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Development of a General Equation for Intensity-Duration-Frequency (IDF): Iraq

تطوير المعادلة العامة للشدة-المدة-التردد (IDF): العراق

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ABSTRACT

In the field of water resource management, rainfall intensity-duration-frequency (IDF) curves are of great importance, especially in the design of hydraulic structures and the assessment of flash-flood risks. The aim of this study is to obtain IDF curves and find empirical equations for rain duration for Al-Najaf city in the southwest of Iraq. Rainfall data for 30 years, from 1989 to 2018, were collected. The practical reduction equation of the Indian Meteorological Department (IMD), with six methods of probability distribution, was used for short intervals (0.25, 0.5, 1, 2, 3, 6, 12, and 24 hours) with a specified recurrence period (100, 50, 25, 10, 5, and 2 years). The Kolmogorov-Smirnov, chi-squared, and Anderson-Darling goodness of fit tests were used with the help of EasyFit 5.6 software. The findings revealed that the highest intensity of rainfall occurs during a repeated cycle of 100 years with a duration of 0.25 hours, while the lowest intensity of rainfall occurs during a repeated cycle of 2 years with a duration of 24 hours. In the results obtained from the six methods, as well as the superiority of the log Pearson type III method, the consistency of the fit tests showed some convergence.

الملخص

في حقل إدارة الموارد المائية ، تعتبر منحنيات شدة هطول الأمطار - المدة - التردد (IDF) ذات أهمية كبيرة، لا سيما في تصميم المنشآت الهيدروليكية وكذلك تقييم مخاطر الفيضانات المفاجئة. الهدف من الدراسة هو الحصول على منحنيات (IDF) وإيجاد معادلات تطبيقية لمدة هطول الأمطار لمدينة النجف والواقعة في جنوب غرب العراق، بعد جمع البيانات الخاصة بهطول الأمطار لمدة 30 عامًا من بداية عام 1989 ونهاية بالعام 2018, مع استخدام معادلة التقليص التطبيقية لإدارة الأرصاد الجوية الهندية (IMD) مع ستة طرائق لتوزيع الاحتمالات خلال فترات زمنية قصيرة و كما يلي: (0.25 ، 0.5 ، 1 ، 2 ، 3 ، 6 ، 12 ، و 24) ساعة وضمن فترات عودة محددة وهي: (100 ، 50 ، 25 ، 10 ، 5 ، و 2) سنة. ثم يتم استخدام اختبارات جودة التطابق، Kolmogorov-Smirnov و chi-square و Anderson-Darling بمساعدة (برنامج Easy fit 5.6). أشارت النتائج إلى أن الحد الأقصى لشدة هطول الأمطار يحدث في فترة عودة مدتها (100 سنة) ولمدة (0.25 ساعة) ، بينما الحد الأدنى لشدة هطول الأمطار يحدث في فترة عودة مدتها (2 سنة) ولمدة 24 ساعة. في النتائج التي تم الحصول عليها للتقنيات الست بالإضافة إلى تفوق تقنية Log-Pearson Type III أظهرت جودة اختبارات التطابق تقاربًا إلى حد ما.

KEYWORDS
الكلمات المفتاحية
EasyFit 5.6 software, IMD equation, Kolmogorov-Smirnov test, log Pearson type III technique, probability distribution, return period
برنامج Easy fit 5.6، التوزيعات الاحتمالية، فترة العودة، فحص Kolmogorov-Smirnov، معادلة IMD، طريقة Log-Pearson III

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1. Introduction

The accurate analysis of precipitation data is very important in hydrological engineering, especially in the design of water resource structures. Daily rainfall frequency analysis is a way of measuring the amount of rain occurring over a certain area within a certain time interval with a certain probability of occurrence (Dupont et al., 2000). The relationship of the intensity-duration-frequency (IDF) curve gives an idea of the estimation and prediction of hydrological events, such as storms of different magnitude and duration. From these curves, it is possible to derive a relationship between the intensity and duration of precipitation, assuming that the series of precipitation is stable. In other words, the intensity and frequency of extreme hydrological events remain steady over time (Al-Awadi, 2016). The rainfall IDF models were first established by Sherman (1905), then Bernard (1932), and so on, and many IDF curves and equations have been developed in many parts of the world, including Iraq. Hadadin (2005) elaborated eight IDF equations for the eight rainfall recording stations in the Mujib Basin in Jordan.

Hussain (2006) used Weibull, Gumbel, and log Pearson type III probability distribution methods to develop an IDF empirical formula for the Baiji station in Iraq. The results showed that the log Pearson type III distribution was the optimum type of distribution for durations of 0.25 and 1 hours, whereas the Gumbel distribution was the optimum type of distribution for a duration of 0.5 hours. Al-Hassoun (2011) established an empirical equation to assess the intensity of rainfall in Al-Riyadh city, Saudi Arabia. The results indicated that there was not much difference in the estimation of rainfall IDF curves between the Gumbel and log Pearson type III models. Jaleel and Farawn (2013) developed an IDF empirical formula for Basrah city in Iraq. The results indicated that the maximum intensities are of short duration with substantial variations within a return period, while there is little difference in intensities of long duration. Hussein (2014) developed an IDF empirical formula for Karbala province in Iraq, the results of which showed that the log Pearson type III was better than the other methods used.

Al-Awadi (2016) used Gumbel, log normal and log Pearson type III probability distributions to estimate the parameters of an IDF equation for different return periods for Baghdad. This analysis indicates a convergence between the three techniques used, with all of them achieving the appropriate level of significance but with a small advantage for the distribution of the log Pearson type III. Dakheel (2017) established an IDF empirical formula for Al-Nasiriyah city in Iraq by using the log Pearson type III and Gumbel probability distribution methods. The results confirmed that the log Pearson type III method performed the best. Hamaamin (2017) developed IDF curves for Al-Sulaimanya city in Iraq, the results of which showed a good match between the actual intensities and the intensities predicted by the general empirical formula.

Namitha and Vinothkumar (2019) utilized annual rainfall data for 27

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years in Kumulur by using the Gumbel and generalized extreme value techniques. The L-moments procedure was followed to estimate the distribution parameters. The quality of fit of the probability distribution was evaluated by conducting a chi-squared test. It was found that the generalized extreme value distribution method was better than other methods. In this study, an analysis was conducted of the maximum daily rainfall data during a period of 30 years for Al-Najaf city in Iraq to establish IDF curves and derive an empirical equation for various return periods. Six different probability distribution models were selected based on the results of three statistical tests, Kolmogorov-Smirnov, chi-squared, and Anderson-Darling, with the help of EasyFit 5.6 software. This empirical equation will allow the accurate prediction of the maximum value of future rainfall intensity and, thus, increase the efficiency of designs.

2. Material and Methods

2.1. Study Area:

Al-Najaf is one of Iraq's major cities and is located in the southwest of the country within the geographic coordinates of 29°50'00"–32°21'00" N and 42°50'00"–45°44'00" E (Hussain et al., 2017). The prevailing weather conditions of the city are dry to semi dry and hot in the summer season, with temperatures ranging from 40°C to 50°C, and semi dry and cold in the winter season, with temperatures ranging from 8°C to 25°C. The period of precipitation generally begins in November with light rainfall, increases in December and January, and continues through to May. For rainy and dry years, the average annual precipitation has been reported as 190.7 mm and 22.8 mm, respectively (MOTRANS, 2020).

2.2. Data Collection:

In this study, the maximum daily (24 hours) historical annual rainfall data for 30 years (1989 to 2018) was used to establish IDF curves and derive general intensity formulas. These data were obtained from the Iraqi Meteorological Organization and Seismology.

2.3. Reduction of Precipitation Duration:

The maximum daily (24 hours) rainfall data were transformed into smaller durations (namely 0.25, 0.5, 1, 2, 3, 6, and 12 hours) using an equation recommended by the Indian Meteorological Department:

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

where P_t is the required smaller duration precipitation depth (mm), t is the duration (hour), and P_{24} is the maximum daily precipitation (mm). This equation has been examined and used successfully by many researchers and in many different locations in the world (Al Mamun et al., 2018).

2.4. Frequency Analysis Methods:

In this study, six frequency analysis models were used: Cauchy, Dagum, Gumbel max, log normal, log Pearson type III, and Weibull. The statistical distribution models and their functions are shown in Table 1.

Table (1) Probability distribution models and their functions, (Mathwave, 2020).

Statistical Distribution Models	Function
Cauchy	$f(x) = \left(\pi\sigma\left(1+\left(\frac{x-\mu}{\sigma}\right)^2\right)\right)^{-1}$
Dagum	$f(x) = \frac{\alpha k \frac{x-\gamma}{\beta}^{\alpha k-1}}{\beta\left(1+\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)^{k+1}}$
Gumbel max	$f(x) = \frac{1}{\sigma}\exp\left(-z-\exp(-z)\right)$
Log normal	$f(x) = \frac{exp\left(-\frac{1}{2}\left(\frac{\ln(x-\gamma)-\mu}{\sigma}\right)^2\right)}{(x-\gamma)\sigma\sqrt{2\pi}}$
Log Pearson type III	$f(x) = \frac{1}{x\lvert\beta\rvert\Gamma(\alpha)}\left(\frac{\ln(x)-\gamma}{\beta}\right)^{\alpha-1} exp\left(-\frac{ln(x)-\gamma}{\beta}\right)$
Weibull	$f(x) = \frac{\alpha}{\beta}\left(\frac{x-\gamma}{\beta}\right)^{\alpha-1} exp\left(-\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)$

In this table, $\equiv \frac{x-\mu}{\sigma}$, α, and k are the continuous shape parameters, β and σ are the continuous scale parameters, and γ and μ are the continuous location parameters.

2.5. Statistical Distribution Tests:

The EasyFit 5.6 software was used to assess the most suitable probability distribution model by using three types of test, Anderson-Darling, chi-squared, and Kolmogorov-Smirnov. Anderson-Darling 's universal method is used to determine the fit between an observed and predicted cumulative distribution function. The tails in this test take more weight than the Kolmogorov-Smirnov test. The chi-squared test is applied only for a continuous sample of binned data. It is used to test whether a sample is selected from a population with a particular distribution. The Kolmogorov-Smirnov test is applied to decide if a sample is associated with a hypothesized continuous distribution (Mathwave, 2020).

2.6. Derivation of IDF Equations:

Any empirical IDF equation should relate the maximum rainfall intensity with other effective parameters of rainfall duration and frequency (Elsebaie, 2010). Many researchers have introduced other common functions. Four essential equations used to represent the rainfall intensity–duration relationship are

Talbot equation $$I = \frac{c*T^m}{d+b} \qquad (2)$$

Bernard equation $$I = \frac{c*T^m}{d^e} \qquad (3)$$

Sherman equation $$I = \frac{c*T^m}{d^e+b} \qquad (4)$$

Kimijima equation $$I = \frac{c*T^m}{d^e+b} \qquad (5)$$

where *I* is the intensity in units (L/T), *T* is the recurrence period in units (T), *d* is the rainfall duration in units (T), and *c*, *m*, *e*, and *b* are the constant parameters associated with the site's meteorological conditions (Nhat, 2006). In this study, the Bernard equation was chosen to derive the IDF equation, as it is the most widely utilized equation.

3. Results and Discussion

For determining the most appropriate probability distribution model for the distribution of the data of this study, three types of statistical test (Kolmogorov-Smirnov, Anderson-Darling, and chi-squared) were used after conducting a statistical analysis with the help of the EasyFit 5.6 program. As indicated by various probability distributions for the 24hr, 12hr, 6hr, 3hr, 2hr, 1hr, 0.5hr, and 0.25hr durations and the quality of fit based on the results of the Kolmogorov-Smirnov procedure, the values obtained for the six methods can be accepted with a significance level equal to10%.

The IDF curves for Al-Najaf city, according to the six probability distribution models, are shown in Figures 1–6. It is evident that there is a clear variation in the estimation of rainfall intensity for the assumed return periods through the models used. The Cauchy model has a high estimation for rainfall intensities, whereas the Weibull model was the lowest, while the Dagum, Gumbel max, log Pearson type III, and log normal models were close to each other in estimation. The maximum and minimum rainfall intensities recorded during the 1989–2018 period were 2.687 mm/hr and 0.208 mm/hr, respectively. A comparison of this range with the results of the probability models indicated that the closest model is log Pearson type III, followed by the Dagum model, while the Cauchy and Weibull models were the most extreme in their estimations. It should also be noted that in a previous study for the Baghdad area, near the city of Al-Najaf, the log Pearson type III model showed the optimum distribution (Al-Awadi, 2016). According to the plots, most rainfall intensities run parallel to their return periods at different durations. From the IDF curves, it can be noted that any increase in the return period leads to higher rainfall intensity values, while any increase in rainfall duration leads to lower rainfall intensities for all return periods. Table 2 displays the factor values for *c*, *m*, and *e* in the IDF equations, which were obtained by applying the solver tool integrated into the Excel 2010 program for the six models. The final factors for the general equation were taken as average values; thus, the final equation can be written as

$$I = \frac{1.25\,T^{1.423}}{t^{0.666}} \qquad (2)$$

To test the accuracy and performance of equation 2, a comparison was conducted between the calculated values of rainfall intensities using IDF curves and the calculated values of rainfall intensities using equation 2 for all returning periods and durations. The results showed that the values of the coefficient of determination $R^2 = 1$ for all the recurrence periods (2, 5, 10, 25, 50, and 100 years). This means that the equation can be used effectively with a perfect estimation of the calculation of rainfall intensity; thus, it will be reflected positively in the efficiency of the designs for drainage projects in the city and to avoid the occurrence of floods due to the failure of the drainage network to absorb the quantities of rainwater.

Figure (1) IDF using the Cauchy model at Al-Najaf city.

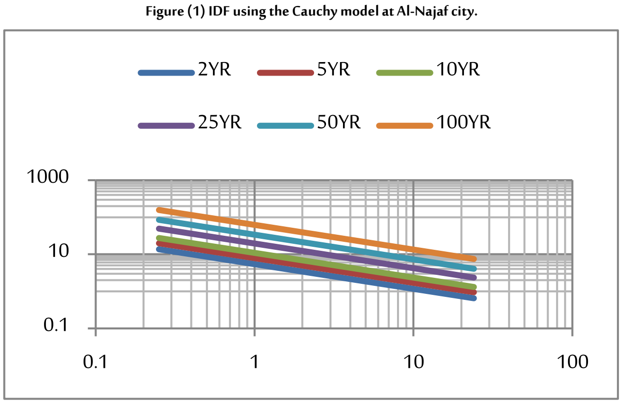

Figure (2) IDF using the Dagum model at Al-Najaf city.

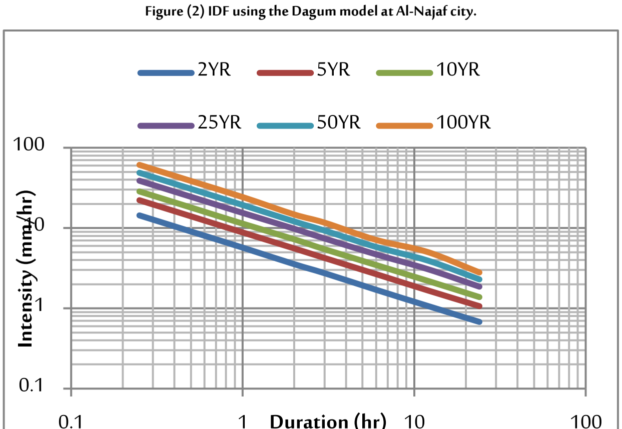

Figure (3) IDF using the Gumbel max model at Al-Najaf city.

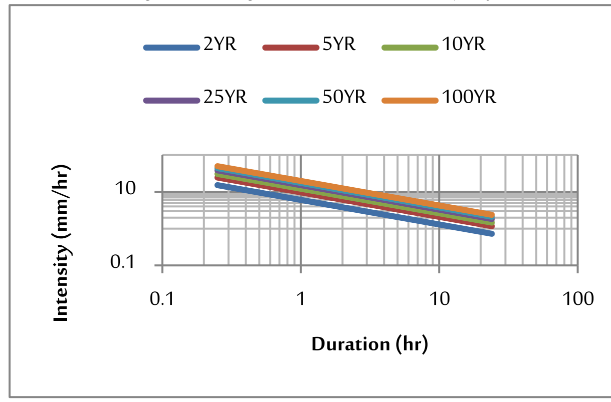

Figure (4) IDF using the log Pearson type III model at Al-Najaf city.

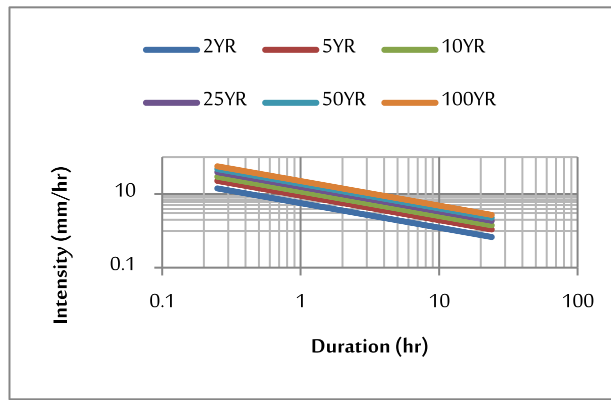

Figure (5) IDF using the log normal model at Al-Najaf city.

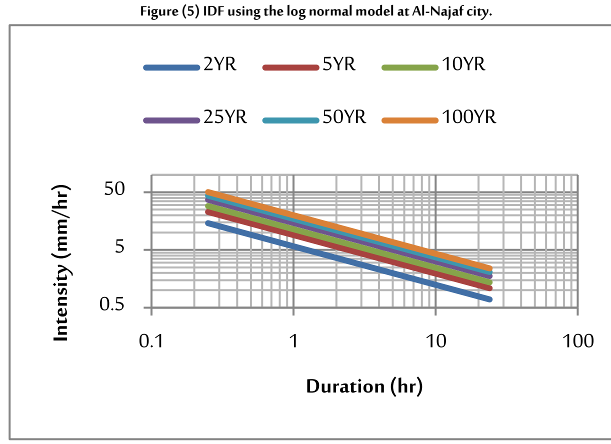

Figure (6) IDF using the Weibull model at Al-Najaf city.

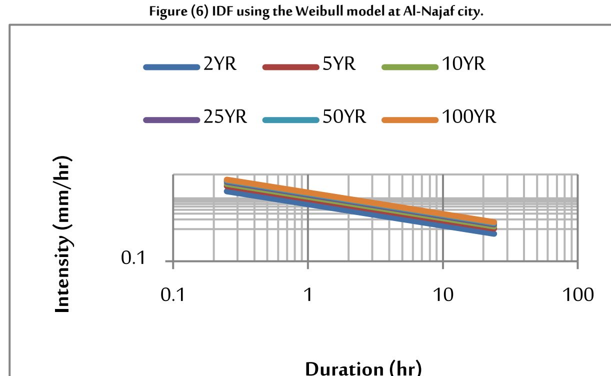

Table (2) Average factors for each probability distribution model.

Factor	Cauchy	Dagum	Gumbel	Log Pearson type III	Log normal	Weibull	Average
c	1.334	1.254	1.256	1.255	1.245	1.158	1.250
m	1.567	1.439	1.426	1.435	1.411	1.260	1.423
e	0.666	0.666	0.666	0.666	0.666	0.666	0.666

4. Conclusions

This study provided a series of steps for developing an IDF empirical equation for Al-Najaf city. This equation can be considered as a useful guide to predict the rainfall intensity for any specific recurrence period of different durations. The most important conclusion is that the highest rainfall intensity occurs in a repeated cycle of 100 years for a duration of 0.25 hours, while the lowest rainfall intensity occurs in the return period of 2 years for a duration of 24 hours. In the results obtained for the six techniques, and with the superiority of the log Pearson type III method, the consistency of the fit tests showed some convergence. However, the Cauchy and Weibull models produced the most extreme estimations.

Biography

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References

Al Mamun, A., bin Salleh, M. N. and Noor, H.M. (2018). Estimation of short-duration rainfall intensity from daily rainfall values in Klang Valley, Malaysia. *Applied Water Science*, **8**(7), 203. DOI: 10.1007/s13201-018-0854-z

Al-Awadi, A.T. (2016). Assessment of intensity duration frequency (IDF) models for Baghdad city, Iraq. *Journal of Applied Sciences Research*, **12**(2), 7–11.

AlHassoun, S.A. (2011). Developing an empirical formulae to estimate rainfall intensity in Riyadh region. *Journal of King Saud University-Engineering Sciences*, **23**(2), 81–8. DOI: 10.1016/j.jksues.2011.03.003

Dakheel, A.A. (2017). Drawing curves of the rainfall intensity duration frequency (IDF) and assessment equation intensity rainfall for Nasiriyah city, Iraq. *University of Thi-Qar Journal*, **12**(2), 63–82. DOI: 10.32792/utq/utj/vol12/2/6

Dupont, B.S., Allen, D.L. and Clark, K.D. (2000). *Revision of the Rainfall-Intensity-Duration Curves for the Commonwealth of Kentucky (Report No. KTC-00-18/SPR-178-98)*. Kentucky Transportation Center, College of Engineering, University of Kentucky Lexington, Kentucky, USA, 1. Available at: https://rosap.ntl.bts.gov/view/dot/21528. (accessed on 20/09/2020).

Elsebaie, H.I. (2010). Developing rainfall intensity–duration–frequency relationship for two regions in Saudi Arabia. *Journal of King Saud University, Engineering Resource*, **24**(2), 131–40. DOI: 10.1016/j.jksues.2011.06.001

Hadadin, N.A. (2005). Rainfall intensity-duration-frequency relationship in the Mujib basin in Jordan. *Journal of Applied Science*, **8**(10), 1777–84.

Hamaamin, Y.A. (2017). Developing of rainfall intensity-duration-frequency model for Sulaimani city. *Journal of Zankoy Sulaimani*, **19**(Part A), 93–102.

Hussain, R.A. (2006). Intensity-duration-frequency analysis for rainfall in Baiji station. *Tikrit Journal of Eng, Sciences*, **13**(4), 116–35.

Hussain, T.A., Al_Kindi, G.Y. and Kadhim, R.J. (2017). Water balance for the city of Al-Najaf Al-Ashraf/Southern Iraq. *Diyala Journal for Pure Science*, **13**(4-part 2), 186–97.

Hussein, A.K. (2014). Deriving rainfall intensity-duration-frequency relationships for Kerbala city. *ALMuthana Journal for Engineering Sciences*, **3**(1), 25–37.

Jaleel, L.A. and Farawn, M.A. (2013). Developing rainfall intensity-duration-freqency relationship for Basrah city. *Kufa Journal of Engineering*, **5**(1), 105–12.

MathWave Technologies. (2020). *Statistical Distribution Information*. Available at: http://www.mathwave.com (accessed on 20/09/2020).

MOTRANS, Ministry of Transportation. (2015). *Meteorological Data of Al-Najaf Province Station*. Iraq: Ministry of Transportation, Iraqi Meteorological Organization and Seismology.

Namitha, M.R. and Vinothkumar, V. (2019). Derivation of the intensity-duration-frequency curve for annual maxima rainfall using generalised extreme value distribution. *Int. J. Curr. Microbiol. App. Sci*, **8**(1), 2626–32. DOI: 10.20546/ijcmas.2019.801.276

Nhat, L.M., Tachikawa, Y. and Takara, K. (2006). Establishment of intensity-duration-frequency curves for precipitation in the monsoon area of Vietnam. *Annuals of Disas. Prev. Res. Inst.*, **49**(Part B), 93–103.