

## IMPROVING URBAN DRAINAGE IN ABIDJAN, CÔTE D'IVOIRE

Kouassi Dongo<sup>1,2\*</sup>, Métangbo Diomandé<sup>2</sup>, Guéladio Cissé<sup>1</sup>, Marcel Tanner<sup>3</sup> and Jean Biémi<sup>2</sup>

<sup>1</sup>Centre Suisse de Recherches Scientifiques en Côte d'Ivoire (CSRS),  
01 BP 1303, Abidjan 01, Côte d'Ivoire

Kouassi.dongo@csrs.ci; k\_dongo@yahoo.fr;

<sup>2</sup>UFR –STRM, Laboratoire des Sciences et Techniques de l'Eau et de  
l'Environnement (LSTE) Université de Cocody-Abidjan,  
22 BP 801 Abidjan 22, Côte d'Ivoire

<sup>3</sup>Swiss Tropical Institute (STI), University of Basel,  
Socinstrasse 57, C.P., CH-4002 Basel (Switzerland)

**ABSTRACT:-** Tropical humid climates of sub-Saharan Africa with a high level of variability build a challenge for hygienic models used in urban drainage. Global models of urban drainage used in this region – for example the Caquot's rate-of-flow model – are based on the parameters of Montana's rain model. This model indicates the evolution of the maximum rainfall intensity according to the duration and the return period. In Côte d'Ivoire, several studies highlighted that adapting Montana's rain model is not satisfactory for particular time slots, which in turn affects urban drainage calculations. This work aims at optimising and designing models which best simulate tropical downpours and improving calculations related to urban drainage in Abidjan and in other urban settings with similar climatic conditions. Various statistical processing undertaken showed that the rainfall distribution in the area of Abidjan is in line with the laws of Gumbel (10 – 30 mn rainfall) and Galton (45 – 240 mn rainfall). Including the data in mathematical conversion formulas made it possible to optimise Montana's parameters and to design a new model that best simulates downpours in Abidjan. In addition, analysis of the Nicholson index revealed a drop in rainfall in Abidjan with a cyclical evolution ( about 17 year period), alternating dry, normal and wet periods. The new model is relevant since it overlaps two very satisfactory models and could be used to improve urban drainage calculations in Abidjan and similar climatic conditions.

**Keywords** Abidjan; climatic variability; Montana's model; sub-Saharan African tropical wet region; urban drainage

### INTRODUCTION

Converting rainfall into drainage flow rate is one of the major difficulties faced by hydrologists, city planners and drainage experts in urban centers (Afouda, 1980).

The importance of the city of Abidjan, firstly to Côte d'Ivoire and then to the West African sub-region, considerably increased during recent decades. As a trade and business centre in West Africa (Dongo, 2001), Abidjan has become an international economic transit point. The rapid urbanization (42.5%) of the city (INS, 2000) and the lack of an adequate drainage system coupled with variations in the hydrological cycle relating to an insufficiency of urban infrastructures, favour the stagnation of rainwater and floods in Abidjan.

The atmospheric precipitations (1800 mm/year) with exceptional rainfalls (heavy and continuous) are so high that the absence of an adequate urban drainage system results not only in temporary floodings but also in the destruction of roads and dwellings (Paquier et al, 2003). Modelling the hydrological behaviour of drainage basins is very important for solving problems related to the evaluation and optimal management of water resources (Touazi and Laborde, 2004). Inadequate wastewater and stormwater management results in poor public health, loss of economic productivity and environmental degradation particularly in complex humid environment (Giraud et al, 1997). Since 1995, several districts of Abidjan have suffered a series of floods and grounds instability which had very serious socio-economic consequences (Boyossoro, 2001). As an example, in 1998, flooding accompanied by a

landslide due to heavy and continuous rainfall resulted in the loss of human lives (5 deaths) and several injuries in the district of Abobo. Flood risk mitigation requires a good knowledge of hydrological flood regime (Javelle et al, 2000).

These facts raise anxiety within the population and are of concern to both the administrative authorities as well as researchers. It therefore becomes urgent to propose measures capable of preventing such consequences and establishing a drainage program which makes it possible to create harmony between man and the complex system, which makes up his physical, natural environment. However, the success of any action in this area depends on the availability of sufficient information, which allows the consequent application of statistical and probabilistic methods. In sub-Saharan Africa and especially in Côte d'Ivoire, the hygienic concept of rainfall drainage most often used in urban drainage is faced with a certain number of constraints: (i) the Montana's rainfall model is not satisfactory (Puech and Gonni in 1984) and underestimates the intensity of rainfalls, (ii) the Caquot's rate-of-flow model used in urban drainage, includes this Montana's model, and (iii) adapting parameters of these models to tropical realities was based on the analysis of a limited amount of data from limited areas for a short observation period. A study aimed at bringing these models up to date deserves being carried out in order to allow them to be optimally used for urban drainage. This work aims at optimizing and designing models, which best simulate tropical precipitations and help in calculations for urban drainage in Abidjan and elsewhere.

Data from a long series of pluviometric observations will be included in a statistical and stochastic procedure at various levels. Climatic variability in the area will be evaluated by analysing Nicholson index. After optimizing Montana's parameters, which are currently used in pluviometric simulation, we'll try to propose a rainfall model which takes into account climatic variability in the area.

## METHODS

### The Montana's rainfall model and its application

Research on the estimation of extreme precipitation events is currently expanding (St-Hilaire et al, 2003). Achievements carried out in the field of pluviometric modelling use several models including selective models involving isolated events (Morel, 1996). IDF Curves show the evolution of the maximum intensity ( $I_{\max}$ ) of rain in its natural state. Montana's formula is in line with this underlying principle for the simulation of rainfall dynamics by the relationship

between "t" (the time during which the intensity  $I_{\max}$  is reached on the average), "T" (rainfall return period), "a(T)" and "b(T)" (coefficients of adjustment):

$$I_{\max}(T; t) = a(T) \times t^{-b(T)} \quad (1)$$

Thus, for a given area, Montana's equation is reliable for the parameters a(T) and b(T) evaluated under satisfactory statistical conditions. In the drainage projects of the city of Abidjan, the parameters used are those defined by the Department of Water of the Ministry of public works and Transport (Ministère des travaux publics et des transports de Côte d'Ivoire, 1986). Some researchers (Sigomnou and Desbordes, 1988) tried to find out models to simulate rainfall dynamic in Côte d'Ivoire. All these values were obtained from short-term simulations.

The major advantage of Montana's formula is that it can easily be represented on a graph. This is of great interest to drainage experts when it comes to estimating the intensity of rainfall. However, the parameters a(T) and b(T) greatly depend on the quality of the recording of the variable "rain", the size of the sample of the data collected, the geographical nature of their recordings and the climatic particularity of the area of data collection. Applying such a relationship to other zones can thus lead to false conclusions (OMS, 1983). Montana's formula is applied in the Caquot's rate-of-flow forecast model where it comes in as essential input data. The literal expression of the rate of flow from an urbanised sloppy basin for a given frequency "F" established by Caquot's work is in the following form between " $Q_{\max}(t)$ " (the maximum rate of flow at the mouth of the basin), "A" (the surface area), "I" (the average slope), "Cr" (the runoff percentage),  $\beta + \lambda$  (the storage and crest lowering effect):

$$Q_{\max}(T; t) = \frac{10^3 C_r A^{1-\varepsilon}}{6(\beta + \lambda)} \times a(T) \times t^{-b(T)} \quad (2)$$

The tests of Caquot's model's adaptation to tropical realities (Lemoine and Cruette, 1974) show that the numerical coefficient used in formula (2) vary from one basin to another. However, these shortcomings should not make us to lose sight of the importance of the parameters a(T) and b(T) because in formula (2) the various parameters are functions of a(T) and or b(T) which are themselves parameters in Montana's formula. This is therefore logical, as we seek to find solutions aimed at correcting the existing shortcomings, to carry out the optimization of these models which are still used in humid tropical environment and singularly in Abidjan.

## Process of optimizing the models

### *Climatic variability analysis methods*

Climatic variability at Abidjan Weather Station was studied by NICHOLSON pluvial index method and statistical analysis of rainfall data. Data used were provided by SODEXAM (Airport and Weather Exploitation and Development Company) and cover a 65-year period (1936-2000). This station, the only to have constant data covering a long period of observation, was considered to be representative of the Abidjan area. Moreover, the observation period (65 years) easily meets the requirements of WMO (World Meteorology Organization) directives which recommend an observation period of at least 30 years. Abidjan station pluviometric fluctuations were calculated based on the Nicholson relationship between “ $i$ ” (Nicholson index), “ $R_{ij}$ ” (the total rainfall level for a season  $i$  and a year  $j$ ); “ $R_{im}$ ” (the average annual rainfall of the season  $i$  during the duration of recording); “ $\sigma$ ” (the standard fluctuation in annual rainfall):

$$I_p = \frac{R_{ij} - R_{im}}{\sigma} \quad (3)$$

The average rainfall for each decade of the observation period was then used to assess the long term variability of rainfall in Abidjan area.

### *Optimizing the models*

When local information on streamflows is insufficient for estimating flood quantiles, a regional flood frequency analysis is usually carried out (Mic et al 2002). In the same way, in the absence of several stations of measures, data from Abidjan-airport station are used to be representative for the whole Abidjan region. The optimization process consists of a series of statistical processing of rainfall data collected at Abidjan Station. This process begins with the examination of available pluviometric diagrams from the 1958-2001 period for a span of time of 10, 15, 30, 45, 60, 90, 120, 180 and 240 mn. The operation consists in finding the maximum rainfall intensities or rare events (Garrido, 2002) from the diagrams (pluviometers) for the various time spaces on each graph for the year considered. Of all rainfall level values obtained, the highest value is selected (statistics of placement). The process is repeated for the specified time spaces and for each year of the observation period. Data (rainfall level) obtained are converted into rainfall intensity based on the following formula between “ $i$ ” (rainfall intensity), “ $H$ ” (rainfall level), “ $t$ ” (duration of rainfall):

$$i = \frac{H}{t} \quad (4)$$

and recorded in a table.

Examining the data is a delicate task which requires dexterity on the part of the operator in order to have accurate data. A quality control also consisted in an examination of the rainfall data by two different operators. Differences in results are re-examined and corrected after comparison. The second stage consists in determining the statistical distribution law of the variables. The data are thus subjected to the most commonly used statistical distribution laws in urban hydrology (Gumbel, Galton and Pearson III). Two statistical fit tests (Kolmogorov and Cramer) believed to be “more powerful” were then applied in order to evaluate the law(s) which best simulate(s) the distribution of the variables. The Kolmogorov test takes into account all the “fractiles” and consists in measuring the difference between the exact distribution function and the empirical distribution function and comparing it to an “acceptable” value. Cramer-Von Mises’ test also aims at determining the law which best expresses the parent population of which the sample is a priori representative. The difference between the two tests is in the fact that the Kolmogorov’s test is more sensitive to the existence of aberrant points in the sample than that of Cramer-Von Mises. The intensity values obtained from the distribution laws applied are included in mathematical simulations. The Excel software is used to create this simulation and the values of correlation are used as indicators for measuring the accuracy of the simulation.

## RESULTS

### **Climatic variability analysis by the Nicholson and statistical methods**

Calculating Nicholson index made it possible to evaluate the various climatic fluctuations from 1936 to 2000 and to determine a normal, a wet and two dry periods (Figure 1).

From 1966 to 1982, regarded as a normal period, the fluctuation tends to be balanced on both sides of the axis. This phenomenon is observed not only by means of the Nicholson indexes variation graphs but also by the fact that approximately 53% of rainfall totals are higher than the average, which is 1910 mm. This normal period experienced a few short dry periods, the most serious being between 1968 and 1973. From 1983 to 2000, more than 89% of the rainfall totals remain lower than the average, confirming the existence of the second dry period.

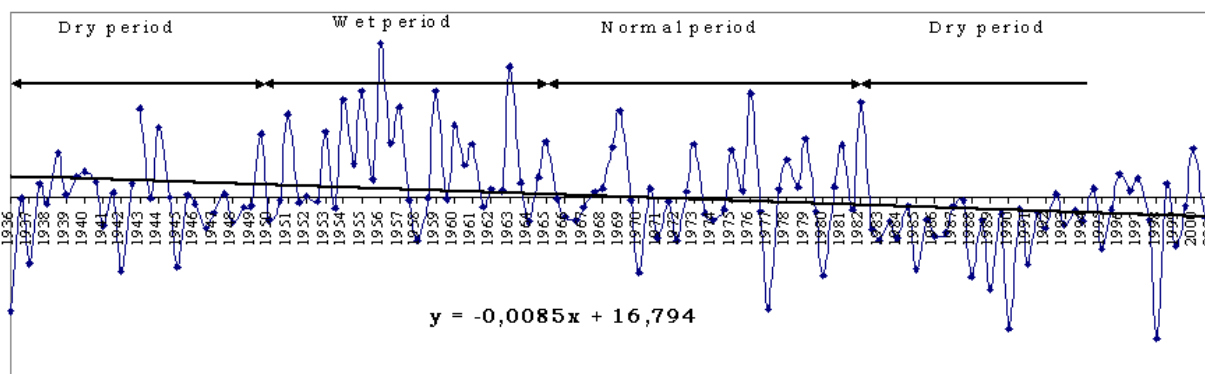


Figure 1: Variation of Nicholson index (rainfall data from 1936 to 2000)

By establishing a correlation between this graph and the major droughts of West Africa, it can easily be noticed that those of 1947-1953, 1968-1973 and 1982-1984 mentioned by Biémi (1992) can be seen. Abidjan Station is thus well included in the major fluctuations of the West African climate. In addition, the pluvial phenomenon chronological evolution in Abidjan is similar to that of a cyclical phenomenon of an estimated period of 16 years.

The importance of the climatic variability in Abidjan is also highlighted by the analysis of the difference between

the annual rainfall average by decade and the inter-annual rainfall average (1910mm) of the observation period (Figure 2).

There is a high variability between average decennial rainfalls. As recent studies mentioned it, no single conclusion is valid concerning fluctuations of rainfall in Abidjan area (Biot et al, 2005). For example, averages decennial rainfall for the decades 1941 to 1951 and 1971 to 1980, are about the same, but both are far less than the averages rainfall for 1951 to 1960 and 1981 to 1990 period.

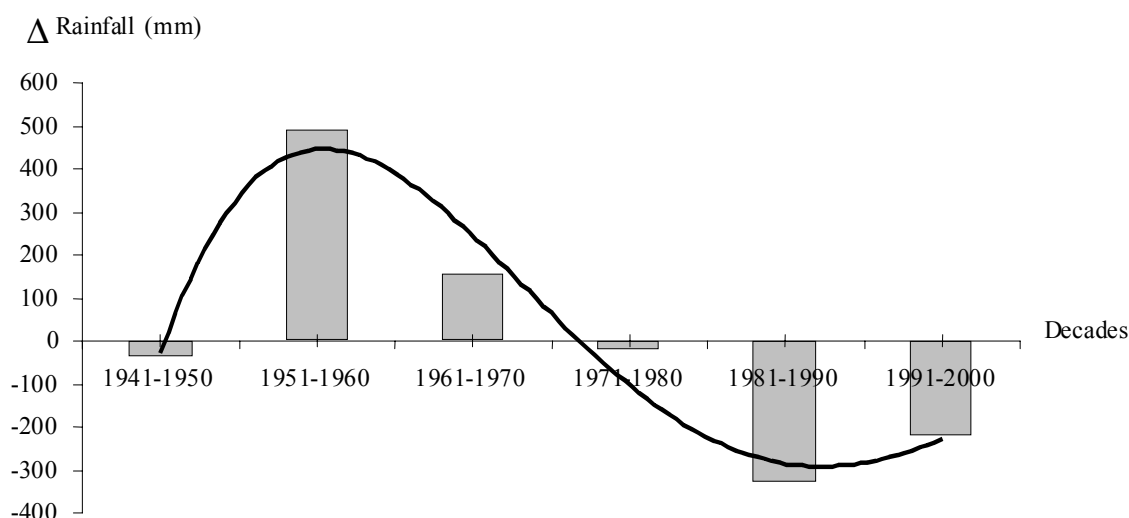


Figure 2: Relationship between average of decennial rainfall and the average of the rainfall of the observation period

**Optimizing Montana’s rainfall model parameters**

Examining the Abidjan Station diagrams made it possible to isolate the maximum rainfall levels. The intensity records studied for various time periods show that a heavy and continuous rain that fell in the Abidjan area on June 14, 1961 has never reoccurred up to the present (Table1).

**Table1. Rainfall variables observed at the Abidjan-Airport weather Station from1958 to 2001**

| Duration (mn) | Intensity (mm/h) | Date            |
|---------------|------------------|-----------------|
| 10            | 336              | June 22 ,1971   |
| 15            | 316.4            | 16-Oct-73       |
| 30            | 202              | October 16,1973 |
| 45            | 136              | 21-May-69       |
| 60            | 104              | 14-Jun-61       |
| 90            | 86.67            | 14-Jun-61       |
| 120           | 78               | 14-Jun-61       |
| 180           | 61               | 14-Jun-61       |
| 240           | 47.13            | 14-Jun-61       |

During the observation period (1958-2001), the highest rainfall can be observed in the last quarter of the dry year of 1973, thus confirming the intense character of the

periods of precipitation, which come after the dry periods in the Abidjan area.

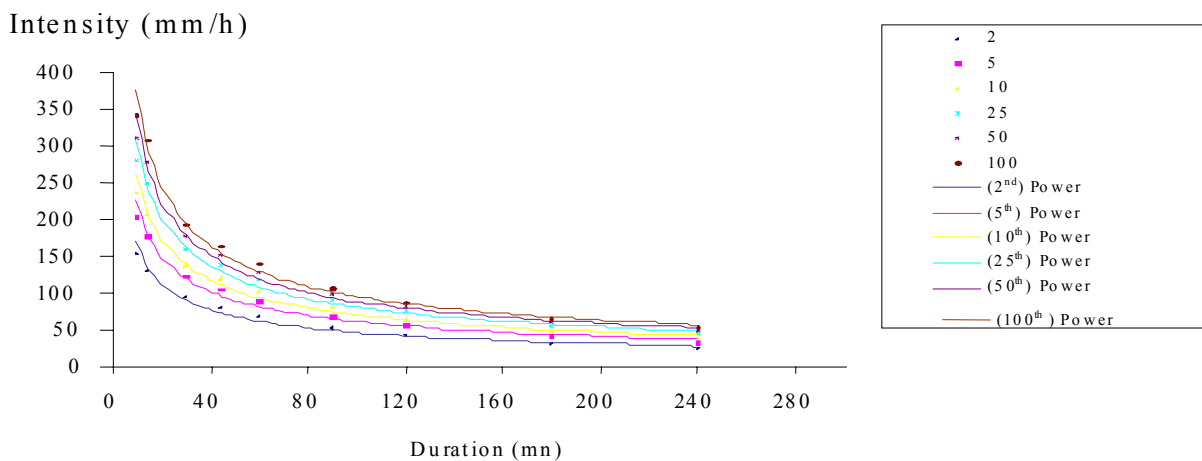
Rainfall data obtained from studies and taken into consideration in the various statistical processing show that short rainfalls (10-30 mn) preferentially obey the Gumbel law while the distribution of long downpours is more connected with Galton law (45-240 mn). Rainfall intensities were therefore estimated based on selected distribution laws. Two groups of curves indicating the distribution of rainfall intensities based respectively on the duration of the downpour and the return period were drawn thanks to the Excel spreadsheet (Figure 3 and 4).

Mathematical adapting of the first group of curves (Figure 3) leads to formulas of exponential (“power”) functions. Such variable dynamics leads to a simulation by means of the common formula given by Réménéras in 1986 between “ $i_M$ ” (rainfall intensity), “ $a(T)$ ”, “ $\alpha$ ” and “ $b(T)$ ” (constants), “ $t$ ” (rainfall duration):

$$i_M = a(T)(t - \alpha)^{-b(T)} \tag{5}$$

Thus, when  $\alpha$  takes the value 0, then equation (5) becomes the Montana formula:

$$i_M = a(T)t^{-b(T)} \tag{6}$$



**Figure 3. Evolution of rainfall intensity (I) with respect to the duration of downpours (t) in Abidjan**

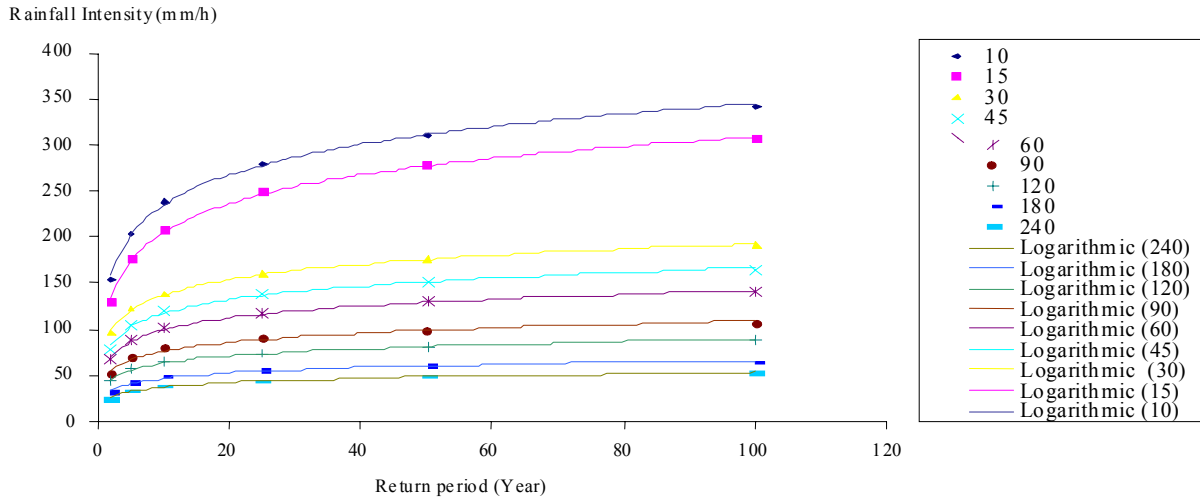


Figure 4.: Evolution of rainfall intensity (I) with respect to the return period (T) in Abidjan

Adjusting the distribution to the trend curves on the Excel spreadsheet makes it possible to determine the values of Montana’s parameters  $a(T)$  and  $b(T)$  (Table 2).

Table 2. Montana’s model Parameters  $a(T)$  and  $b(T)$  for the Abidjan area

| Return period | $a(T)$ | $b(T)$ |
|---------------|--------|--------|
| 100 years     | 1492   | 0.6    |
| 50 years      | 1334   | 0.59   |
| 25 years      | 1181   | 0.58   |
| 10 years      | 982    | 0.57   |
| 5 years       | 835    | 0.57   |
| 2 years       | 628    | 0.57   |

Mathematical adapting of the second group of curves (Figure 4) has to do with logarithmic (Napierian) functions expressed between “ $i_M$ ” (rainfall intensity), “ $a(T)$ ”, “ $\alpha$ ” and “ $b(T)$ ” (constants), “ $t$ ” (rainfall duration) as:

$$i_M = a_T \ln(T) + b_T \tag{7}$$

In addition, a comparative study of the two formulas reveals that the Napierian model explicitly uses the return period “ $T$ ” in its expression while the Montana’s model rather uses the downpour duration “ $t$ ”. This relevant remark led to searching for an overlapping model which takes into account the return period as well as the downpour duration. This led to expressing the Napierian formula constant “ $a_T$ ” and “ $b_T$ ” with respect to the downpour duration “ $t$ ”, by means of the Excel spreadsheet once again. This gives:

$$a_T = kt^w \tag{8}$$

and

$$b_T = \phi t^v \tag{9}$$

and we deduce from these, that:

$$i_M = \kappa t_c^\omega \ln(T) + \phi t_c^v \tag{10}$$

$i_M$  is the maximal intensity,  $\kappa t_c^\omega$  and  $\phi t_c^v$  are constants, ( $T$ ) is return period. The values of the parameters of this new model (formula 10) are contained in the Table 3 below.

Table 3. Parameters of the overlapping formula

| Duration (mn) | [10-15] | [15-30] | [30-45] | [45-60] | [60-90] | [90-120] | [120-180] | [180-240] |
|---------------|---------|---------|---------|---------|---------|----------|-----------|-----------|
| $\bar{K}$     | 68      | 486     | 75      | 178     | 260     | 310      | 405       | 484       |
| $\omega$      | -0.15   | -0.88   | -0.329  | -0.55   | -0.65   | -0.69    | -0.74     | -0.78     |
| $\phi$        | 386     | 254     | 344.67  | 573     | 839     | 903      | 1430      | 1510      |
| $v$           | -0.48   | -0.33   | -0.425  | -0.55   | -0.65   | -0.66    | -0.76     | -0.77     |

## DISCUSSION

The originality of this work lies in fact that values characteristic and largely representative of the area of study were taken into account. The advantages of Caquot's model which includes Montana's model have already been discussed elsewhere (Réméniéras, 1972; Lémoiné and Cruette, 1974; Cruette, 1975; Ikounga, 1976 in Afouda, 1978; Desbordes, 1987). The following discussion concerns the relevance of the results in comparison to the methodology and data used.

Firstly, it can be noted that the parameters  $a(T)$  and  $b(T)$  of Montana's model were estimated according to a methodology involving data specific to the area of study. It is therefore evident that these estimates differ from those generally used in urban drainage in the Abidjan area. A comparison between the values of  $a(T)$  and  $b(T)$  obtained within the framework of this work and those generally used in calculations relating to urban drainage (Table 4), reveals that the adaptation in use underestimates rainfall intensity in the Abidjan area. In actual fact, this current adaptation was realised on the basis of data collected over short observation periods, whereas such an approach is not satisfactory from the representative point of view (OMM, 1983) and does not take into account climatic variability in the area.

**Table 4. Comparison of the parameters  $a(T)$  and  $b(T)$  of Montana's model**

| Return period | Parameters currently used in Abidjan area |        | Optimized parameters for Abidjan area |        |
|---------------|---|--------|---------------------------------------|--------|
|               | $a(T)$                                    | $b(T)$ | $a(T)$                                | $b(T)$ |
| 50 years      | -   | -      | 1334                                  | -0.59  |
| 25 years      | -   | -      | 1181                                  | -0.58  |
| 10 years      | 460                                       | -0.37  | 982                                   | -0.57  |
| 5 years       | 418                                       | -0.37  | 835                                   | -0.57  |
| 2 years       | 365                                       | -0.37  | 628                                   | -0.57  |
| 1 year        | 310                                       | -0.37  | -                                     | -      |

Moreover, desiring a more effective rainfall dynamics evaluation in the Abidjan area led to working out a new rainfall model. This new formula (equation 10) best simulates rainfall dynamics in the Abidjan area. Actually, it was designed from involving two important factors of the pluvial phenomenon: the duration ( $t$ ) and the return period ( $T$ ) and imply four parameters allowing it to give reliably account of the rainfall dynamics. This model thus, simulates the rainfall with a very good correlation, very close to 1 (Table 5).

**Table 5. Coefficients of correlation values of different return periods**

| Return period (T) | Coefficient of determination $R^2$ |         |          |          |          |           |
|-------------------|------------------------------------|---------|----------|----------|----------|-----------|
|                   | 2 years                            | 5 years | 10 years | 25 years | 50 years | 100 years |
| Montana's Model   | 0.9842                             | 0.9855  | 0.9866   | 0.9882   | 0.9893   | 0.9903    |
| Overlapping model | 0.9998                             | 0.9999  | 0.9999   | 0.9999   | 1.0000   | 0.9999    |

## CONCLUSION

Rainwater is vital for life and for many human activities. The problem of converting rainfall which falls onto a sloppy basin into drainage flow rate, measured at its outlet, continues to be at the center of the concerns of the hydrologists when it comes to urban drainage management.

In African cities and particularly in humid tropical environment, Montana (rainfall) and Caquot (rate-of-flow) models commonly used are very often faced with constraints when it comes to adapting to tropical realities.

Thus, floods and erosions continue to considerably affect the population and the urban economy.

In this study, climatic variability in Abidjan area has been studied based on data from 1936 to 2001. This investigation reveals that Abidjan region is submitted to an important fluctuation of rainfall.

Montana's model parameters were then optimized for the Abidjan area. This optimization which was done on the basis of statistical processing involving rainfall data collected after a long series of observations, made it possible to realize that the current adaptation of Montana's

model in use in the Abidjan area is not satisfactory and underestimates intensity rainfall. In addition, a new overlapping model which best simulates the dynamics of downpours in Abidjan was designed and its parameters optimised.

Though apparently theoretical, the proposed model is inspired by observations carried out on two important parameters of the pluviometric phenomenon; in particular the duration (t) of downpour and its return period (T). The discussion already indicates that this model is relevant since it links two formulas which are already considered to be satisfactory. The implementation of these results and effects on urban drainage in Abidjan would be interesting for evaluating the suggested model.

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#### REFERENCES

- Afouda A. A., (1978): A unified approach to watershed modelling. *Nordic hydrology*, vol. 9 161p.
- Afouda, A. A.,(1980) : théorie de modèles de transformation pluie-débit en milieu semi urbain, Chiers ORSTOM, série hydrologie, volume XII, n° 2, 90p.
- Biémi J., (1992): Contribution à l'étude géologique, hydrogéologique et par télédétection des bassins versants subsahariens du socle précambrien d'Afrique de l'Ouest : Hydrostructurale, Hydrodynamique, Hydrochimie et Isotopie des aquifères discontinus de sillons et aires granitiques de la Haute Marahoué (Côte d'Ivoire). *Thèse de Doctorat d'Etat ès-Sciences Naturelles, Université d'Abidjan*, 479 p.
- Biot S., Brou Y., T., Oswald J., Diedou A., (2005) : Facteurs de la variabilité pluviométrique en Côte d'Ivoire et les relations avec certaines modifications environnementales; *SECHERESSE*, volume 16, Numéro 1, pp 5-13
- Boyossoro K., (2001) : Insécurité et géorisque en Afrique de l'Ouest: Apport de la télédétection et des SIG à l'étude des phénomènes de risques dans la région semi-montagneuse de Man (Ouest de la Côte d'Ivoire) *Thèse de Doctorat 3è cycle, Université d'Abidjan*, 167p.
- Cruette J., (1975) : modèles de crues en zone urbaine en Afrique occidentale. *Symposium sur l'hydrologie des crues, Nairobi*.
- Desbordes M., (1987) : Contribution à l'analyse et à la modélisation des mécanismes hydrologiques en milieu urbain; thèse Doct. D'Etat: *Université des Sciences et Techniques du Languedoc*, 242 p.
- Dongo K., (2001): Etude de l'Evolution du Système d'Assainissement "Eaux usées" de la ville d'Abidjan, *DEA Sciences de la Terre, Option Hydrogéologie, Université de Cocody\_Abidjan* 81p
- Garrido M., (2002) : Modélisation des événements rares et estimations des quantiles extrêmes, Méthode de sélection de modèles pour les queues de distribution, Thèse de doctorat, Université Grenoble1, 231p.
- Giraud, F., Faure, J.B., Zimmer, D., Lefeuvre, J.C., Skaggs, R.W., (1997) : Modélisation hydrologique d'une zone humide complexe. *Journal of irrigation and drainage engineering* vol.123, n° 5, pp 344-353
- Gonni C. D. et Puech C., (1984) : Méthode de calcul des débits de crue décennale pour les petits et moyens bassins versants d'Afrique de l'Ouest et Centrale, *CIEH, Ouagadougou*. 91 p.
- Ikounga M., (1976) : Les modèles d'écoulement en hydrologie urbaine. *Mémoire de DEA, Université Pierre et Marie Curie, Paris*, pp1-53
- INS, (2000): Recensement Général de la population et de l'Habitat, RGPH 98. *Document de synthèse* 96 p
- Javelle P., Galéal G. & Grésillon J.M., (2000): The flow-duration-frequency approach: former and new developments. *Journal of water sciences*, 13 (3), pp305-323.
- Lemoine L. et Cruette J., (1974) : Adaptation de la formule de Caquot aux régimes des régions intertropicales. *Société hydrotechnique de France, XIII<sup>ème</sup> journée de l'hydraulique, Paris*.
- Mic, R., Galéa G. & Javelle P., (2002): Floods regional modelling of the Cris watershed : classical regional and reference models approach, *Journal of water sciences* 15 (3) : pp 677-700.
- Ministère des travaux publics et des transports de Côte d'Ivoire. Direction de l'eau, (1986) : Instructions techniques relatives aux réseaux d'assainissement. Version 1, 173p



- Morel A., A., H., (1996) : L'assainissement des eaux pluviales en milieu urbain tropical subsaharien. Programme d'Alimentation en Eau et d'Assainissement, PNUD-Banque Mondiale GREAO, 167 p
- OMM, (1983): Guides des pratiques hydrologiques Volume II *Analyse, prévision et autres applications*, 293p.
- Paquier, A., Tanguy, J.M., Haider, S. & Zhang B., (2003): Estimation of the flood levels for a flash flood in urban area: comparison of two hydrodynamic models on the 1988's Nîmes flood. *Journal of water sciences*, 16 (1): pp 79 – 102.
- Réménérias G., (1976, 1986): Hydrologie de l'ingénieur, Ed.Eyrolles, Paris, 456p., 456p.
- Sighomnou, D. et Desbordes, M., (1988) : Recherche d'un modèle de pluie de projet adapté aux précipitations de la zone tropicale africaine ; Cas d'Adiopodoumé – Abidjan (Côte d'Ivoire); in, *Hydrologie Continentale*, n°2, pp 131-139.
- St-Hilaire, A., Ouarda, T.B.M.J., Lachance, M., Bobée, B., Barbet, M. & Bruneau P., (2003) : Regional precipitation frequency analysis: a literature review of recent developments *Journal of water sciences* 16 (1): pp 27 – 54.
- Touazi, M. & Laborde J.P., (2004) : Modélisation pluie-débit à l'échelle annuelle en Algérie du nord. *Revue des Science de l'Eau*, 17 (4) : pp 503-516.