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# Excel Solver Wizard Model Development for Abeokuta's Rainfall Intensity, Duration and Frequency

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**Abstract.** In hydraulic engineering systems, the kind and speed of water flow that results from rainfall activity in a particular catchment are constant variables. Twenty-five (25) years' worth of Abeokuta daily rainfall data (amount and duration) were provided by the Nigerian Meteorological Agency (NIMET), Abuja. After that, frequency analysis was performed on this data to produce intensity-duration-frequency models. The Excel Optimization Solver wizard was used to get the mean rainfall levels for the following time intervals: 5, 10, 15, 20, 30, 45, 60, 90, 120, 180, 240, 300, and 420 minutes. The data was then subjected to frequency analysis. For return periods of 2, 5, 10, 25, 50, and 100 years, defined and non-specified IDF models were created using the Normal distribution and Pearson type 3 distributions. Abeokuta has not witnessed these models' development. Values of the mean squared error (MSE) and coefficient of determination ($R^2$) were used to assess the probability distribution functions' fitness. The normal distribution has $R^2$ and MSE values between 0.977 and 0.991 and 85.73 and 118. 14, but the Pearson type 3 distribution has values between 0.964 and 0.997 and 42.88 and 118.68. It is recommended that the Ministry of Works utilize probability distribution models to anticipate rainfall intensities in the city of Abeokuta, in order to set acceptable design objectives.

**Keywords:** Excel Optimization Solver, Normal distribution, Pearson Type 3 distributions, Goodness of fit test, IDF models, Abeokuta.

## 1. Introduction

In all river basins, efficient management of water resources can be beneficial in fulfilling the first and second Sustainable Development Goals of the UN, which are to end poverty and ensure food security (https://sdgs.un.org/goals). Rainfall Intensity Duration Frequency links are created using statistical analytic techniques on rainfall volume and duration, and these connections can be effectively utilized for the study and design of flood control systems. As per David et al. (2019), effective planning and design measures for extreme events such as floods, droughts, and rainstorms have a higher chance of success when there is a proper comprehension of the frequency of severe events. El-Sayed (2011) argued that projects involving water resources required a strong foundation in IDF modeling. Rainfall volume and duration data from rain gauge stations are frequently analyzed using probability distribution functions. The maximum intensity of rainfall is the dependent variable, while other relevant variables, such as rainfall length and frequency, are represented as independent variables in the IDF formulae, which are empirical equations.. Chow et al. (1988) state that several of these probability functions are used in practical hydrological applications. Researchers and academics from all around the world have become interested in correct assessment of the intensity-duration-frequency relationship due to its widespread application (Mohammed Zakman, 2016). The IDF models in Port Harcourt show that coverage in Nigeria has spread from the North Central region to the South-East and South-South [Ilaboya & Nwachukwu, 2022; Nwaogazie & Masi, 2019) and Eket in the Awka Ibom State (Nwaogazie & Uba, 2001). For return periods of two to ten years, these results validate the IDF theory. With sufficient knowledge of the IDF, climate smart agriculture methods can be put into reality. The removal of barriers faced by small-scale farmers, such as lack of access to technical skills, inadequate market access, and inadequate investment, depends on the management of natural resources (land and water)

(Morton, 2007).

The creation of these models is essential to the effective building of structures designed to mitigate flooding in Abeokuta. The last flooding disaster occurred in 2022, resulting in several million Naira in property losses and fatalities.

## 2. Research Methodology

### 2.1 Description of the Study Area

Abeokuta serves as the capital of Ogun State, which is situated in southwest Nigeria. Situated on the east bank of the Ogun River, amidst a collection of rocky outcrops in a forested savanna, it is roughly 130 kilometers by sea or 77 kilometers north of Lagos by train, with an approximate metropolitan area of 879 km$^2$. The location lies within latitudes 07°09'20" N and longitudes 03°20'42" E, and the elevation is 64 meters above sea level. Figure 1 provides a graphic representation of the study region.

### 2.2 Data Collection

The data was given by the Nigerian Meteorological Agency (NIMET) and covered the 25-year period from 1986 to 2010. Data spanning from five to four hundred and twenty minutes was divided into segments. Using the ranking data, rainfall intensities might be calculated for the creation of several models.

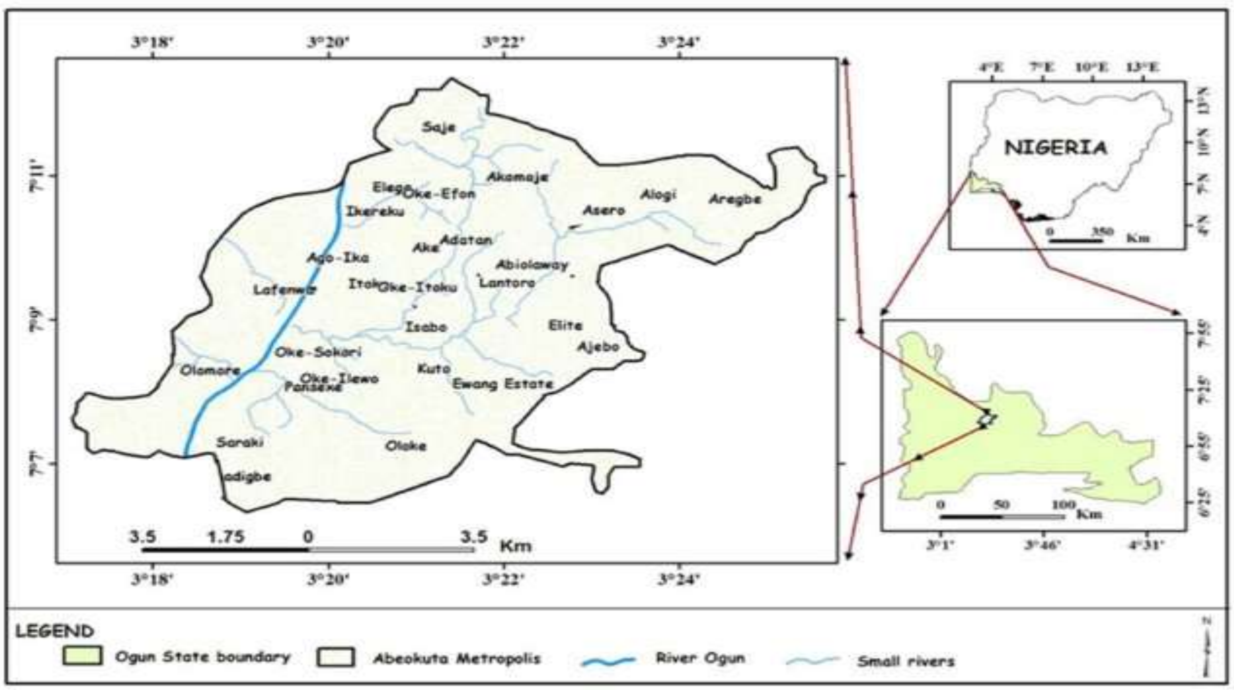



***Figure 1:*** *Map of Ogun State showing Abeokuta (Google., 2024)*

### 2.3 Data Analysis

The following durations were chosen to have the largest amount of rainfall: 5, 10, 15, 20, 30, 45, 60, 90, 120, 180, 240, 300, and 420 (minutes). Equation (1) illustrates the mathematical expression of the IDF link described by (Chen, 1983; David et al., 2019):

$$I = f(T,d) \qquad (1)$$

Note: duration is d; return period is T; intensity is I.

The rainfall amount is converted to intensity (mm/hr) by dividing the total by the time (minutes) and multiplying the result by 60. For example, a 20-minute rainfall period of 32.6 mm results in an intensity of (32.6/20) x 60 = 97.8 mm/hr.

Table 1 displays all of Abeokuta's intensities for various time frames.

For the station under consideration, rainfall intensity magnitude was determined using a frequency analysis method. The earlier study by (Nwaogazie & Masi, 2019) demonstrated that Pearson Type III and the Normal distribution best suit rainfall models that have been established; as a result, these two probability distribution functions were accepted for computing rainfall intensities for particular return periods.

### 2.4 Normal Distribution

One often utilized probability distribution for determining the values of rainfall intensity is the normal distribution. Equation (2) was used to calculate the numbers for the intensity of the rain:

$$X_T = X + K_T S \qquad (2)$$

where XT represents the intensity of the rainfall (hydrologic event magnitude).

**Table 1:** Ranked Observed Annual Rainfall Data for Different Durations for Abeokuta

| Annual Maximum Rainfall Amount (mm) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rank | Duration of rainfall (mm) | | | | | | | | | | | | |
| | *5* | *10* | *15* | *20* | *30* | *45* | *60* | *90* | 120 | 180 | 240 | 300 | 420 |
| *1* | 35.1 | 45.2 | 54.3 | 62.1 | 70.3 | 84.3 | 88.6 | 89.7 | 108.3 | 122.8 | 128.3 | 128.3 | 128.3 |
| *2* | 31.8 | 45.0 | 47.4 | 58.1 | 64.8 | 70.3 | 84.3 | 89.3 | 89.3 | 108.3 | 122.8 | 122.8 | 122.8 |
| *3* | 28.0 | 42.9 | 45.2 | 55.6 | 64.6 | 67.2 | 82.3 | 88.6 | 88.6 | 92.2 | 108.3 | 108.3 | 108.3 |
| *4* | 27.5 | 41.4 | 45.0 | 54.3 | 62.8 | 64.9 | 70.3 | 88.1 | 88.1 | 89.3 | 102.4 | 103.0 | 103.0 |
| *5* | 24.6 | 38.5 | 44.7 | 47.4 | 62.1 | 64.8 | 67.2 | 82.3 | 82.3 | 88.6 | 92.2 | 102. 4 | 102.4 |
| *6* | 24.1 | 36.9 | 42.9 | 45.2 | 58.1 | 64.6 | 64.9 | 82.0 | 82.0 | 82.3 | 89.3 | 92.2 | 92.2 |
| *7* | 19.4 | 35.1 | 42.3 | 45.0 | 47.4 | 64.1 | 64.8 | 67.2 | 67.2 | 82.0 | 88.6 | 89.3 | 89.3 |
| *8* | 18.6 | 31.8 | 41.8 | 44.7 | 45.2 | 64.0 | 64.6 | 65.9 | 65.9 | 67.2 | 82.3 | 88.6 | 88.6 |
| *9* | 16.4 | 28.5 | 41.4 | 42.9 | 44.7 | 63.7 | 64.0 | 64.8 | 64.8 | 65.9 | 82.0 | 82.3 | 85.1 |
| *10* | 16.3 | 28.0 | 38.5 | 42.3 | 42.9 | 62.1 | 63.7 | 64.6 | 64.6 | 64.8 | 78.8 | 82.0 | 82.3 |
| *11* | 15.6 | 27.5 | 36.9 | 41.8 | 41.8 | 58.7 | 62.1 | 64.0 | 64.0 | 64.6 | 70.6 | 76.1 | 82.0 |
| *12* | 15.5 | 25.4 | 35.1 | 41.4 | 41.4 | 58.2 | 58.7 | 63.7 | 63.7 | 64.2 | 67.6 | 74.6 | 81.4 |
| *13* | 15.1 | 24.6 | 32.8 | 41.0 | 41.0 | 47.4 | 58.2 | 58.7 | 58.7 | 64.0 | 65.9 | 72.8 | 75.9 |
| *14* | 14.2 | 24.5 | 31.8 | 40.8 | 40.8 | 45.2 | 47.4 | 58.2 | 58.2 | 63.7 | 64.8 | 65.9 | 74.6 |
| *15* | 14.0 | 24.1 | 30.1 | 38.5 | 38.5 | 42.9 | 44.5 | 55.6 | 56.0 | 61.4 | 64.6 | 64.8 | 71.8 |
| *16* | 13.5 | 23.4 | 28.0 | 36.9 | 36.9 | 41.8 | 44.1 | 53.8 | 55.6 | 58.7 | 64.0 | 64.6 | 68.3 |
| *17* | 13.4 | 20.7 | 28.0 | 31.8 | 35.3 | 41.4 | 42.9 | 50.9 | 53.8 | 58.7 | 63.7 | 64.2 | 67.9 |
| *18* | 12.5 | 19.7 | 26.8 | 30.8 | 33.8 | 41.0 | 42.6 | 49.4 | 53.6 | 58.2 | 62.4 | 64.0 | 65.9 |
| *19* | 12.4 | 19.5 | 24.1 | 30.1 | 31.8 | 40.4 | 41.8 | 48.7 | 49.4 | 54.2 | 59.6 | 63.7 | 64.8 |
| *20* | 11.5 | 18.6 | 23.7 | 29.5 | 30.1 | 38.7 | 41.0 | 47.4 | 47.4 | 53.8 | 58.7 | 62.4 | 64.6 |
| *21* | 11.3 | 17.6 | 22.5 | 26.0 | 29.8 | 38.5 | 38.5 | 43.6 | 47.3 | 51.5 | 58.7 | 61.7 | 63.7 |
| *22* | 10.0 | 17.0 | 22.4 | 24.8 | 28.3 | 34.1 | 38.0 | 43.0 | 45.0 | 51.2 | 58.2 | 61.1 | 62.4 |
| *23* | 9.8 | 16.9 | 20.1 | 24.6 | 28.2 | 32.4 | 37.5 | 42.9 | 44.7 | 49.4 | 56.7 | 60.7 | 61.7 |
| *24* | 9.8 | 16.4 | 19.5 | 24.1 | 25.4 | 32.3 | 35.7 | 42.6 | 43.6 | 47.4 | 56.4 | 58.7 | 61.1 |
| *25* | 9.6 | 16.4 | 19.3 | 22.2 | 24.6 | 31.0 | 35.5 | 40.9 | 42.9 | 46.6 | 53.8 | 58.7 | 59.2 |

Using the Excel optimization solver, the non-linear power law provided by Equation (4) was calibrated to yield the model parameters C, m, and a.

$$K_T = w - \frac{2.515517 + 0.802853w + 0.010328w^2}{1 + 1.432788w + 0.189269w^2 + 0.001308w^2} \qquad (3)$$

where w = Intermediate Variable and is given in Equation(3a) as:

$$w = \left[In\left(\frac{1}{P^2}\right)\right]^{1/2} \quad (3a)$$

and P = exceedance probability given in Equation (3b) as:

$$P = \frac{1}{T} \quad (3b)$$

where T = return period

Example: Normal distribution frequency factor for a 5 years return period

$$P = \frac{1}{5} = 0.2$$

$$w = \left[In\left(\frac{1}{0.2^2}\right)\right]^{1/2} = 1.794$$

Substituting our values into Equation (3) we have;

$$K_T = w - \frac{2.515517+0.802853(1.794)+0.010328(1.794)^2}{1+1.432788(1.794)+0.189269(1.794)^2+0.001308(1.794)^3}$$

$$K_T = 0.841457$$

Table 2 displays the calculated $K_T$ values for the Normal distribution for various return durations.

**Table 2:** Normal distribution frequency factor

| Return Period | 2 | 5 | 10 | 25 | 50 | 100 |
|---|---|---|---|---|---|---|
| P | 0.5 | 0.2 | 0.1 | 0.04 | 0.02 | 0.01 |
| W | 1.17741 | 1.794123 | 2.145966 | 2.537272 | 2.79715 | 3.034854 |
| $K_T$ values | -1E-07 | 0.841457 | 1.281729 | 1.751077 | 2.054189 | 2.326785 |

E. IDF Model Calibration

Sherman's IDF model is given as (4)

$$I = \frac{CT_r^m}{T_d^e} \quad (4)$$

$T_r$ stands for return period (year), I for intensity of rainfall, C, m, and a for model parameters, and $T_d$ for duration (hours).

The model parameters C, m, and a were obtained by calibrating the non-linear power law given by Equation (4) using an Excel optimization solver.

### 2.5 Test for Good Fit Quality

The rainfall intensities were fitted by the Pearson Type 3 and the Normal distribution using the Anderson-Darling test, with significant values of 0.711 and 0.754 at the 5% confidence level, respectively.

## 3. Results and Discussion

Based on the estimated coefficient of determination, R2, and mean square error values for a specific return period, Table 3 shows that the Normal distribution model best fits the largest amounts of rainfall.

Equation (1) was utilized in the computation of rainfall intensity values. Table 1 displays the mean and standard deviation of the normal distribution of rainfall intensity. By changing the values of XT, KT, and S from Table 1, Equation (2) may be used to calculate the probability equivalent of rainfall intensity using a Normal Distribution for a duration of 10 minutes and a return period of 5 years.

The rainfall intensities were fitted by the Pearson Type 3 and the Normal distribution using the Anderson-Darling test, with significant values of 0.711 and 0.754 at the 5% confidence level, respectively.

$$X_T = 116.3 + (0.841x\ 51.8)) = 159.86 \text{ mm/hr}$$

### 3.1 Calibration of Specified Return Period IDF Models

According to David et al. (2019), the Sherman equation IDF models were calibrated for specified return lengths. Table 3 displays the results for the Normal distribution along with the $R^2$ and mean square error (MSE) coefficients of determination.

Model parameters C, m, and a, are generated for a particular duration and return period after Equation (4) is calibrated using Excel optimization software. These IDF models are return period specific, as opposed to the non-specific models that are shown in Table 3. (see Equation 7).

**Table 3:** Developed IDF Models for different return periods using Normal Distribution rainfall intensity values for Abeokuta

| Return Period | IDF Model ± | Coefficient of Determination ($R^2$) | Mean Squared Error (MSE) |
|---|---|---|---|
| 2 | $I = \frac{4.898T_r^{6.764}}{T_d^{0.543}}$ | 0.977 | 85.73 |
| 5 | $I = \frac{2.251T_r^{3.603}}{T_d^{0.573}}$ | 0.985 | 94.57 |
| 10 | $I = \frac{1.695T_r^{2.703}}{T_d^{0.584}}$ | 0.988 | 100.59 |
| 25 | $I = \frac{1.312T_r^{2.054}}{T_d^{0.594}}$ | 0.980 | 107.93 |
| 50 | $I = \frac{1.193T_r^{1.734}}{T_d^{0.600}}$ | 0.991 | 113.15 |
| 100 | $I = \frac{1.107T_r^{1.504}}{T_d^{0.604}}$ | 0.991 | 118.14 |

± return period specific models for Normal Distribution for Abeokuta

### 3.2 Evaluation of iterative Equation Solver in Excel

The Excel Solver software was used to evaluate the model's parameters over a 100-year defined return period. The generic IDF model presented in Equation has undergone ten (10) iterations (7).

**Table 4:** Model Parameters for Sherman's Specific IDF Model Calibration

| Iteration | C | m | a |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| 2 | 1.08689 | 1.4 | 0.824064 |
| 3 | 1.129055 | 1.611199 | 0.727277 |
| 4 | 1.132479 | 1.635577 | 0.721812 |
| 5 | 1.137515 | 1.662717 | 0.772641 |
| 6 | 1.137736 | 1.663208 | 0.776114 |
| 7 | 1.137797 | 1.663488 | 0.77664 |
| 8 | 1.137797 | 1.663488 | 0.776639 |
| 9 | 1.137797 | 1.663488 | 0.776639 |
| 10 | 1.137797 | 1.663488 | 0.776639 |

**Table 5:** Tabular Computation of Coefficient of Determination for Abeokuta

| Intensity | $Intensity_{pred}$ | (I - Ip)2 | (I-Iavg)2 |
|---|---|---|---|
| 192.1498641 | 207.892929 | 247.8440829 | 14668.11 |
| 155.0966423 | 143.436046 | 135.9695073 | 7065.876 |
| 128.463877 | 115.444493 | 169.5043489 | 3297.745 |
| 112.3163251 | 98.9639205 | 178.2867085 | 1703.91 |
| 81.16415026 | 79.6511058 | 2.28930367 | 102.5414 |
| 65.78223051 | 64.1071879 | 2.805767634 | 27.62183 |
| 52.68677814 | 54.9554029 | 5.146658379 | 336.7629 |
| 39.42640188 | 44.2308529 | 23.08274969 | 999.2854 |

| | | | |
|---|---|---|---|
| 30.27733462 | 37.9165648 | 58.35783719 | 1661.422 |
| 21.74873497 | 30.517145 | 76.88501435 | 2429.42 |
| 18.13831768 | 26.1605922 | 64.35688805 | 2798.363 |
| 15.11094943 | 23.2144685 | 65.66702178 | 3127.821 |
| 11.13080687 | 19.3872836 | 68.16940809 | 3588.857 |
| Average = 71.038 | | Sum = 1098.365 | Sum = 41807.74 |

Additionally, a General IDF model was created. Thirteen durations in total multiplied by six return periods equals seventy-eight input data points. Table 1 contained all of the input data.

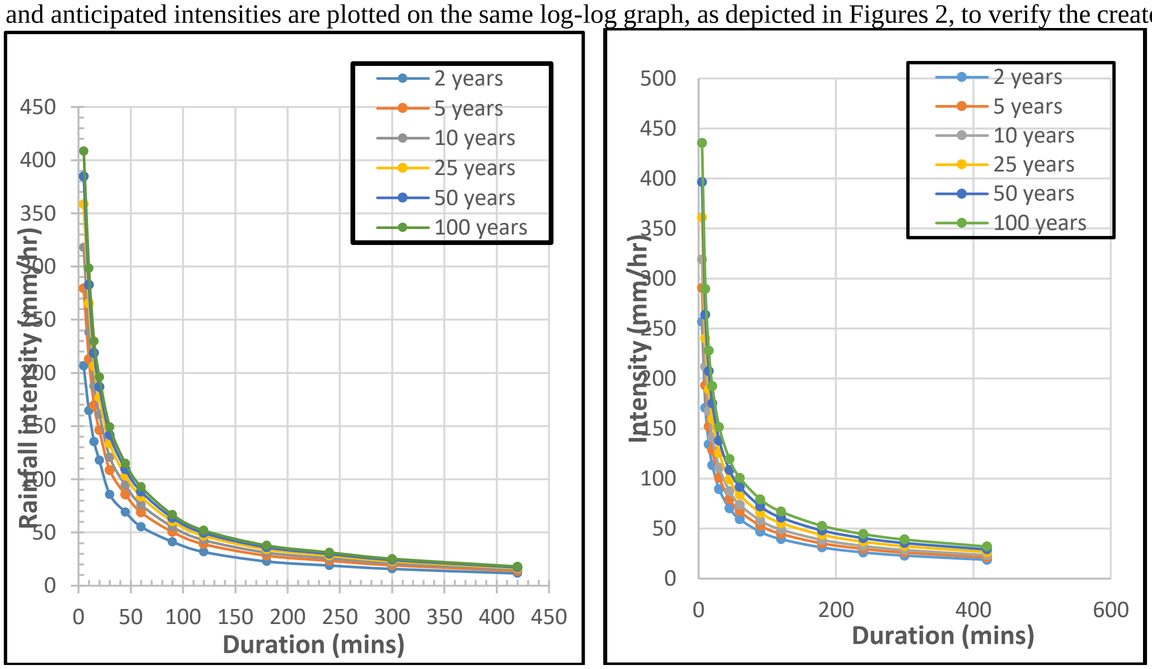
Using Excel Optimization Solver, a general (non-specified) IDF model was created using programmed least squares equations. The outcome was Equation (7).

$$I = \frac{603.235 T_r^{\ 0.135}}{T_d^{\ 0.589}} \qquad (7)$$

Coefficient of determinant ($R^2$) = 0.984; Mean Squared Error = 149.53

Comparison of the Intensities of the Predicted and Observed Rainfall

With this model, one can forecast the intensity of rain for any length of time and for any return period. The observed and anticipated intensities are plotted on the same log-log graph, as depicted in Figures 2, to verify the created model.




***Figures 2:** Plots for observed and predicted intensities*

Evaluation of Excel Optimization vs Regression Approach Model parameters, R2, and MSE solver outputs

Table 6, which is an expansion of Table 5, demonstrates unequivocally that the outcome obtained by the Excel Optimization Solver option is more dependable than the standard simultaneous solution utilizing a matrix, such as Gauss elimination, inverse or determinant approach, or normal regression method.

**Table 6:** Results from Regression Approach and Excel Solver Optimization Approach (Normal distribution, 100-year return period)

| Method | C | m | A | $R^2$ | MSE |
|---|---|---|---|---|---|
| Regression | 65.42 | 3.533 | 0.575 | 0.865 | 324.40 |
| Excel solver | 1.138 | 1.663 | 0.776 | 0.996 | 132.47 |

## 4. Conclusion

The generated models for the Normal distribution and Pearson Type 3 distributions show the pattern of higher intensities occurring at lower durations that is noted in the literature. The PDFs' rainfall intensity predictions and the observed intensity values matched fairly well. In terms of return period-specific R2 0.995 and MSE 23.64, the Normal distribution model came out on top. Design intensity for drainage design can be obtained using the proposed models, allowing for efficient flood management.

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