The Development of Intensity-Duration Frequency Curve for Ulu Moyog and Kaiduan Station of Sabah

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ABSTRACT: This paper aims to develop the intensity-duration frequency curve for Ulu Moyog and Kaiduan station and to determine the suitable distribution to be used to analyze the rainfall data. Rainfall data is analyzed using Log-Pearson and Gumbel's distribution. Rainfall data are taken from 2 station, Ulu Moyong station and Kaiduan station. The IDF curve was plotted by Log-Pearson III distribution and Gumbel's distribution and the values obtained are the estimated rainfall. The observed rainfall and estimated rainfall are used to test the goodness of fitting for the estimation. Chi-square test is used to test the goodness of plotting for the observed hydrological data. From the analysis by Chi-square test in both stations, it is concluded that Gumbel's (Ulu Moyog: 2.84, Kaiduan:2.95) gave more fitness compared to Log-Pearson III distribution(Ulu Moyog:12.63 , Kaiduan:34.66). Therefore, Gumbel's distribution is a better distribution to be used in the west coast of Sabah.

KEYWORDS: Intensity duration frequency curve, gumbel's distribution, Log-pearson III, chi-square test, Flood

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TRANSACTIONS ON SCIENCE AND TECHNOLOGY

INTRODUCTION

Flood is one of the natural disasters that is caused by excessive water from rainfall that fails to discharge in a short period. On October 7th 2014, continuous rainfall had caused flood at west coast area of Sabah especially at Penampang district (Nancy L, 2014). The West cost of Sabah, Malaysia is already well known to be a monsoon country where floods is counted as one of Malaysia most significant natural disaster, Thus correct and updated rainfall intensity-duration frequency curves is important therefore, rainfall Intensity-Duration Frequency relationship should be verified so that the drainage system and hydro works can be designed sufficiently to transport the water out to the sea.

It is compulsory to establish rainfall intensity-duration-frequency (IDF) relationship that cover the design rainstorm profiles such that the rainwater will effectively transported out to the lakes or river in time before it floods. Extreme rainfall related disaster such as flood that affecting human life, properties and other being in negative way can be prevented by performing extreme rainfall analysis (Ariff et al. 2012). Intensity-Duration Frequency curve is one of the most significant devices in designing hydraulic related structure and to counter future hydraulic based problem. Probability of rainfall occurrence at given average rainfall intensity in an area represented graphically using Intensity-Duration frequency curve (Dupont & Allen 2006).

IDF curve shows the relation between mathematical expression of rainfall intensity, I, return period, and duration, d, T (Ariff et al. 2012). The graph of IDF curve is made up by three parameters, which is rainfall duration (hours rained at that intensity), rainfall intensity (mm/hr), and rainfall frequency/return period (How frequent the storms repeat itself). Return period basically is the frequency of a storm to repeat itself. It is the probability of occurrence of an event of a random variable such as rainfall. Stated that a 20cm rainfall in 24 hour has a return period of 10 year, its means the same magnitude of rainfall or greater than 20cm per 24hr will only occur once in every 10 years

LITERATURE REVIEW

Rainfall data plays important role in hydrological design such that it will be used to produce the IDF curve and design of water management infrastructures (Hailegeorgis et al. 2013).Intensity Duration Frequency curve is important method used to estimate the rainfall, that are derived based on historical rainfall data obtained from various rainfall stations. Malaysian Storm Water Management (MSMA) provides the IDF curves in Malaysia.

Updated IDF is essential such that the rainfall volume and intensity is increasing to provide the most accurate analysis for designation. It is crucial to review and update the current Intensity-Duration Frequency (IDF) curve for water management infrastructure design to prepare for future climate changes (Mirhosseini et al. 2013). However, there's a lack of information regarding to the number of IDF equations provided in Sabah.

Mathematical simplicity of IDF curves, made the construction of IDF curves easier where it can be constructed using univariate rainfall analysis approach (Ariff et al. 2012). The actual duration of the rainfall events does not represented by the 'duration' the since window-based analysis approaches is mostly used to construct IDF curves (Ariff et al. 2012). Derivation of IDF curves is either using window-based analysis value from each year or values which exceed a certain threshold value to construct the yearly highest series or partial duration series respectively, where the threshold value determined by physical or analytical solution (Ben-zvi, 2008).

Elsebaie (2012) made a research at two region which are Hafr AlBatin region and Najran region and according to the results, the IDF curves show that the rainfall is directly proportional with return period and in all returns period rainfall intensities decrease with rainfall duration. The results obtained have good consistency for both methods. The IDF relations are tabulated by (Elsebaie 2012) for the two regions. The result from the two methods (Gumbel & log Person III) show small difference between their results respectively for Najran region. Gumbel method gives slightly higher result than Log Pearson III. As for Hafr AlBatin region, Gumbel method gives higher result than the result obtained by Log Pearson III when they applied to Zone IV (Elsebaie, 2012).

From the research of (Elsebaie, 2012), he concluded that Gumbel method gave some larger rainfall intensity estimates compared to LP3 distribution. His result agrees to the past research by (AlHassoun, 2011) that in general the result obtained by using this two methods are very close at most of the return periods and having same trend. (Elsebaie, 2012) also conclude that Gumbel distribution is acceptable at the 5% level of significances by the Chi-Squared goodness of fit test and few cases for LP3 distribution for fitting were not good

METHODOLOGY

Weibull plotting position

The exceedence probability was analyzed using the Weibull Plotting Position. The formula of Weibull is:

$$P = \frac{m}{N+1} \quad (1)$$

Where, m is order of number, N is number of the record and P is probability of exceedence

The probability will be obtained using following relationships:

$$P = \frac{1}{T} \quad (2)$$

$$F = 1 - \frac{1}{T} \quad (3)$$

Where, p is probability of exceedence (Probability that an event will exceeded in a year), T is return Period and F is frequency (rate of event occurring). For each year the rainfall data intensity will be regressed in opposite to duration of the rainfall. After fitting the regression, rainfall data from 2 minutes to 320 minutes were estimated. Hence, standard deviations and mean of the data for the durations will be determined.

Gumbel's method

Extreme value distribution and is commonly known as Gumbel's distribution. It is a probability analysis that commonly used for extreme values in hydrologic and meteorological studies for prediction of flood or rainfalls. The following equation used to provide the inflow for every periods of return.

$$Q = \bar{Q} + K \cdot S \quad (4)$$

Where, Q is value of variate with a return period, T, $\bar{Q}$ is Mean of the variate, S is standard deviation of the sample, K is frequency factor expressed as:

$$K = \frac{Y_T + Y_n}{S_n} \quad (5)$$

Y_T is Gumbel's reduced variate

Log pearson type III

In this method, the variate is first transformed into Logarithmic form (Base 10) and the transformed data is then analyzed. If 'X' is the variate of a random hydrologic series, then the series of (Z) variates, where Z = log x, are first obtained. For 'Z' series, for any occurrence interval 'T', the equation is:

$$Z_Q = Z_m + K_Z \cdot S_Z \quad (6)$$

where, Z_m= Mean of (Z_m) values, S_Z = Standard deviation of the (Z_Q) variate sample, K_Z = Frequency factor usually taken from table with value of coefficient of skew "C_S" and recurrence interval (return period T), C_S is coefficient of skew of variate, Z_Q, After finding Z_Q with equation above, the corresponding value of Q is obtained by:

$$Q = 10^{Z_Q} \quad (7)$$

Goodness of fit (Chi-square test)

Chi-square test decides the best fit distribution. The equation for chi-square test is:

$$X^2 = \sum_{i=1}^{K} \frac{(Oi - Ei)}{Ei} \quad (8)$$

Where, Oi is the observed rainfall and Ei is the expected rainfall and will have chi-square distribution with (N-k-1) degree of freedom, By comparing both distribution Chi-square value, the smallest Chi-square value will be chosen as the best probability distribution. The chi-square test will determine the probability distributions is a suitable model or not, at the 5% significance level as it was used by researches such as (Elsebaie, 2012) concluding that Gumbel's distribution is acceptable at 5% level of significances by chi-square test.

RESULT AND DISCUSSION

Ulu Moyog Station

Figure 1, Gumbel's distribution and figure 2, Log-Pearson III shows the intensity Duration Frequency curves by the distribution respectively for Ulu Moyog Station. The data range is 29 years from 1986 to 2014. Development of IDF curves by Gumbel's distribution show a more constant decreasing curve than Log-Pearson III Distribution. The graph shows that the intensity decreases over time. The line for return period of 100 years tops the graph and followed by 50 year, 25 year, 10 year, 5 year and 2 year. Both figures also show that the 5-minute duration have the highest intensity and decrease over time. 1440-minute duration (equivalent to 24 hour) have the minimum intensity for all the return periods.

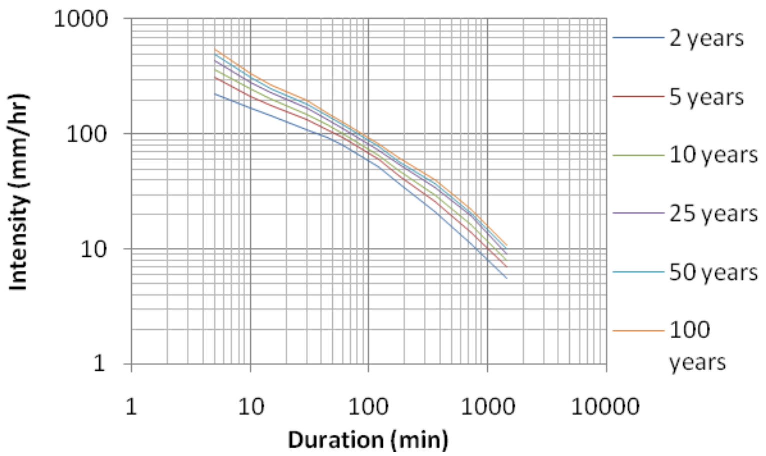

Figure 1. Development of IDF curves for Ulu Moyog by Gumbel's Distribution

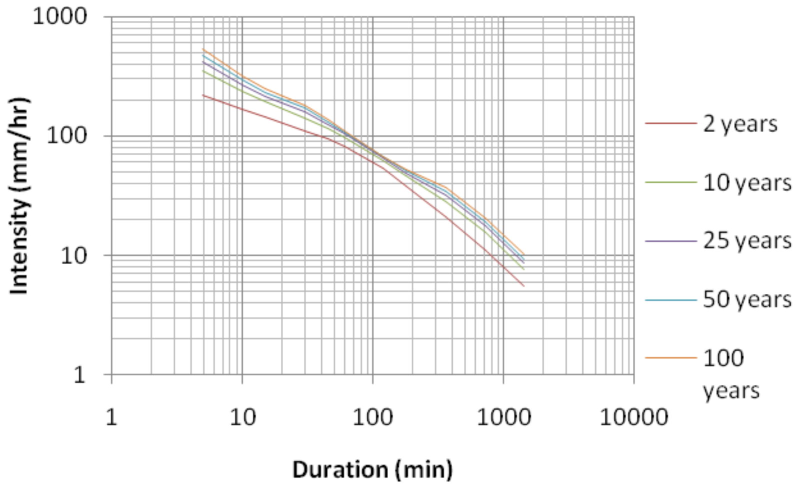

Figure 2. Development of IDF curves for ulu Moyog by LP3 distribution

Table 1. Chi-Square values of daily rainfall at different return periods for LP3 distribution and Gumbel's distribution for Ulu Moyog station

Return Period (Years)	Gumbel's distribution	Log-Pearson Type III distribution
2	0.089608	0.086548
5	0.030952	0.170718
10	0.018082	0.566944
25	0.343112	2.08407
50	0.842132	3.922007
100	1.52396	5.808662
X^2cal	2.847845	12.63895

Table 1 shows the Chi-Square values by Log-pearson III distribution and Gumbel's distributions for Ulu Moyog station. Significant level of 5% is used for this research and since there are two parameters that are used to compare with the observed data, the degree of freedom is 1. The critical value from chi-square tables gives a value of 3.84. Hence, comparing the critical Value with Chi-Square value by Log-Pearson III and Gumbel's distribution, Values by Gumbel's distributions are accepted and value by Log-pearson type III distribution are rejected.

Kaiduan Station

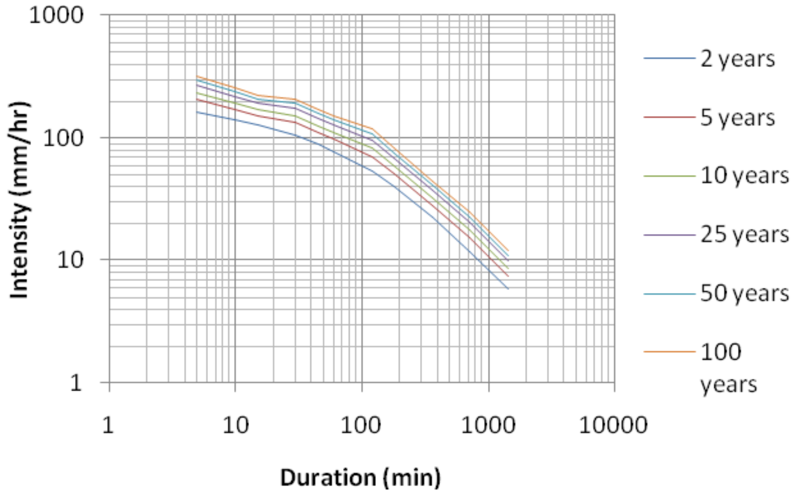

Figure 3. Development of IDF curves By Gumbel's Distribution for Kaiduan

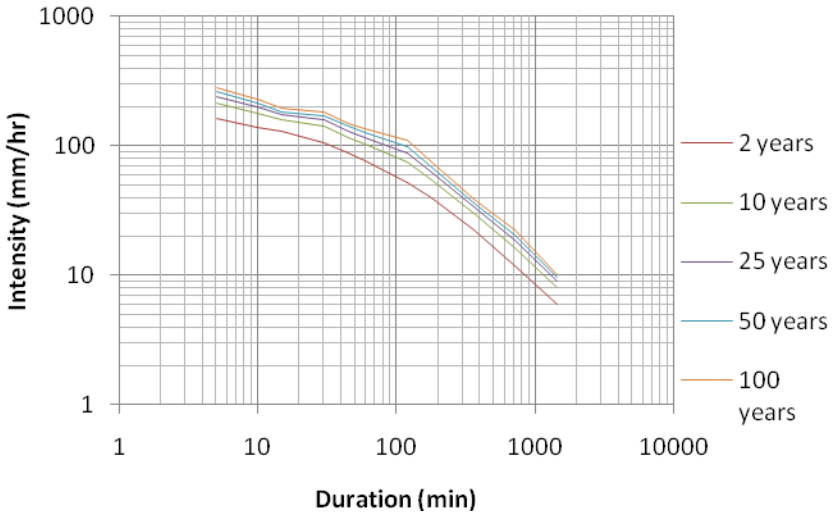

Figure 4 Development of IDF curves by LP3 Distribution for Kaiduan

Figure 3 and figure 4 are the Intensity Duration frequency curves by Log-Pearson III and Gumbel's distribution respectively. The period of data provided is 11 years starting from 2004 to 2014. For the Development of IDF curves by Gumbel's distribution, besides the 2 year return period, other periods seems to have a not constant decrease. The intensity is decreasing over duration but not smooth. This might due to lack of data provided as the period of data provided for Kaiduan is only 11 years. The development of IDF curves by Log-Pearson III distribution also have similar phenomenon, where the 2 year return period have a relatively smooth curves, while other return periods are decreasing but not in a smooth manner. The duration is 5-min and ends at 1440-min (equivalent to 24 hour).

Table 2. Chi Square values of daily rainfall at different return periods for Gumbel's and LP3 distribution for Kaiduan station

Return Period (Years)	Gumbel's distribution	Log-Pearson Type III distribution
2	0.004165	0.256711
5	0.001762	0.476449
10	0.054015	1.071422
25	0.418625	5.067219
50	0.914422	10.46204
100	1.564665	17.32999
X^2cal	2.957654	34.66383

Table 2 shows the Chi-square values by Gumbel's distribution and Log-Pearson type III distributions for Kaiduan Station. Significant level 5% is used for this research. There are only two parameters used to compare with the observed data and therefore, the degree of freedom is 1. The critical value from Chi-square tables gives a value of 3.84. Comparing the critical value with Gumble distribution Chi square, Gumble distribution is accepted with 2.957 chi-square value. However, Log-Pearson III distribution Chi-square value is higher than the critical value and therefore rejected.

Therefore, the degree of freedom is 1. Significant level of 5% used satisfies the past research by (Millington et al. 2011). From the results, it shows that the Chi-square values by Gumbel's distributions are more acceptable compared to Log-pearson III distribution. Although from past research there are other probability distribution that shows better fits than Gumbel's distribution, such as research by (Ewemoje & Ewemooje 2011) that concludes that Log-pearson III probability distribution is best to predict the 25-, 50-, and 100-year maximum flood return periods. (Mahdavi et al. 2010) found that even though there are more data fitness due to the increase of statistical period length of Gumbel's distribution but still Log-pearson III concluded as the best fitted distribution. However, the obtained score of distributions indicates that there is no apparent predominance for any distributions.

CONCLUSION

The result from this paper accepting Gumbel's distribution as the best fitted distribution by Chi-square test at 5% of significances. However it is very important to decide the best distribution for a region accordingly before estimating the value of annual precipitation for a certain region.

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REFERENCES

[1] AlHassoun, S. A. (2011). Developing an empirical formulae to estimate rainfall intensity in Riyadh region. *Journal of King Saud University - Engineering Sciences*, **23**(2), 81–88.

[2] Ariff, N. M., Jemain, A. A., Ibrahim, K. & Zin, W.W. (2012). IDF relationships using bivariate copula for storm events in Peninsular Malaysia. *Journal of Hydrology*, **470**, 158-171.

[3] Ben-zvi, A. (2008). Rainfall intensity-duration-frequency curves from large samples. *11th*

International Conference on Urban Drainage, 31 August-5 September 2008, Edinburgh,Scotland, UK.

[4] Dupont, B. S. & Allen, D. L. (2006). *Transportation Research Record: Journal of the Transportation Research Board, No. 1977*. University of Kentucky,USA.

[5] Elsebaie, I. H. (2012). Developing rainfall intensity–duration–frequency relationship for two regions in Saudi Arabia. *Journal of King Saud University - Engineering Sciences*, **24**(2), 131–140.

[6] Ewemoje, T. A. & Ewemooje, O. S. (2011). Best distribution and plotting positions of daily maximum flood estimation at Ona River in Ogun-Oshun river basin, Nigeria. *Agricultural Engineering International: CIGR Journal*, **13**(3), 1–13.

[7] Hailegeorgis, T. T., Thorolfsson, S. T. & Alfredsen, K. (2013). Regional frequency analysis of extreme precipitation with consideration of uncertainties to update IDF curves for the city of Trondheim. *Journal of Hydrology*, **498**, 305–318.

[8] Mahdavi, M., Osati, K., Sadeghi, S. A. N., Karimi, B. & Mobaraki, J. (2010). Determining suitable probability distribution models for annual precipitation data (a case study of Mazandaran and Golestan provinces). *Journal of Sustainable Development*, **3**(1), 159-168.

[9] Millington, N., Das, S. & Simonovic, S. P. (2011). *The comparison of GEV, Log-Pearson Type 3 and Gumbel distribution in the Upper Thames River Watershed under Global Climate Models*, Ontario, Canada.

[10] Mirhosseini, G., Srivastava, P. & Stefanova, L. (2013). The impact of climate change on rainfall Intensity-Duration-Frequency (IDF) curves in Alabama. *Regional Environmental Change*, **13**(SUPPL.1), 25–33.

[11] Nancy L. (2014). *Kibabaig worst hit in Penampang floods*. Borneo Post, (http://www.theborneopost.com/2014/10/08/kibabaig-worst-hit-in-penampang-floods/). Accessed on January 6 2017.