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Development of a Parametric Flood Frequency Curves of Rainfall Magnitude Associated with Return Periods

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Abstract

A relationship between rainfall magnitudes and return periods for River Kaduna catchment meteorological stations is developed in this study. The K. NN algorithm was used to simulate the future rainfall values, using a transitory window of 14 days, a weather generating model was used to test the summary of statistical data. Auto and cross correlation tool was use to compare the relationship between rainfall magnitudes of the stations. For each rainfall duration, sample mean and standard deviation of the series of annual maximum values was used to estimate rainfall intensities values associated with return periods. The Gumbell tool was also used to standardized the character of rainfall across stations with varying length of record and used to compute rainfall magnitudes The inter relationship showed that rainfall magnitude increase with return periods and that data from gauged station can be transferred to other stations within a catchment area. Results from the relationship will serve a tool for understanding the variation between gauged and ungauged meteorological stations. The developed curves can be used to pick parameters for the design of hydrologic, hydraulic and water systems

1.0. Introduction

The design of water infrastructure that is partially or fully submerged in water depends on estimating the amount of water that fall within a given period of time. Climate change and increase in impervious surfaces have resulted in frequent flooding in most of the urban cities around the globe. In Nigeria for instance, this is partly due to the fact that most of water infrastructures are design on the basis of rainfall intensity duration curves that were developed in the 1970s. Knowledge of the amount, intensity and distribution of rainfall are important for all stake holders in water resources management. Rainfall according to [1] is an integral part of the hydrologic cycle, and hydrologist must be able to quantify rainfall amount in order to design structures that deal with collection, conveyance and storage of excess rainfall.[2] Showed that Intensity Duration Frequency relationship of rainfall amounts is one of the most commonly used tools in water resources engineering for planning, design and operation of water resources projects. Intensity Duration Curves according to [3], 2006 are graphical representations of the amount of water that falls within a given period of time in a catchment and are used by engineers in the design of urban drainage works. Intensity Duration Frequency relationship according to [4] is a mathematical relationship between the rainfall intensity, the duration and the return periods. Quantification of rainfall amount according to [4] is generally carried out using Isopluvial maps and Intensity- Duration- Frequency

(IDF Curves). In synthesizing Isopluvial maps for Nigeria using IDF equations derived from daily rainfall data, [5] generated annual series of daily maximum rainfall at seven synoptic stations in central Nigeria. The series generated by [5] were fitted with Gumbel Extreme value type I distribution and rainfall depths at various return periods were obtained. In a similar way, [6] analysed rainfall intensity for synoptic stations in northern Nigeria using rainfall data of network of fifteen stations and seven different time duration for standard return periods. The maximum data series obtained by [6] was fitted to Gumbel Type I distribution and linear regression analysis was then used to obtain the Intensity Duration Curves for the various lacations. In Nigeria, studies on the development of Intensity Duration Frequency curves by [7],[8],[9] emphasized the importance of using Intensity Duration Frequency Curves.

2.0 Materials and Methods

2.1 Historical Data

Precipitation in the study area has an uneven spartial and temporal distribution. The average annual precipitation is usually below 300mm, and mostly concentrated between the months of May and September. In Kaduna River catchment there are seven (7) meteorological data collection points located at Kaduna North, Kaduna South, Zaria, Kauru, Kangimi, Zonkwa and Saminaka. The geographical location of the stations as determined from Latitudes and Longitudes as shown in Fig 1. Missing historical data records for the stations were infilled with mean values in the study conducted by[10]. Available data consist of records from the stations for the period 1975-2000.

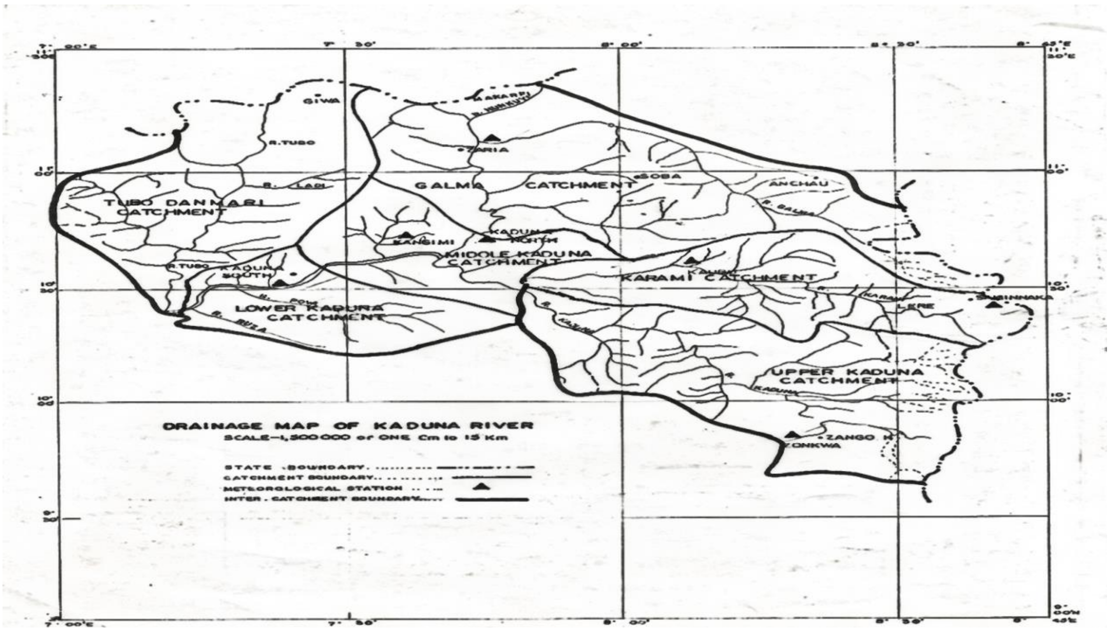

Fig 1 Drainage Map of Kaduna River

2.2 Nearest Neighbor Weather Generating Model

Evaluating the performance of the K-NN model depends to a large extend on the choosing the K-nearest neighbours and the width of the temporary window. A temporary window of 14 daysproposed by [11] was adopted in the study. August 8 was considered as the simulation date, and therefore the window of days consists of all days between August 1 and August 15 excluding August 8. The data block of potential neighbors from which resampling was done is 375. The K numbers of nearest neighbor was valid and suggest good performance of the model. The Mahannodis distances were used as frequency of the weighing factor from which the discrete probability distribution of the variable of interest was evaluated. The generated random variable was compared with the discrete probability distribution and the day was selected as the weather for region under review. Resampling of data proposed by [12] was applied to perturb the historic data and also to generate data outside the historical record by estimating conditional standard deviation for all the K nearest neighbour. Algorithm steps 1 to 6 according to work of [13] was applied to compute the regional means, determined the size of data block, compute mean vectors, compute the covariance, determined the number of the nearest neighbour to be retained for resampling and the weather for the first simulation day of the historical data. Future simulation of the variable was achieved by adopting the algorithm steps 6 to 10 [13]. The weather for day t + 1 which is first simulation was determined by; computing the Mahanobis distances between the mean vector and current days weather, the distances are sorted in ascending order, A discrete probability that gives high weight to the closest neighbour was selected. A random number is selected which is the cumulative probability based on the weight attached. The observed values subsequent to the selected nearest neighbour was selected as and adopted to represent the weather for day t + 1. The algorithm steps 6 to 10 [1] can be repeated to generate as many years of synthetic data as required.

2.3 Model Performance Testing

The output of the weather generating model can tested using summary of the statistical data graphically using the box and whiskers plots [14]. The Auto and Cross Correlation are computed on a daily time step and then average on a monthly basis using the following expressions;

$$autocorr(k) = \frac{1}{(n-k)\sigma^2}\sum_{i=1}^{n-k}(x_i - \bar{x})(x_{i+k} - \overline{x}) \quad (1)$$

Where k is the time lag, x_i is the data value, $\bar{x}$ the mean, σ^2 the variance of the data. Autocorrelations takes on value between [-1,+1].

The crosscorrelation was used to compare the time series rainfall between the stations. Its mathematical form is;

$$Crosscorr(k) = \sum_{i=1}^{n-k}(x_i - \bar{x})(y_{i+k} - \overline{y}) / \left(\sum_{i=1}^{n-k}(x_i - \overline{x})^2)\ (y_{i+k} - \overline{y})\right)^{-1/2} \quad (2)$$

Where x_i and y_i are the two time series to be compared. The range of the correlation values is between [-1,+1].

2.4 Rainfall Intensity Duration Frequency Analysis

. Intensity duration frequency analysis according to [14]. is used to capture the essential characteristics of point rainfall for shorter durations and IDF analysis provides a convenient to summarize regional rainfall information that can be used in municipal storm water management practices. In the analysis, time series records of different durations were gathered and annual extreme are extracted from the records for the seven stations. In fitting probability distribution function to discharge variability of Kaduna river,[12] used Normal. Log Normal, Log Pearson type III and Gumbel tools to check whether the mean annual variability of the river basin is consistent with the Generalized Extreme Value (GEV). From the measure of discrepancy, it was observed that at selected level of significance, all the theoretical distribution function are acceptable.

The frequency factor is obtained using the relationship;

$$K_T = \frac{-\sqrt{6}}{\pi}\left[0.5227 + 1n\left(1n\left(\frac{T}{T+1}\right)\right)\right] \quad (3)$$

The frequency factor associated with return periods is presented in Table 1. For each duration, sample mean and standard deviation of the series of annual maximum ($x_1 \ldots\ldots\ldots x_{14}$) is computed from the following expressions;

$$\bar{X} = \frac{1}{M}\sum_{i=1}^{n} X_i, \text{ and } S = \frac{1}{m-1}\sum_{i=1}^{n}(X_i - \bar{X})^2 \quad (4)$$

Results is presented in Table 2.However in estimating rainfall quantities, [15] considered that fitting probability distribution function using Gumbell tool is necessary to standardized the character of rainfall across stations with varying lengths of records, and is used to compute the rainfall magnitude for the transitory window of 14 days, the results is presented in Table 3 The Gumbel extreme value distribution [15] is of the form;

$$x_T = \mu_2 + K_T\sigma_2 \quad (5)$$

Where x_T represent the magnitude of the T- year event, μ_2 and σ_2 are the mean and standard deviation of the annual maximum series and K_T is the frequency factor depending on the return period T.

3.0 Results and Discussions

Table 1 Frequency Factors

T	2	5	10	25	50	100	1000
K_T	- 0.16432	0.7194574	1,3046532	2.0438459	2.5922880	3.1366806	4.9355236

Table 2 Mean and Standard Deviation of Annual Maximum rainfall (mm) 14 days transitory window

Upper Kaduna catchment	Kangimi	Lower Kaduna cathment	Zonkwa	Kauru	Saminaka	Zaria
140.5	126.4	98.0	79.3	70.3	153.7	95.6
80.4	71.6	134.0	47.5	46.0	30.1	86.1
157.4	159.4	115.0	151.6	96.1	93.3	168.5
302.2	130.4	180.3	241.5	158.2	241.8	153.8
246.7	141.5	125.9	75.5	163.2	76.0	2.2.8
253.0	152.7	130.3	73.5	75.5	97.5	141.7
435.2	197.0	88.0	142.5	81.4	245.2	105.2
151.2	61.9	135.4	112.3	53.9	135.0	122.6
287.8	198.1	47.3	236.4	98.7	144.6	41.9
166.3	163.9	207.8	155.3	126.0	134.0	88.7
395.3	216.9	135.0	95.6	78.9	162.6	63.6
299.3	267.3	283.9	263.7	83.8	126.5	169.8
292.6	111.0	149.5	247.8	124.2	173.0	130.9
126.5	246.6	163.6	247.3	48.0	66.1	182.2
Mean						
238.1714	160.335	142.428	154.914	93.1571	134.242	125.242
Stdev.P						
101.143	58.1407	54.480	75.047	36.1402	58.9433	46.618

Table 3 Rainfall Magnitudes for Transitory window

Return Periods	Upper Kaduna catchment	Kangimi	Lower Kaduna cathment	Zonkwa	Kauru	Saminaka	Zaria
2	221.58	150.79	133.48	142.60	87.22	124.57	117.79
5	310.89	202.13	181.59	208.86	119.13	179.61	158.03
10	370.07	235.14	213.46	252.76	140.27	211.09	184.71
25	444.90	279.12	253.83	308.29	167.02	254.71	218.47
50	500.32	311.52	283.69	349.41	186.02	287.01	243.61
100	555.34	342.66	313.32	390.24	206.48	319.07	268.27
1000	737.39	447.31	411.39	525.39	271.53	425.19	350.37

The results obtained from simulating the mean and standard deviation of the annual maximum to get the rainfall magnitudes associated return is presented in Fig 2 above. From the figure it can be observed that there is progressive increase in magnitudes for all the station which could be adduced to emerging phenomenon like climate change. Analyzes conducted in determining the relationship between rainfall and precipitation duration show changes in flood intensity related to frequency, duration and timing of intensity levels.

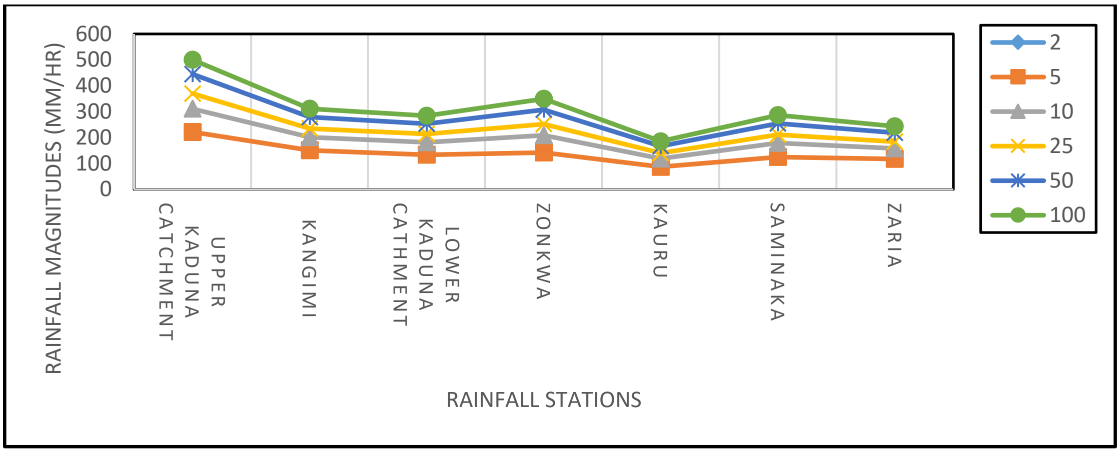

Fig 2 Relationship between Rainfall Magnitude and Return period

4.0. Conclusion

A relationship between rainfall magnitudes and return periods is developed in this study. The developed curves can be used to pick parameters for the design of hydrologic, hydraulic and water systems. The results of the study can be used to compare changes in precipitation event magnitude and precipitation duration.

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