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DEVELOPMENT OF RAINFALL INTENSITY DURATION FREQUENCY (IDF) CURVES FOR DESIGN OF HYDRAULIC STRUCTURES IN KANO STATE, NIGERIA

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ABSTRACT

Rainfall intensity is an essential parameter in the design of any hydraulic structure. The IDF curves are used to design hydraulic structures such as culverts, bridges, roads, urban drainage systems, and many more. Colonial masters developed the first IDF curve for Kano State based on records of 1938 - 1944 (6 years) followed by Oyenbade (1982), and since then, it has not been reviewed or updated. As a result of changes in rainfall patterns that have taken place over time and the climate change, the Oyenbade IDF curves might no longer be suitable for hydraulics design in Kano State. Therefore, this research aims to develop the new IDF curves and establish empirical equations of rainfall intensity that can be used for safe and economic hydraulics design in Kano State. India Meteorological Department (IMD) reduction formula was used to disaggregate maximum daily rainfall of Kano gauge station into the rainfall of shorter durations. Lognormal probability distribution was found to fit best the data set of all the durations using Easyfit 5.0 software and estimate rainfall intensities for 2, 5, 10, 25, 50, and 100 years return periods. It was found out that rainfall intensities increase with the increase in return periods but decreases with an increase in duration. The coefficient of determination 'R^2' for all return periods indicated a strong relationship in IDF models developed. Hence, the new IDF curves developed should estimate rainfall intensities for hydraulics design in Kano State. The derived IDF models could be used for better results and accuracy.

Keywords: *probability distributions, IMD reduction formula, return periods, rainfall duration, easy fit software 5.0*

INTRODUCTION

An intensity-duration-frequency (IDF) curve relates the rainfall intensity with its duration and frequency of occurrence [1],[2]. The design of any infrastructure requires an understanding of the desired function of the structure and the physical environment in which it must perform this function. Thus, in stormwater management, the dimensions of various infrastructure system components are based on the return period of heavy rainfall events [3]. This information is often expressed as IDF curves obtained from a statistical study of extreme events. Depending on the application purpose, they may be constructed using different time steps from instantaneous maximum daily intensity to annual, monthly, weekly intensities [4].

For decades now, there have been considerable attention and research on the IDF relationship worldwide. However, many of these researches on the development of IDF curves have shortcomings, especially in developing countries like Nigeria. Nwaogazie [5] developed IDF curves and equations for calculated return periods for Oyu City, Nigeria, using ten years of rainfall data. The data used is insufficient according to [6], and the nature of data used was not stated, that is, whether daily or monthly rainfall data—the [6] specified minimum of 25 years of data for hydrological analysis. In like manner, Sule [7] synthesized Isopluvial maps for some selected states in Nigeria using IDF equations derived from daily rainfall, and Kano State was not among the selected ones.

Rainfall intensity is an essential parameter in the design of any hydraulic structure. Colonial masters developed the first IDF curve for Kano State based on records of 1938 - 1944 (6 years), followed by Oyebande [8], which developed IDF curves for various regions of Nigeria in which Kano falls in Zone VIII (Bauchi, Zaria, Kano, Gusau and Samaru). The curves were developed based on the rainfall data available at that time, and some of the data used in some stations were not sufficient. One of the main assumptions in creating these curves was that the rainfall data for a site is stationary. That is, climatic trends and variability in a region have negligible effects on the curves. But as has been proved in recent time, variability and trends exist in the long rainfall data of Kano [9]. As a result of changes in rainfall patterns that have taken place, the Oyenbade IDF curves might no longer be suitable for hydraulic design. The IDF curves developed by colonial masters and Oyenbade since the 1940s and 1982 have not been reviewed or updated for Kano city [9]. Cook et al. [10] also reported that increases in rainfall events resulting from climate change are a significant threat to infrastructure systems, especially stormwater infrastructure systems. Higher rainfall intensities lead to more severe storms, with expected increases in residential, street, and flash flooding damages. This further invalidated Oyeband's IDF curves.

The information sourced from the Kano State Ministry of Works and Planning revealed that Kano State is adopting the IDF curves contained in the Federal Ministry of Works Highway Manual Part 1. The development of accurate methods for estimating design rainfall intensities for a particular city, region, or country requires ongoing measurement of rainfall using gauges that can measure the rate of rainfall or intensity [11]. The method adopted in the manual is a summary of a detailed report prepared by Oyebande [11]. The second method for estimating rainfall intensity as contained in the Highway manual is the IDF equation which was part of the original 1973 edition of the Highway Design Manual and is based on the British West African Meteorological Services in Nigeria [11]. The equation is used where IDF curves have not been developed. However, in recent time many researchers have developed for some cities and regions in Nigeria, for example Nwaogazie [5], developed for Oyo city, Okonkwo and Mbajiorgu [12] developed for Southeastern Nigeria, and Sule [7] developed for some cities in Nigeria. Unfortunately, Kano city was not captured. Hence this paper is set to close this gap by improving and updating the existing one.

There are several methods of developing IDF curves in literature for example; Awofadeju et al. [13] developed IDF curves for eight significant towns in five state in South Western Nigeria throughout twenty-nine years (1984-2012) data using maximum annual rainfall and USDA generalised accumulated rainfall curve for storm type A to estimate short duration interval. The rainfall intensity values were calculated for the duration of 15, 30, 45, 60, 90, 120, and 240 minutes for a return period of 2, 5, 10, 20, 50, 100, and 200 years respectively, using Gumbel Extreme Value Type 1 distribution. The non-parametric Kolmogorov-Smirnov test and the Chi-Square test were used to confirm the appropriateness of the fitted distributions for the locations, and the IDF curves were developed. Awofadeju et al. [13] claimed that the methods employed by Sule [7] and Oyebande [8] were too simplistic and lacking rigorous analyses. Hence, new ones were developed for the region. Suthakaran et al. [14] developed Rainfall Intensity Duration Frequency (IDF) curves for the Colombo region using annual maximum rainfall values. Log Pearson type III (LP3) and Gumbel Extreme Value (EV1) were investigated. LP3 distribution was the best-fitted distribution for 1, 4, 6, and 24 hours of annual peak precipitation. At the same time, EVI was the most appropriate distribution for other durations, and the IDF curve for the region was developed. Wambua [15] estimated rainfall IDF curves for a tropical River basin in Kenya using empirical functions to generate rainfall of shorter durations ranging from 1 to 12 hours and derived IDF empirical models using regression analysis.

A mathematical model between Peak Flood Discharge and Return Period using Gumbel's Extreme Value Distribution and rainfall of shorter durations (5 minutes, 10 minutes, 15 minutes, 30 minutes, 1 hour, etc.) were estimated using India Meteorological Department (IMD) reduction formula [4]. This model was developed to predict precipitation depth for various return period storms. The derived precipitation depth was utilized to generate an intensity duration frequency curve with different region return periods. This research also adopted the IMD reduction formula for the estimation of rainfall of shorter durations.

The IDF curves are used in the design of hydraulic structures such as culverts, bridges, roads, and urban drainage systems, land-use planning and soil conservation studies, management of municipal infrastructure including sewers, stormwater management ponds and street curb, Risk assessment of dams, and bridges, Design of roof and stormwater drainage systems and for the design of flood control structures [15],[16]. This paper aims to develop new IDF curves for Kano State, Nigeria.

Rainfall Disaggregation

Many hydrological applications, such as drainage systems, flood forecasting, require rainfall data of shorter durations. In contrast, the network of recording rain gauges (providing short-duration data) is rare compared to that of daily rain gauges. Access to fine-time scale rainfall data is of prime importance for IDF analysis, among other hydrological applications. However, such data of considerable length are usually not available in most parts of the world, especially in developing countries. Hence, it is often necessary to disaggregate (break down) the daily rainfall data into shorter time intervals.

Urban hydrology is characterised by rapid runoff and short response times on impervious surfaces and small timescales and space scales compared to rural hydrology. Rainfall data for urban hydrology applications are therefore required to resolve these spatial and temporal scales sufficiently. However, following Schellart et al. [17], and others, the errors in such rainfall input data are among the most important sources of uncertainty in urban hydrological models. For extreme events, e.g., flash flooding, uncertainties related to spatial variability and rainfall measurement errors are expected to be even more significant, e.g., [18]. Hence there is a need for high-quality and acceptable resolution rainfall inputs into urban hydrological models to reduce uncertainty in hydrological responses.

To overcome the lack of fine-resolution temporal and spatial precipitation data crucial for hydrological, meteorological, and agricultural applications, disaggregation of available data from one temporal and spatial scale to another seems to be the most efficient alternative [19]. Several disaggregation techniques exist in water resources literature that allowed the generation of acceptable resolution temporal and spatial precipitation data using the widely available daily precipitation data. Disaggregation techniques include the Bartlett-Lewis Rectangular Pulse model, e.g. [20] and [21], the chaotic approach [22], and non-parametric methods such as Artificial Neural Networks [19] and the K-nearest neighbor (K-NN) technique [23], [24].

Many Nigerian researchers used generalised accumulated rainfall patterns developed by USDA Soil Conservation Service to break down recorded daily rainfall data into shorter duration rainfall data, e.g., [7],[12],[13]. Yusop et al. [25] and Abdellatif et al. [26] used the Bartlett Lewis Rectangular Pulse model to disaggregate daily to hourly precipitation. Lu and Qin [27] used an integrated spatial-temporal downscaling-disaggregation approach based on K-NN. Rupp et al. [28] used a cascade model for disaggregation of daily to hourly precipitation.

Yates et al. [29] developed and applied a non-parametric weather generator based on K-NN for the simulation of regional-scale climate scenarios. Sharif and Burn [23] improved the K-NN-based weather generator developed by Yates et al. [29] by adding a random component to obtain precipitation data beyond the range of historical observations; this component is essential in simulating hydrologic extremes [30].

For this study, India meteorological reduction formula was used for the temporal disaggregation of daily precipitation to hourly and sub-hourly scales. India meteorological reduction formula was used because it contains no variables that are location specific.

DATA AND METHOD

Data collection

Daily maximum rainfall data for the record of 50 years (1968 – 2018) used for this research was collected from three rainfall stations; Nigerian Meteorological Agency, Geography Department Bayero University Kano (BUK), and Center for Dryland Agriculture BUK.

Study Area

Kano State is located in Northwestern Nigeria on latitude 12°N and longitude 8.30°E within the semi-arid Sudan savannah zone of West Africa. Kano has a mean height of about 481 m above sea level [31]. On May 27, 1967, the state was created from part of the Northern Region, Kano state borders Katsina State to the north-west, Jigawa State to the north-east, Bauchi State to the south-east and Kaduna State to the south-west. Kano State has 44 Local Government Areas with a total area of 20,230 km^2 with 13,076,90 people [32].

The temperature of Kano usually ranges between a maximum of 33°C and a minimum of 15.8°C, although sometimes, during the harmattan, it falls to as low as 10°C. Kano has two seasonal periods: four to five months of the wet season and a long dry season lasting from October to April. The movement of the South West maritime air masses originating from the Atlantic Ocean influences the wet season, which starts from May to September.

The mean annual rainfall is about 800 mm around metropolitan Kano. Significant temporal variation occurs in rainfall received, and no two consecutive years record the same amount. The movement of the tropical maritime air masses from the southwest to the North determines the weather of Kano State during the wet season [31].

Three large watersheds distinguish the hydrogeology of Kano; the outfall to River Challawa, the outfall to River Jakara, and the other are to River Wateri. These basins are considered the primary receptacles of runoff from the city. Figure 1 showed the map of the Kano metropolis.

Method

Development of Rainfall Intensity Duration Frequency (IDF) Curve for Design of Hydraulic Structures involved Data preparation, Disaggregation of maximum daily rainfall, Fitting probability distributions on the data set, computation of rainfall intensity, computation of mean, stand deviation and coefficient of skewness, computation of frequency factor, Estimation of rainfall intensities for various return periods and/or Derivation of IDF curves using empirical Equations.

Disaggregation of Daily Rainfall Data into Shorter Durations

The rainfall depths available from gauging stations in Kano State are of 24 hr duration, and the development of IDF Curves required rainfall of shorter durations of 15 minutes, 30 minutes, 1 hr, 2 hr, 4 6 hr, 12 hr, and 24 hr. Since rainfall of shorter durations is not available for Kano, the India Metrological Organization reduction formula was used to disaggregate daily rainfall data into short durations. The India Metrological Organization reduction formula is as given below,

$$P_t = P_{24}\left(\frac{t}{24}\right)^{1/3} \tag{1}$$

where P_t = required rainfall depth in mm at t-hr duration, P_{24} = daily rainfall in mm and t = duration of rainfall for which the rainfall depth is required in an hour [3],[16].

Fitting the probability distribution

From the literature review, the generally used probability distributions when considering extreme events in hydrology are Gumbel Extreme Value Type I, Log Pearson Type III, Log-normal, and Normal distributions were considered for this research. To select which of these distributions to use, the following steps were followed:

1. For each duration (for example, 0.25 hr), the four probability distributions selected were fitted to the Annual Maximum Series data using the EasyFit 5.0 software.
2. The best fit for each distribution was assessed using the Chi-square, Anderson-darling, and Kolmogorov-Smirnov test-of-goodness-of-fits at a 5% significance level for each duration using Easyfit 5.0.

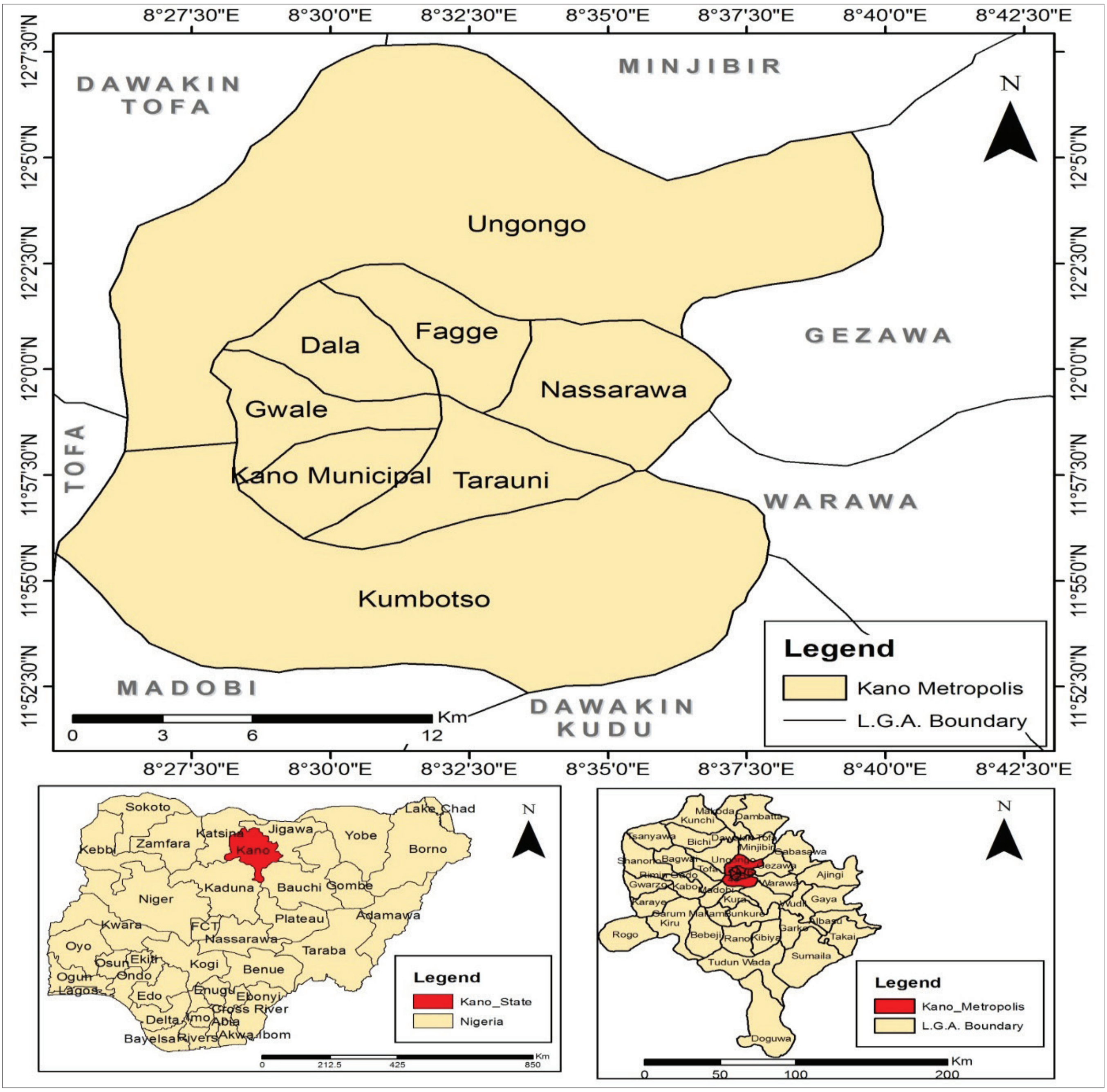

Figure 1 Map of the Study Area

3. After the fitting, the distributions were ranked to determine the appropriateness of the fitting.
4. Finally, the least sum of the statistic model identification criterion (LSSMIC) was employed to get the best fit model.
5. Then, the distribution(s) that provided the best fit was used for the frequency analysis.
6. For this study, Lognormal distribution provided the best fit and was used for further analysis.

The rainfall intensity

The rainfall data were converted to intensity by dividing the rainfall by duration given as:

$$i = \frac{p}{t} \tag{2}$$

where, i = intensity in mm/hr, P = rainfall in mm and t = time in hr.

Mean, stand deviation, and coefficient of skewness

The mean, standard deviation, and coefficient of skewness of all the selected durations were calculated using the following equations:

$$\text{Mean} = \bar{x} = \frac{p}{t} \sum_{i=1}^{m} x_i \quad (3)$$

$$\text{Standard deviation} = S = \left(\frac{1}{m-1} \sum_{i=1}^{m} (x_i - \bar{x})^2 \right)^{1/2} \quad (4)$$

$$\text{Coefficient of skewness } Cs = \frac{n\Sigma(x_i - \bar{x})^2}{(N-1)(N-2)S^3} \quad (5)$$

Frequency factor

The frequency factor was computed for all the selected return periods based on the selected distributions. For this study, Lognormal probability distribution was used. The frequency factors for different distributions are described below.

Design rainfall intensity

Design rainfall intensity was then obtained using Equation 6, and the results were plotted. According to [33], the magnitude of hydrological event X_T may be represented as the mean plus the departure of the variate from the mean given as:

$$X_T = \bar{x} + K_T S \quad (6)$$

where, X_T is the magnitude of hydrological event, $\bar{x}$ is the mean, K_T is the frequency factor, and S is the standard deviation.

Derivation of IDF curves using empirical Equations

The use of IDF curves is perceived to be difficult, and hence, there is a need to derive the empirical models that could replace IDF Curves. The IDF formulae are the empirical equations representing a relationship among maximum rainfall intensity as the dependent variable and other parameters of interest such as rainfall duration and frequency as independent variables [15]. Four forms of IDF empirical models that are commonly used in hydrology applications are as follows;

$$\text{Talbot Equation} \quad i = \frac{a}{b + t_d} \quad (7)$$

$$\text{Bernard Equation} \quad i = a * (t_d)^{-c} \quad (8)$$

$$\text{Kimijima Equation} \quad i = \frac{a}{b + t_d^c} \quad (9)$$

$$\text{Sharman Equation} \quad i = \frac{a}{(b + t_d)^c} \quad (10)$$

where i = rainfall intensity in mm/hr, t_d = rainfall duration in hours, a, b and c are parameters to fit the IDF curves. The least Square Method was used to estimate parameters x and y for various return periods.

Table 1 Frequency factors for various distributions

S/N	Distributions	Frequency factor
1	Gumbel's Extreme Value Type I	$K_T = -\frac{\sqrt{6}}{\pi} \left[0.5772 + ln\left(ln\left(\frac{T}{T-1}\right)\right)\right]$
2	Normal	$K_T = \frac{XT-\mu}{\sigma} = z = \frac{2.515517 + 0.802853w + 0.010320w^2}{1.432788w + 0.18926w^2 + 0.001308w^3}$, $w = [ln(1/p^2)]^{1/2}$ $(0 < p \leq 0.5)$ when $p > 0.5$, $1 - p$ is substituted for p in the equation above.
3	Log-normal	The same applied to normal except that it is the logarithm of variables that is applied. i.e $y = log_x$
4	Log-Pearson Type III	When skewness $C_s = 0$, the frequency factor is equal to the standard normal variable z. when C_s , K_T is approximated by Kite (1977) as $K_T = z + (z^2 - 1)k + 1/3(z^3 - 6z)k^2 - (z^2 - 1)k^3 + 2k^4 + 1/3k^5$ where $k = C_s/6$. K_T can also be obtained from standard statistical Table.

Source: [33]

However, research conducted by Shivakumar & Anila [3] on Equations 7 and 8 indicated that Equation 8 provided the best fit. Therefore, this research adopted Equation 8 to derive IDF empirical models for Kano State.

RESULTS AND DISCUSSIONS

Descriptive statistics of the rainfall data duration series

Statistic parameters of the 24 hr rainfall duration series indicated that the rainfall sample means and standard deviation for 50 years of data are 82.57 mm and 25.09, respectively. The sample skewness is 0.233, Excess kurtosis is –1.030, variance is 154.4, and coefficient of variation is 0.151. The descriptive statistics for 0.25 hr, 0.5 hr, 1 hr, 2 hr, 4 hr, 6 hr, and 12 hr are as presented in Table 2.

Generally, from Table 2, it is observed that the skewness values of all the data durations are approximately the same, with a value of 0.233. This means that the distribution of each data duration is approximately symmetrical. Furthermore, the excess kurtosis of all the data duration is approximately the same and less than 0. This means that the distribution of each data duration is platykurtic with a central peak lower and broader, and its tails are shorter and thinner than a normal distribution. Table 2 shows descriptive statistics results for all the duration series using Easyfit 5.0 software.

Fitting the probability distribution to rainfall data of various duration

For this study, Gumbel Extreme Value Type I, Log Pearson Type III, Log-normal, and Normal distributions were considered for each data duration series. Easyfit 5.0 software was used to fit probability distributions to each duration of rainfall data. The probability density function graph, cumulative distribution graph, goodness of fit test, and the least sum of statistic model identification criterion (LSSMIC) were used to assess the suitability of each probability distribution.

Visual identification of best model for 0.25 hr (First step)

The probability density function (PDF) graph shown in Figure 2 for the fitted distributions shows by visual identification that all the tested distributions are most likely to fit the data. Obviously, from the PDF graph (Figure 2), Lognormal provides the best fit for the data. However, with the help of the goodness of fit test and LSSMIC, the best-fitted distribution was identified. The histogram shows that the frequency distribution is unimodal and approximately symmetrical. This is in line with the skewness statistics result obtained in Table 2. The cumulative function graph shown in Figure 3 showed the non-exceedance probability of a given rainfall magnitude.

Goodness of fit test (second step)

According to the goodness of fit tests, the probability distribution with the lowest statistic value is the best fitting distribution. Table 3 shows the statistics result

Table 2 Statistical description of rainfall data duration series

Rainfall Duration	0.25hr	0.5hr	1hr	2hr	4hr	6hr	12hr	24hr
Sample size	50	50	50	50	50	50	50	50
Range	9.320	11.740	14.800	18.640	23.490	26.890	33.880	42.690
Mean	18.030	22.720	28.630	36.070	45.440	52.020	65.540	82.570
Variance	7.363	11.68	18.560	29.450	46.750	61.270	97.240	154.400
Std. Deviation	2.713	3.418	4.308	5.427	6.837	7.828	9.861	12.420
Coef. of variation	0.151	0.151	0.151	0.151	0.151	0.151	0.151	0.151
Std. Error	0.384	0.483	0.609	0.768	0.967	1.107	1.395	1.757
Skewness	0.233	0.233	0.233	0.233	0.233	0.233	0.233	0.233
Excess kurtosis	–1.030	–1.030	–1.030	–1.030	–1.030	–1.030	–1.030	–1.030

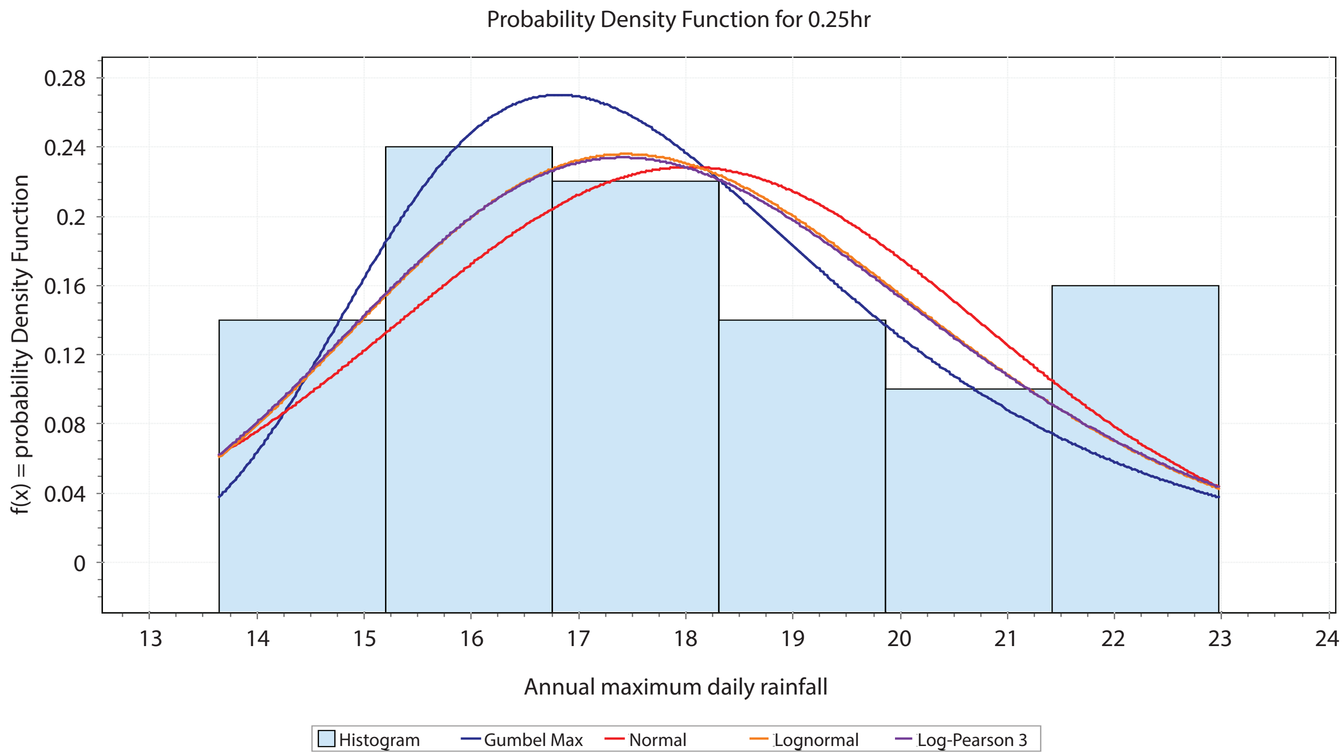

Figure 2 Probability density functions of four selected distribution for 0.25hr

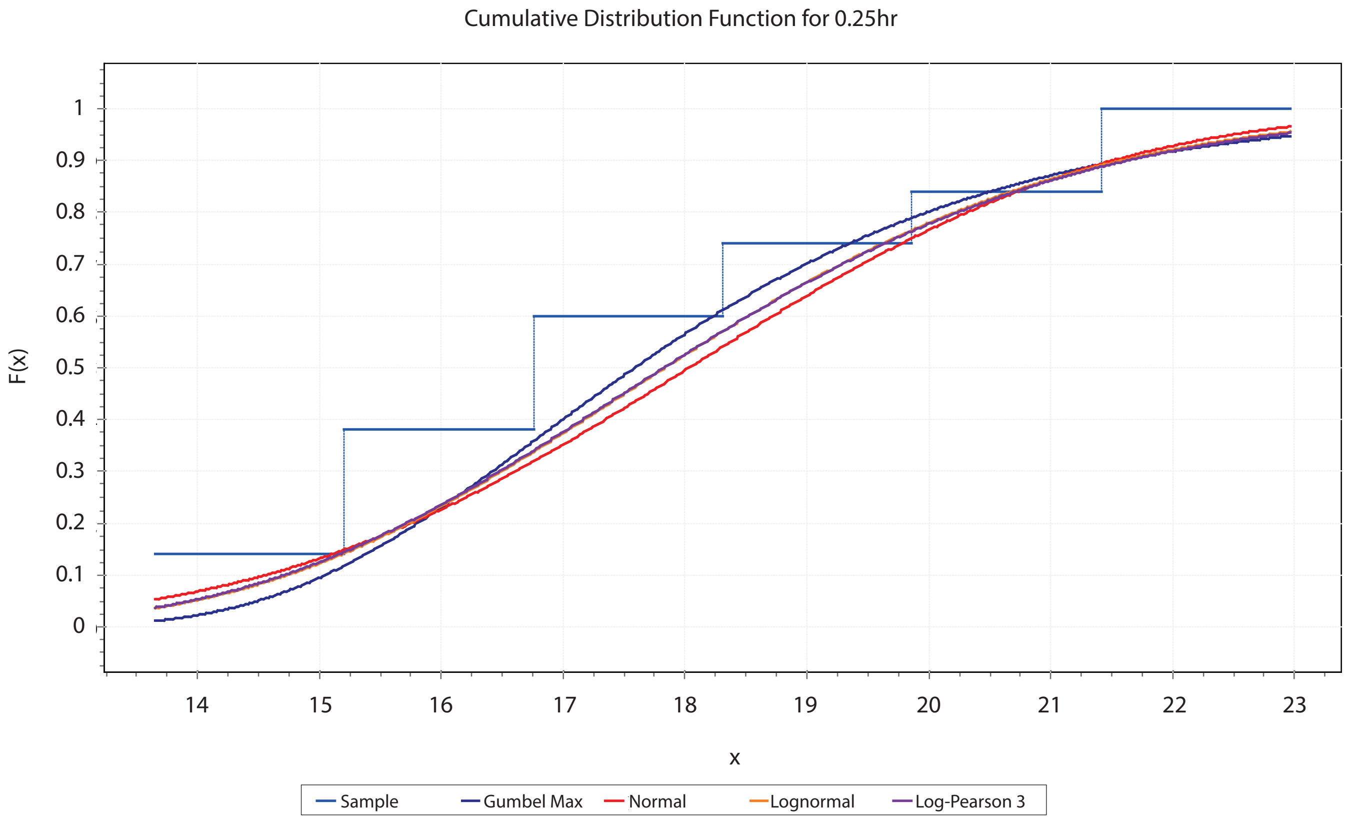

Figure 3 Cumulative distribution functions of four selected distribution for 0.25hr

Table 3 Goodness of fit tests results for 0.25 hr duration

Distribution	Chi-square		Anderson-darling		Kolmogorov-Smirnov	
	Statistic	Rank	Statistic	Rank	Statistic	Rank
Gumbel	2.686	2nd	0.8408	4th	0.1017	3rd
Log-normal	1.749	1st	0.5004	2nd	0.1006	2nd
Log-Pearson III	1.921	3rd	0.4697	1st	0.0979	1st
Normal	2.88	4th	0.6205	3rd	0.1077	4th

of Chi-square, Anderson-darling, and Kolmogorov-Smirnov test-of-goodness-of-fits for 0.25hr duration.

From Table 3, it is observed that Lognormal and Log-Pearson distributions may provide the best fit. According to Chi-square, the Lognormal distribution was ranked 1st, and it was ranked 2nd by Anderson-darling and Kolmogorov-Smirnov goodness of fit tests. It could be observed that Log-Pearson type III was ranked first by the Kolmogorov-Smirnov test and Anderson-darling and ranked 3rd by Chi-square test. Normal distribution was ranked 4th by Chi-square and Kolmogorov-Smirnov test and ranked 3rd by Aderson-Darling test.

Identification of the best fit model (Final stage) using LSSMIC

Obviously, from the goodness of fit test (Table 3), Log-Pearson III and lognormal distributions might provide the best fit. However, the aim was to get the best fit model, which was achieved with the help of LSSMIC. Table 4 shows the best fit model of the four probability distributions considered.

From Table 4, it could be observed that Lognormal distribution has the least statistical value of 1.3500, followed by Log-Pearson type 3 distribution with the statistical value of 1.4886. Hence, Lognormal distribution provided the best fit to 0.25 hr duration of annual maximum rainfall of Kano station and used for subsequent analysis.

Similarly, the probability distribution fitting was carried out on 0.5 hr, 1 hr, 2 hr, 4 hr, 6 hr, 12 hr, and 24 hr rainfall data duration series. The goodness of fit tests and LSSMIC were equally conducted to ascertain the best fit amongst the tested distributions (Gumbel Extreme Value Type I, Log Pearson Type III, Log-normal, and Normal). Lognormal distribution provided the best fit model for all the data duration series and hence used for subsequent analysis.

Mean and standard deviation of the rainfall intensity

The mean and standard deviation of rainfall intensities for each data duration is computed using Equations 2.3 and 2.4. Table 5 shows the results of the mean and standard deviation of each duration series.

Frequency factor

The results of probability distribution fitting showed that Lognormal distribution best fit all the rainfall data durations. Hence, the frequency factor for the selected return periods (2, 5, 10, 25, 50, and 100 years)

Table 4 Best fit model for 0.25 hr

Distribution	Kolmogorov-Smirnov	Anderson-darling	Chi-square	Abs.(1-X^2)	LSSMIC	Best fit
	Statistic	Statistic	Statistic			
Gumbel	0.1017	0.8408	2.6860	1.6860	2.6285	
Lognormal	0.1006	0.5004	1.7490	0.7490	1.3500	Best
Log-pearson 3	0.0979	0.4697	1.9210	0.9210	1.4886	
Normaal	0.1077	0.6205	2.8800	1.8800	2.6082	

Table 5 Mean and standard deviation of rainfall intensity for various durations

Duration	0.25hr	0.5hr	1hr	2hr	4hr	6hr	12hr	24hr
Mean	77.78	49.00	30.87	19.45	12.25	9.35	5.89	3.71
Std. Dev.	22.92	13.81	8.7	5.48	3.45	2.64	1.66	1.035

was calculated using the Lognormal distribution frequency factor's equation provided in Table 1. Table 6 shows the frequency factors for different return periods.

Estimation of design rainfall intensity

The design rainfall intensities were obtained using Equation 6. Figure 4 showed that rainfall intensity is directly proportional to the return period and inversely to the rainfall duration. The rainfall intensities decrease with an increase in rainfall duration for a given return period. For a given rainfall duration, the rainfall intensities increased with an increase in the return period. Also, for a given return period, rainfall intensities decrease with an increase in rainfall duration. Hence, it can be said that rainfall of low intensity and long duration would generate small quantities of runoff. At the same time, high intensity and short duration would generate large quantities of runoff. For the design of safe and economic structures, high return periods should be considered to design large hydraulic structures such as dams and bridges. Low return periods should be considered to design small hydraulic structures such as drainage systems and culverts. These results corroborate with findings by many researchers around the globe, such as [1]-[2],[15]-[16].

IDF models for various return periods

The IDF models developed for Kano state are tabulated in Table 7.

Table 6 Frequency for various return factor (K_T) periods

T(Year)	2	5	10	25	50	100
K_T	-1.320E-06	0.841	1.282	1.75	2.054	2.327

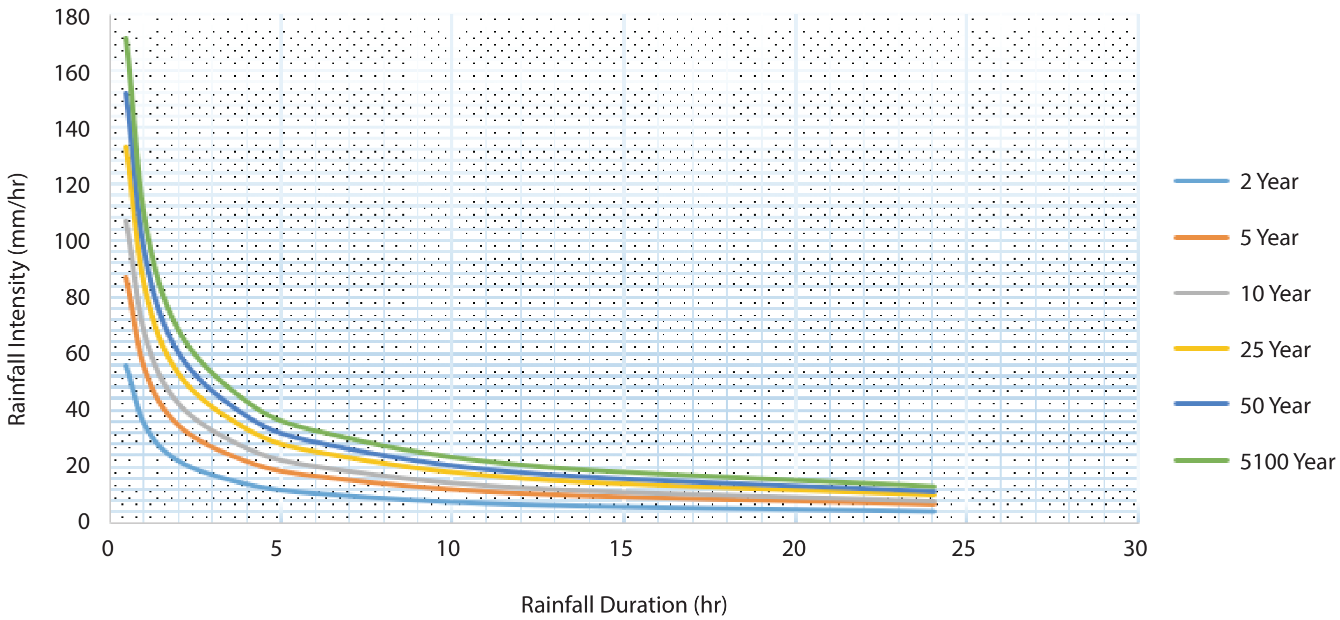

Figure 4 IDF curves for Kano State

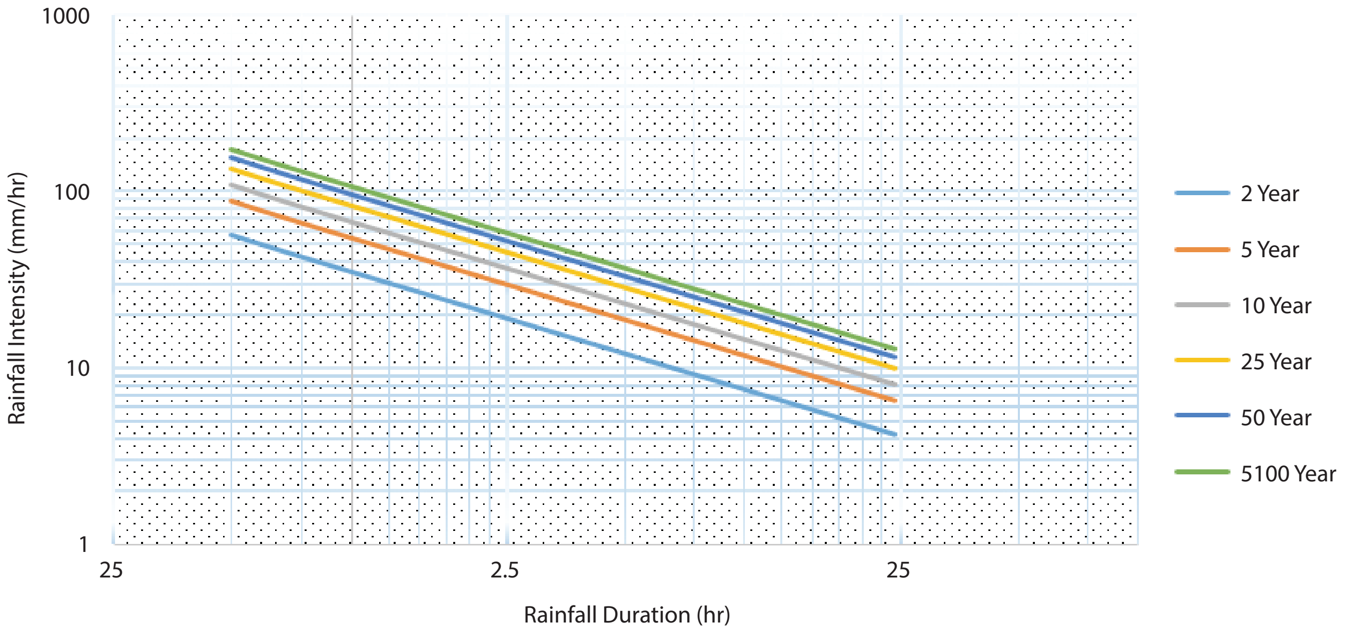

Figure 5 IDF curves in log scale

Table 7 IDF models

Return Period	a	C	Equations	Correlation Coefficient
2	28.312	–0.667	$i = 28.312*(t_d)^{-0.667}$	$R^2 = 1$
5	32.116	–0.666	$i = 32.116*(t_d)^{-0.666}$	$R^2 = 1$
10	34.307	–0.666	$i = 34.307*(t_d)^{-0.666}$	$R^2 = 1$
25	36.806	–0.666	$i = 36.806*(t_d)^{-0.666}$	$R^2 = 1$
50	38.515	–0.666	$i = 38.515*(t_d)^{-0.666}$	$R^2 = 1$
100	40.122	–0.666	$i = 40.122*(t_d)^{-0.666}$	$R^2 = 1$

Many engineers' use of IDF curves is cumbersome because of the complexity, inaccuracy, and error due to parallax resulting from reading the graphs. The derivation of IDF empirical models provided a better alternative. For this study, the least square method was used to obtain constant parameters 'a' and 'c'. From Table 7, it could be observed that the constant parameter 'c' for all the return periods is the same with a value of –0.666 except that of two years return period with a value of –0.667. The coefficient of determination 'R^2' for all return periods was 1, indicating a solid relationship in IDF models developed. Hence, instead of using IDF curves in estimating rainfall intensities for various return periods, the derived IDF models should be used for better results and accuracy.

CONCLUSION AND RECOMMENDATION

The new IDF curves developed should be used in estimating rainfall intensities for various return periods, and the derived IDF models could be used for better results and accuracy. The new IDF curve can be used to design drainage systems and maintain urban water management systems such as culverts, drains, sewers, bridges, etc. The existing IDF curve should no longer be used because it was developed using poor data records and developed for a long time. Disaggregated rainfall data of Kano State gauging stations can be used for hydrological analysis. It is strongly recommended that the new IDF curves should be reviewed or updated every four to five years because of climate change and variability patterns of rainfall data.

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