IDF curves in the parts of United States and obtained these curves at ungauged sites using the newly developed rainfall frequency analysis techniques.

Projections from climate models suggest that the probability of occurrence of intense rainfall in future will increase due to the increase in green-house gas emission (Chow, 1988). Although, researches related to the analysis of extreme precipitation indices have projected an increase in the annual total precipitation during the second half of the past century; the number of days with precipitation is also expected to increase, with no consistent pattern for extreme wet events (David, 1961). Such changes in extreme events according to (Kothyari, 1992), can have enormous ecological, societal and economic impacts in the form of floods, droughts, heat waves, summer and ice storms, which may have great implications for municipalities: a small shift in the climate normals can have large consequences on the existing infrastructure; climate change will affect any municipalities (big or small, rural or urban) by damaging existing municipal infrastructure (bridges/roads), natural systems (watersheds, wetlands and forests) and human system (health and education).

The design standards at present are based on the historic climate information and required level of protection from natural phenomena as well as climatic change scenario. Under a changing climate, it has become a priority for municipalities to search for appropriate procedures, planning and management to deal with and adapt to changing climatic conditions. Present study aims to provide an insight into the future changes in the intensity of extreme rainfall events associated with model and scenario uncertainties and suggest methods for quantifying these uncertainties (Solaiman and Simonovic, 2011). The result is presented in the form of probability based intensity duration- frequency (IDF) curves appropriate for the future climatic conditions. Okonkwo and Mbajiorgu (2010) developed IDF curves for south eastern Nigeria using two methods, graphical and statistical and the results were compared. IDF data developed from the graphical and statistical methods were very close for the lower return periods of 2 to 10 years, but differ for higher return periods of 50 to 100 years. However, the difference was not significant at 5% level. Much work has been done by Eman, (2011) using ARCGIS to construct IDF curves, Isopluvial maps and proposed regional IDF formula parameters for Sinai Peninsula in the north eastern part of Egypt. In this study, rainfall intensity for various return period and rainfall duration of some gauged sites are estimated, using ArcView GIS model, in order to generate a regional rainfall intensity map an make related prediction for ungauged catchments located in the eastern part of Nigeria.

Materials and Methods

The Maximum Annual Precipitation series is obtained at each station for different durations and fitted to one of the statistical distributions; General Extreme value (GEV). The distribution selected based on fitting comparison criteria of RRI map. Then, this distribution is used to find 24 hr intensity-duration-frequency values at 2, 5, 10, 25, 50 and 100 years.

These 24-hr IDF values are spatially interpolated using ArcView GIS model to obtain RRI maps for all durations and return periods and hence the ploting of IDF curves of selected catchments in Eastern Nigeria.

Accordingly the IDF curves are constructed for ungauged sites to estimate rainfall intensity for various return periods and rainfall durations. The regionalization of the parameters of rainfall intensity-duration-frequency equations was generated for ungauged using gauged stations to estimate rainfall intensity for various return period and rainfall duration.

Data collection and analysis

The hydrological data available for Imo State was obtained from the Anambra-Imo River Basin Development Authority (AIRBDA), a Federal Government Agency that collects and keeps rainfall and runoff data in the south-eastern part of Nigeria for hydrological analysis and other uses. The available rainfall record is from 1976 – 2001. In addition, rainfall data from the neighbouring States of Cross River, Anambra and Edo States, collected from the Calabar Airport Rainfall Station, Onitsha Meteorological Station and Benin city Station respectively, were obtained. To account for the extreme climatic variability in the future due to climate change, 20% increase in rainfall was assumed to occur using the historical dataset of 26 years as the base period. The daily maximum annual rainfall was selected i.e extreme values for excedence probability followed by analysis of the data as shown in Tables 1-2 from which Figures 1-8 were drawn.

The intensity generating sheet is prepared using the following formulae:

$$\text{Rainfall Intensity}, I = \frac{\text{Daily Rainfall (mm)}}{24\ \text{(hrs)}}\ \text{(mm/hr)} \qquad (1)$$

$$\text{Mean}, \overline{X} = \frac{\sum(I)}{n} \qquad (2)$$

where I = Rainfall intensity

n = number of occurrence

$$\text{Standard deviation}, S.D = \sqrt{\frac{\sum(\overline{X} - I)^2}{n-1}} \qquad (3)$$

$$\text{Skewness} = \frac{\sum(X_i - \overline{X})^3}{(n-1)(S.D)^3} \qquad (4)$$

$$\text{Alpha}, \alpha = \frac{4}{(\text{Skewness})^2} \qquad (5)$$

$$\text{Beta}, \beta = \frac{S.D}{\sqrt{\alpha}} \qquad (6)$$

$$\text{Gamma}, \gamma = \overline{X} - \alpha\beta \qquad (7)$$

$$\text{Excedence probability}, P = 1 - \text{Gammadist}\ [(I - \gamma), \alpha, \beta, \text{True}] \qquad (8)$$

Return period is genarated by the formula,

$$\text{Return period}, T = \frac{1}{P} \qquad (9)$$

Table 1: Analysis Sheet

Month	Mean	Max.	Min.	Mean+(Standard Deviation)	Mean-(Standard Deviation)	Mean+3Std	Mean-3Std
Jan	24.98	105.3	0	60.23155614	-10.27155614	130.7346684	-80.77466843
Feb	34.51	212	0	85.47538454	-16.45538454	187.4061536	-118.3861536
Mar	100.335	259.7	0	159.8593716	40.81062839	278.9081148	-78.23811484
Apr	148.515	225.6	0	216.1852242	80.84477585	351.5256725	-54.49567246
May	255.3245	361.5	89.39	327.2154247	183.4335753	470.9972742	39.65172583
Jun	339.715	498.3	185.9	435.6192136	243.8107864	627.4276408	52.00235923
Jul	366.318	650.1	222	478.0232688	254.6127312	701.4338064	31.20219357
Aug	340.6675	641	151.95	470.5635822	210.7714178	730.3557467	-49.02074668
Sep	364.283	622.2	142.9	511.7889235	216.7770765	806.8007706	-78.23477057
Oct	223.623	399.4	0	345.4398861	101.8061139	589.0736583	-141.8276583
Nov	59.535	167.8	19.9	99.74008314	19.32991686	180.1502494	-61.08024943
Dec	12.245	52.4	0	28.65098334	-4.160983344	61.46295003	-36.97295003

Table 2: Analysis Sheet

Month	Mean	Max.	Min.	Mean+(Standard Deviation)	Mean-(Standard Deviation)	Mean+3Std	Mean-3Std
Jan	22.24263158	68.6	0	45.38965871	-0.90439555	91.68371297	-47.19844981
Feb	50.19842105	176.7	0	104.0762452	-3.679403108	211.8318935	-111.4350514
Mar	139.9105263	291	4.6	215.9183687	63.90268392	367.9340535	-88.11300086
Apr	192.3194737	300.3	9.97	268.3312753	116.3076721	420.3548785	-35.71593113
May	264.5626316	442.4	8.79	354.9402036	174.1850595	535.6953478	-6.570084603
Jun	371.4642105	619.9	15.72	537.0903146	205.8381065	868.3425226	-125.4141016
Jul	407.0315789	661.4	196.9	538.4330928	275.6300651	801.2361204	12.82703746
Aug	381.0894737	728.7	120.4	525.194863	236.9840844	813.4056415	-51.22669412
Sep	409.3868421	621.3	235.33	518.4555294	300.3181548	736.5929041	82.18078011
Oct	319.2473684	489.1	141.2	400.2678279	238.2269089	562.3087469	76.18598999
Nov	148.7263158	416.8	58.1	244.7327151	52.71991645	436.7455138	-139.2928822
Dec	28.60526316	94.8	0	60.14351989	-2.93299357	123.2200333	-66.00950703

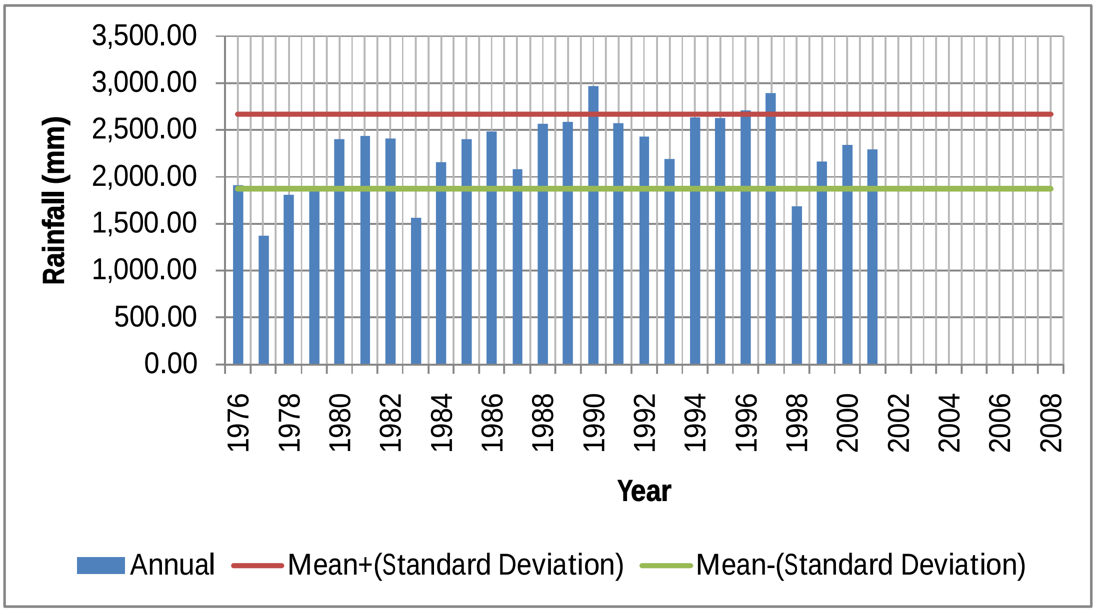

Figure 1: Annual Rainfall Amounts

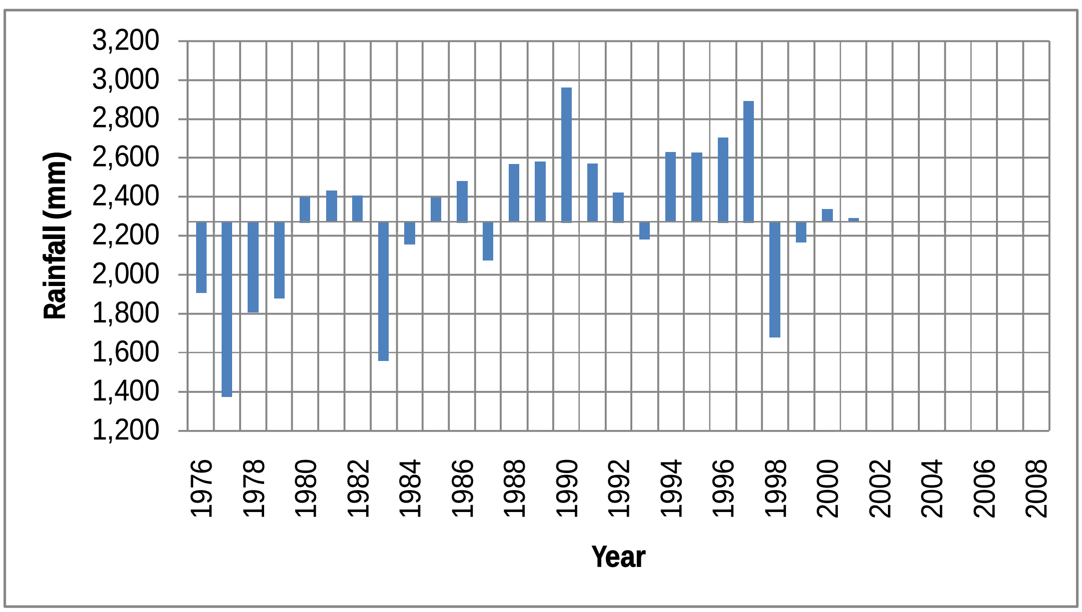

Figure 2: Annual Rainfall Amounts over Long-Term Mean

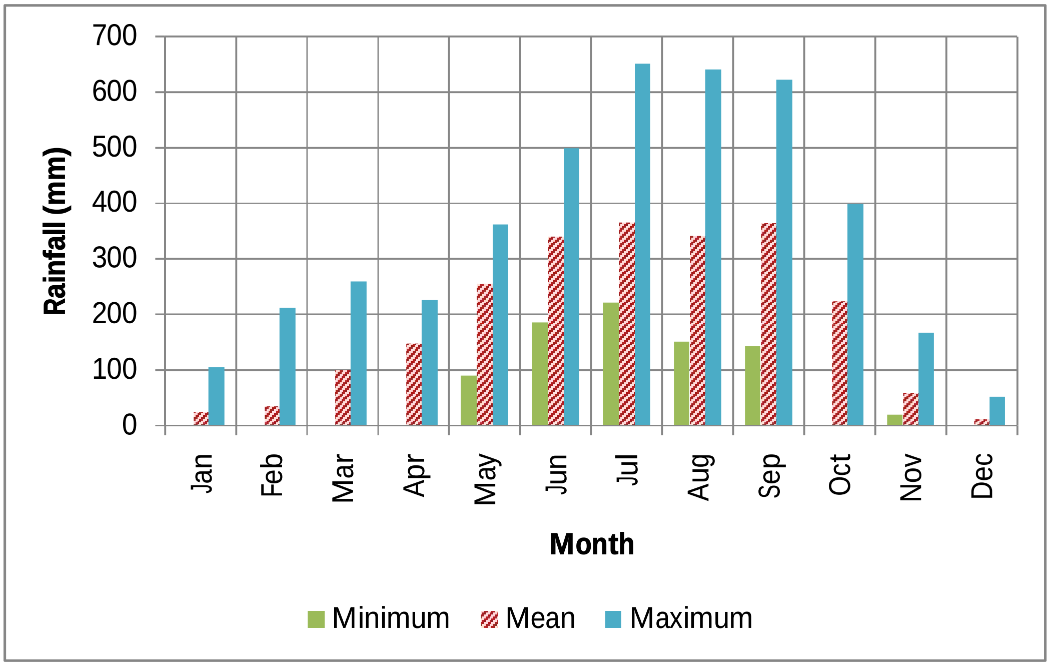

Figure 3: Monthly Rainfall Pattern

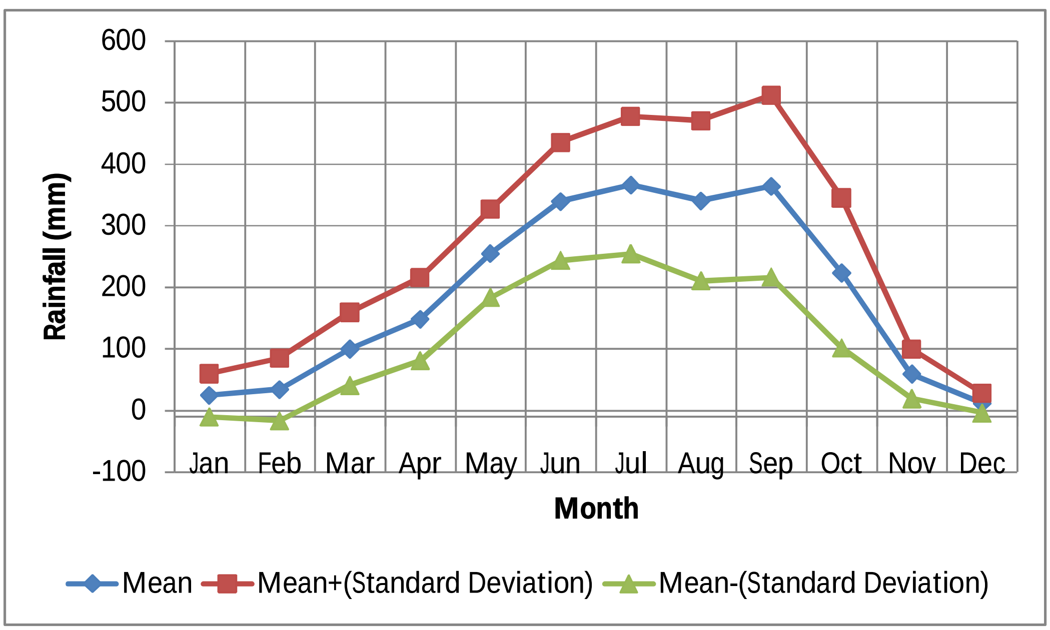

Figure 4: Seasonal Rainfall Pattern

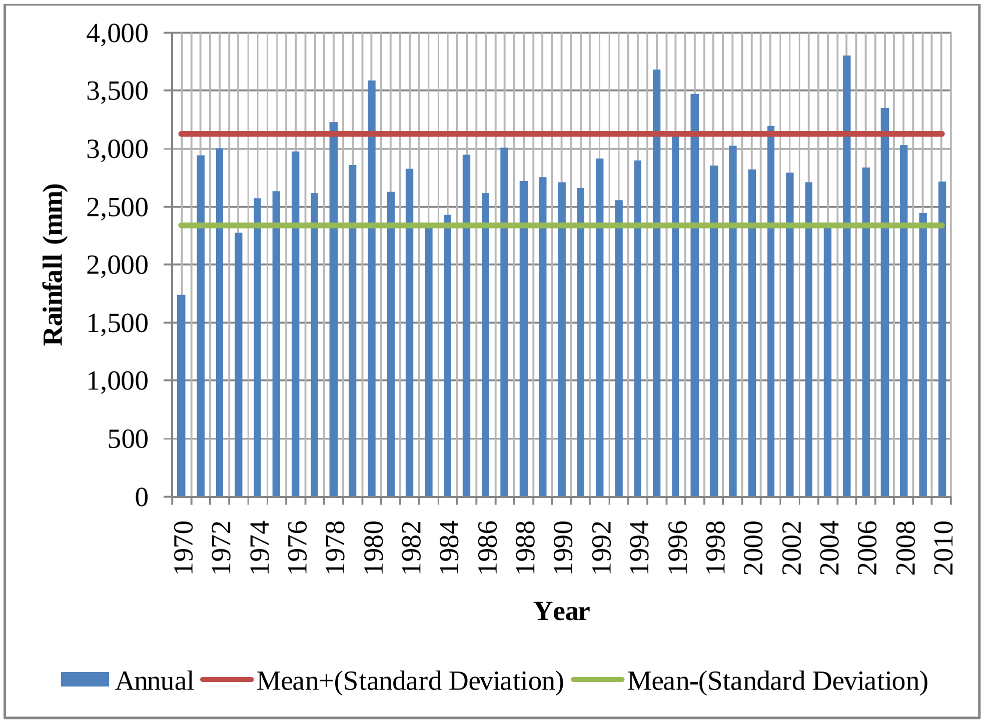

Figure 5: Annual Rainfall Amounts

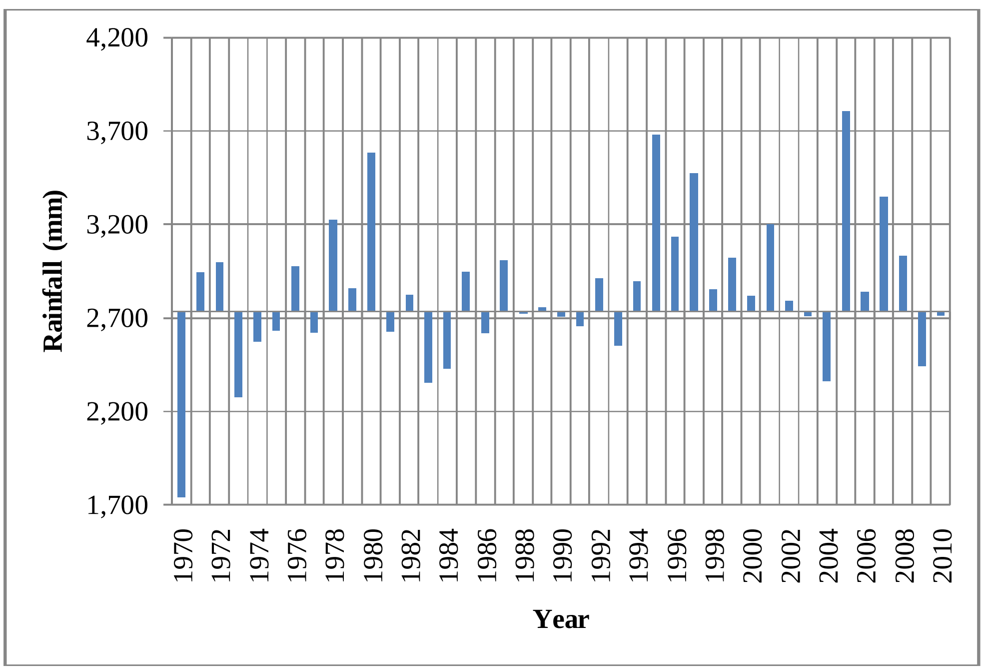

Figure 6: Annual Rainfall Amounts over Long-Term Mean (2,735 mm)

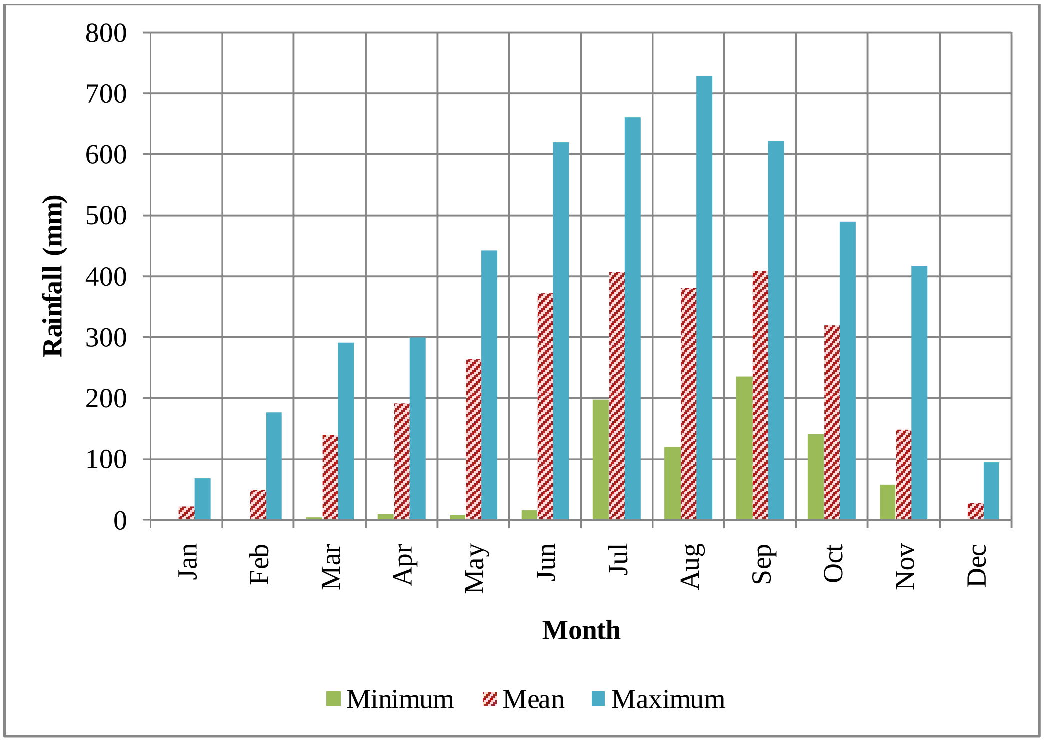

Figure 7: Monthly Rainfall Pattern (1970 - 2010)

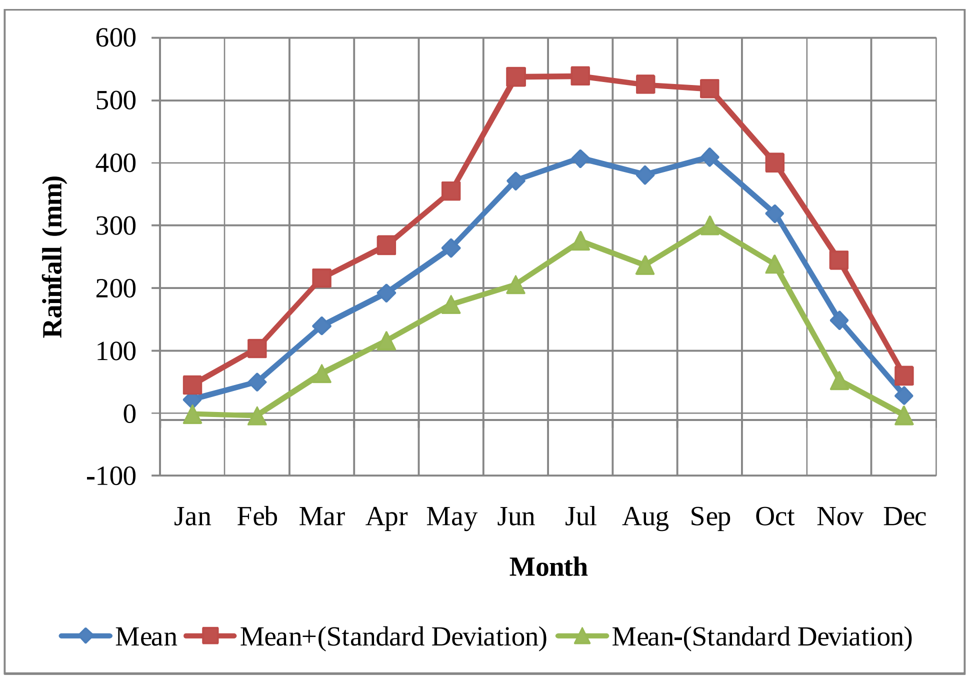

Figure 8: Seasonal Rainfall Pattern (1970 - 2010)

Definition of Concept

For many hydrologic analyses, planning or design problems, reliable rainfall intensity estimates are necessary. Rainfall intensity duration frequency relationship comprises the estimates of rainfall intensities of different durations and recurrence intervals.

Methods

The typical technique for establishing rainfall IDF curves is conducted via three steps.

Step I: Statistical analysis of the available rainfall records from the different rainfall stations which include statistical analysis to check the pattern of flow of the data, as shown in Figures 1-8.

Step II Determination of rainfall intensities, I (mm/hr): This is computed for 12-hr and 24-hr durations for that of Calabar rainfall data and 24-hr duration for Imo, Anambra and Benin city rainfall data following the nature of the rainfall data available for extreme values.

Step III: Extraction of annual extremes from the records and fitting of a probability distribution (Tables 3 - 5) was used to generate the 12-hr and 24-hr duration rainfall intensity curve as shown in Figures 9-12.

Step IV: Creation of Regional Rainfall Intensity (RRI) map (Figures 14 - 21) from the rainfall intensity frequency curve, for each return period shown in (Tables 6-7). An ArcView GIS model was used to generate a map applying the “inverse distance weighting method” for the interpolation of the stations’ value.

Step V: Determination of IDF curves; for the case of only 24-hr duration records available, an empirical template developed for the Nigeria Erosion Watershed Management Project (NEWMAP) model (Table 8) was used to plot the IDF curve shown in Figures 13(a and b).

Table 3: Intensity generation sheet

Rank	Daily Rainfall (mm)	Rainfall Intensity (mm/hour)	Exceedance Probability	Return Period	24-Hour Duration Rainfall Intensity
1	196.0644583	8.16935243	0.006821788	146.5891249	8.16935243
2	159.3903108	6.64126295	0.112042428	8.925190356	6.64126295
3	156.4032706	6.516802941	0.133247851	7.504811446	6.516802941
4	153.5481405	6.397839188	0.156051538	6.408139349	6.397839188
5	148.1828054	6.174283557	0.205773624	4.859709335	6.174283557
6	145.2895752	6.0537323	0.236279422	4.232277162	6.0537323
7	145.0391007	6.043295864	0.239038709	4.183422853	6.043295864
8	141.7108636	5.904619315	0.277419523	3.604648981	5.904619315
9	136.7976658	5.699902741	0.339430503	2.946111177	5.699902741
10	132.5958544	5.524827267	0.396628075	2.521253698	5.524827267
11	132.0146961	5.500612338	0.404778186	2.470488863	5.500612338
12	130.0350558	5.418127326	0.432883469	2.310090523	5.418127326
13	129.4396572	5.393319051	0.441426117	2.265384763	5.393319051
14	122.182386	5.090932751	0.547148308	1.827658032	5.090932751
15	120.7109101	5.029621252	0.568557253	1.75883782	5.029621252
16	120.1	5.004166667	0.577404	1.731889631	5.004166667
17	117.9946348	4.916443117	0.607628164	1.645743332	4.916443117
18	115.7976767	4.824903197	0.638584466	1.565963553	4.824903197
19	112.8	4.7	0.679522448	1.471621729	4.7
20	109.8	4.575	0.71858513	1.391623565	4.575
21	107.2182236	4.467425984	0.750378469	1.332660839	4.467425984
22	106.6578418	4.444076743	0.757034176	1.320944326	4.444076743
23	102.7732574	4.282219058	0.800567553	1.249113827	4.282219058
24	88.95255192	3.70635633	0.915188419	1.09267117	3.70635633
25	72.05244197	3.002185082	0.979195861	1.021246147	3.002185082
26	71.2	2.966666667	0.980839415	1.019534885	2.966666667
	Mean	5.247999004			
	Standard Deviation	1.137720301			
	Skewness	0.119763005			
	Alpha	278.8782356			
	Beta	0.068128401			
	Gamma	-13.75152929			

Table 4: Intensity generation sheet

Rank	Daily Rainfall (mm)	Rainfall Intensity (mm/hour)	Exceedance Probability	Return Period	12-Hour Duration Rainfall Intensity
		Extrapolate	0.005	200	20.5
1	216	18	0.016247463	61.54807164	18
2	192.5	16.04166667	0.038466686	25.99652079	16.04166667
3	181	15.08333333	0.057640016	17.34905828	15.08333333
4	171.2	14.26666667	0.08050437	12.42168596	14.26666667
5	168.9	14.075	0.08693705	11.50257573	14.075
6	156.1	13.00833333	0.131789415	7.587862788	13.00833333
7	153.8	12.81666667	0.141695781	7.057373152	12.81666667
8	144.6	12.05	0.187898178	5.322031369	12.05
9	140.7	11.725	0.210937194	4.740747626	11.725
10	136	11.33333333	0.241661443	4.138020473	11.33333333
11	133.5	11.125	0.259373293	3.855447062	11.125
12	117.6	9.8	0.395070075	2.531196522	9.8
13	117	9.75	0.400960643	2.494010369	9.75
14	115.6	9.633333333	0.414910852	2.410156292	9.633333333
15	108.6	9.05	0.488694377	2.046268683	9.05
16	105.4	8.783333333	0.524393172	1.906966098	8.783333333
17	104	8.666666667	0.540331856	1.8507145	8.666666667
18	101	8.416666667	0.575027455	1.739047399	8.416666667
19	100.8	8.4	0.57736295	1.732012767	8.4
20	98	8.166666667	0.610283147	1.638583672	8.166666667
21	95.8	7.983333333	0.636351986	1.571457341	7.983333333
22	95.6	7.966666667	0.638726598	1.56561509	7.966666667
23	93.3	7.775	0.666042791	1.501405034	7.775
24	93.2	7.766666667	0.667229625	1.498734412	7.766666667
25	91.6	7.633333333	0.686188493	1.457325515	7.633333333
26	88.6	7.383333333	0.721448834	1.386099684	7.383333333
27	85.5	7.125	0.757176018	1.320696873	7.125
28	85.1	7.091666667	0.761712942	1.312830523	7.091666667
29	83.5	6.958333333	0.779655424	1.282617897	6.958333333
30	83.3	6.941666667	0.781873256	1.278979671	6.941666667
31	81.7	6.808333333	0.799392514	1.250949918	6.808333333
32	80	6.666666667	0.817523893	1.223205839	6.666666667
33	74.3	6.191666667	0.873769974	1.144465969	6.191666667
34	73.9	6.158333333	0.877409138	1.139719153	6.158333333
35	67.4	5.616666667	0.929681443	1.07563726	5.616666667
36	64.7	5.391666667	0.947187652	1.055757006	5.391666667
	Mean	9.490277778			
	Standard Deviation	3.156654913			
	Skewness	1.016092796			
	Alpha	3.874300004			
	Beta	1.603727158			
	Gamma	3.276957644			

Table 5: Intensity generation sheet

Rank	Daily Rainfall (mm)	Rainfall Intensity (mm/hour)	Exceedance Probability	Return Period	24-Hour Duration Rainfall Intensity
		Extrapolate	0.005	200	10.1
1	216	9	0.020521841	48.7285708	9
2	192.5	8.020833333	0.05496662	18.19285966	8.020833333
3	181	7.541666667	0.085853324	11.64777262	7.541666667
4	180.6	7.525	0.087153931	11.47395182	7.525
5	179.8	7.491666667	0.089805626	11.13515986	7.491666667
6	175.5	7.3125	0.105260423	9.500246852	7.3125
7	173.8	7.241666667	0.111957454	8.931964479	7.241666667
8	171.3	7.1375	0.122445892	8.166872614	7.1375
9	168.9	7.0375	0.133261663	7.504033644	7.0375
10	162.5	6.770833333	0.16591514	6.027177501	6.770833333
11	143.5	5.979166667	0.299123557	3.343100127	5.979166667
12	137.3	5.720833333	0.354731456	2.819033904	5.720833333
13	126.6	5.275	0.462942459	2.160095666	5.275
14	126.1	5.254166667	0.468311851	2.135329264	5.254166667
15	123.2	5.133333333	0.499874973	2.000500231	5.133333333
16	122	5.083333333	0.513119914	1.94886219	5.083333333
17	120.5	5.020833333	0.529800526	1.887502846	5.020833333
18	118.8	4.95	0.548841477	1.822019731	4.95
19	117.7	4.904166667	0.561221329	1.781828216	4.904166667
20	117	4.875	0.56911745	1.75710655	4.875
21	112.2	4.675	0.62338105	1.604155274	4.675
22	111.1	4.629166667	0.635779135	1.57287326	4.629166667
23	108.8	4.533333333	0.661553761	1.511592947	4.533333333
24	104.1	4.3375	0.713150888	1.402227799	4.3375
25	101	4.208333333	0.745980179	1.34051819	4.208333333
26	98	4.083333333	0.776509041	1.287815013	4.083333333
27	97.5	4.0625	0.781459783	1.279656384	4.0625
28	97.5	4.0625	0.781459783	1.279656384	4.0625
29	95.8	3.991666667	0.797968572	1.253182187	3.991666667
30	95.4	3.975	0.801777037	1.247229534	3.975
31	94.8	3.95	0.807433137	1.238492643	3.95
32	89.5	3.729166667	0.854184437	1.170707352	3.729166667
33	85.1	3.545833333	0.888116687	1.125978168	3.545833333
34	83.3	3.470833333	0.900609622	1.110359001	3.470833333
35	81.1	3.379166667	0.914743698	1.093202393	3.379166667
36	77.2	3.216666667	0.936690945	1.067587986	3.216666667
	Mean	5.309027778			
	Standard Deviation	1.547360945			
	Skewness	0.688142291			
	Alpha	8.447019423			
	Beta	0.532402253			
	Gamma	0.811815606			

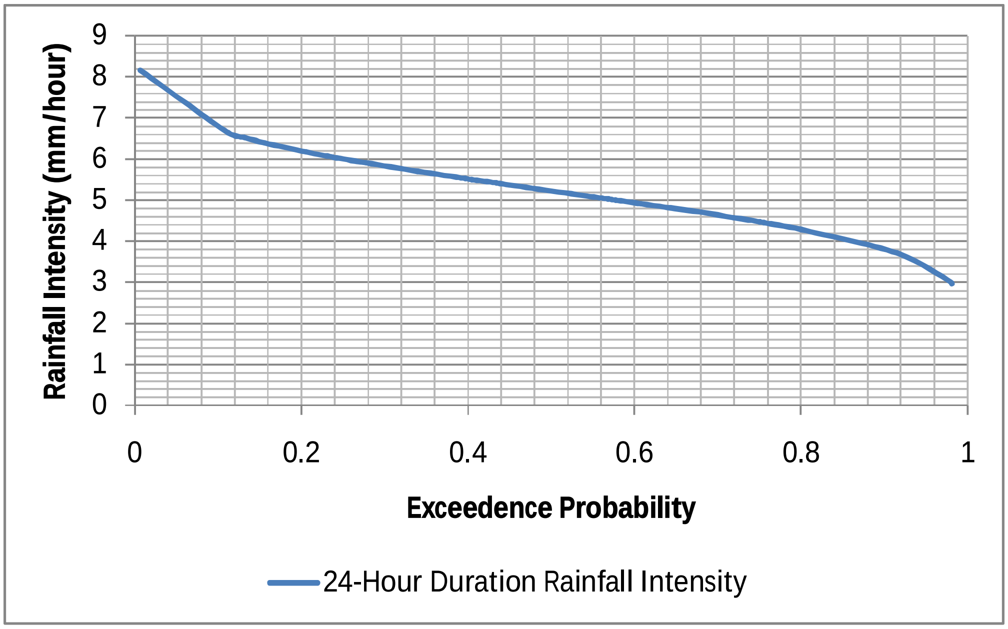

Figure 9: Rainfall Intensity Frequency Curve using Table 3

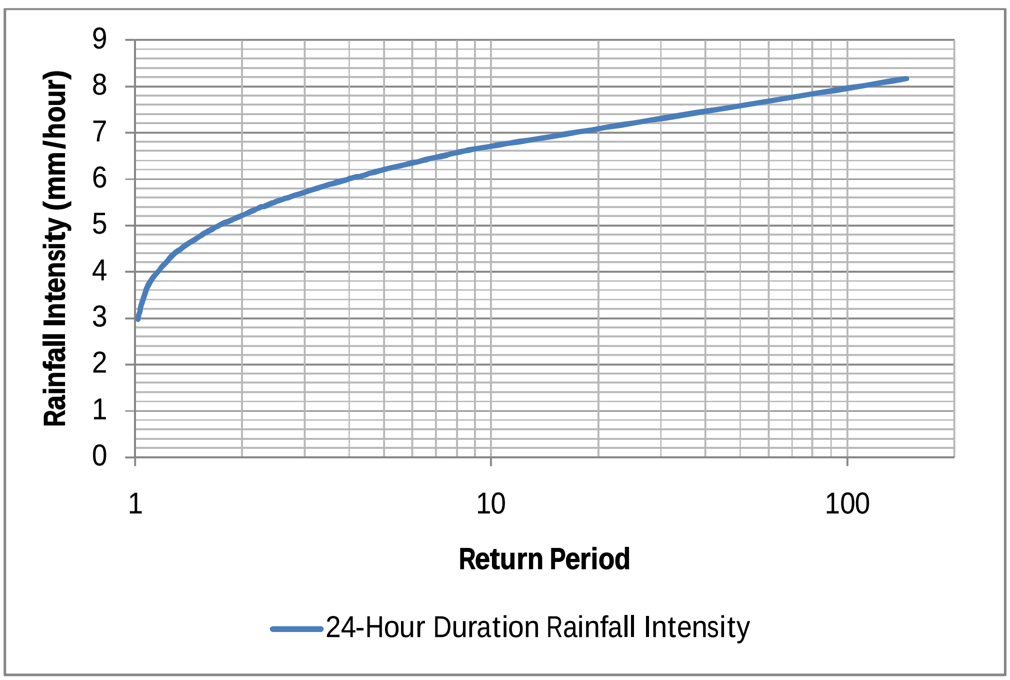

Figure 10: Rainfall Intensity-Return Period Curve using Table 3

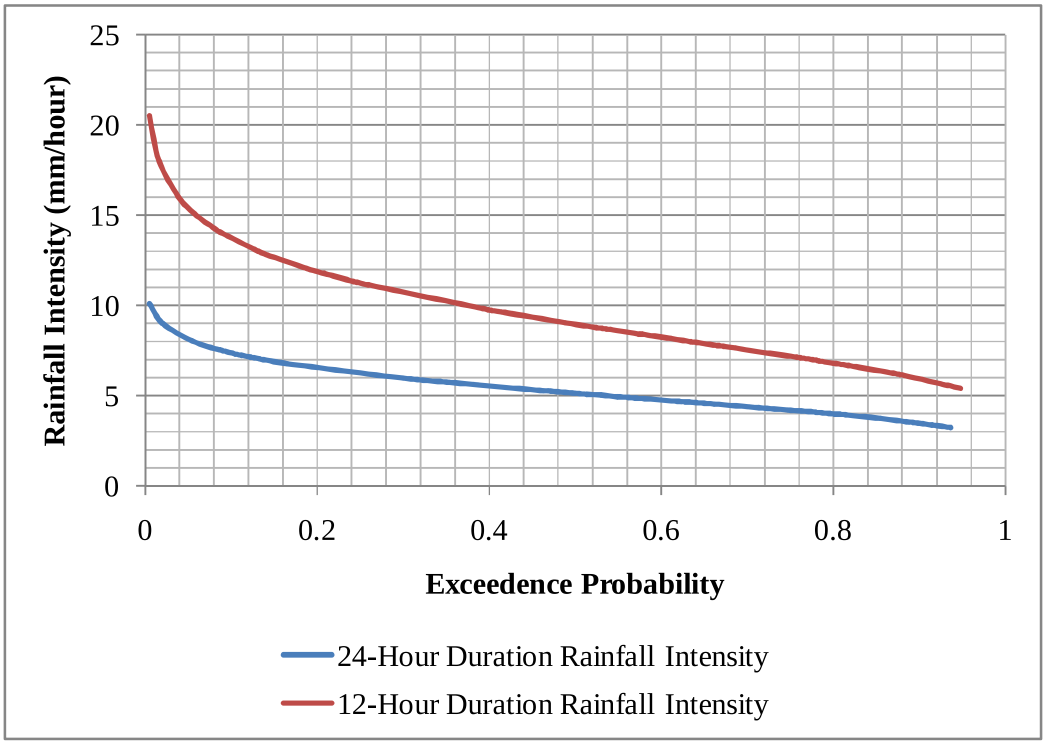

Figure 11: Rainfall Intensity-Frequency Curve (1970 - 2005) using Tables 4-5

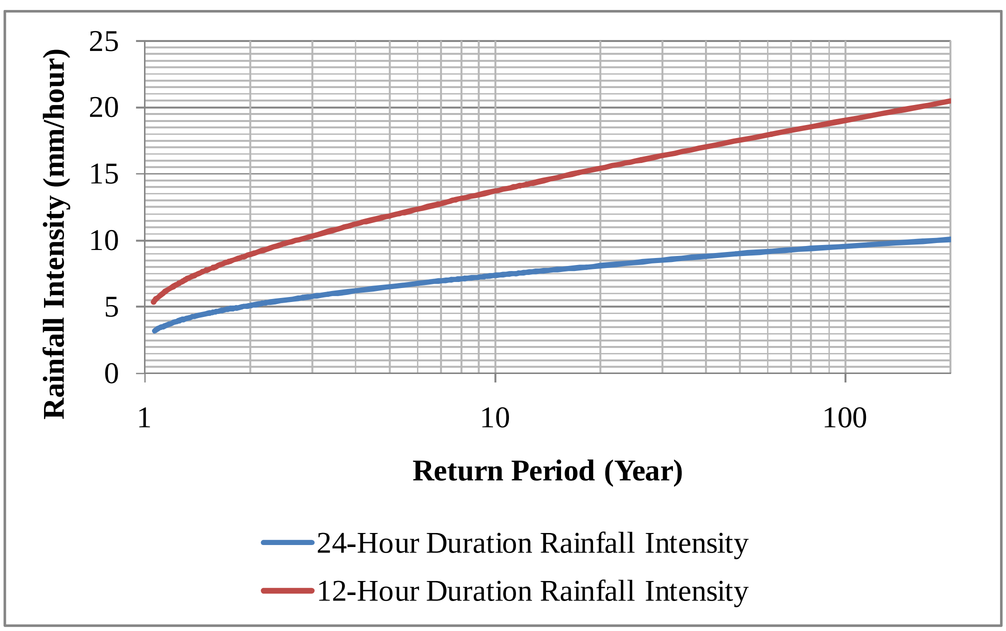

Figure 12: Rainfall Intensity-Return Period Curve (1970 - 2005) using Tables 4-5

Table 6: Gauged rainfall stations- historic data set

Station	x-long	y-lat	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
Benin	5.68	6.34	4.4	5.4	6.1	6.9	7.5	8.1
Onitsha	6.78	6.15	4.4	5.5	6.2	6.9	7.5	8
AIRBDA-Owerri	7.19	5.66	5.2	6.2	6.7	7.1	7.6	8
Calabar	8.35	4.95	5.1	6.5	7.5	8.5	9	9.6

Table 7: Gauged rainfall stations- climate change scenario

Station	x-long	y-lat	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
Benin	5.68	6.34	5.3	6.2	6.7	7.4	7.8	8.2
Onitsha	6.78	6.15	5.2	6.3	7	7.8	8.3	8.9
AIRBDA-Owerri	7.19	5.66	6.2	7.4	8	8.6	9.1	9.6
Calabar	8.35	4.95	6	7.5	8.5	9.5	10.3	11

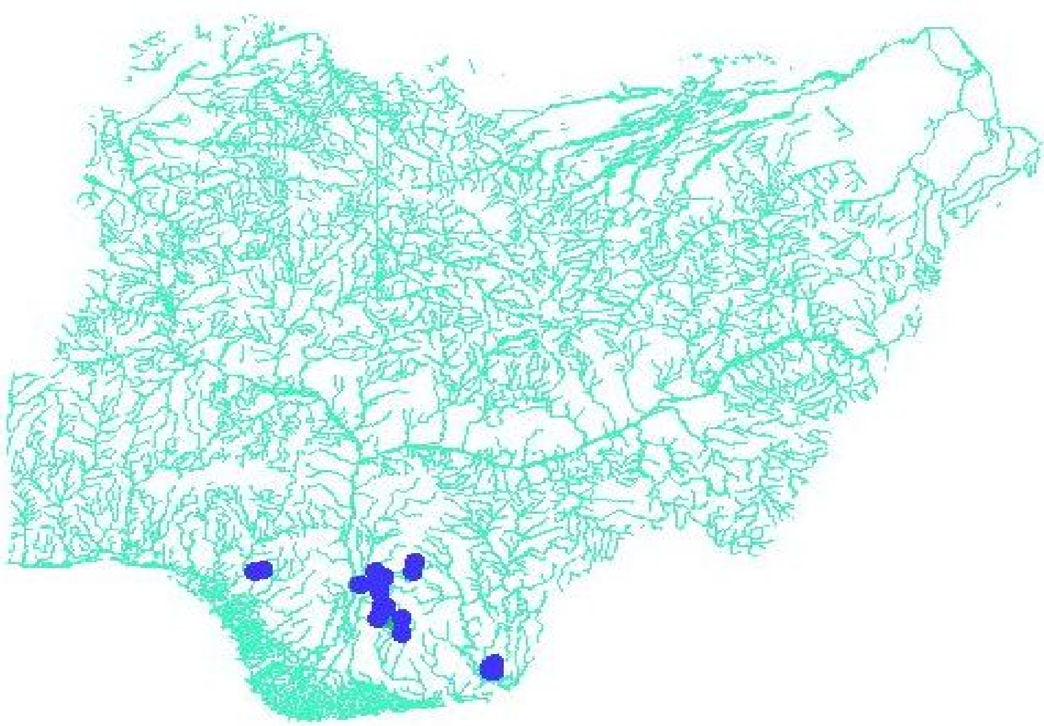

Figure 14: Map of Nigeria showing some selected erosion sites

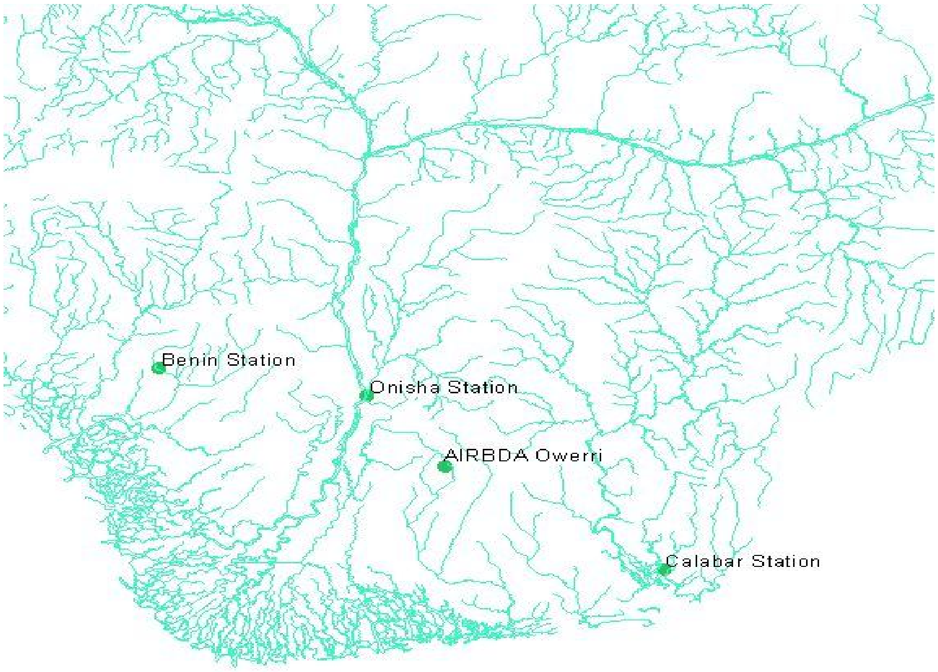

Figure 15: Map of Nigeria showing the rainfall guage stations

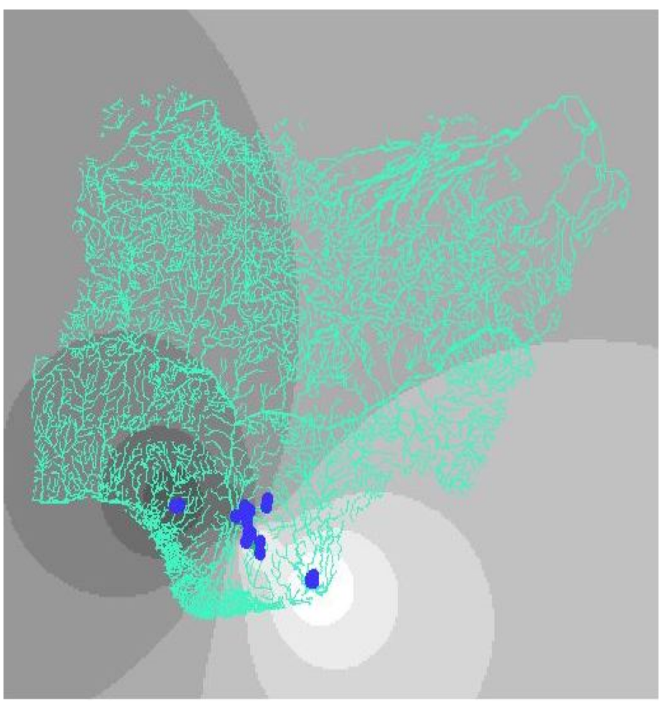

Figure 16: 2 years return period

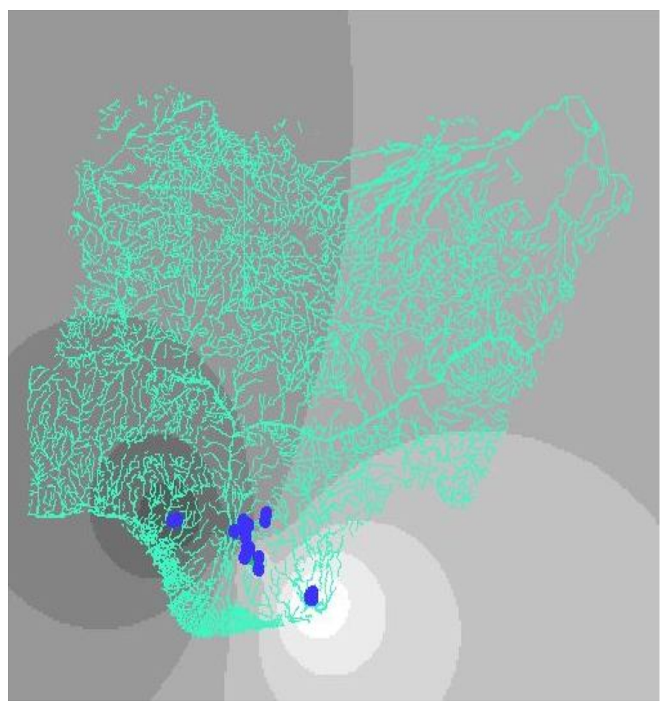

Figure 17: 5 years return period

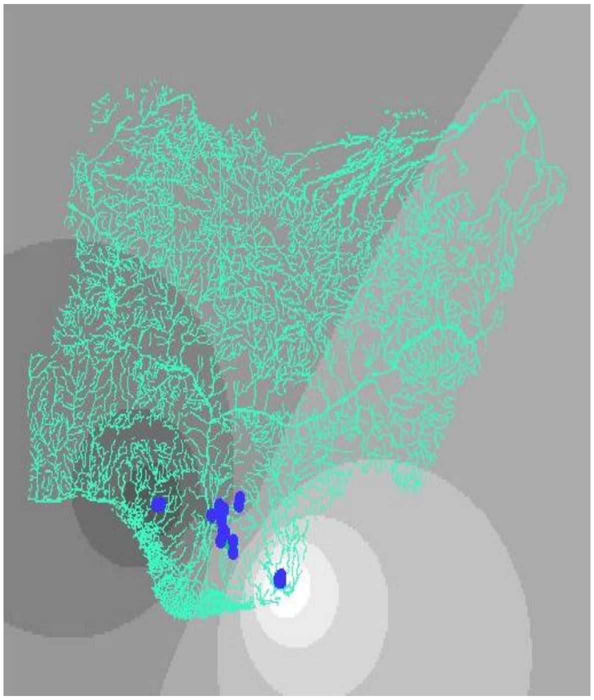

Figure 20: 10 years return period

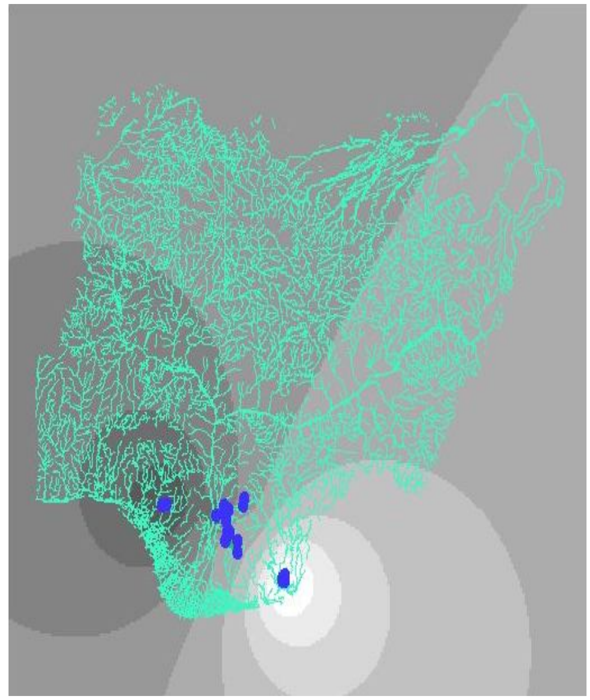

Figure 20: 25 years return period

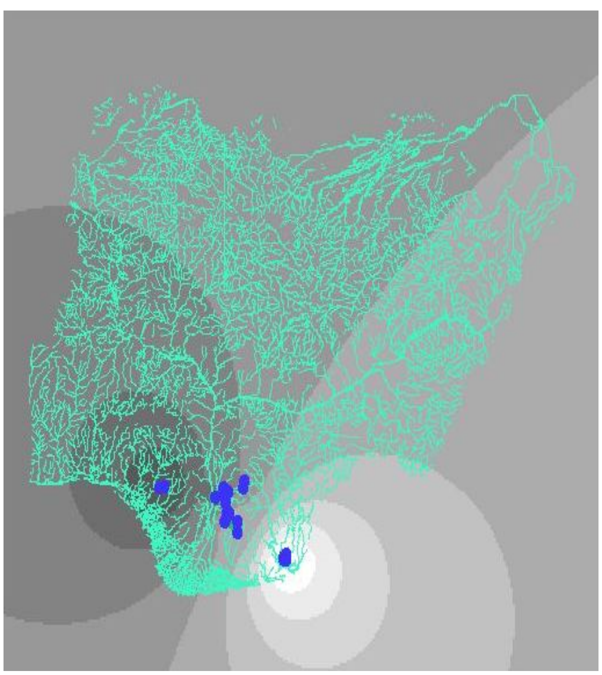

Figure 20: 50 years return period

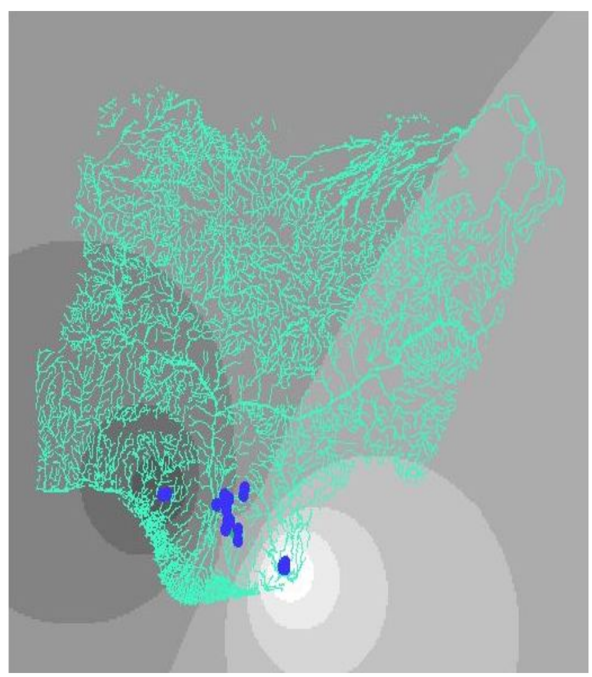

Figure 21: 100 years return period

Table 8: NEWMAP Empirical Template

Duration	100-Year	50-Year	25-Year	10-Year	5-Year	2-Year	100-Year	50-Year	25-Year	10-Year	5-Year	2-Year
1440	1	1	1	1	1	1	9.4175	8.8906	8.3876	7.728	7.0978	5.9242
720	1.979167	1.944444	1.882353	1.833333	1.815385	1.764706	18.6388	17.28728	15.78842	14.168	12.88524	10.45447
360	3.917101	3.780864	3.543253	3.288178	3.295621	3.114187	36.8893	33.61415	29.71939	25.41104	23.39166	18.44907
180	7.752595	7.35168	6.669652	5.962562	5.98282	5.495624	73.01006	65.36085	55.94237	46.07868	42.46486	32.55717
180	1	1	1	1	1	1	73.01006	65.36085	55.94237	46.07868	42.46486	32.55717
120	1.315385	1.304348	1.4	1.277778	1.428571	1.090909	96.03632	85.25328	78.31932	58.87832	60.66409	35.51692
100	1.181287	1.166667	1.071429	1.130435	1.15	1.25	113.4464	99.46216	83.91356	66.5581	69.7637	44.39615
80	1.138614	1.142857	1.2	1.153846	1.217391	1.2	129.1717	113.671	100.6963	76.7978	84.92972	53.27538
60	1.173913	1.2	1.222222	1.266667	1.142857	1.333333	151.6363	136.4053	123.0732	97.27722	97.06254	71.03384
40	1.362963	1.333333	1.272727	1.263158	1.28125	1.25	206.6746	181.8737	156.6386	122.8765	124.3614	88.7923
20	1.326087	1.375	1.464286	1.5	1.487805	1.466667	274.0686	250.0763	229.3637	184.3147	185.0255	130.2287
10	1.483607	1.454545	1.414634	1.388889	1.442623	1.5	406.6099	363.7473	324.4658	255.9927	266.922	195.343

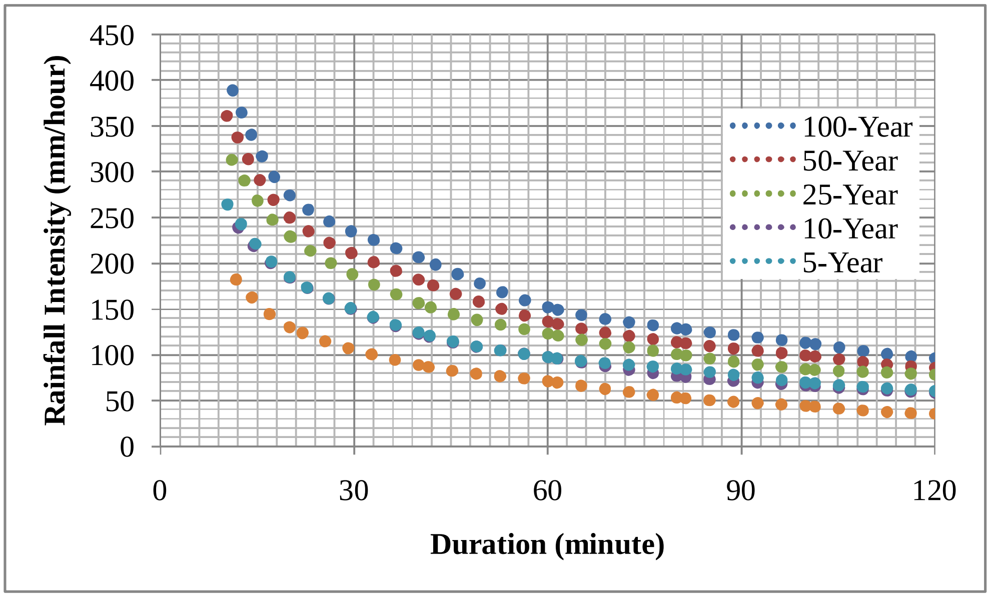

Figure 13(a): Developed Rainfall Intensity-Duration-Frequency Curve (duration ranging from 0-120 minutes)

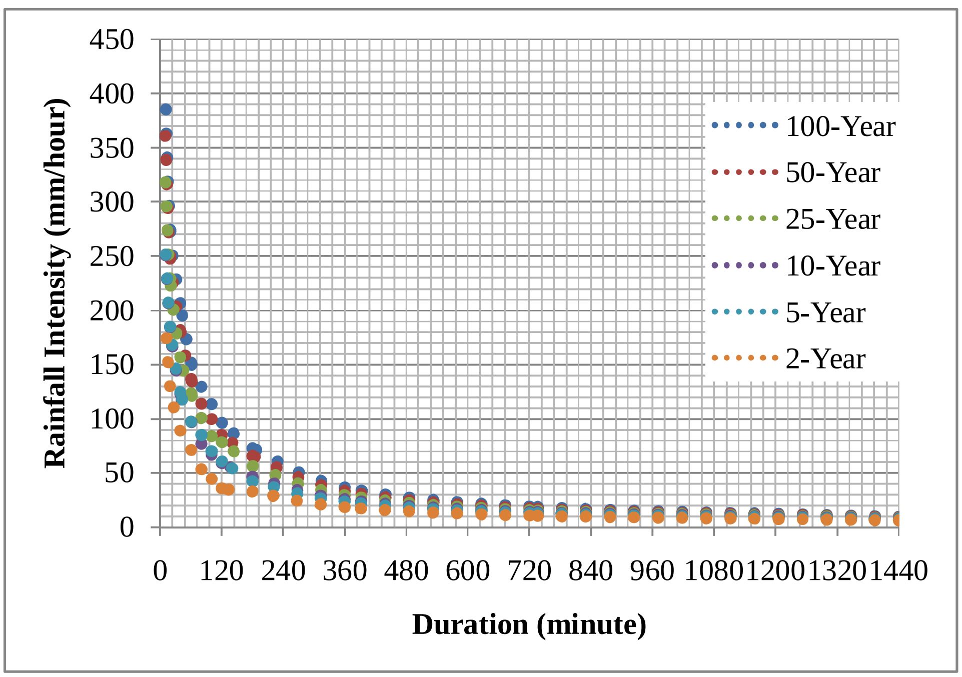

Figure 13(b): Developed Rainfall Intensity-Duration-Frequency Curve (duration ranging from 0-1440 minutes)

Conclusion

Historical rainfall records are needed to obtain design estimates for both small and large projects. This study is an attempt to provide much needed, useful design data and guidance for water resources development in Eastern catchment of Nigeria.

The Maximum Annual Precipitation series as obtained at each station for different durations remained an acceptable tool for generating a-24 hr intensity-duration-frequency values at 2, 5, 10, 25, 50 and 100 years.

The regionalization of the parameters of rainfall intensity-duration-frequency equations generated for ungauged stations estimate rainfall intensity for various return period and rainfall duration. These 24-hr IDF values spatially interpolated using ArcView GIS model to obtain RRI maps for all durations and return periods should apply to catchments in eastern Nigeria.

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