Journal of Applied Sciences

ISSN 1812-5654

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 10 (9): 704-715, 2010
ISSN 1812-5654

Update of Intensity-Duration-Frequency Curves for Precipitation of Short Durations in Tropical Area of West Africa (Cote D'ivoire)

[1]G.E. Soro, [1]T.A. Goula Bi, [1]F.W. Kouassi and [2]B. Srohourou
[1]Laboratory Geosciences and Environment, U.F.R.S.G.E., University of Abobo-Adjame,
02 BP 801 Abidjan 02, Abidjan, Côte d'Ivoire
[2]SODEXAM/Direction of National Meteorology, Department Studies,
Development and Environment, 15 BP 990 Abidjan 15, Abidjan, Côte d'Ivoire

Abstract: The purpose of this study is to update the rainfall intensity-duration-frequency curves. In this perspective, annual maximum series of 13 synoptic stations have been analyzed over the period 1955 to 2001. The statistical analysis shows that most series are well fit by the Gumbel and the Lognormal distributions. The parameters of Montana model obtained by this present study are well above those currently used by engineers for the design of urban drainage systems. The values of the parameters have doubled or even tripled in some cases. The previous intensity-duration-frequency curves underestimate the maximum intensities of rainfall durations lower than 20 min and overestimate those exceeding 20 min. These changes in the parameters of Montana and the intensity-duration-frequency curves certainly have an impact on the design of hydraulic structures and roads.

Key words: Design rainfall, intensity-duration-frequency curves, urban drainage system, West Africa, côte d'ivoire

INTRODUCTION

The design of any hydraulic structure requires a precision of the level of performance desired. This level of performance is often determined by the potential damage and severity of weather hazards that could cause failure, malfunction or overflow structure in question. Thus, in the case of stormwater management, the dimension of various components of the infrastructure system (case of pipes and canals sanitation) is based on the return period of heavy rainfall events (Monhymont and Demarée, 2007; Segond *et al*., 2007). This information is often expressed as Intensity-Duration-Frequency (IDF) curves obtained from a statistical study of extreme events. In West Africa, very little studies (Oyebande, 1982; Puech and Chabi-Gonni, 1984) were carried out on the intensity-duration-frequency curves for precipitation. This is mainly due to the fact that in this part of the globe, the data of rainfall extremes of short duration are generally rare, expensive and difficult to obtain.

In Côte d'Ivoire, the model which was used for construction of the intensity-duration-frequency curves is that of Montana, fitted with the data previous to the year 1979 over periods of 10 years on average. A technical document has been realized in 1979 and is used today by all the engineers for the design of urban drainage structures.

The probabilistic approach used in this study is based only on the Gumbel distribution. Recently, the applicability of this distribution has been criticized both on theoretical and empirical grounds. Thus, new theoretical arguments based on comparisons of actual and asymptotic extreme value distributions as well as on the principle of maximum entropy indicate that the Extreme Value Type 2 distribution should replace the Gumbel distribution (Koutsoyiannis, 2004a). In addition, several empirical analyses using long rainfall records agree with the new theoretical findings (Coles *et al*., 2003; Koutsoyiannis, 2004b; Goula *et al*., 2007; Muller *et al*., 2009).

Furthermore, the empirical analyses show that the Gumbel distribution may significantly underestimate the largest extreme rainfall amounts. The choice of statistical models (GEV, Lognormal and Gumbel) is significant as it is directly related to the safety of hydraulic structures, establishment of flood zones and estimation of extreme events.

Moreover, manifestations of global warming across the planet are recognized today (IPCC, 2001). The fact that this warming will affect the intensity and frequency of

---

Corresponding Author: G.E. Soro, Laboratory Geosciences and Environment, U.F.R.S.G.E., University of Abobo-Adjame, 02 BP 801 Abidjan 02, Abidjan, Côte d'Ivoire Tel: +225 07371070

rainfall is well accepted by the scientific community (De Toffo *et al.*, 2009). To better protect people, it is necessary to update rainfall intensity-duration-frequency relationships using by water resources engineers to design and manage infrastructure. This is the aim of the present study carried out on extreme rainfall of short duration in Côte d'Ivoire.

MATERIALS AND METHODS

Data rainfall used: The national raingauge network was used in this study. It consists of 14 synoptic stations (Fig. 1). The San Pedro station was not chosen because the large number of missing data. The locations of synoptic stations for which data were available are reported in Table 1. For these 13 rainfall stations, annual maximum series of durations ranging from 15 min to over 4 h were analyzed. The data have been provided by the Côte d'Ivoire Meteorological Service (SODEXAM). The record lengths of each rainfall data series varied form a minimum of 14 years to over 43 years.

Annual maximum series used for statistical analysis must comply with the hypothesis of homogeneity, stationarity and randomness. To verify these hypotheses three non parametric tests were used.

The homogeneity test of Wilcoxon (1945) allows to carry out comparisons between two subsamples and to check if the averages of the two subsamples are significantly different (Baudez *et al.*, 1999). The Kendall (1975) trend test is based on the correlation between the ranks of a time series and their time order (Yue and Pilon, 2004). It is a rank-based nonparametric method used to detect the trends in the series. Non-parametric trend detection methods are less sensitive to outliers (extremes) than are parametric statistics such as Pearson's correlation coefficient (Wang *et al.*, 2008). As the Kendall test requires independent series, serial dependence was also tested using the non-parametric Wald and Wolfowitz test (1943).

The null hypotheses were set to no independence, no stationarity and no homogeneity and these were not rejected at the 5% significance level.

Methodology: The objective of the rainfall intensity duration frequency curves is to estimate the maximum intensity of rainfall for any duration and return period. The classical approach for building IDF curves has three steps (Nhat *et al.*, 2006). In first step, a probability distribution function is fitted to each duration sample. In second step, the quantiles of several return periods T are calculated using the estimated distribution function from step one. Lastly, the IDF curves are determined by fitting a parametric equation for each return period, using regression techniques between the quantiles estimates and the duration.

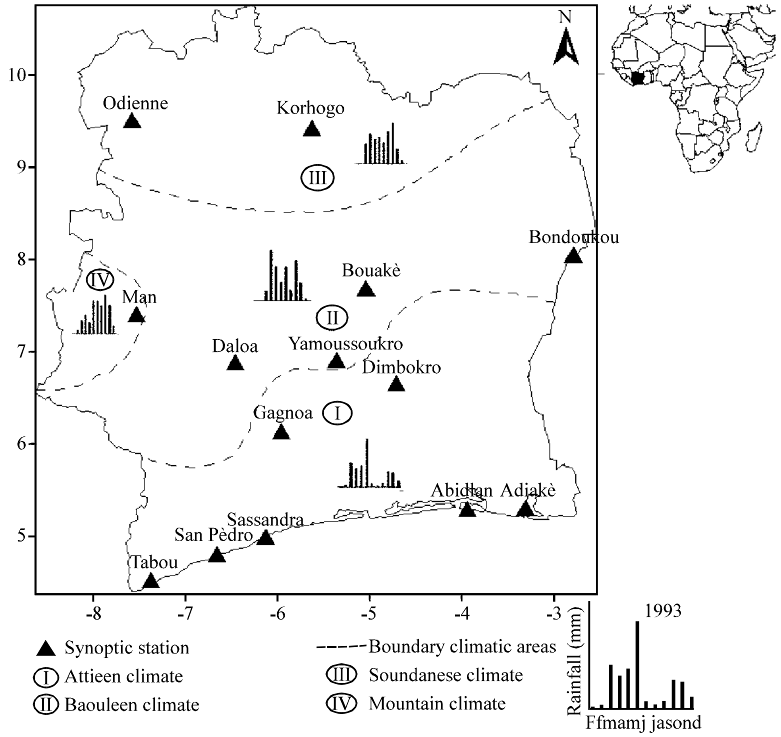

Fig. 1: Geographical locations of raingauges and the principal climatic areas of the Côte d'Ivoire

Table 1: Characteristics of rainfall stations used

N° order	Code	Stations	Latitude	Longitude	Elevation (m)	Record period	Record length (years)
1	1090000100	Abidjan	5°15 N	3°56 W	7	1958-2001	42
2	1090001300	Adiaké	5°18 N	3°18 W	35	1975-2000	23
3	1090004600	Bondoukou	8°03 N	2°47 W	371	1970-2000	30
4	1090005600	Bouaké	7°44 N	5°40 W	376	1959-2001	42
5	1090009100	Dimbokro	6°39 N	4°42 W	92	1968-1999	31
6	1090008000	Daloa	6°52 N	6°25 W	276	1982-1999	14
7	1090010300	Gagnoa	6°08 N	5°57 W	205	1976-2001	26
8	1090012000	Korhogo	9°25 N	5°37 W	381	1971-2001	30
9	1090014200	Man	7°24 N	7°31 W	340	1957-2001	43
10	1090017200	Sassandra	4°57 N	6° 5 W	62	1969-1993	25
11	1090016000	Odienné	9°30 N	7°34 W	434	1969-2001	33
12	1090018400	Tabou	4°25 N	7°22 W	20	1964-1998	34
13	1090008000	Yamoussoukro	6°54 N	5°21 W	196	1979-1995	14

Table 2: Probability distribution functions used

Name	Probability density function	Parameters
Generalized extreme value distribution	$f(x)=\frac{1}{\alpha}\left[1-\frac{k}{\alpha}(x-u)\right]^{1/k-1}\exp\left\{-\left[1-\frac{k}{\alpha}(x-u)\right]^{\frac{1}{k}}\right\}$	u, α, k
Gumbel	$f(x)=\frac{1}{\alpha}\exp\left[-\frac{x-u}{\alpha}-\exp(-\frac{x-u}{\alpha})\right]$	u, α
Lognormale 2	$f(x)=\frac{1}{x\sigma\sqrt{2\pi}}\exp\left[-\frac{(\ln x-\mu)^2}{2\sigma^2}\right]$	μ, σ

Fitting of distribution functions: The first step is to fit a distribution function to each group comprised of the data values for a specific duration. Random hydrological variables that are extremes, such as maximum rainfall and floods are described by several extremes value distributions (Koutsoyiannis, 2004a; Overeem *et al*., 2008; Huard *et al*., 2009) or often Lognormal distribution (Goula *et al*., 2007; Raiford *et al*., 2007).

For this study, three statistical distributions were retained (Table 2). The empirical probability chosen for this statistical analysis is that of Gringorten (Koutsoyiannis *et al*., 1998). The maximum likelihood method was used to determine distribution parameter of maximum precipitation.

Adequacy testing: There are different methods to compare and select the distribution that best fits a given sample. It is possible to visually examine the quality of the fit between the empirical probability exceedance and a distribution, both plotted on probability paper. However, this method is based only on the judgment of the hydrologist and can be sometimes subjective. For this study, two selection criteria were used, both based on the likelihood function: The Akaike (1974) and the Bayesian (Schwarz, 1978) information criteria, respectively given in Eq. 1 and 2:

$$AIC = -2\log(L) + 2k \tag{1}$$

$$BIC = -2\log(L) + 2k\log(N) \tag{2}$$

where, AIC is the Akaike information criterion; BIC is the Bayesian information criterion; L is the likehood function; k is the number of parameters; N is the sample size.

Equation 1 and 2 both include k the number of parameters. Thus, parsimony is taken into account when selecting the best distribution using these two criteria.

The best fit is the one associated with the smallest BIC and AIC values (Rao and Hamed, 2001). The BIC criterion tends to penalize three parameter distributions more severely than the AIC and sometimes the optimal fitted distribution differs form one criterion to another. In the case of different selections by the AIC and BIC criterion, the distribution identified by the BIC criterion was selected to emphasize parsimony.

Empirical IDF formula: In the third step, the empirical formulas are used to construct the rainfall IDF curves. The least-square method is applied to determine the parameter to empirical IDF equation that is to represent the intensity-duration relationships.

For this present study, Montana equation is used to describe the rainfall intensity-duration relationships. This power-law was used to establish IDF curves for precipitation in West Africa (Puech and Chabi-Gonni, 1984) and in others regions of the world (Koutsoyiannis *et al*., 1998; De Michele and Salvadori, 2005). Montana equation is defined as (Ben-Zvi, 2009):

$$I(T) = a(T)/d^{b(T)} \tag{3}$$

where, I(T) is the rainfall intensity (mm h^{-1}); d is the duration (h); a(T) and b(T) are the constant parameters related to the metrological conditions; T is the return period.

RESULTS AND DISCUSSION

Results

Hypotheses tests: The hypotheses of independence, homogeneity and stationarity were checked respectively using Wald-Wolfowitz, Wilcoxon and Kendall tests. All these tests indicate that these annual maximum intensities series obtained are independent and identically distributed.

Best fitted probability distributions: The Gumbel (EV1) and Lognormal (LN2) distributions are the best models for fitting series. The Gumbel and Lognormal models fit well respectively 48 and 47 annual maximum intensities series. The remaining 9 series were fitted by the Generalized Extreme Value distribution (GEV).

Figure 2a-d show the Gumbel, GEV and Lognormal distributions fitted by Maximum Likelihood method for annual maximum intensities series of four rainfall stations.

The Lognormal and Gumbel distributions have nearly the same asymptotic behavior. Indeed, the Lognormal distribution belongs to the domain of attraction of the Gumbel distribution. This two distribution functions have an exponential asymptotic behavior. Figure 3a-h show the locations of the best fitted distributions. There is geographical area where the distributions are predominant. The Log-Normal and Gumbel are predominant in the North, East and West regions. The Generalized Extreme Value distribution is predominant in central region. There is no distribution that predominates in south Côte d'Ivoire.

Parameters of distribution: The parameters of distributions estimated by Maximum Likelihood method form the annual maximum intensities series of Abidjan, Bouake, Man and Korhogo rainfall stations are shown in

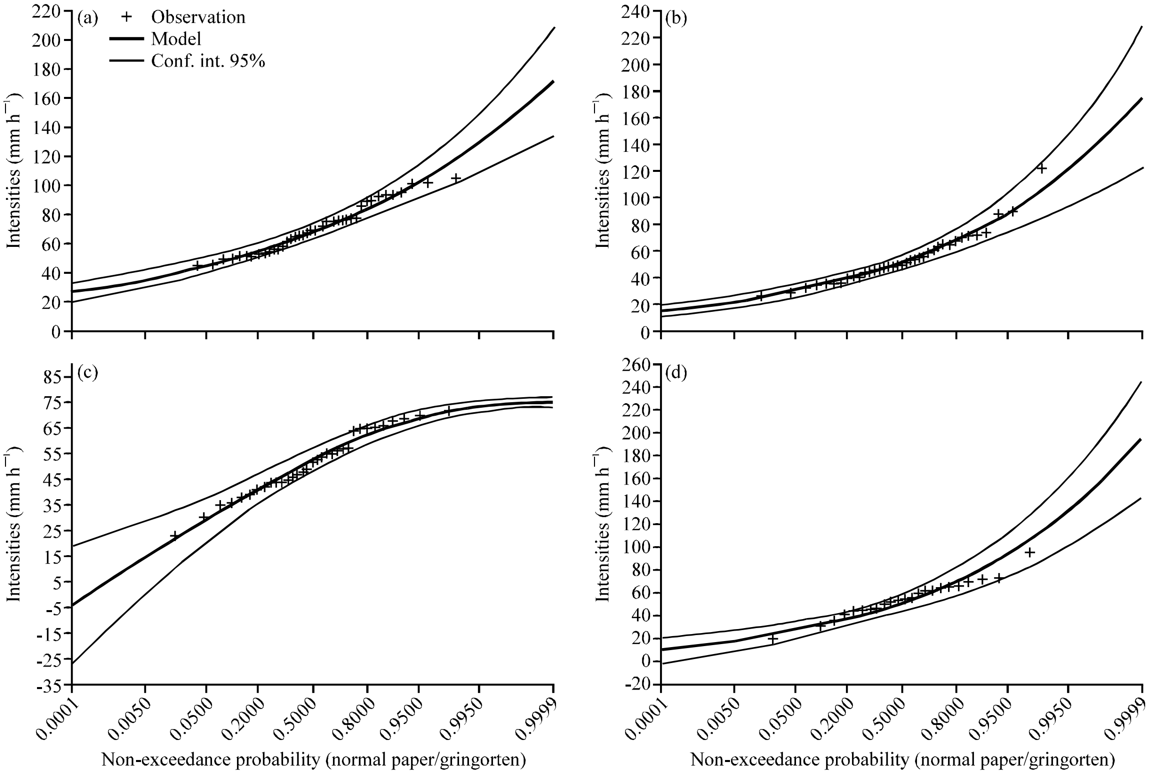

Fig. 2: Log normal, GEV and Gumbel distributions fitted by Maximum Likelihood method for annual maximum intensities rainfall series of Abidjan, Man, Bouake and Korhogo stations (duration 1 h). (a) annual maximum intensities for abidian station fifted with model: Log-normal 2 (Maximum likelihood), (b) annual maximum intensities for Man station fifted with model: Log-normal 2 (Maximum likelihood), (c) annual maximum intensities for bouake station fifted with model: GEV (Maximum likelihood) and (d) annual maximum intensities for Korhogo station fifted with model: Gumbel (Maximum likelihood)

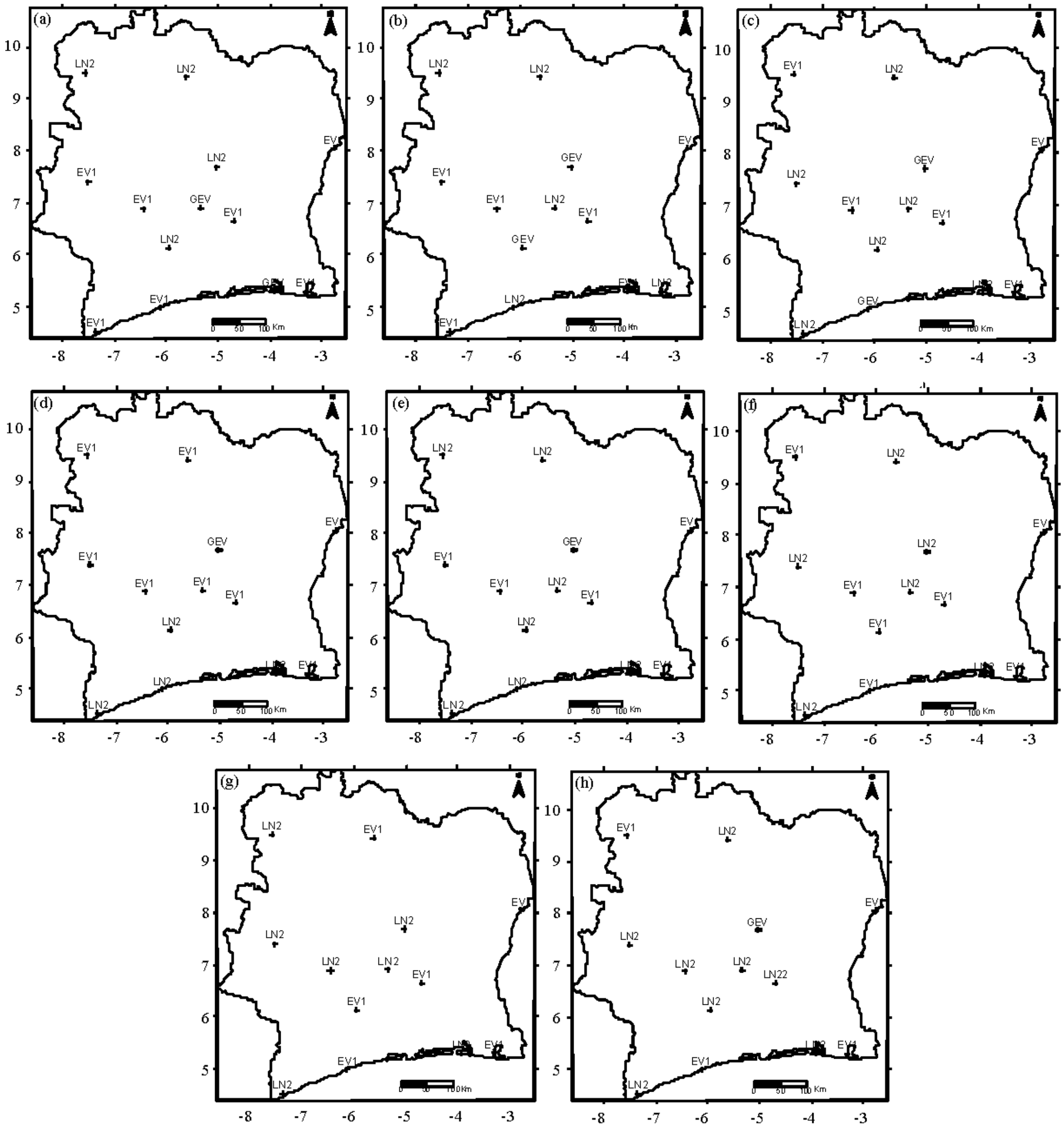

Fig. 3: Locations of the best fitted distributions of (a) 15, (b) 30, (c) 45, (d) 60, (e) 90, (f) 120, (g) 180 and (h) 240 min (EV1: Gumbel distribution; LN2: Log Normal two parameters; GEV: Generalized extreme value distribution)

Table 3. The location parameter (μ) of Lognormal distribution (LN2) decreases with rainfall duration while its scale parameter (σ) increases with the rainfall duration. The value of location parameter varies between 4.79 and 2.73 mm h^{-1}. Its scale parameter fluctuates on average around 0.30 mm h^{-1}. The scale parameter (u) of Gumbel distribution (EV1) varies between 7.91 and 43.18 mm h^{-1}. The location parameter of Generalized Extreme Value distribution (GEV) and its particular case (Gumbel distribution) fluctuates on average around 53 mm h^{-1}. The shape parameter (k) of Generalized Extreme Value distribution describes the type of asymptotic distribution of annual maximum intensities. At Abidjan Station (duration of 15 and 30 min), this shape parameter is negative. These rainfalls of 15 and 30 min duration belong to attraction domain of the Frechet distribution. At

Table 3: The parameters of distributions estimated by Maximum Likelihood method form the annual maximum intensities series of Abidjan, Bouake, Man and Korhogo rainfall stations

		Parameters				
		μ	σ	u	α	
Duration (min)	Distributions	(mm h^{-1})				k (-)
Abidjan						
15	GEV			135.54	32.05	-0.24
30	GEV			116.10	28.00	-0.16
45	EV1			87.94	22.42	
60	LN2	4.38	0.23			
90	LN2	4.21	0.25			
120	LN2	3.93	0.28			
180	LN2	3.74	0.29			
240	LN2	3.42	0.31			
Bouaké						
15	LN2	4.79	0.38			
30	GEV			23.40	77.50	0.31
45	GEV			18.63	60.18	0.58
60	GEV			14.33	47.77	0.47
90	LN	3.54	0.28			
120	LN2	3.30	0.31			
180	LN2	3.04	0.30			
240	GEV			4.12	13.91	0.22
Man						
15	EV1			108.74	43.18	
30	EV1			72.64	25.34	
45	LN2	4.14	0.33			
60	EV1			45.72	14.40	
90	EV1			33.62	10.23	
120	EV1			26.56	7.91	
180	LN2	3.05	0.32			
240	LN2	2.80	0.33			
Korhogo						
15	LN2	4.69	0.21			
30	LN2	4.40	0.28			
45	LN2	4.15	0.31			
60	EV1			45.77	16.31	
90	LN2	3.59	0.33			
120	LN2	3.35	0.35			
180	EV1			17.54	6.86	
240	LN2	2.73	0.37			

Bouake station, the shape parameter is positive, so the rainfalls of 15, 45, 60 and 240 min belong to the domain attraction of the Weibull distribution.

Empirical quantiles: The empirical quantiles estimated from parameters of distributions are shown in Fig. 4a-d. It is observed that the intensities generated (quantiles) decrease with duration and increase with the return period. At Bouake, Korhogo and Man stations, the difference between quantiles of return period 1 year and those associated of recurrence interval 2 years is great. This seems linked to the difficulty of statistical distributions to estimate quantiles of little return period.

Rainfall intensity-duration-frequency relationships: The Intensity-Duration-Frequency (IDF) curves for the precipitation were established using the parameters of Montana model and the results for Abidjan, Bouake, Korhogo and Man stations are displayed in Fig. 5a-d on

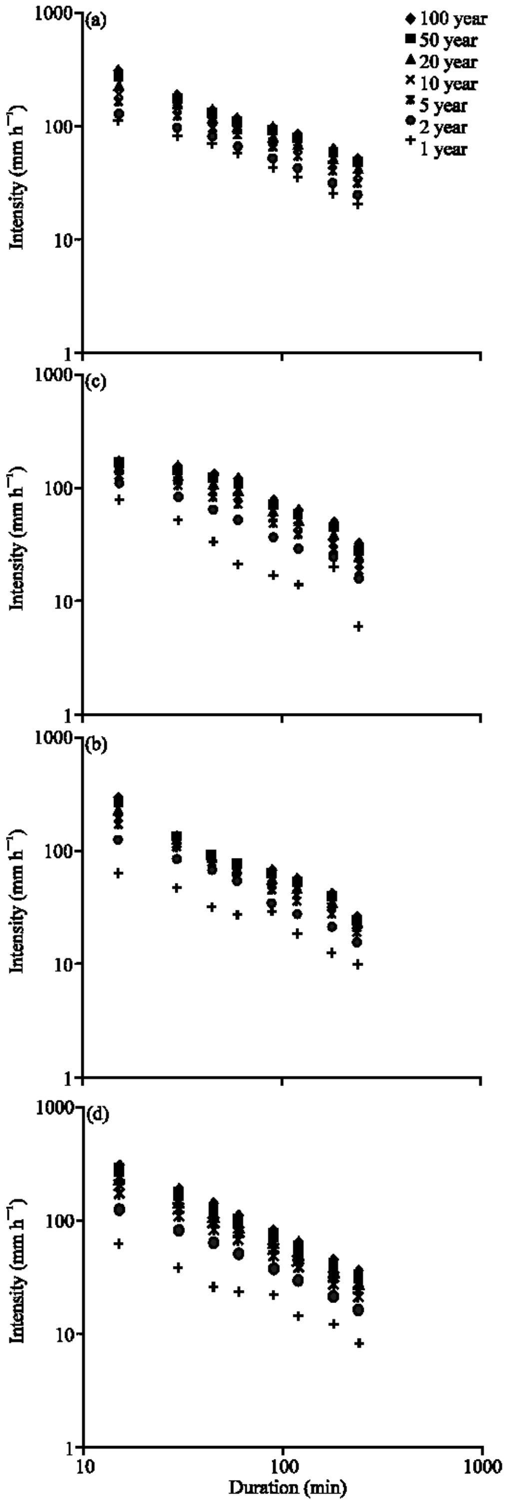

Fig. 4: Maximum rainfall intensities for different time intervals and return periods obtained form the cumulative density function: (a) Abidjan, (b) Bouake, (c) Korhogo and (d) Man

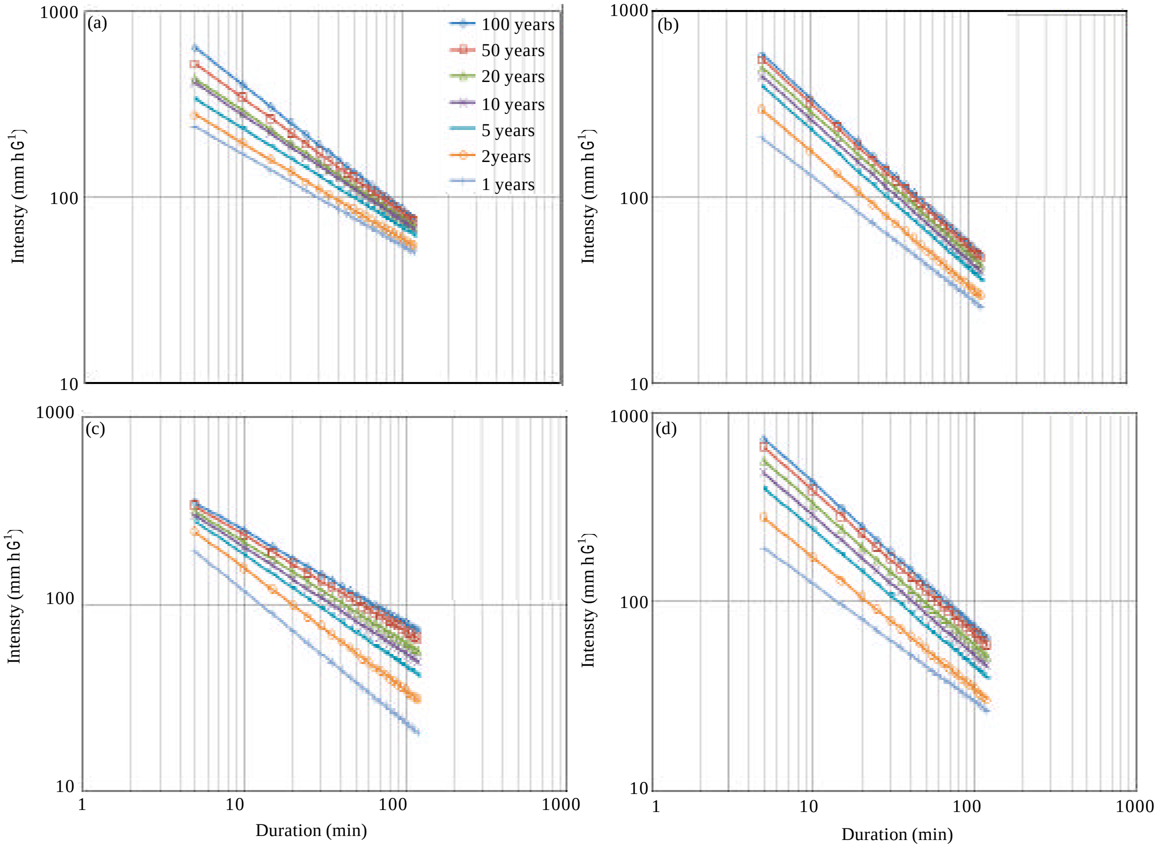

Fig. 5: Intensity-duration-frequency curves for Abidjan (a), Bouake (b), Korhogo (c) and Man (d) rainfall stations on a log-log scale

double logarithmic axes. On double logarithmic axes, the intensity-duration-frequency curves are represented by parallel lines. These curves establish a relationship between the average rainfall intensity (mm h^{-1}), the duration of this rainfall (minutes) and rainfall event frequency (years). Generally, the rainfall intensity decreases with time aggregation and increases with the return period. In addition, there is a separation of intensity-duration-frequency curves when the return period decreases.

Comparison of parameters Montana model: The parameters obtained in this study are widely above those currently used by hydraulic engineers for the design of urban drainage system (Table 4). For 10 years return period, the values of parameter a(T) doubled (Abidjan, Adiake, Bondoukou, Dimbokro, Man, Sassandra stations) or even tripled in some cases (Yamoussoukro station). In terms of relative bias, the gap between the news parameters and the previous parameters vary form 44 to 102% (Fig. 6a, b). As we consider the root mean square error, the differences between the parameters vary form 160 to 370%. For the parameters b(T), the differences between the parameters (news and previous) fluctuates around 0.20 on average.

Table 4: News and previous parameters Montana model for a return period 10 years

	Parameters of Montana model			
	a (mm h^{-1})		b (-)	
Rainfall station	Previous study (DCAD, 1979)	Present study	Previous study (DCAD, 1979)	Present study
Abidjan	460	1026	0.37	0.57
Adiaké	460	1050	0.37	0.59
Bondoukou	532	1227	0.46	0.70
Bouaké	532	1518	0.46	0.76
Dimbokro	532	785	0.46	0.60
Daloa	570	763	0.48	0.63
Gagnoa	570	1143	0.48	0.68
Korhogo	532	736	0.46	0.56
Man	570	1564	0.48	0.74
Odienné	532	608	0.46	0.51
Sassandra	570	1287	0.48	0.64
Tabou	570	729	0.48	0.53
Yamoussoukro	532	1629	0.46	0.82

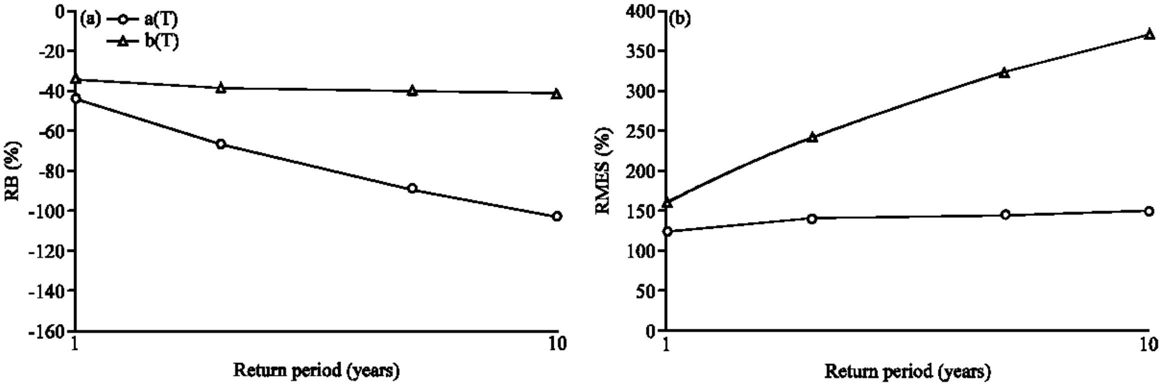

Fig. 6: (a) Relative Bias (RB) and (b) Root Mean Square Error (RMSE) calculated for calculated from the previous parameters (DCAD, 1979) and those of the present study

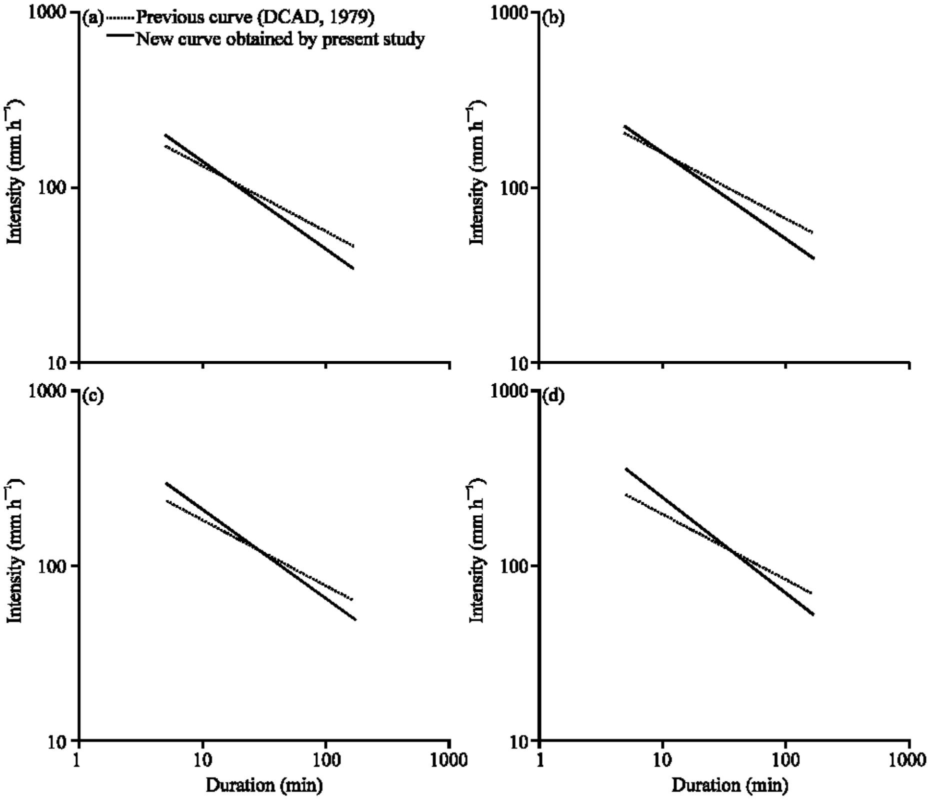

Fig. 7: IDF curves for return periods 1, 2, 5 and 10 years form the technical document (DCAD, 1979) and those of the present study for the Abidjan station on a log-log scale. Return period (a) 1 year, (b) 2 year, (c) 5 year and (d) 10 year

In terms of relative bias, the differences between the parameters vary form 34 to 44%. For the root mean square error, the gap between the parameters varies form 123 to 149%.

Comparison of intensity-duration-frequency curves: The impact of parameters evolution on the Intensity-Duration-Frequency (IDF) curves was analyzed. It finds a significant gap between the IDF curves currently used by hydraulic engineers and those provided by this present study (Fig. 7a-d and 8a-d). The annual maximum intensities of duration lower than 20 min are currently underestimated (Fig. 7, 8). This underestimation of intensities from the IDF curves decreases with the return

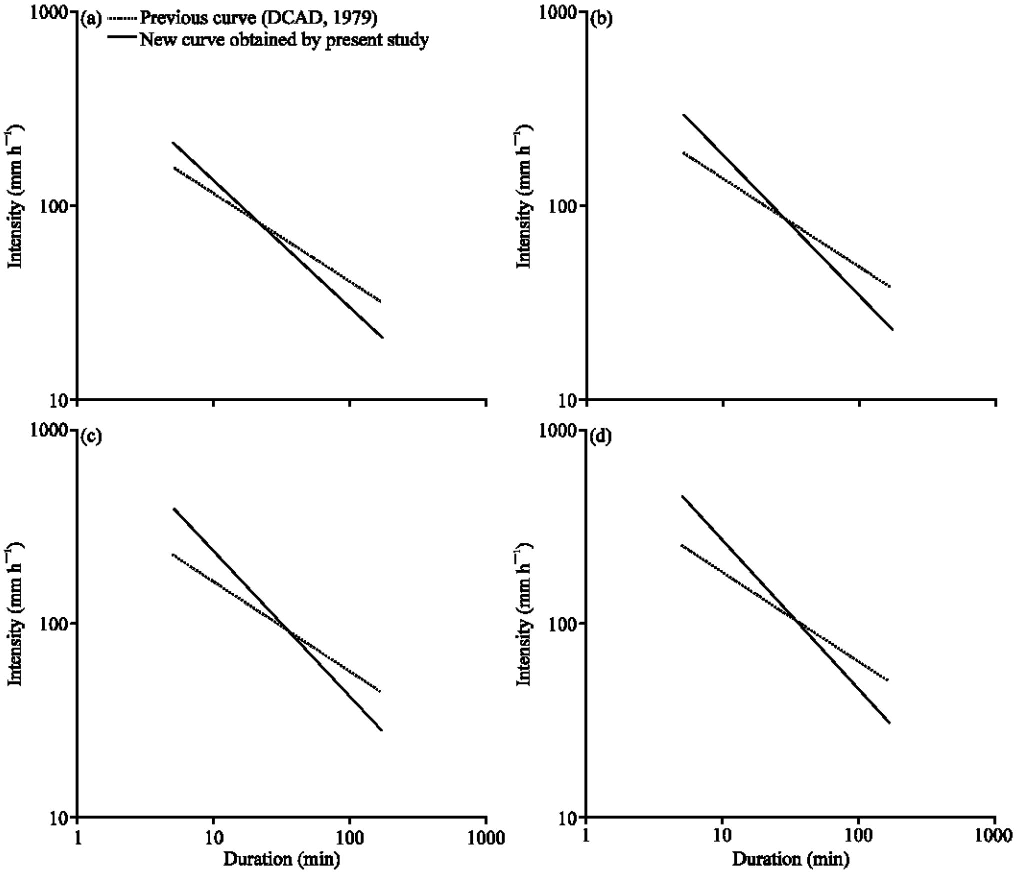

Fig. 8: IDF curves for return periods 1, 2, 5 and 10 years form the technical document (DCAD, 1979) and those of the present study for the Bouake station on a log-log scale. Return period (a) 1 year, (b) 2 year, (c) 5 year and (d) 10 year

period of rainfall. The annual maximum intensities of duration higher than 20 min are currently overestimated. This overestimation is amplified when the return period decreases (Abidjan and Man stations).

DISCUSSION

Distribution function of annual maximum intensities rainfall: The results of this present study show that only 9% the annual maximum intensities series were best fitted by the Generalized Extreme Value distribution (GEV). This distribution function does not seem be appropriate to describe the maximum intensities of Côte d'Ivoire. This inappropriateness of the GEV distribution was observed by Raiford *et al.* (2007) in South and North Georgia (United States). However, other recent studies (Ben-Zvi, 2009; Kigumbi and Mailhot, 2009; Veneziano *et al.*, 2009; Overeem *et al.*, 2008) showed that GEV law well describes the tail of distribution of annual maximum intensities rainfall.

In Côte d'Ivoire, the inappropriateness of the GEV distribution for fitting of annual maximum intensities may be due in part to the comparison criteria (BIC and AIC) used for selection of statistical laws. Indeed, those criteria because of principle of parsimony tend to favor the two-parameter laws (Gumbel and Lognormal distribution).

To this is we can add the difficulty of estimation the Generalized Extreme Value distribution (GEV) law shape parameter (k) when the rainfall series are below 30 years.

The statistical analysis shows that most series are well fit by the Gumbel and the Lognormal distributions. Thus, the majority of annual maximum intensities have a tail that belong the domain attraction of Gumbel. This asymptotic behavior (exponential type) was also observed at the statistical distribution of annual maximum intensities rainfall of short duration of Poland (Twardosz, 2009), North Eastern Algeria (Benabdesselam and Hammar, 2009), Cyprus (Endreny and Pashiardis, 2007) and Yangambi in Congo Kinshasa (Monhymont and Demarée, 2007).

Parameters of Montana model and intensity-duration-frequency curves for precipitation: The parameters of Montana provided by previous study were compared to those obtained in the present study. The analysis shows that these previous parameters are largely outdated. On the 13 synoptic stations used, the parameters have almost doubled and even tripled in some cases. These results converge with those of Kouassi *et al.* (2007) at the Abidjan area.

According to Soro *et al.* (2008) several factors could give plausible explanation the parameters evolution. The sample size is one factor that could explain the parameters evolution. Indeed, annual maximum intensities series used in the present study are higher than those used by the previous study. For example, at Bondoukou station, the previous parameters were obtained by fitting 5 years of rainfall observations (1974-1978) while this present study used 30 years of rainfall observations (1970-2000). Similarly, at Odienne station, the previous parameters (DCAD, 1979) were calibrated with 10 years of data (1969-1978) while this study used 33 years (1969-2001). The small sample size used to estimate the previous parameters has the effect of introducing considerable error during the estimation of extreme quantiles (Puech and Chabi-Gonni, 1984).

Moreover, these authors also suggest caution in using the results of technical document for Bondoukou Dimbokro stations. The previous parameters of those stations were obtained respectively with samples of 5 and 9 years of rainfall observations.

The goodness of fit through the choice of statistical model can also explain the parameters evolution. The parameters currently used by hydraulic engineers have been fitted with quantiles form only the Gumbel distribution. This arbitrary choice of the Gumbel distribution may lead to an underestimation of extreme quantiles. This is confirmed by several studies (Wilks, 1993; Koutsoyiannis, 2004a,b; Muller *et al*., 2008) which reject the prevalence of the Gumbel distribution. These authors affirm that use of Gumbel distribution without reasoning or possible comparison with other models can lead to bad estimation of risk.

The parameters evolution of Montana model has had an impact on the shape of intensity-duration-frequency curves for rainfall. Thus, one noted an underestimation of annual maximum intensities rainfall for duration lower than 20 min and an overestimation for those higher 20 min. In Ghana, Endreny and Imbeah (2009) found that the intensity-duration-frequency curves evolution of Accra and Ho stations was mainly due to the size of the data used.

CONCLUSION

This present study has enabled the updating of intensity-duration-frequency curves for precipitation of Côte d'Ivoire. The statistical analysis shows that most series are well fit by the Gumbel and the Lognormal distributions. The Generalized Extreme Value distribution is quite unlikely to apply to annual maximum intensities rainfall because the sample size used (often below 30 years). This study shows that the parameters of Montana currently used by hydraulic engineers for the design of urban drainage system are largely exceeded.

Indeed, the values of these parameters have almost doubled and even tripled in some stations. This leads inevitably to an underestimation or in some cases an overestimation of project for flow urban drainage system.

ACKNOWLEDGMENTS

Direction of National Meteorology of Côte d'Ivoire is gratefully acknowledged for providing the data rainfall.

REFERENCES

Akaike, H., 1974. A new look at the statistical model identification. IEEE Trans. Automat. Control, 19: 716-723.

Baudez, J.C., C. Loumagne, C. Michel, B. Palagos, V. Gomendy and F. Bartoli, 1999. Modélisation hydrologique et hétérogénéité spatiale des bassins-vers une comparaison de l'approche globale et de l'approche distribuée. Etude et Gestion des Sols, 6: 105-184.

Ben-Zvi, A., 2009. Rainfall intensity-duration-frequency relationship derived from large partial duration series. J. Hydrol., 367: 104-114.

Benabdesselam, T. and Y. Hammar, 2009. Estimation de la Réponse hydrologique d'un bassin versant urbanisé. Eur. J. Scientific Res., 29: 334-348.

Coles, S., L. Perrichi and S. Sisson, 2003. A fully probabilistic approach to extreme rainfall modeling. J. Hydrol., 1: 35-33.

DCAD, 1979. Instructions techniques relatives aux réseaux d'assainissement des agglomérations. Direction de l'eau, Ministère des Travaux Publiques et des Transports, Côte d'Ivoire, pp: 35.

De Michele, C. and G. Salvadori, 2005. Some hydrological applications of small sample estimators of generalized Pareto and extreme value distribution. J. Hydrol., 301: 37-53.

De Toffo, S., A.N. Laghari and W. Rauch, 2009. Are extreme rainfall intensities more frequent? Analysis of trends in rainfall patterns relevant to urban drainage systems. Water Sci. Technol., 59: 1769-1776.

Endreny, T.A. and N. Imbeah, 2009. Generating robust rainfall intensity-duration-frequency estimates with short-record satellite data. J. Hydrol., 371: 182-191.

Endreny, T.A. and S. Pashiardis, 2007. The error and bias of supplementing a short, arid climate, rainfall record with regional vs. global frequency analysis. J. Hydrol., 334: 174-182.

Goula, B.T.A., B. Konan, Y.T. Brou, I. Savané, V. Fadika and B. Srohourou, 2007. Estimation of daily extreme rainfall in a tropical zone: Case study of the Ivory Coast by comparison of Gumbel and Lognormal distributions. Hydrol. Sci. J., 52: 49-67.

Huard, D., A. Mailhot and D. Sophie, 2009. Bayésien estimation of intensity-duration-frequency curves and the return period associated to a given rainfall event. Stoch. Environ. Res. Risk Assess., 23: 1-7.

IPCC, 2001. Climate Change 2001: The Scientific Basis. In: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Houghton, J.T. (Eds.). Cambridge University Press, New York pp: 881.

Kendall, M.G., 1975. Rank Correlation Methods. Griffin Publishers, London, pp: 202.

Kigumbi, A. and A. Mailhot, 2009. Intensity-Duration-Frequency curves (IDF): Comparison of the estimators of the partial durations and the annual maxima. Hydrol. Sci. J., (In Press).

Kouassi, D., M. Diomandé, C. Guéladio, M. Tanner and J. Biémi, 2007. Improving urban drainage in Abidjan, Côte d'Ivoire. Afr. J. Sci. Technol., 8: 8-16.

Koutsoyiannis D., 2004a. Statistics of estimation of extreme rainfall I. Theoretical of investigation. Hydrol. Sci. J., 49: 575-590.

Koutsoyiannis, D., 2004b. Statistics of extremes and estimation of extreme rainfall: II. Empirical investigation of long rainfall records. Hydrol. Sci. J., 49: 591-610.

Koutsoyiannis, D., D. Kozonis and A. Manetas, 1998. A mathematical framework of studying rainfall intensity-duration-frequency relationships. J. Hydrol., 206: 118-135.

Monhymont, B. and G.R. Demarée, 2007. Intensity-Duration-frequency curves for precipitation at Yangambi, Congo, derived by means of various models of Montana type. Hydrol. Sci. J., 51: 239-253.

Muller, A., J.N. Bacro and M. Lang, 2008. Bayesian comparison of different rainfall depth-duration-frequency relationship. Stoch. Environ. Res. Risk. Assess., 22: 33-36.

Muller, A., P. Arnaud, M. Lang and J. Lavabre, 2009. Uncertainties of extreme rainfall quantiles estimated by a stochastic rainfall model and by a generalized Pareto distribution. Hydrol. Sci. J., 54: 417-429.

Nhat, L.M., Y. Tachikawa and K. Takara, 2006. Establishment of intensity-duration-frequency curves for precipitation in the monsoon area of Vietnam. Ann. Dis. Prev. Res. Inst., 49: 93-102.

Overeem, A., A. Buishand and I. Holleman, 2008. Rainfall depth-duration-frequency curves and their uncertainties. J. Hydrol., 348: 124-134.

Oyebande, L., 1982. Deriving rainfall intensity-duration-frequency relationships and estimates for regions with inadequate data. Hydrol. Sci. J., 27: 353-367.

Puech, C. and D. Chabi-Gonni, 1984. Rainfall depths-duration-frequency curves for precipitation of duration 5 minutes at 24 hours. Hydrological series, (CIEH), Ouagadougou, Burkina Faso, pp: 155.

Raiford, J.P., N.M. Aziz, A.A. Khan and D.N. Powell, 2007. Rainfall Depth-Duration-Frequency for South Caroline, North Carolina and Georgia. Am. J. Environ. Sci., 3: 78-84.

Rao, A.R. and K.H. Hamed, 2001. Flood Frequency Analysis. CRC Press, New York, United States, pp: 350.

Schwarz, G., 1978. Estimating the dimension of a model. Ann. Stat., 6: 461-464.

Segond, M.L., N. Neokleous, C. Makropoulos, C. Onof and C. Maksimovic, 2007. Simulation and spatio-temporal disaggregation of multi-site rainfall data for urban drainage applications. Hydrol. Sci. J., 52: 917-935.

Soro, G.E., B.T.A. Goula, F.W. Kouassi, K. Koffi and B. Kamagaté *et al*., 2008. Courbes Intensité Durée Fréquence des Précipitations en climat tropical humide: Cas de la région d'Abidjan (Côte D'Ivoire). Eur. J. Scientific Res., 21: 394-405.

Twardosz, R., 2009. Probabilistic model of maximum precipitation depths for Krakow (Southern Poland, 1886-2002). Theor. Appl. Climatol., 98: 37-45.

Veneziano, D., A. Langousis and C. Lepore, 2009. New asymptotic and preasymptotic results on rainfall maxima from multifractal theory. Water Resour. Res., 45: W11421-W11421.

Wald, A. and J. Wolfowitz, 1943. An exact test for randomness in the non parametric case based on serial correlation. Ann. Math. Stat., 14: 378-388.

Wang, W., X. Chen, P. Shi and P.H.A.J.M. Van Gelder, 2008. Detecting changes in extreme precipitation and extreme streamflow in the Dongjiang River Basin in Southern China. Hydrol. Earth Syst. Sci., 12: 207-221.

Wilcoxon, F., 1945. Individual comparisons by ranking methods. Biometr. Bull., 1: 80-83.

Wilks, D.S., 1993. Comparison of three-parameter probability distributions for representing annual extreme and partial duration precipitation series. Water Resour. Res., 29: 3543-3549.

Yue, S. and P. Pilon, 2004. A comparison of the test t-test, Mann-Kendall and bootstrap test for trend detection. Hydrol. Sci. J., 49: 21-37.