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## CONTENTS

The Use of Lichens as Bio-Indicators and a Cost-Effective way for Heavy Metals Pollution Monitoring in Ambient Air in The Western Area and Southern Province of Sierra Leone <b>Abdul Sannoh &amp; Ronnie. A.D. Frazer-Williams</b> -----	1-13
Academic Mentorship and Lecturers' Productivity in Public Universities in Lagos State, Nigeria <b>SHITTU, Taofeek Olawale; OLA, Bolanle Adeyemi &amp; ADEPOJU, Funke Femi</b> -----	14-20
Paradoxes of the use of Technologies in Secondary Education System in Africa <b>Femi Sunday Akinwumi &amp; Adeola Iyabosola Ayo-Ayinde</b> -----	21-30
Social Insecurity and Proneness to Get- Rich-Quick-Syndrome among Adolescents in Lagos State, Nigeria: Counselling for National Development <b>A. O. Badejo &amp; Stella Ngozi Chinwuba-Anameje</b> -----	31-40
Design and Production of an Improved Cook Stove with Swinging Combustion Chamber to Enable Refueling for Continuous Operation <b>Sheriff Kamara</b> -----	41-59
Teachers' Welfare as a Veritable Tool for Effectiveness among Public Secondary Schools In Lagos State, Nigeria <b>Ladipo, Sunday Akinremi</b> -----	60-63
Free Education Program in Sub Saharan Africa: A Comparative Analysis of Sierra Leone and Nigeria <b>James VIBBI &amp; Abidat Oluwashola MOHAMMED</b> -----	64-76
Managing Education for Innovation and Security in the Development of Sub-Shara Africa: Policy Formulation and Implementation Option <b>John Oluyemi EGBEBI &amp; Opeyemi Aderonke OYEKAN</b> -----	77-85
Cross-Cultural Influences on Girl-Child Education in Ojo Riverine Area of Lagos State, Nigeria <b>Enitan Omolara Falade &amp; Prof. Olawunmi Ayodeji Badejo</b> -----	86-92
Establishing a School Climate That Proritizes Child Safety to Promote Sustainable National Development <b>Henry Adewale Odunayo; Nurudeen Olalekan Orunbon &amp; M. O. B. Mohammed</b> -----	93-102
Gender Equality: A Must for Sustainable Development in Africa <b>Aisha Fofana Ibrahim &amp; Claudine Anita Hingston</b> -----	103-110
Teachers' Reward System and Academic Performance of Public Senior Secondary School Students in Lagos State, Nigeria <b>ANIFOWOSHE, Olawale Jamiu &amp; MOHAMMED, M. O. B.</b> -----	111-116

Records Management Practices and Productivity of Academic Heads of Department in Public Universities in Lagos State, Nigeria <b>Afolabi, Abolanle Omotunde; Shittu, Taofeek Olawale &amp; Mohammed, M. O. B. -----</b>	<b>117-124</b>
Estimating Rainfall Intensity Duration-Frequency (IDF) Curves for River Rokel Catchment in Tonkolili District Using Satellite Rainfall Data <b>Amadu Barrie; Osman Koroma &amp; Melvin B Scott-----</b>	<b>125-135</b>
Religious Education, Security Challenges, and National Development in Nigeria <b>Exradallenum Olusegun Akinsanya, Opaaje, Samuel Sunday &amp; Aina, Omololu Olukayode -----</b>	<b>136-147</b>
Integrating Sustainable Water Resources Management Practices into Public University Administration in Lagos State, Nigeria: A Multi-Variable Analysis <b>Adepoju, Funke Femi-----</b>	<b>148-155</b>
Examining the Nexus between Inadequate Educational Facilities as Proxy for Migration and Personal Remittance in Nigeria: Impact on Socio-Economic Development <b>Rufai, Musiliu Dada; Anagun, Adeyemi Michael &amp; Olayide, Bilkis Omolara.....</b>	<b>156-165</b>

# ESTIMATING RAINFALL INTENSITY DURATION-FREQUENCY (IDF) CURVES FOR RIVER ROKEL CATCHMENT IN TONKOLILI DISTRICT USING SATELLITE RAINFALL DATA

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## Abstract

*Extreme rainfall events have been a frequent cause of economic, social, and environmental disasters and are critical to hydrologic design and risk assessment. Rainfall Intensity-Duration-Frequency (IDF) relationship is one among the plethora of tools used for planning, designing and operating water resource development infrastructures. The study aimed at establishing IDF curves for the river Rokel catchment in Tonkolili district using satellite rainfall data. The Chi-square goodness of fit test was used to test the goodness of fit of empirical data to the two theoretical frequency distributions in this study. From the results of the Chi-square goodness of fit test on annual maximum series of rainfall, it was established that all of the data fit the two distributions at the level of significance of  $\alpha = 0.05$ , which yields  $\chi^2_{crit} = 54.56$ , and  $\alpha = 0.1$ , which yields  $\chi^2_{crit} = 50.65$  are both greater than  $\chi^2_{cal} = 1.42$  and  $1.75$  for Gumbel and GEV distribution respectively for a degree of freedom of  $N-1 = 39$ . The frequency analysis shows that the Gumbel distribution gives a maximum intensity of 420.76 mm/hr at return period of 500 years with duration of 0.083 hours and minimum intensity of 4.63 mm/hr at return period of 2 years with duration of 24 hours. The GEV distribution gives a maximum intensity of 419.47 mm/hr at return period of 500 years with duration of 0.083 hours and minimum intensity of 4.61 mm/hr at return period of 2 years with duration of 24 hours.*

**Key words:** Rainfall, Intensity-duration frequency relationship, Goodness of fit test, Probability distributions.

## Introduction

The design of water resources projects with inadequate data remains a continual engineering challenge, despite modern and widespread observational techniques (Barrie & Scott, 2021). In particular, Intensity Duration-Frequency (IDF) curves for precipitation are urgently needed for water resources projects in tropical Africa. IDF curves for precipitation determine the relationship between the mean intensity, the duration, or more precisely the aggregation time, and the frequency of an event (Akpen GD, 2019). This information is required for water resources projects, sewer system design, or water quality management projects in large urban areas.

Extreme environmental events, such as floods, droughts, rainstorms, and high winds, have severe consequences for human society. Planning for weather-related emergencies, design of engineering structures, reservoir management, pollution control, and insurance risk calculations, all rely on knowledge of the frequency of these extreme events (Wambua, 2019). The assessment of extreme precipitation is an important problem in hydrologic risk analysis and design. This is why the evaluation of rainfall extremes, as embodied in the IDF relationship, has been a major focus of both theoretical and applied hydrology (Dakheel, 2017).

Many previous studies have been done on rainfall analysis in various regions of the world, reported that the IDF relationship is a mathematical relationship between the rainfall intensity  $i$ , the duration  $d$ , and the return period  $T$  (or, equivalently, the annual frequency of exceedance, typically referred to as "frequency" only) (Das et al., 2016). Rainfall IDF is also defined as a relationships of graphical representations of the amount of water that falls within a given period of time (Dupont, 2000). These graphs are used to determine when an area will be flooded, and when a certain rainfall rate or a specific volume of flow will reoccur in the future (Devkota, 2018).

Rainfall frequency analyses are used extensively in the design of systems to handle storm runoff, including roads, culverts and drainage systems (Fadhel et al., 2017). (Smith, 1993) states that the "the precipitation frequency analysis problem is to compute the amount of precipitation  $y$  falling over a given area in a duration of  $x$  min with a given probability of occurrence in any given year." for engineering design applications. It is necessary to specify the temporal distribution of rainfall for a given frequency, or return interval (H.A et al., 2016). IDF or Depth-Duration Frequency (DDF) curves "allow calculation of the average design rainfall intensity or depth for a given exceedance probability over a range of durations" and is the result of the rainfall frequency analysis (B.F & R.T, 2016). (L.A & D.W, 2005) established that IDF estimates are important statistical summaries of precipitation records used for hydrologic engineering design.

## **MATERIALS AND METHODS**

### **Collection of Precipitation Data**

The Old Magburaka Bridge across the River Rokel was selected as the meteorological station. There are only few meteorological stations operated in Sierra Leone as shown in Figure 3.3. The data used in this project was obtained from the Climate Hazards Group Infrared Precipitation (CHIRP). The data consists of daily rainfall depth for a period of forty (40) years. Table 3.1 shows the geographical position, elevation and record length of precipitation data for the selected satellite station.

### **Description of Study Area**

The River Rokel (also Seli River; previously Pamoronkoh River) is the largest river in the Republic of Sierra Leone in West Africa. The river basin measures 10,622 square kilometers in size, with the drainage divided by the Gbengbe and Kabala hills and the Sula Mountains. The River Rokel rises in the 900 metres high interior plateau of the Loma mountains, in the Guinea Highlands of north central Sierra Leone, flow south west about 390 km through hill ranges and, together with a smaller, parallel stream called Port Loko creek which feeds into the Rokel estuary before the Atlantic Ocean. The estuary, after it joins the Bankasoka River, is also called the Sierra Leone River, is 40 km in length and has a width of 6.4 - 16.1 km. Freetown and Pepel are the two ports located on the shores of the estuary. As the estuary widens and joins the Atlantic its width is about 11 km. The southern shore is the deepest and forms a natural harbour, which is reported to be the third largest in the world. The section of the Rokel River in this study is located in Tonkolili District, Northern Province of Sierra Leone. Magburaka is the district's capital and largest city. Masingbi, Yele, Mile 91, Bumbuna, Yonibana and Matotoka are among the other major towns. In the town of Magbass in Tonkolili district was the home to Sierra Leone's former largest sugar factory as well as one of the largest sugar factories in west Africa. Tonkolili district had 530,776 residents. The district is made up of eleven chiefdoms and covers a total size of 7,003 km<sup>2</sup>.



Tonkolili district is bordered on the Northwest by Bombali district, on the east by Kono district and on the southeast by Kenema district and Bo district.



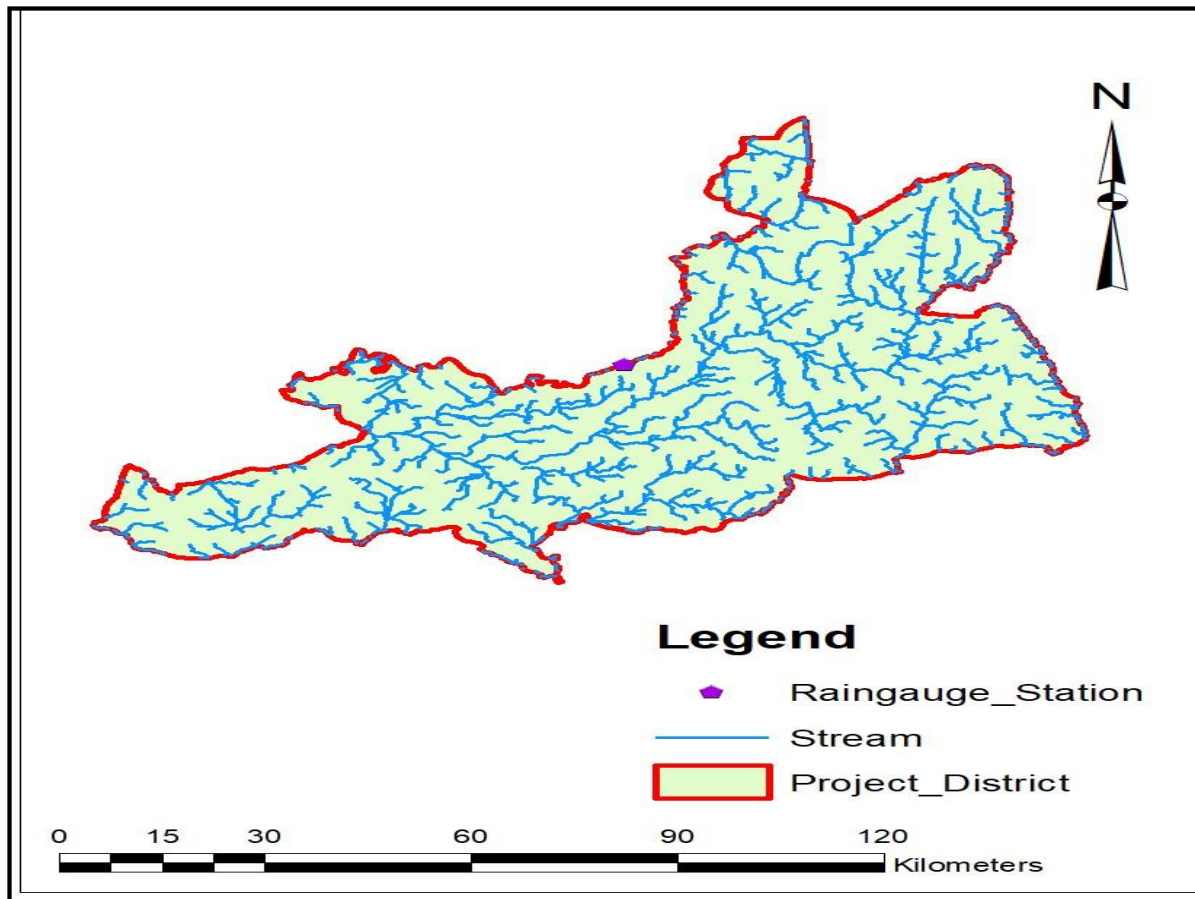
### **Data analysis**

The total rainfall received in a given period at a location is highly variable from one year to another. The variability depends on the type of climate and the length of the considered period. The data used in this study was from 1981-2020.

### **Maximum daily rainfall series**

A total of 40 daily maximum annual precipitation data were analyzed as shown in Table 4.3. The mean annual precipitation of River Rokel catchment is 108.74 mm with a standard deviation of 23.51 mm. As a declining tendency in precipitation is proved for the catchment of River Rokel, a decreasing trend was supposed. The distribution of daily maximum annual rainfall received during different months for 40 years periods is presented in Figure 4.3. From Figure 4.3, it can be seen that August received the highest amount of daily maximum annual rainfall (71%) followed by July (29%).





Year	Maximum Annual Rainfall Series (mm)	Date
1981	143.64	5-July
1982	117.98	5-August
1983	123.77	31-August
1984	81.52	4-July
1985	89.89	16-July
1986	109.78	31-August
1987	83.50	26-August
1988	88.71	3-August
1989	109.12	27-August
1990	136.40	20-August
1991	109.30	5-August
1992	89.55	27-August
1993	97.43	28-August
1994	130.07	6-August
1995	78.97	21-July
1996	100.28	1-July
1997	102.90	3-July
1998	145.52	9-August
1999	92.73	17-August
2000	70.74	2-August

2001	78.09	23-July
2002	110.16	2-August
2003	119.53	2-August
2004	106.77	9-August
2005	98.98	4-August
2006	117.88	24-July
2007	134.14	21-August
2008	161.31	27-July
2009	86.83	27-August
2010	85.80	16-July
2011	131.40	3-August
2012	104.69	30-August
2013	141.75	28-August
2014	100.66	8-August
2015	95.89	11-August
2016	169.23	27-July
2017	98.26	6-August
2018	124.06	29-August
2019	88.44	31-July
2020	94.10	15-August

### Gumbel (EV I) Distribution

For the case where  $k = 0$ , the solution is less simple since two parameters must be found,  $\alpha$  and  $U$ . The parameters are obtained through the use of the following expressions (R & A, 2015):

$$M_{100} = E(X_i) = \frac{1}{n} \sum_{i=1}^n x_i \quad (5.9)$$

$$M_{101} = \frac{1}{n} \sum_{i=1}^n x_i (1 - F_i) \quad (5.10)$$

$$\alpha = \frac{M_{100} - 2M_{101}}{\ln 2} \quad (5.11)$$

$$U = M_{100} - 0.5772\alpha \quad (5.12)$$

### GEV Distribution

For the case where  $k \neq 0$ , or where  $k$  is unknown, the solution is less simple since three parameters must be found,  $\alpha$ ,  $U$  and  $k$ . The unbiased estimates of the parameters are obtained through the use of the following expressions, (Boucher, 2017):

$$b_0 = M_{100} = E(X_i) = \frac{1}{n} \sum_{i=1}^n x_i \quad (5.13)$$

$$b_1 = M_{110} = E(X_i F_i) = \frac{1}{n} \sum_{i=1}^n (x_i F_i) \quad (5.14)$$

$$b_2 = M_{120} = E(X_i F_i^2) = \frac{1}{n} \sum_{i=1}^n (x_i F_i^2) \quad (5.15)$$

An approximate estimator of the shape parameter for the GEV distribution is given by:

$$C = \frac{2b_1 - b_0}{3b_2 - b_0} - \frac{\ln 2}{\ln 3} \quad (5.16)$$

For estimation of the shape parameter  $k$  the approximation given (J.R et al., 1985):

$$k = 7.859C + 2.9554C^2 \quad (5.17)$$

Then, the scale and location parameters can be estimated from (Hosking et al., 1985):

$$\alpha = \frac{(2b_1 - b_0)k}{[1+k(1-2^{-k})]} \quad (5.18)$$

$$U = b_0 + \frac{\alpha[\Gamma(1+k) - 1]}{k} \quad (5.19)$$

Where  $\Gamma$  is the gamma function (Press et al., 1992, for methods of calculation).

### GOODNESS OF FIT TEST

The validity of a probability distribution function proposed to fit the empirical frequency distribution of a given sample may be tested graphical and analytical methods. The test used in this study is the chi square test. Chi-square goodness of fit test is one of the most commonly used tests for goodness of fit of empirical data to specified theoretical frequency distributions. The test makes a comparison between the actual number of observations and the expected number of observations that fall in the class intervals. The expected numbers are calculated by multiplying the expected relative frequency by total number of observations. The Chi-square test statistic is calculated by:

$$\chi^2_{cal} = \sum_{i=1}^k \frac{(O_i - E_i)^2}{E_i} \quad (5.20)$$

Where,  $O_i$  is the observed rainfall and  $E_i$  is the expected rainfall and will have chi-square distribution with  $(N - 1)$  degree of freedom (df).

The hypothesis that the data follows a specified distribution is accepted if:

$$\chi^2_{cal} < \chi^2_{crit} \quad (5.21)$$

### IDF EMPIRICAL EQUATION

To derive an equation for calculating the rainfall intensity ( $I$ ) for the River Rokel catchment, there are some required steps for establishing an equation to suit the calculation of rainfall intensity for a certain recurrence interval and specific rainfall period which depends mainly on the results obtained from the IDF curves.

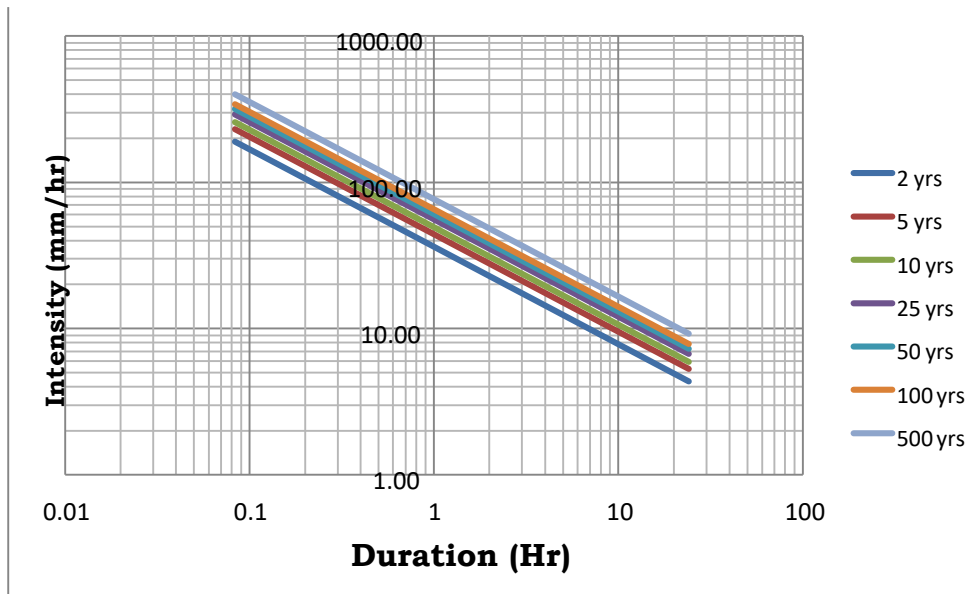
The relation between intensity, frequency and duration for River Rokel catchment in Tonkolili district is given by a power expression (Alhassoun, 2011):

$$I = \frac{CT^m}{t^n} \quad (5.22)$$

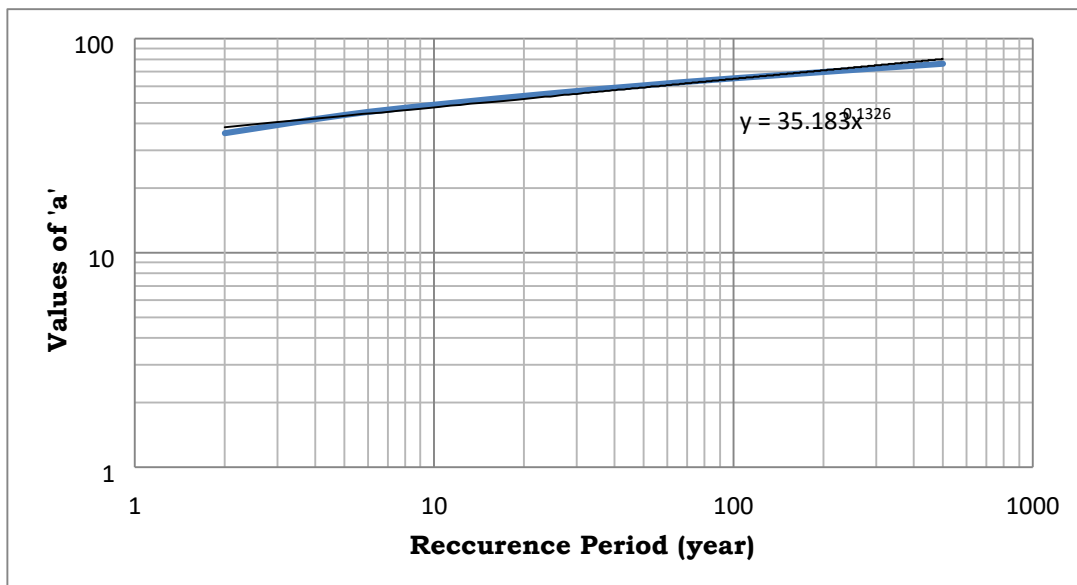
Where:  $I$  is the intensity in mm/hr,  $T$  is the frequency of occurrence in year,  $t$  is the duration of the storm in (hr),  $C$ ,  $m$  and  $n$  are regional coefficient to be determined from the given data.

## RESULTS AND DISCUSSION

### Gumbell's distribution



From the graph,  $n = 0.667$  and values of  $a = 36.243, 44.047, 49.214, 55.742, 60.585, 65.392$  and  $76.501$  for 2-year, 5-year, 10-year, 25-year, 50-year, 100-year and 500-year recurrence intervals. To obtain the values of  $C$  and  $m$ , derived values of ' $a$ ' are plotted on log-log Scale against corresponding recurrence intervals. The constants ' $C$ ' and ' $m$ ' of the intensity, frequency and duration relationship are determined by plotting the data of Return Period Vs. ' $a$ '. The resulting graph is shown in Figure 5.3. Values obtained are  $C = 35.183$  and  $m = 0.1326$ .

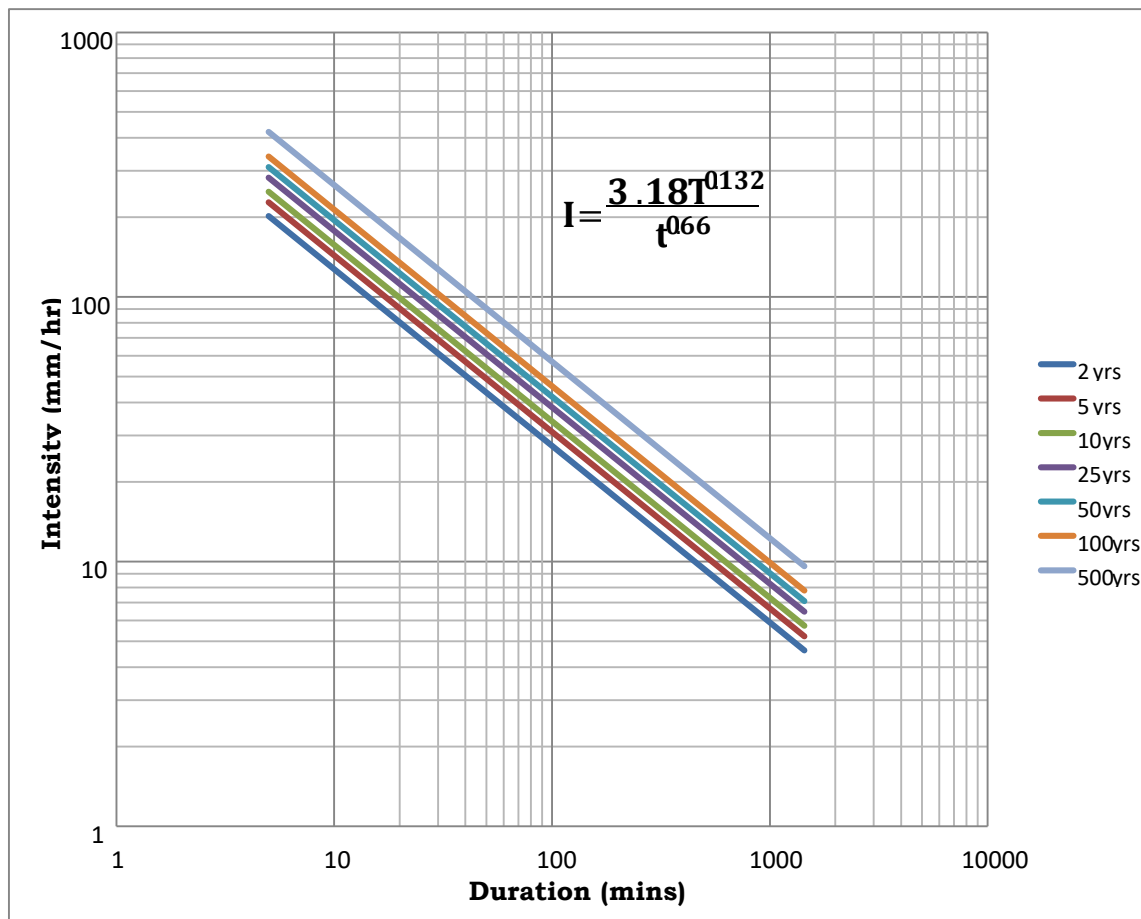


The IDF curve equation is obtained as:

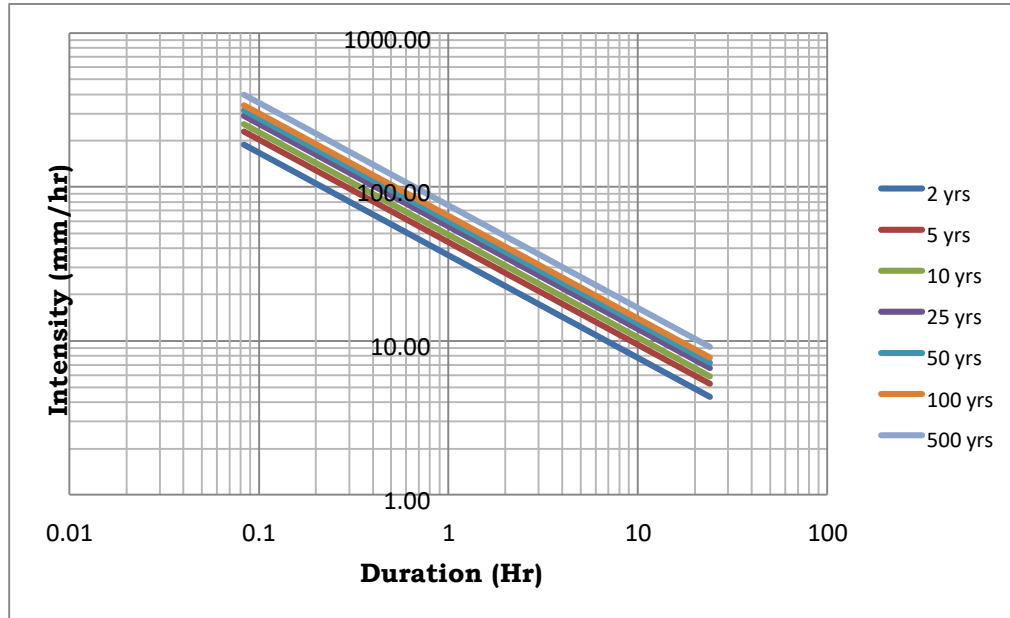
$$I = \frac{35.183T^{0.1326}}{t^{0.667}} \quad (5.23)$$

In order to plot the RIDF curves, the intensity - frequency - duration equation given in Equation (5.23) is employed to generate the Intensity-DurationFrequency data for 2-year, 5-year, 10-year, 25-year, 50-year, 100-year and 500-year recurrence periods.

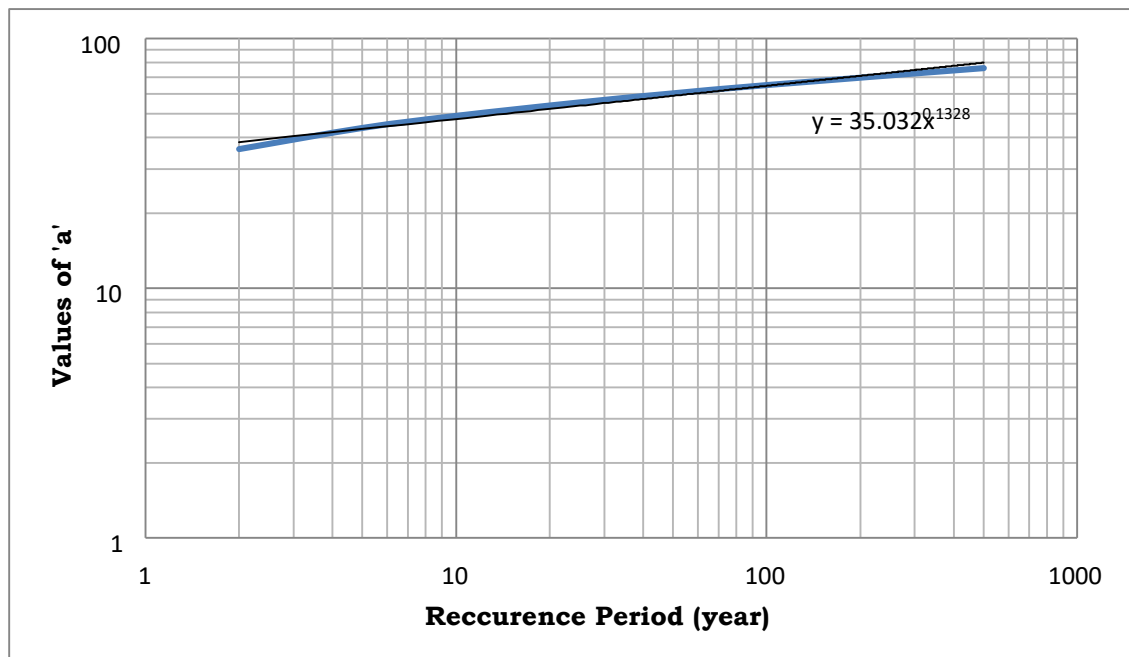
A graph of Intensity (mm/hr) against Time (mins) is plotted for 2-year, 5-year, 10-year, 25-year, 50-year, 100-year and 500-year storms are shown in Figure 5.4. The Gumbel distribution gives a maximum intensity of 420.76 mm/hr at return period of 500 years with duration of 0.083 hours and minimum intensity of 4.63 mm/hr at return period of 2 years with duration of 24 hours.



### GEV distribution



From the graph,  $n = 0.667$  and values of  $a = 36.037, 43.877, 49.039, 55.556, 60.386, 65.177$  and  $76.237$  for 2-year, 5-year, 10-year, 25-year, 50-year, 100-year and 500-year recurrence intervals. To obtain the values of  $C$  and  $m$ , derived values of ' $a$ ' are plotted on log-log Scale against corresponding recurrence intervals. The constants ' $C$ ' and ' $m$ ' of the intensity, frequency and duration relationship are determined by plotting the data of Return Period Vs. ' $a$ '. The resulting graph is shown in Figure 5.7. Values obtained are  $C = 35.032$  and  $m = 0.1328$ .

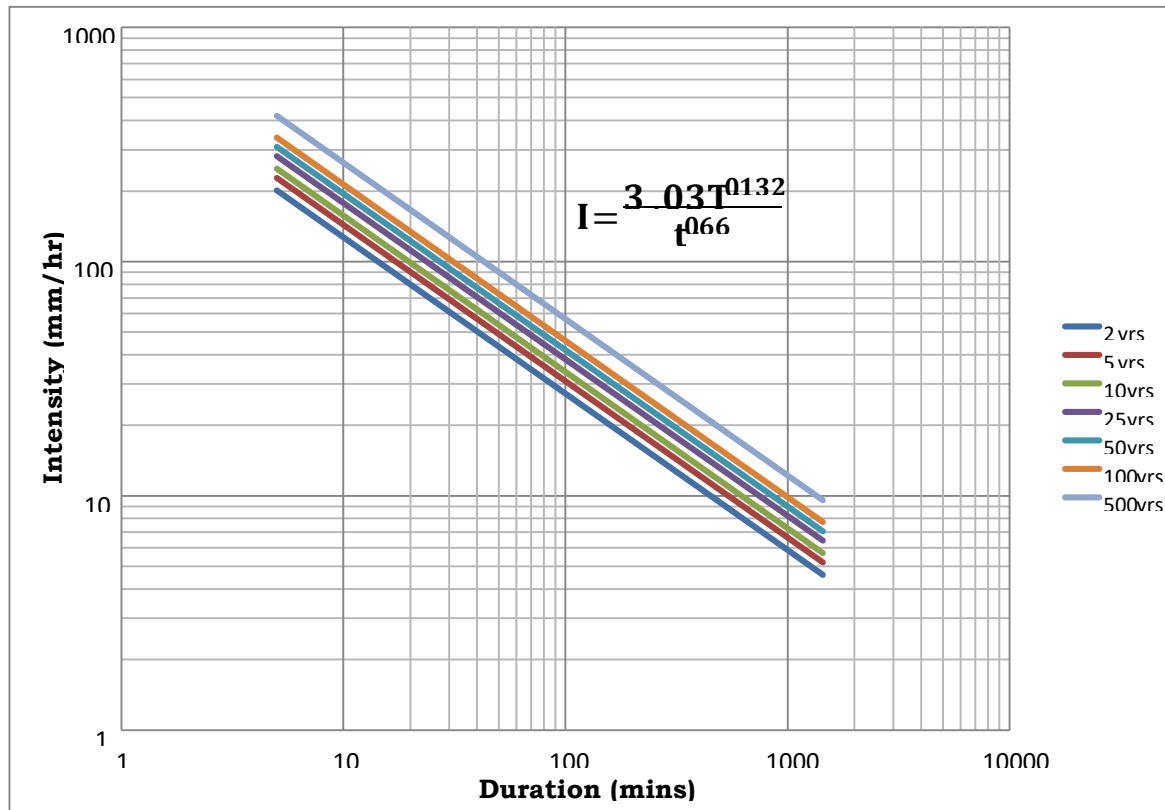


The IDF curve equation is obtained as:

$$I = \frac{35.032T^{0.1328}}{t^{0.667}} \quad (5.24)$$

In order to plot the RIDF curves, the intensity - frequency - duration equation given in Equation (5.24) is employed to generate the Intensity-Duration-Frequency data for 2-year, 5-year, 10-year, 25-year, 50-year, 100-year and 500-year recurrence periods.

A graph of Intensity (mm/hr) against Time (mins) is plotted for 2-year, 5-year, 10-year, 25-year, 50-year, 100-year and 500-year storms are shown in Figure 5.8. The GEV distribution gives a maximum intensity of 419.47 mm/hr at return period of 500 years with duration of 0.083 hours and minimum intensity of 4.61 mm/hr at return period of 2 years with duration of 24 hours.



## Conclusion

Establishing rainfall IDF relationships requires past rainfall data of good quality and continues for long period, which is normally not available in most dry countries. Although, many studies have been done to establish the rainfall IDF relationships in various regions of the world, but only few studies have been conducted in Sierra Leone of which the River Rokel catchment in Tonkolili district is the subject of this study. The following conclusions can be made from this project:

- (i) That the accumulated yearly rainfall gives a clear indication of the yearly variation of rainfall in River Rokel catchment in Tonkolili district and annual rainfall varied between 3244.18 mm (year 1992) and 2329.16 mm (year 2004). The average and standard deviation of the total annual rainfall for this 40-year period are respectively 2860.26 mm and 236.08 mm for 40 years periods.
- (ii) The distribution of daily maximum annual rainfall received during different months for 40 years periods depicted that August received the highest amount of daily maximum annual rainfall (71%) followed by July (29%).
- (iii) The Chi-square test shows that the Gumbel probability distribution function gives the



best estimation of the distributed predicted rainfall data as it has the smallest Chi-square value of 1.42 compared to GEV distribution function with a Chi-square value of 1.75.

- (iv) The frequency analysis shows that the Gumbel distribution gives a maximum intensity of 420.76 mm/hr at return period of 500 years with duration of 0.083 hours and minimum intensity of 4.63 mm/hr at return period of 2 years with duration of 24 hours. The GEV distribution gives a maximum intensity of 419.47 mm/hr at return period of 500 years with duration of 0.083 hours and minimum intensity of 4.61 mm/hr at return period of 2 years with duration of 24 hours.

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