Test of simulation of discharges from an ungauged basin in the South-West Côte d'Ivoire in equatorial climate

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Abstract— Being able to estimate discharges in an ungauged basin would facilitate knowledge and planning of water resources in certain areas. The conceptual hydrological modeling of a basin simulates these discharges. This work aims to determine the discharges of an ungauged basin by simulating discharges from basins in the area. Thus, flows simulations based on the hypothesis of the similarity of the hydrological behavior allowed the determination of the mean monthly discharges of the Nero, Dodo and San Pedro rivers in the South-West Côte d'Ivoire. This hydrological modeling by the GR2M software considering these 3 ungauged basins from January 1983 to March 1988 proved to be relatively effective with 12 mm as the average absolute error on the monthly water slides. These results are supported by those of the rainfall-discharge simulations with the observed discharges rates of these rivers, which produce absolute errors of the same order, illustrated by Nash coefficients which vary from 68.5 to 75.5.

Index Terms— conceptual hydrological modeling, Côte d'Ivoire, GR2M, Nash coefficients, rivers, simulating discharges, ungauged basin

1 Introduction

Freshwater rivers represent about 0.003% of the world's freshwater reserves. It is very negligible compared to nearly 79% of snow, polar ice and mountains or 21% of groundwater [1]. This natural, renewable and easily accessible resource is not inexhaustible. The intensification of the effects of climate change is an additional pressure in addition to the withdrawals that reduce it. IPCC scientists then recommend that states reduce CO_2 emissions by 45% by 2030 to limit the rise in earth's temperature and thus the consequences on ecosystems [2]. Policies for the sustainable management of water resources are therefore reasonably well established around the world. This efficient planning requires a good spatial knowledge of the values of the hydroclimatic parameters. The difficulty of instrumentalizing rivers for natural reasons, lack of financial means or sufficient will of managers limit the knowledge of flow in certain areas. The determination of discharges in ungauged basins is a solution to this problem. This study contributes to this by approaching it in the south-west of Côte d'Ivoire which has many ungauged basins. Hydrological modeling is a tool for interpolation and extrapolation of data for which conceptual hydrological models are preferentially used [3]. The objective of this work is to experiment with a method for determining discharges in ungauged basins. It revolves around 3 parts that are successively a presentation of the study area, the data and methods used, the results obtained followed by the discussion and a conclusion and references.

2 Presentation of the Study Area

This study focuses on four coastal basins located in south-western Côte d'Ivoire. These are the Tabou, Dodo, Nero and San Pedro (Fig. 1). They belong to the equatorial climate with four seasons, two rainy seasons and two dry seasons. Evergreen forest and plains where the altitude does not exceed 200 meters characterize the vegetation and terrain in southern Côte d'Ivoire. The coastline stretches for nearly 500 km consists in its western half of rocky cliffs to the west of Sassandra and clayey sand to Cape Palmas (Liberian border). These are highly desaturated lateritic soils that cover much of the southern Côte d'Ivoire.

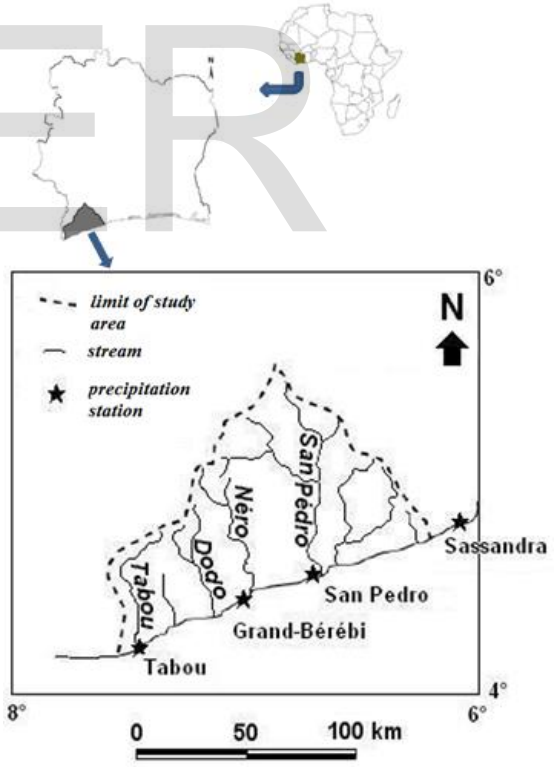


Fig. 1; Location of the study area

3 Data and Methods

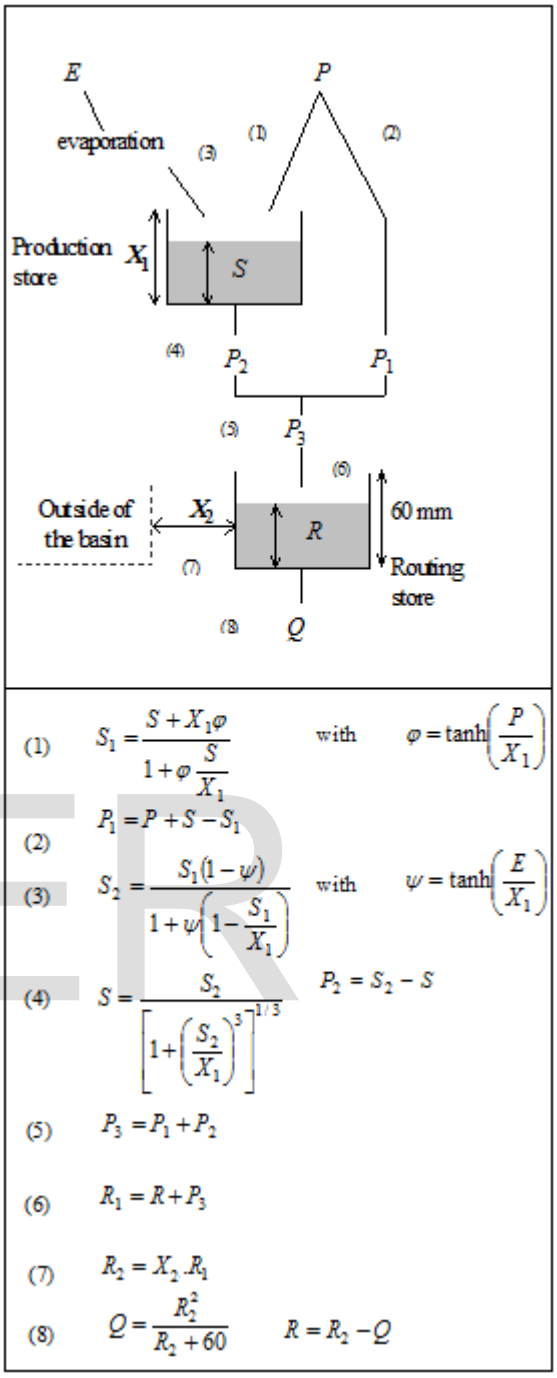
3.1 Data

The data used are the monthly series of rainfall and potential evapotranspiration (PET) observed at stations of Tabou and San Pedro. Monthly discharges of Tabou measured at Olodio and Yaka, Dodo at Wéoulo, Nero at Grand - Bérébi, San Pedro at Faé and the pumping station. These data are spread over the period 1977-2003 and come from the National Weather for rainfall and potential evapotranspiration and the Sub-Department of Hydrology for the discharges series.

3.2 Method

3.2.1 GR2M model

Discharges simulations are performed using the application of the GR2M model on Microsoft Office Excel (version 1.0). The GR2M (Génie Rural à 2 paramètres Mensuels) model is a rainfall-runoff global conceptual model with two parameters developed at Cemagref. This version is the one proposed by [4]. Its structure is that of a conceptual model with interconnected reservoirs that rainfall (P) fell on the basin feeds as and when to be transformed into flow (Q) at the outfall (Fig. 2). Thus, a production reservoir and a routing reservoir plus an opening on the outside other than the atmospheric environment are noted. These three functions are used to simulate the hydrological behavior of the basin [5].



$$(1)\quad S_1 = \frac{S + X_1\varphi}{1 + \varphi\frac{S}{X_1}} \quad \text{with} \quad \varphi = \tanh\left(\frac{P}{X_1}\right)$$

$$(2)\quad P_1 = P + S - S_1$$

$$(3)\quad S_2 = \frac{S_1(1-\psi)}{1+\psi\left(1-\frac{S_1}{X_1}\right)} \quad \text{with} \quad \psi = \tanh\left(\frac{E}{X_1}\right)$$

$$(4)\quad S = \frac{S_2}{\left[1+\left(\frac{S_2}{X_1}\right)^3\right]^{1/3}} \quad P_2 = S_2 - S$$

$$(5)\quad P_3 = P_1 + P_2$$

$$(6)\quad R_1 = R + P_3$$

$$(7)\quad R_2 = X_2 . R_1$$

$$(8)\quad Q = \frac{R_2^2}{R_2 + 60} \quad R = R_2 - Q$$

Fig. 2 ; Structure of the GR2M model [4]

The model has two optimizable parameters:

X_1: Reservoir Production (mm) capacity.

X_2: Underground trade coefficient

The performance evaluation of the GR2M model will be done with the criterion of [6] :

$$Nash\,(Q) = 100 \times \left[1 - \frac{\sum_i (Q_0^i - Q_c^i)^2}{\sum_i (Q_0^i - Q_m^i)^2}\right]$$

With : Q_0^i : observed monthly discharge ; Q_c^i : calculated monthly discharge ; Q_m^i : mean monthly discharge observed over the entire observation period.

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The values taken by the Nash indicate the performance of the model [7] :

- Nash ≥ 90% : the model is excellent;
- 80%< Nash < 90% : the model is very satisfying ;
- 60% < Nash < 80% : the model is satisfactory ;
- Nash <60% : the model is bad.

3.2.2 Discharge simulation Method on an ungauged basin

Considering comprehensively analyzed area (Southwestern of Côte d'Ivoire) as hydrologically homogeneous (basin A), the mean of monthly rainfall depth and potential evapotranspiration are estimated with the available data. The mean of the two climatic variables that constitute GR2M model entries to perform calibrations for different periods of 62 months. Thus calibration over the same period X, but on different sub-basins (A_0 to A_n will use the same input data (monthly rainfall and PET) with different discharge monthly means series (Fig. 3).

For a basin A_0 that considered ungauged on any period X such from January 1983 to March 1988 (62 months), the parameters obtained after the model calibration on another Y period of 62 months of basin A_0 (January 1993 to March 1998, for example) are used to perform a simulation on the X period of another sub-basin that A_0. This transposition of parameters from calibration over a period of A_0 basin, other than X, is achieved through simulations on the X period of the other sub-basins components area (A_0 à A_n). A combination of simulated discharges where the Nash coefficients are acceptable is performed to obtain the discharges of A_0 basin over the period X.

The efficiency of this method will be appreciated by one hand comparing simulated and observed discharges by computing the absolute values of the differences. On the other hand, for a rainfall-runoff simulation performed under the same conditions as above but considering the basin A_0 gauged the period X.

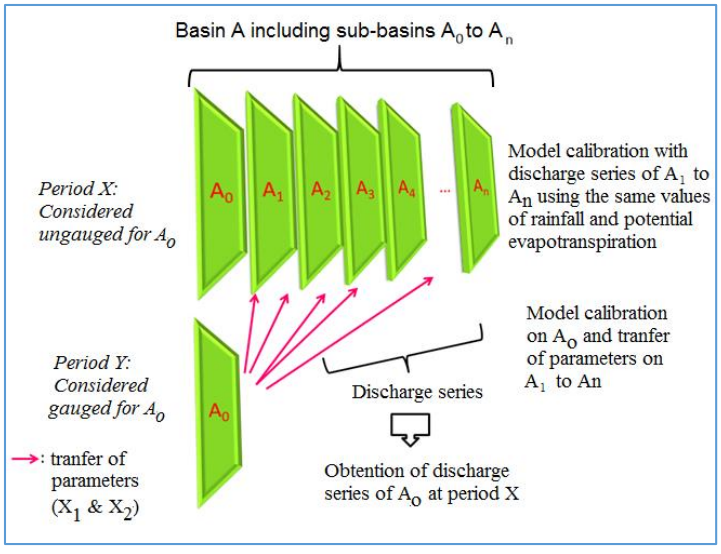

Fig. 3; Discharge simulation method on ungauged basin.

4 Results and Discussion

4.1 Results

Simulations over the period January 1983 to March 1988 of six basins produce Nash coefficients ranging from 43.6 to 76.7% of which three are above 68% (Table 1). These three basins which series permit to have these acceptable values of Nash are supposed ungauged in this period for the rest. These are Dodo at Wéoulo, Nero at road of Grand - Bérébi and San Pedro at Faé (Table 1).

Transpositions of calibration parameters to these basins in the aim to estimate their discharges give Nash coefficients ranging from 66.1 to 73.8 (Table 2).

Table 1; Nash coefficients obtained after the calibration of the GR2M model over the period 01/1983 - 03/1988

Hydrometric station	Nash coefficient (%)
Tabou at Yaka	65.5
Tabou at Olodio	58.0
Dodo at Wéoulo	76.7
Néro at road of Grand-Bérébi	75.1
San Pedro at the pumping station	43.6
San Pedro at Faé	68.9

Table 2 ; Nash coefficients obtained by transfer of calibration parameters of a watershed for the period 01/1983 - 03/1988 of another

stations whose flow rates are estimated	**Dodo**		**Néro**		**San Pedro**	
Stations used for the simulations	**Néro**	**San Pedro**	**Dodo**	**San Pedro**	**Néro**	**Dodo**
Nash coefficients after paramaters transfer	72.1	66.1	73.8	67.3	73.5	73.5
Period of ungauged basin from which the parameters passed	01/1991 - 03/1996	01/1990 - 03/1995	01/1994 - 03/1999	01/1992 - 03/1997	01/1993 - 03/1998	01/1993 - 03/1998

San Pedro at Faé (2127 km²), Nero at route de Grand - Bérébi (1210 km²) and Dodo at Wéoulo (640 km²) being descending order of basins area used for simulation in ungauged mode. It therefore appears that the best results are obtained when a smaller basin is used for simulating the runoff of a pool of

larger basin (Table 2). Coefficients below 70 Nash are observed using the discharges series of the San Pedro to estimate those of the Dodo or Néro. Above 70 against coefficient of Nash are obtained to estimate the discharges of the San Pedro or Néro with the discharges of the Dodo.

These simulations on ungauged basins permit to obtain monthly discharges underestimate or overestimate the observed discharges over the period 01/1984 - 03/1988 (Fig. 4). The absolute differences between mean monthly depth of runoff simulated and observed vary from 11, 12 and 13 mm respectively for discharges of Dodo at Wéoulo, San Pedro at Faé and Nero at road of Grand - Bérébi. The mean error of ungauged simulation of these three user stations is 12 mm. The simulated discharges are comparable to those obtained by considering these basins as gauged. In fact, the simulation with validation on the period 01/1983 - 03/1988 of calibration parameters on another phase of the same series allows to obtain runoff depth having respective absolute differences means 11, 12 and 14 mm with observed runoff depth at gauging stations. The Nash coefficients of these simulations considered gauged basins graduated range from 68.5 to 75.5 (Table 3). These acceptable values permit to assess the effectiveness of simulation in ungauged basins in south-western of Côte d'Ivoire.

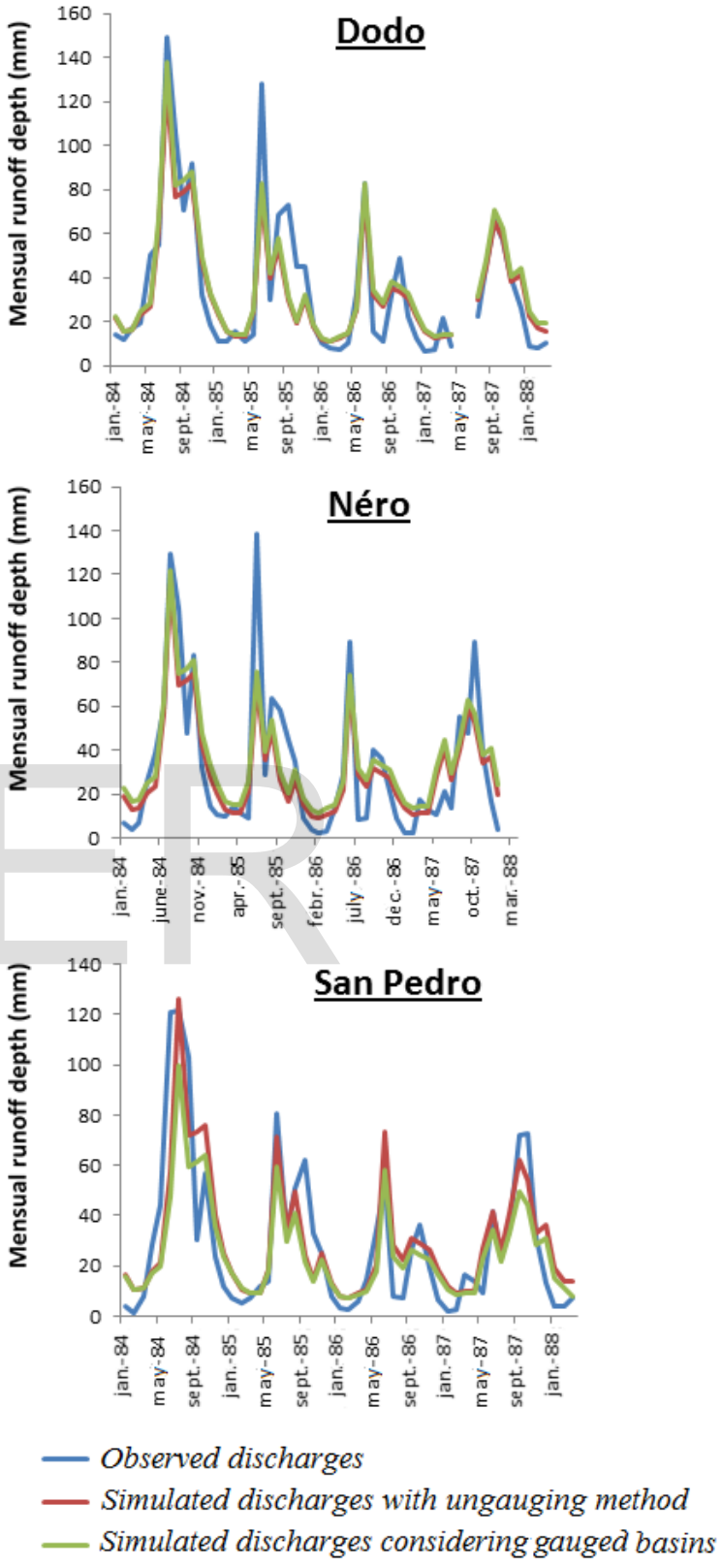

Fig. 4 ; Hydrographs of Dodo, San Pedro and Nero with observed discharges, simulated discharges in ungauged mode and simulated discharges on gauged basins.

Table 3 ; Nash Coefficients of calibration-validation process considered Dodo at Wéoulo, San Pedro at Faé and Nero at road off Grand Bérébi as gauged basins

	Dodo	Néro	San Pedro
Calibration period	01/1991-03/1996	01/1994-03/1999	01/1990-03/1995
Nash of calibration	76,7	75,1	68,9
Validation Period	01/1983-03/1988	01/1983-03/1988	01/1983-03/1988
Nash of validation	75,5	71,5	68,5

4.2 Discussion

Transpositions of calibration parameters of the GR2M model were made between river basins in South-western Côte d'Ivoire. Better results could be obtained if the basins were of similar size. Indeed, [8] noted that the effect of scale, in particular different thicknesses of floor boundary parameters on the transposition of the basins of different sizes. Transfer parameters of a smaller basin to another larger, however, seem to reduce this scale effect. Le Lay [8] also conducted a better transposition of parameters of a sub-basin Ouémé to Bérétou (Bénin) to the main basin.

For lack of to have similar sizes, it is the similarity of the hydrological behavior of used basins in the study which permit ungauged basin simulations. This confirms obtaining better performance for ungauged estimates by the approaches based on the similarities or neighborhoods between basins [9], [10]. These are also more efficient than those linking model parameters to measurable physiographic characteristics of the basin, used by some authors [11], [12]. This explains the use of a homogeneous environment by several authors [13], [14], [15], [16] for the determination of the discharges of ungauged basins.

Perrin [7], Rojas-Serna [10] were able to regionalize the parameters of a conceptual model (GR4J) from a number of climate descriptors or descriptors of the basin. For the success of such an undertaking, they had to use a large number of basins, 429 and 1111 respectively. The lower number of basins in the study area does not allow the application of this method with the conceptual model GR2M.

4 Conclusion

The assumption of homogeneity of hydrologic southwestern Ivory Coast allows for simulations in ungauged mode. Thus, the simulated discharges for the period 01/1983 03/1988 to have a mean accuracy of ± 12 mm. Indeed, the absolute mean error of 11, 12 and 13 mm are observed respectively for the monthly runoff depth of Dodo at Wéoulo, San Pedro at Faé and Nero at road of Grand - Bérébi. The results of these simulations are comparable to those considered these basins gauged which producing respectively 11, 12 and 14 mm as errors in estimating the same monthly runoff depth. Nash coefficients of these last simulations range from 68.5 to 75.5. Determination of monthly discharges of ungauged basins by modeling as using those of the surrounding basins is therefore reliable.

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