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CONCERNING THE EXPERIMENTAL MEASUREMENTS OF INFILTRATION FOR THE RUNOFF MODELISATION OF THE URBAN WATERSHEDS IN WESTERN AFRICA

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Abstract

The author first shows that the urban runoff is found to be greatly influenced by the natural grounds contribution in the cities of Western Africa. He presents then the results of an experimental infiltration measures campaign made in Ouagadougou. At last, he proposes a well-suited runoff model in urban african environment and indicates how the experimental values of the infiltration have to be used to extend the use of the model to any ungauged watershed.

Introduction

Nowadays, a lot of flood damages occur in the african cities, and are due in a large part to a bad conception of the stormwater drainage. Indeed, most of the technical methods used in Africa are some european methods, and do not fit the specific conditions of the African watersheds.

It is especially true for the problems of sewerage sizing, which are generally solved in Africa by using the well-known rational method. So it's the reason why we were asked by the Comite Interafricain d'Etudes Hydrauliques, CIEH, to prospect and set up a runoff model able to take into account the local specific conditions of the urban watersheds in Western Africa.

We have been working for two years with rainfall and runoff datas collected in six cities of Western Africa : Niamey, Ouagadougou, Bamako, Lomé, Cotonou and Abidjan, which means 24 watersheds, with nearly three years of data for each.

I The specific conditions of the urban runoff in western Africa

1 1 The precipitations

The african rainstorms are very rough, as it is shown on the table 1, which compares rainfall intensities, in millimeter per hour, between two european cities, Paris and Montpellier, in the south of France, and three african cities, Niamey, Ouagadougou and Abidjan : these intensities, corresponding to a two years return period rainfall, are considered in respect with lags of 5,15 and 30 minutes, and one can notice that, for the last one, the rainfall intensities ratios are nearly two between Montpellier and Abidjan, and nearly four between Paris and Abidjan

So the rainfall intensities are expected to exceed the infiltration ability of the natural grounds And, it means that the runoff contribution of the natural grounds may be not negligible

Table 1 : Rainfall intensities of a two-years return period rainfall

Δt	5 mn	15 mn	30 mn
Niamey	160	110	79
Ouagadougou	184	128	92
Abidjan	171	142	104
Montpellier	126	69	48
Paris	82	41	27

1.2 The urbanization

Most of the watersheds that we have been studying are representative of the african traditional urbanisation. Of course, other kinds of urbanisation exist besides, but we chose to study especially the case of traditionnal urbanisation for two reasons :

- first, the traditionnal urbanisation is the most to be found in the african cities
- second, a similar kind of urbanisation is nowadays growing up in the suburbs, because of a very high demographic increasing rate

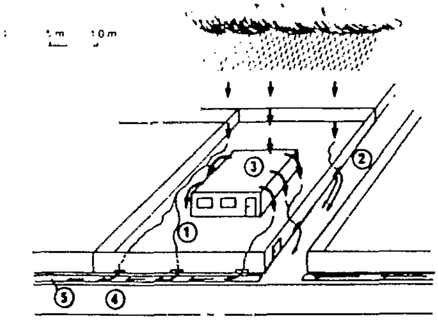


Fig 1 Runoff on a typical elementary unit of traditionnal urbanisation

Figure 1 represents a typical elementary unit of the traditionnal urbanization. The natural grounds are the house yards (1) and one of the nearby road (2) : notice that they receive all the flow coming from the impervious house roofs (3). The other impervious area is the lower road (4), which is directly connected to the drainage system (5)

Such a repartition of the urbanized areas makes that the same runoff comes from both natural grounds and impervious areas that are not connected to the sewer system. So only the impervious areas that are directly connected to the sewer system would be able to produce an earlier peak. But these are very few and do not exceed 10% for the most of the traditional urbanization watersheds that we have been studying.

More generally, the impervious areas ratios do not exceed 30%. So, considering § 1.1, it clearly appears that we have to take into account the contribution of the natural grounds for a proper evaluation of both runoff volumes and peaks.

This is the reason why we were interested in the infiltration processes on natural grounds and we performed 4 measurement campaigns in Ouagadougou, Niamey, Abidjan and Lomé.

2 An example of the infiltration experimental values : Ouagadougou

2.1 Description of the measurement device

In order to estimate the infiltration processes, we measured plot runoff under simulated rainfalls. The rain simulator that we used has been improved by ORSTOM for ten years, and reproduces with a good accuracy the rainfall characteristics :

- raindrops kinetic energy : first conceived by pedologists to study ground erosion, the sprinkler lies on a five meters high framework,

- raindrops size : the sprinkler produces a stream for which various raindrops size are available by modulating the water pump alimentation flow,
- rainfall intensity : it varies with the scanning of the sprinkler

Rainfall is concentrated on a one meter sided square plot, from which the flow is collected on the downstream side and runs to a tank, where the water level is recorded by a limnigraph

2 2 The experimental procedure

Besides the characterisation of the soil morphology - runoff ability relation, the experiments that we carried out were aiming at measuring the effects of parameters such as rain intensity or soil moisture on both runoff and infiltration processes

A quite good representations of our studied watersheds soils was obtained by 6 selected plots Soil moisture influence is shown by carrying out for a given plot, repeated experiments on a two days period : extreme soil moisture conditions are generally supplied by the first and the last rainfalls In the following, the initial moisture condition is assumed to be caracterised by a Kohler index, Ik, which can be computed using the reccurrence relation .

$$Ik(n) = \Big(P(n-1) + Ik(n-1)\Big) exp(-0{,}5\ ta)$$

where ta is , in day, the lag between the (n-1)th rainfall P(n-1) and the nth one P(n) We admitted that index values over 70 meant a saturated soil

2.3 The experimental results

The first important result is that, for a given Ik, the infiltration or runoff values obtained on all the plots are very close one to the others Furthermore, considering the initial soil moisture only as dry ($I_k \sim 0$) or saturated ($I_k \sim 70$) :

- runoff coefficients range from 75 up to 85% on dry soils, from 91 up to 98% on saturated soils, considering a forty millimeter high rainfall
- imbibition rainfall (i.e initial retention losses) ranges from 1,7 up to 4,0 mm on dry soils, from 0,3 up to 1,7 on saturated soils
- a permanent regime of infiltration is quickly reached from 20 up to 40 mn on dry soils, from 10 up to 25 mn on saturated soils

  Then the infiltration intensity ranges from 4 up to 6 mm/h on dry soils from 1 up to 2 mm/h on saturated soils
- at last, the rainfall intensity has no significative influence on the infiltration intensity

So, two synthetic curves have been drawn, corresponding to lower ($I_K \sim 0$) and higher ($IK \sim 70$) soil moisture conditions. These curves are displayed on the figure 2, and were built from the median values that we got on all the plots, considering a 40 mm/h rainfall intensity to represent imbibition rainfall.
These curves supply the values of the infiltration losses for any rainfall of a given duration : for example, in the case of a rainfall of 60 mm duration, the infiltration losses are found, by integrating in respect with time, to be equal to 8,8 mm on dry soils and 4,4 mm on saturated soils.

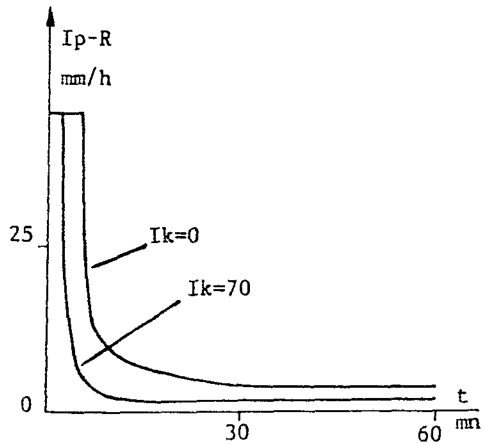


Figure 2 : median curves of the infiltration intensities

Now, let's see how will be used this kind of results in runoff modelisation problem.

3 The modelisation of the runoff volume

3.1 Definition of a production function

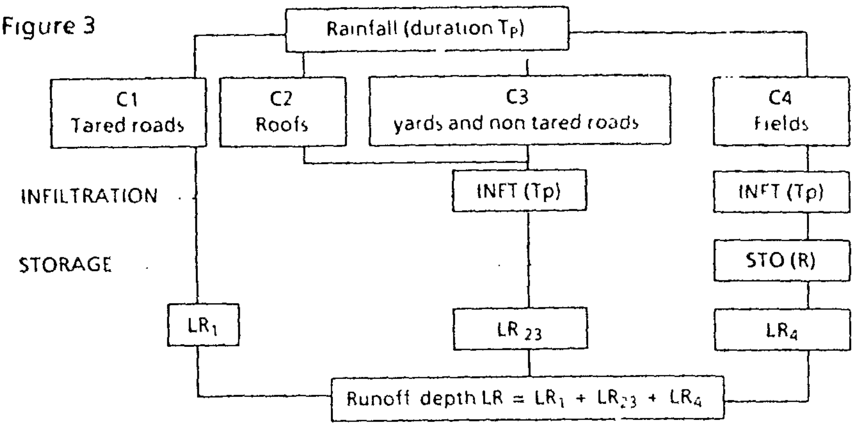
According to the specific conditions of urban watersheds in Western Africa, we looked for a model able to take into account the runoff contribution of the natural grounds. Figure 3 shows the runoff schema that we selected, for a rainfall of a given duration.
The runoff losses are both infiltration and storage losses that are considered in a conceptual way :
INFT is a Horton type function of the part of the rainfall whose intensity is more than 5 mm/h (the height of this rainfall part is Pc) :

$$INFT(T_p) = aT_p/60 + b\left(1 - exp(-c.T_p)\right)$$

STO is a function of the active runoff R = Pc-W.(P-Pc) - INFT(Tp)

$$STO(R) = ST.\left(1 - exp(kR)\right)exp(-kR1) \qquad if\ R > 0$$
$$= 0 \qquad else$$

Figure 3



with $$R_1 = -\frac{1}{k} Log\left(1 - \frac{STOC'_i}{ST}\right)$$

and $STOC'_i$ = storage depth at the beginning of the rainfall n°i, computed step by step by

$$STOC'_i = STOC_{i-1} \cdot exp(-ds\, ta)$$

where $STOC_{i-1}$ is the storage depth at the end of the rainfall n°i-1, and ta is the lag in hours, between the beginning of the rainfall n°i and the end of the rainfall n°i-1

Such a scheme leads to the following equations :

$$LR = C\,P + (1-C)R - (1-C-C3)\,ST\,(1-exp(-kR))\,exp(-kR_1) \quad \text{if } R>0$$

$$LR = C\,P + C3\,R \quad \text{if } R<0$$

where C is the ratio of impervious areas

At last, the production function is characterized by 8 parameters

four of them are conceptually connected to infiltration a, b, c, W

three of them are conceptually connected to surface storage ST, k, ds

one of them is conceptually connected to urbanization C3

3.2 The calibration of the production function

The determination of the parameters values have been performed by the Nelder and Mead's optimisation procedure (Rao, 1978)

The basic sample was constitued from 26 rainflow events observed in Ouagadougou in 1975 on a 48 ha area watershed with a 10 % impervious part 13 events were submitted to the calibration test and the 13 others were the validation sample

Table 2 indicates what are the parameters values we got.

Table 2

a	b	c	W	ST	k	dS	C3
4,4	4,7	0,091	0,7	16,8	0,076	0,028	0,17

This kind of procedure supplies quite a good adjustment (figure 4) between observed and computed values of the runoff volumes, as the mean deviation is only 0,4 mm in the case of the calibration sample, and 1,4 mm in the case of the validation sample.

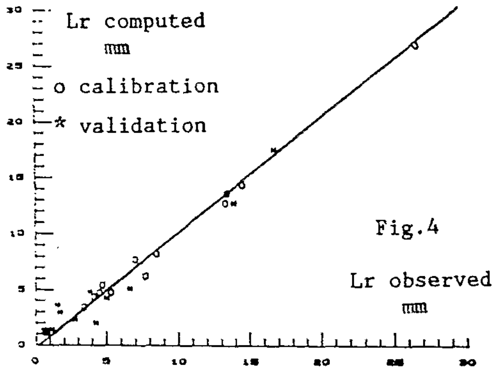


Fig.4

3.3 The transposition of the production function

We've just seen that the production function reproduced with a good accuracy the runoff volumes. Now, to extend the use of the model to any ungauged watershed, the question is to know if the parameters are really significant as we thought they were. Especially concerning what we called infiltration, can the parameters a, b and c be compared to experimental values that we found in 2.3. For our example, <u>the answer is yes</u>, as it is shown on figure 5, on which are displayed the infiltration depth against time : (1) and (2) are issued from the experimental curves of § 2.3., and (3) is the one computed with a = 4,4, b = 4,7 and c = 0,091.

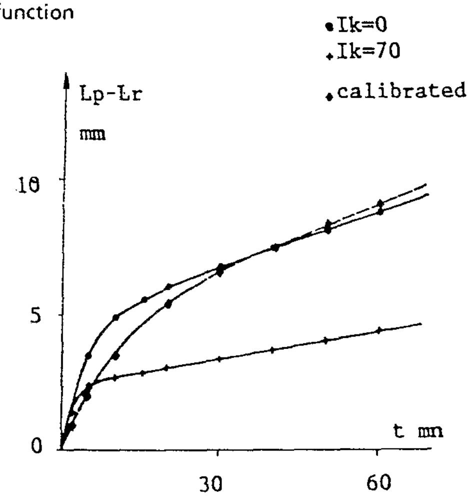


Figure 5 : relationship between experimental and calibrated infiltration losses

Notice that the computed curve is very close to the experimental curve corresponding to Ik = 0 : it might be because most of the Ik of our basic sample are themselves close to 0.

4 Conclusion

For most of the african urban watersheds, runoff coefficients cannot be considered as the ratio of impervious areas This is highlighted by the example of both Niamey's and Cotonou's watersheds that, for a same imperviousness rate equal to 30%, have runoff coefficients that are equal to 60% in Niamey and 20% in Cotonou, considering a one year period return rainfall

A good knowledge of the infiltration processes should be very useful for prediction and the fact that we got a very close relationship between the experimental values and the mode lized conceptual values of infiltration in the case of Ouagadougou, makes for hoping so

Our work is now to improve these results with the whole watersheds set that we are studying

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