maximum annual runoff for the selected catchments. A flowchart of the overall study methodology is presented in Figure 2, detailing homogeneity test of the region, computation of FFC, dimensionless index flood model and RFFC.

2.1. Study Area

In 76358 km^2 area, east of the lower Niger and south of Benue valley is located the southeast Nigeria (Figure 1). This region lies between latitudes 4^{0}N and 7 ^{0}N and between longitudes 7^{0}E and 9 ^{0}E. Ofomata [17] reported that there is always a wet season from April to July and a short wet season from September to October after a brief break in rainfalls in August. In geopolitical terms, southeast Nigeria consists of five states namely: Abia, Anambra, Ebonyi, Enugu and Imo. The study area has lowlands and cuesta landscapes. The height of the lowlands is less than 400 meters and consisted of the Niger-Anambra lowlands and Bende-Ameke-Umuahia in Anambra and Abia states respectively [17]. On the other hand, the cuesta landscapes are about 350 meters high, found mainly in the Nsukka-Okigwe cuesta and Awka-Orlu uplands found in Enugu and Abia states respectively [17]. Rainforest-savanna vegetation dominates the area with Iron rich tropical soils. Monthly discharge records that were used to cover 31years for the selected Rivers Adada and Ajali in Enugu, Otamiri in Imo, Ivo in Ebonyi and Imo (Umuopara) in Abia (Table 1).

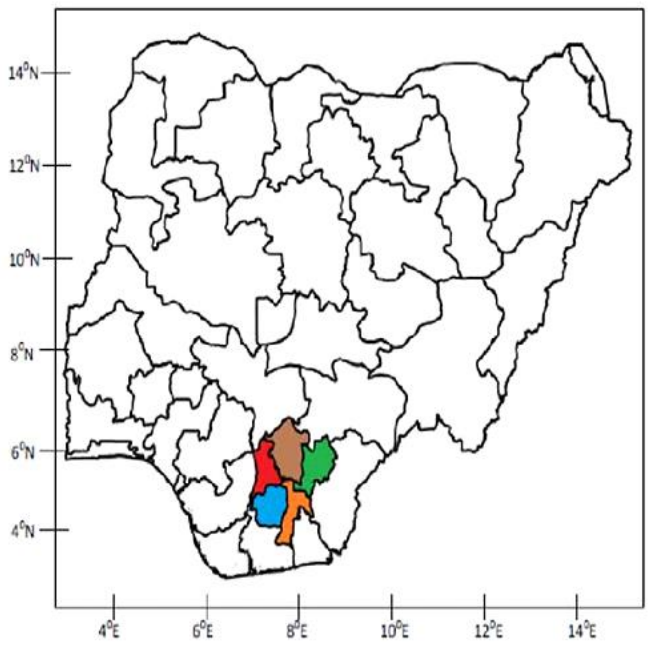

FIGURE : 1A

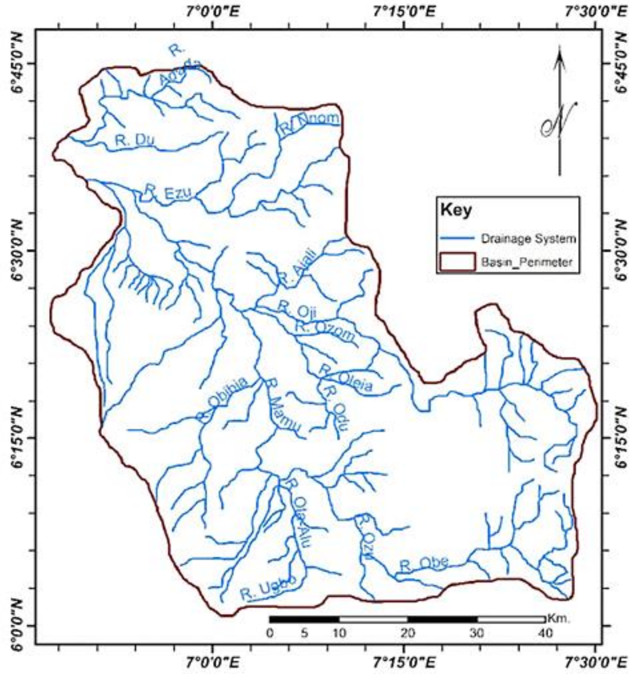

FIGURE: 1B

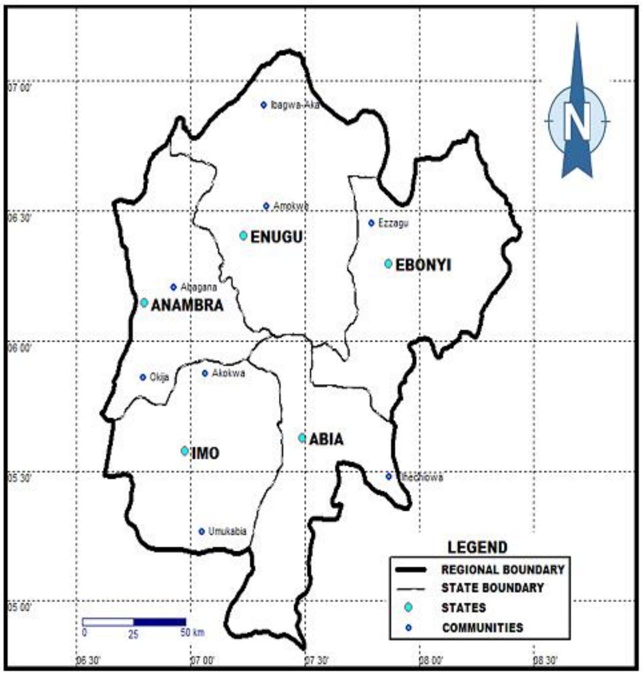

FIGURE 1C

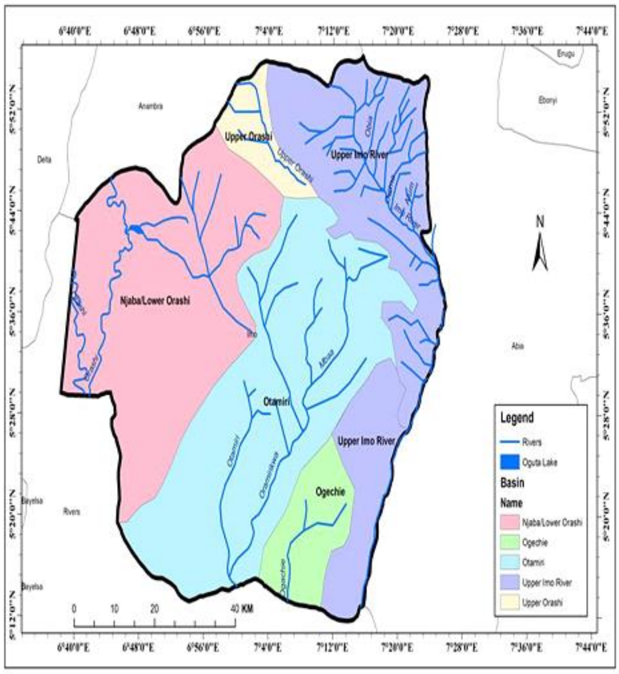

FIGURE 1D

Figure 1A. Map of Nigeria showing the location of the southeast region, Figure 1B: Map of Enugu state showing Rivers Adada, Ivo and Ajali, Figure 1C: Map of Southeast Nigeria, Figure 1D: Map of Imo State showing Rivers Otamiri and Imo

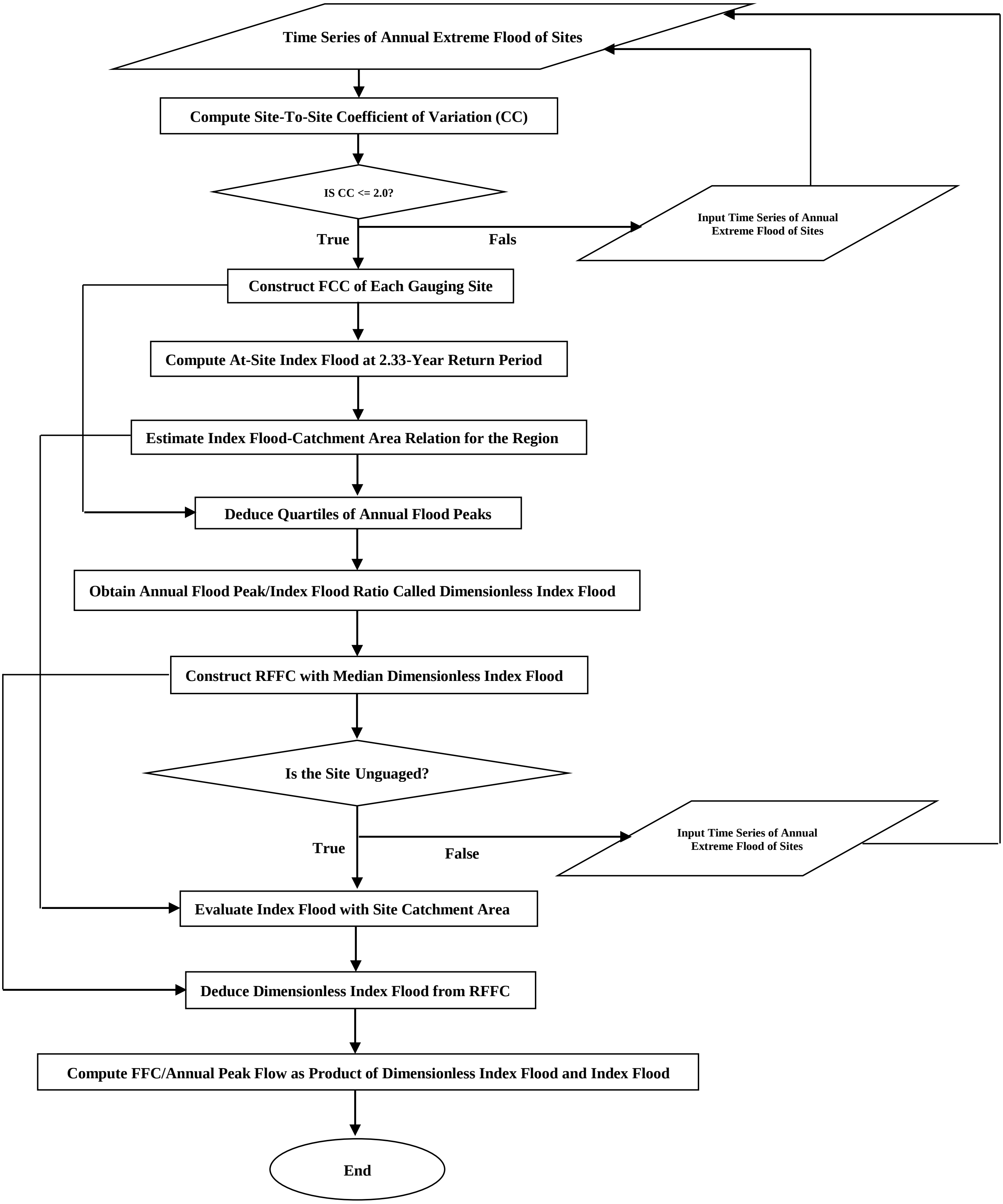

Figure 2. Flow chart of Research Methodology

Table 1. Geographical Locations of the Rivers [16]

State of Location	River	Station	LAT.	LONG.	Catchment Area (Km^2)	Mean Annual Flood (m^3/s)	Zero Level of Gauge (M)
Imo	Otamiri	Nekede	05°26’	07°02’E	100	14.227	97.71
Abia	Abia	Umuopara	05°33’N	07°25’E	1450	168.8595	86.50
Enugu	Adada	Umulokpa	06°38’N	07°11’E	890	52.33149	NA
Enugu	Ajali	Aguobu-umumba	07°19’N	07°13’E	900	12.62679	NA
Ebonyi	Ivo	Imezi-Olo	06°28’N	06°11’E	125	11.45337	NA
Imo	Orammiriuka	Olakwo	05^{0}25’N	07^{0}07’E	795	8.55	96.99

NA* = Not available

2.2. Assumptions of Regional Flood Frequency Analysis

The streams selected for RFFA should be as nearly similar in hydrologic characteristics as possible [18]. Acreman and Sinclair [19] asserted that they should also have similar rainfall and evapotranspiration regimes. In the RFFA, it was assumed that for a given return period, the peak flow ratio was the same for all stations. This is true only when the coefficient of variation of flood peak is the same for all the sites. All available streamflow data within the chosen study area were used to identify gauged catchments with similar hydrological responses.

2.3. Confirmation of Hydrological Homogeneity of the Region

RFFA generally consisted of determining whether watersheds were homogeneous and estimating the index flood model for the homogeneous region. The hydrological homogeneity of the sub-catchments within the region of study was initially ascertained. Streamflow data were used for the homogeneity test of the sites in the region. This was determined using the values of mean coefficient of variation ($\overline{CV}$) and the site-to-site coefficients of variation of the coefficient of variation (CC). The regional mean coefficient of variation and standard deviation were estimated using the following equations:

$$\bar{Q}_i = \frac{\sum_{j=1}^{n_i} Q_{ij}}{n_i} \tag{1}$$

$$\sigma_i = \sqrt{\frac{\sum_{j=1}^{n_i}(Q_{ij}-\bar{Q}_i)^2}{n_i-1}} \tag{2}$$

$$CV_i = \frac{\sigma_i}{\bar{Q}_i} \tag{3}$$

Where $\bar{Q}_i$ = mean flow rate of site i, Q_{ij}= flow rate of station j in region i, σ_i= standard deviation of stream flow rate. CV_i=coefficient of variance. The regional mean coefficient of variation and standard deviation were then estimated as follows:

$$\overline{CV} = \sum_{i=1}^{N} \frac{CV_i}{N} \tag{4}$$

$$\sigma_{CV} = \sqrt{\frac{\sum_{i=1}^{N}(CV_i-\overline{CV})^2}{N}} \tag{5}$$

While Kachroo et al. [20] asserted that a region was homogeneous if the coefficient CC was small but Sine and Ayalew [18] were more precise in suggesting that a region was declared homogeneous if σ_{CV} was less than or equal to 2.

Table 2. Maximum Annual Discharge Values of the selected Rivers [16]

Year	Maximum Annual Discharge (m^3/s)					
	Adada River, Enugu	Ajali River, Anambra	Otamiri Discharge, Imo	Ivo River, Ebonyi	Imo River, Abia	Orammiriukwa River Imo
1983	46.71	12.61	10.70	11.33	158.37	6.70
1984	57.13	12.55	9.38	11.18	156.04	7.95
1985	50.53	11.80	11.78	10.91	126.20	7.62
1986	45.67	12.27	13.54	10.91	194.40	8.09
1987	47.86	12.44	14.60	10.91	115.00	8.95

1988	47.99	12.62	12.90	10.90	223.20	12.45
1989	50.15	12.61	15.54	10.91	42.85	12.48
1990	50.15	12.68	13.07	11.09	188.11	6.65
1991	56.75	12.61	15.10	11.21	227.93	9.70
1992	51.95	12.68	13.21	11.27	114.23	5.42
1993	50.35	12.60	13.77	11.31	94.17	10.68
1994	51.25	12.63	14.64	11.35	187.47	8.28
1995	48.95	12.59	10.77	11.37	294.57	9.19
1996	49.82	12.63	12.94	11.37	72.69	9.15
1997	49.23	12.60	10.38	11.41	205.18	6.13
1998	52.80	12.54	15.55	11.41	149.67	12.39
1999	55.23	12.66	14.44	11.44	204.83	5.16
2000	51.38	12.66	12.11	11.45	136.83	8.15
2001	52.51	12.66	16.15	11.47	106.99	7.15
2002	53.38	12.52	14.66	11.46	101.47	11.19
2003	53.93	12.68	16.71	11.49	154.87	6.70
2004	49.71	12.52	16.73	11.43	61.86	7.95

2.4. Regional Flood Frequency Analysis

Two curves were developed. In the first curve, the mean annual peak flow also called index flood was plotted against the basin area. The second curve plotted peak flow ratio (dimensionless index flood) as a function of the return period. The ratio of the peak flow for a given return period to the index flood gave the dimensionless index flood. The FFC for any other ungauged basin located in this region was deduced from these two curves.

2.4.1. Flood Frequency Analysis

Using a common time base for all the catchments under study, annual peak floods for all the river catchments were assembled. The Weibull formula shown in Equation 6 was used to compute the return periods of observed flood peaks that were assigned ranks (m) while arranged in descending order.

$$F_m = \frac{m}{n} \times 100 \tag{6}$$

Where m is the nominal rank of the sorted values and n is the total number of observations. For each station, the annual peak flood was plotted against its return period on an extreme value, probability paper to obtain the FFC of each gauging station and subsequently, the index flood for each station, which is the flood with 2.33-year return period, was determined.

2.4.2. Formulation of Regional Flood Model

Previous studies have applied watershed as the principal variable for predicting the index flood [21, 22]. Consequently, the expression relating the basin areas (A in km^2) with the index flood (Q_m) was formulated as an exponential function such that:

$$Q_m = CA^b \tag{7}$$

In Equation 7, C and b are parameters to be determined through least square estimation. The model was calibrated using MS Excel spreadsheet.

3. Results and Discussions

3.1. Results of Homogeneity Test

The spatial distribution of the mean annual flood indicates that Orammiriukwa catchment is located in a region whose range of mean annual discharge is between 131.32 and 6.42 m^3/s. In Table 3, the homogeneity statistic was estimated as 1.175. Although this is higher than the values of 0.39 obtained in a previous study by Lee and Kim [23] in an entirely different region of Chungju basin, Korea, the value of $\sigma_{CV} = 1.175$ obtained in this study is less than 2. Hence, according to Sine and Ayalew (2004) [18], the six river sub-basins of Anambra-Imo river can be declared homogeneous as $\sigma_{CV} = 1.175 < 2$.

Table 3. Coefficient of variation (CV) homogeneity test result

River and State of Location	$\bar{Q}_i = \frac{\sum_{j=1}^{n_i} Q_{ij}}{n_i}$	$\sigma_i = \sqrt{\frac{\sum_{j=1}^{n_i}(Q_{ij}-\bar{Q}_i)^2}{n_i-1}}$	$CV_i = \frac{\sigma_i}{Q_i}$
Otamiri, Imo State	11.4236	2.12483	0.186004
Imo, Abia State	131.315	87.372	0.665362
Adada, Enugu State	48.5771	3.86757	0.079617
Ajali, Anambra State	12.3867	0.271846	0.021947
Ivo, Ebonyi State	11.0486	0.197558	0.017881
Orammiriukwa, Imo State	6.417	1.836	0.286115
		$\overline{CV} = \sum_{i=1}^{N} \frac{CV_i}{N}$	0.209488
		$\sigma_{CV} = \sqrt{\frac{\sum_{i=1}^{N}(CV_i-\overline{CV})^2}{N}}$	0.246169
		$CC = \frac{\sigma_{cv}}{CV}$	1.175101

3.2. Result of Station-wise Flood Frequency Analysis

Figure 3 shows the plot of annual peak flood against its return period to give the at-site FFC of each gauging station under study. From Table 4, the estimated flood quartiles for the different gauged catchments indicate that Rivers Otamiri and Ivo have similar values while the gauging sites of Imo River at Umuopara and River Ajali also have similar values. This observed pattern in the magnitude of extreme floods was also observed in the at-site FFA of Gasnga River at Haridwar and Garhmukeshwar gauging sites, India by Kamal et al. [6]. In their study, Kamal et al. [6] had attributed this similarity of flood quartiles between two river catchments to hydrologic homogeneity and similar flow regimes. Among the five different gauged catchments used in the at-site FFA, only River Adada in Enugu state have distinct values of estimated flood quartiles. The at-site FFC fitted directly to the data can therefore be said to perform quite well for most of the gauging sites.

Table 4. Averaging Estimated Flood Quartiles

	Return Period (Years)					
	1.25	**2**	**5**	**10**	**25**	**50**
Rivers	**Flow (m^3/s)**					
Otamiri	11.96	13.77	15.93	16.86	18.71	19.82
Umuopar	87.38	154.87	213.97	242.25	294.57	311.04
Adada	49.79	51.90	54.93	57.20	62.54	74.92
Ajali	87.38	154.87	213.97	242.25	294.57	311.04
Ivo	11.40	11.45	11.48	11.49	11.51	11.52
Median Flows	49.79	51.90	54.93	57.20	62.54	74.92

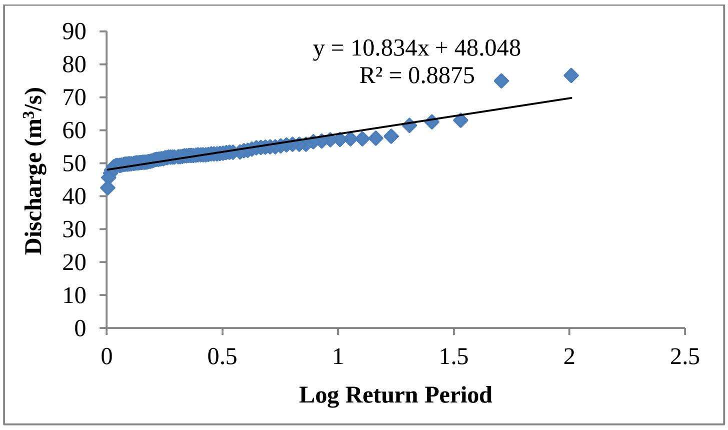

Figure 3a. Adada River River Flood Frequency Curve

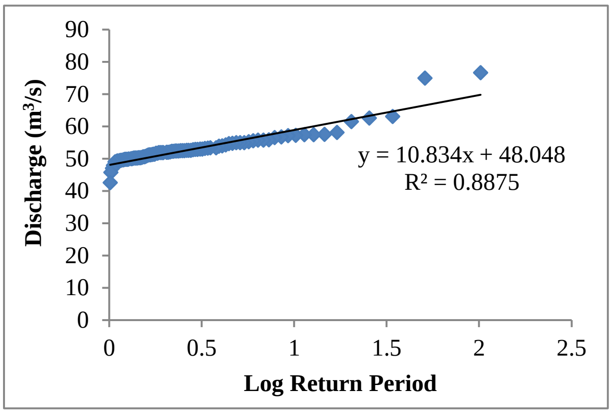

Figure 3b. Ivo River Flood Frequency Curve

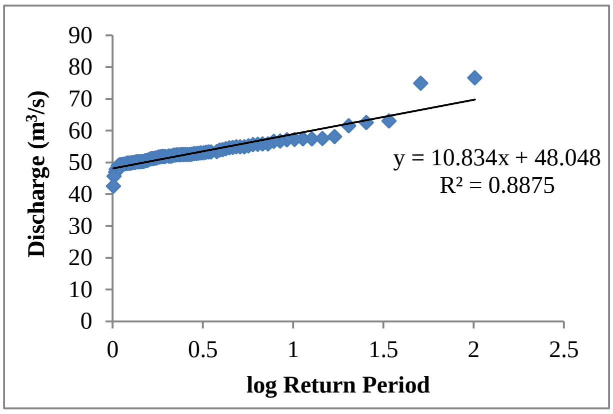

Figure 3c. Imo River (Umuopara Station) River Flood Frequency Curve

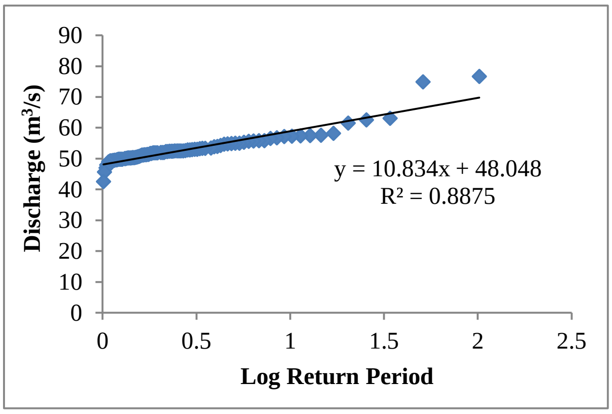

Figure 3d. Ajali River Flood Frequency Curve

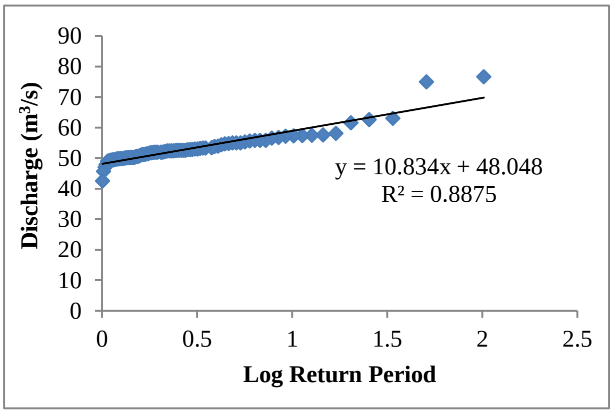

Figure 3e. Otamiri River Flood Frequency Curve

Figure 3. At-site Flood Frequency Curves

3.3. Derived Regional Flood Frequency Curve of the Region

Table 4 shows the deduction of median flood quartiles from the estimated quartiles and in Table 5, median flood quartiles were non-dimensionalized by dividing by the respective index flood of each gauging site to obtain the dimensionless index flood. The RFFC obtained by plotting the dimensionless index flood against the return period is presented in Figure 4. This approach was adapted from Stedinger et al. [24] who successfully applied the median plotting, formula in RFFC. From the RFFC, it can be seen that the dimensionless index flood increased as the return period increased. This implied that there is a positive relationship between the dimensionless index flood and return period. Engeland et al. [25] made similar findings when they conducted the FFA for four catchments in Norway. Also, a positive linear relationship between dimensionless index flood and GEV reduced variant was reported by Dubey [15] in Narmada basin, central India.

This observation also agrees with the estimated extreme flood quartiles in all the gauging sites of this study, which increased as return period increased or AEP decreased. The coefficient of determination, R^2, was calculated as R^2= 0.9936, thus confirming the validity of the RFFC. This result is valid for this specific region as it agrees with Dubey [15], who obtained R^2 =1 for RFFC developed for 16 gauging sites in Narmada basin, India.

Table 5. Computation of Dimensionless Index Flood

	Return Period (Years)					
	1.25	**2**	**5**	**10**	**25**	**50**
Rivers	**Flow/Mean Flow**					
Otamiri	0.84	0.97	1.12	1.18	1.32	1.39
Umuopara	0.52	0.92	1.27	1.43	1.74	1.84
Adada	0.95	0.99	1.05	1.09	1.20	1.43
Ajali	6.92	12.27	16.95	19.19	23.33	24.63
Ivo	1.00	1.00	1.00	1.00	1.00	1.01
Median Flow/ Mean Flow	0.95	0.99	1.12	1.18	1.32	1.43

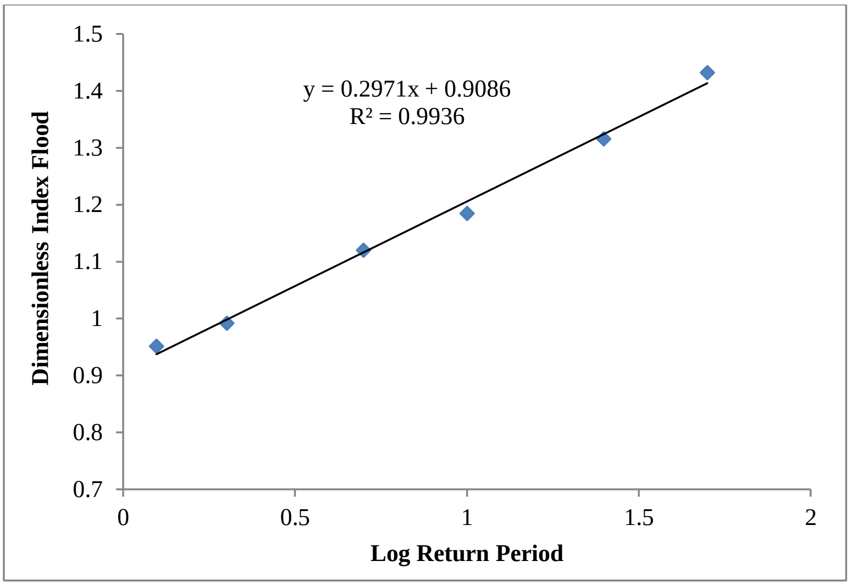

Figure 4. Regional Flood Frequency Curve

3.4. Index Flood Model of the Region

The index flood model was estimated as:

$$Q = 0.495A^{0.6676} \quad (8)$$

Equation 8 shows that the exponent and the coefficient of the watershed area obtained were 0.06676 and 0.495 respectively. In comparison, Lee and Kim [23], Kim et al. [26] and Dubey [15] reported the following pairs of values for the exponent and the coefficient of watershed area as (0.907, 2.987), (0.873, 3.895) and (0.698, 8.87) respectively. Evidently, the values obtained in this study fall within the range of values obtained in previous studies which serve as a confirmation of the model acceptability. The model validity was further confirmed by calculating R^2= 0.5019.

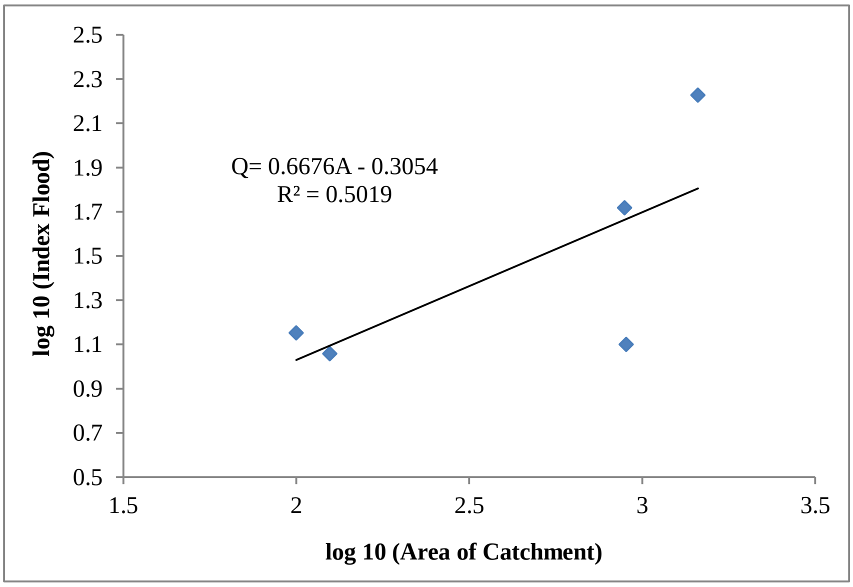

Figure 5. Least Square Line of the Mean Flood Model

However, the model performance is rated lower than those obtained by Lee and Kim [23] and Dubey [15] in similar studies in which R^2= 0.99 and 0.945 respectively. To buttress the validity of the model, the deficient model performance is linked to fewer number of small gauged catchments (A<1000km^2) used in this study due to scarce gauging sites in the region, in contrast to the 16 and 20 large gauging sites used in previous studies [15, 23]. This is further confirmed in Figure 5 which presents the linear fit for the index flood-basin area scatter plot. Although outliers can be seen in the plot, yet most of the points appeared equidistant on either side of the fight.

3.5. Derivation of Flood Frequency Curve (FFC) for Ungauged Station

To better assess the effectiveness of the model in the region, the following steps were adopted for deriving FFC for the ungauged station of Orammiriukwa River, located in the region. The estimated flood model was employed to evaluate the index flood of River Orammiriukwa basin with an area of 795 km^2 and finally the dimensionless index flood was deduced for the selected return periods. The flood peaks were obtained as products of the dimensionless index flood and the index flood obtained from the flood model. Finally, the FFC the river was plotted. The estimated RFFC shown in Figure 6b have similar properties as the at-site FFC is shown in Figure 6a; the annual extreme floods positively and linearly correlate with the return periods. The estimated extreme flood quartiles obtained by RFFA and at-site FFA, are compared in Table 6.

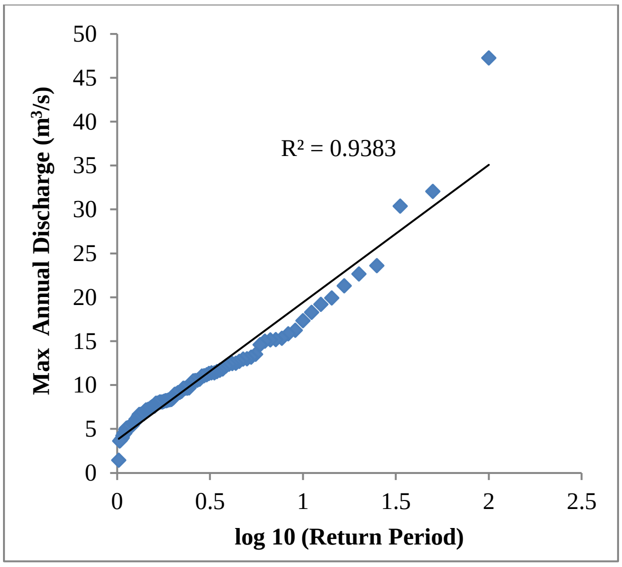

Figure 6a. At-site FFC of River Orammirukwa

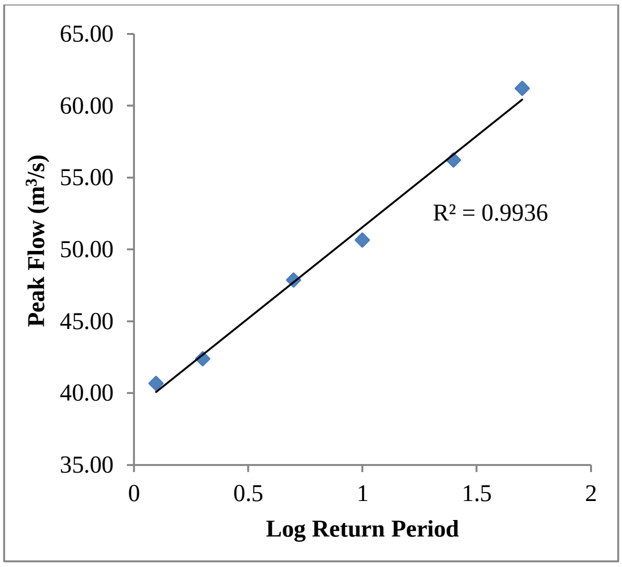

Figure 6b. Derived FFC of River Orammirukwa

RFFA estimates seem to overestimate the flood magnitude for all return periods. Lee and Kim [23] asserted that the relatively large differences seen between the RFFC and at-site FFC estimates are partially due to the model structure, which was constrained to index flood-basin area relation. Improved estimates are therefore possible by incorporating other catchment features such as basin physiography and climatic characteristics. Table 6 show that the differences in the estimates of extreme floods from RFFA and at-site FFA slightly increase as the watershed area decreases. Also, the percentage errors were relatively high, decreasing with increase in the return period (Table 6). Although, the relative errors of the mean annual flood for this study were higher than those of the previous study by Kim et al. [26], similar model performance were observed by Lee and Kim [23] where the uncertainty in model performance increased with data ambiguity. Notwithstanding the poor model performance adjudged by the high relative errors, it is believed that better outcomes are possible by addressing input variable limitations

Table 6. Flood Quartiles of At-site and Regional Frequency Analyses of River Orammirukwa

At-Site peak flow (m^3/s)	5.8	8.51	12.99	17.35	23.61	32.07
Regional peak flow (m^3/s)	40.67	42.39	47.87	50.64	56.22	61.2
Return Period (years)	1.25	2	5	10	25	50
Percentage Error (%)	601	398	268	191	138	91

4. Conclusion

The spatial extent of stream gauging network is rarely sufficient for accurate estimates of extreme floods needed for design purposes. In this study, the dimensionless index flood model was regionalized in terms of watershed area. The adopted approach highlighted the deficiencies and opportunities of combining index flood model and RFFC to ascertain quartiles of extreme flood. The at-site FFC generally produced large flood estimates for long return periods. The performance of this model framework was tested in six gauging sites of Anambra-Imo river basin, southeast region of Nigeria. Results of homogeneity tests confirmed Anambra-Imo river basin, southeast Nigeria as a hydrological homogeneous region. Although, index flood correlated significantly with basin area, the results of the study revealed a lack of agreement between flood estimates from RFFA and at-site FFC for an assumed ungauged site of Orammiriukwa located in the region. The results show the tendency of RFFA to overestimate flood quartiles at all return periods. Despite the poor performance of the model, the flood estimation method explored in the study is conceptually simple. It should be noted that the large disparity between flood values of RFFA and at-site FFA does not necessarily invalidate the model as its metrics and features are consistent with those obtained in previous similar studies. Nevertheless, better results are expected if the spatial distribution of gauging station is improved along with the model structure. In future studies, it is potentially useful to develop regional flood models for the different regions of Nigeria, but scarcity of long and precise flood records would continue to be a grave challenge.

5. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] Tanaka, Tomohiro, Yasuto Tachikawa, Yutaka Ichikawa, and Kazuaki Yorozu. "Impact Assessment of Upstream Flooding on Extreme Flood Frequency Analysis by Incorporating a Flood-Inundation Model for Flood Risk Assessment." Journal of Hydrology 554 (November 2017): 370–382. doi:10.1016/j.jhydrol.2017.09.012.

[2] Robson, Alice, and Duncan Reed. "Flood Estimation Handbook: Statistical Procedures for Flood Frequency Estimation." Centre for Ecology & Hydrology, Wallingford, (2008).

[3] Ekeu-wei, Iguniwari Thomas. "Evaluation of Hydrological Data Collection Challenges and Flood Estimation Uncertainties in Nigeria." Environment and Natural Resources Research 8, no. 2 (April 23, 2018): 44-54. doi:10.5539/enrr.v8n2p44.

[4] Ekeu-wei, Iguniwari Thomas, and George Alan Blackburn. "Catchment-Scale Flood Modelling in Data-Sparse Regions Using Open-Access Geospatial Technology." ISPRS International Journal of Geo-Information 9, no. 9 (August 25, 2020): 512. doi:10.3390/ijgi9090512.

[5] Pawar, Uttam, and Pramodkumar Hire. "Flood Frequency Analysis of the Mahi Basin by Using Log Pearson Type III Probability Distribution." Hydrospatial Analysis 2, no. 2 (April 7, 2019): 102–112. doi:10.21523/gcj3.18020203.

[6] Kamal, Vikas, Saumitra Mukherjee, P. Singh, R. Sen, C. A. Vishwakarma, P. Sajadi, H. Asthana, and V. Rena. "Flood Frequency Analysis of Ganga River at Haridwar and Garhmukteshwar." Applied Water Science 7, no. 4 (February 1, 2016): 1979–1986. doi:10.1007/s13201-016-0378-3.

[7] Sahoo, Bibhuti Bhusan, Ramakar Jha, Anshuman Singh, and Deepak Kumar. "Bivariate Low Flow Return Period Analysis in the Mahanadi River Basin, India Using Copula." International Journal of River Basin Management 18, no. 1 (February 19, 2019): 107–116. doi:10.1080/15715124.2019.1576698.

[8] Bhat, M. Sultan, Akhtar Alam, Bashir Ahmad, Bahadur S. Kotlia, Hakim Farooq, Ajay K. Taloor, and Shabir Ahmad. "Flood Frequency Analysis of River Jhelum in Kashmir Basin." Quaternary International 507 (February 2019): 288–294. doi:10.1016/j.quaint.2018.09.039.

[9] Parhi, Prabeer Kumar. "Flood Management in Mahanadi Basin Using HEC-RAS and Gumbel's Extreme Value Distribution." Journal of The Institution of Engineers (India): Series A 99, no. 4 (June 21, 2018): 751–755. doi:10.1007/s40030-018-0317-4.

[10] Samantaray, Sandeep, and Abinash Sahoo. "Estimation of Flood Frequency Using Statistical Method: Mahanadi River Basin, India." H2Open Journal 3, no. 1 (January 1, 2020): 189–207. doi:10.2166/h2oj.2020.004.

[11] Malekinezhad, H., H.P. Nachtnebel, and A. Klik. "Comparing the Index-Flood and Multiple-Regression Methods Using L-Moments." Physics and Chemistry of the Earth, Parts A/B/C 36, no. 1–4 (January 2011): 54–60. doi:10.1016/j.pce.2010.07.013.

[12] Nathan, R.J., and T.A. McMahon. "Identification of Homogeneous Regions for the Purposes of Regionalisation." Journal of Hydrology 121, no. 1–4 (December 1990): 217–238. doi:10.1016/0022-1694(90)90233-n.

[13] Haddad, Khaled, and Ataur Rahman. "Regional Flood Frequency Analysis in Eastern Australia: Bayesian GLS Regression-Based Methods Within Fixed Region and ROI Framework – Quantile Regression Vs. Parameter Regression Technique." Journal of Hydrology 430–431 (April 2012): 142–161. doi:10.1016/j.jhydrol.2012.02.012.

[14] Leclerc, Martin, and Taha B.M.J. Ouarda. "Non-Stationary Regional Flood Frequency Analysis at Ungauged Sites." Journal of Hydrology 343, no. 3–4 (September 2007): 254–265. doi:10.1016/j.jhydrol.2007.06.021.

[15] Dubey, A. "Regional Flood Frequency Analysis Utilizing L-moments: A Case Study of Narmada Basin." Int. Journal of Engineering Research and Applications 4, 2 (2014):155-161.

[16] Anambra-Imo River Basin Development Authority (AIRBDA) "Hydrological Year Book" (2010)

[17] Ofomata, G.E.K. "Soil Erosion in Enugu Area of Nigeria." Nigerian Geographical Journal 8 (2001): 45-49.

[18] Sine, A. and Ayalew, S. "Identification and Delineation of Hydrological Homogeneous Regions-The case study of Blue Nile River Basin." Proceedings, Lake Abaya Research Symposium (2004).

[19] Acreman, M.C., and C.D. Sinclair. "Classification of Drainage Basins According to Their Physical Characteristics; an Application for Flood Frequency Analysis in Scotland." Journal of Hydrology 84, no. 3–4 (May 1986): 365–380. doi:10.1016/0022-1694(86)90134-4.

[20] Kachroo, R. K., S. H. Mkhandi, and B. P. Parida. "Flood Frequency Analysis of Southern Africa: I. Delineation of Homogeneous Regions." Hydrological Sciences Journal 45, no. 3 (June 2000): 437–447. doi:10.1080/02626660009492340.

[21] Lim, Yeo H., and Donovan L. Voeller. "Regional Flood Estimations in Red River Using L-Moment-Based Index-Flood and Bulletin 17B Procedures." Journal of Hydrologic Engineering 14, no. 9 (September 2009): 1002–1016. doi:10.1061/(asce)he.1943-5584.0000102.

[22] Kumar, Rakesh, and Chandranath Chatterjee. "Regional Flood Frequency Analysis Using L-Moments for North Brahmaputra Region of India." Journal of Hydrologic Engineering 10, no. 1 (January 2005): 1–7. doi:10.1061/(asce)1084-0699(2005)10:1(1).

[23] Lee, Do-Hun, and Nam Won Kim. "Regional Flood Frequency Analysis for a Poorly Gauged Basin Using the Simulated Flood Data and L-Moment Method." Water 11, no. 8 (August 18, 2019): 1717. doi:10.3390/w11081717.

[24] Stedinger, J.R., Vogel, R.M. and Foufoula-Georgiou, E. "Frequency analysis of extreme events." In Handbook of Hydrology; Maidment, D.R., Ed.; McGraw-Hill Inc.: New York, NY, USA, (1993): 18.1-18.66.

[25] Engeland, Kolbjørn, Donna Wilson, Péter Borsányi, Lars Roald, and Erik Holmqvist. "Use of Historical Data in Flood Frequency Analysis: a Case Study for Four Catchments in Norway." Hydrology Research 49, no. 2 (November 20, 2017): 466–486. doi:10.2166/nh.2017.069.

[26] Kim, Nam Won, Jeong Eun Lee, Jeongwoo Lee, and Yong Jung. "Regional Frequency Analysis Using Spatial Data Extension Method : I. An Empirical Investigation of Regional Flood Frequency Analysis." Journal of Korea Water Resources Association 49, no. 5 (May 31, 2016): 439–450. doi:10.3741/jkwra.2016.49.5.439.