Open Journal of Modern Hydrology, 2022, 12, 109-124
https://www.scirp.org/journal/ojmh
ISSN Online: 2163-0496
ISSN Print: 2163-0461

Calibration and Validation of the GR2M Hydrologic Model in the Kouilou-Niari Basin in Southwestern Congo-Brazzaville

Christian Ngoma Mvoundou[1], Christian Tathy[1,2], Harmel Obami-Ondon[1], Guy Blanchard Matété Moukoko[1], Richard Romain Niere[1]

[1]Laboratory of Mechanics, Energy and Engineering, Higher National Polytechnic School, Marien Ngouabi University, Brazzaville, Congo
[2]Department of Exact Sciences, Higher Teacher's Training School, Marien Ngouabi University, Brazzaville, Congo
Email: tathychristian@yahoo.fr

How to cite this paper: Mvoundou, C.N., Tathy, C., Obami-Ondon, H., Moukoko, G.B.M. and Niere, R.R. (2022) Calibration and Validation of the GR2M Hydrologic Model in the Kouilou-Niari Basin in Southwestern Congo-Brazzaville. *Open Journal of Modern Hydrology*, **12**, 109-124.
https://doi.org/10.4236/ojmh.2022.123007

Received: May 20, 2022
Accepted: July 26, 2022
Published: July 29, 2022

Abstract

The hydrologic simulation of a catchment area, described as the transformation of rainfall into runoff, generally uses hydrologic model. This work opts for the global conceptual hydrologic model GR2M, a monthly time step model, to study the Kouilou-Niari basin, the second most important ones of the Republic of Congo. This includes two parameters to model the hydrologic behavior of a catchment area. The choice of the conceptual model GR2M is justified by the reduced number of parameters and the monthly time scale. The objective of this study is to determine the characteristic parameters of the GR2M model, by a calibrating and a validating procedure. The use of these parameters enables to follow the evolution of the water resources from the climatic variables. It has been first carried out a characterization of some physical, geological and climatic factors governing the flow, by dealing with the main climatic variables which constitute the inputs of the hydrologic model. Then, a hydrologic rainfall-runoff modeling allows to calibrate and validate the model at monthly time scale. Taking into account the number of parameters involved in hydrologic processes and the complexity of the catchment area, this model gives acceptable results throughout the Kouilou-Niari basin. The values of the Nash-Sutcliffe criterion and those of the correlation coefficient obtained are greater than 80% in validation, which explains the performance and robustness of the GR2M model on this basin.

Keywords

Kouilou-Niari Catchment Area, Rainfall-Runoff Modeling, GR2M Model, Nash-Sutcliffe Criterion, Calibration Phase, Validation Phase

1. Introduction

Although the Kouilou-Niari basin is only the second largest catchment area in the country after that of the Congo River, it is the most important economically due to its numerous industrial and agricultural activities. Located in a very rainy region, it is often confronted with climatic hazards such as floods, which are responsible for much destruction. Unfortunately, since 1983, there are no hydrological stations in operation in this basin, and it does not benefit from any infrastructure for the efficient management of its resources, nor from any warning system for the prevention of its behaviour. Hence the interest of the present study in order to contribute to the understanding and forecasting of the hydrological functioning of this basin.

In hydrology, modeling is a predominant activity and a hydrologic model, is an essential tool to understand dynamics of a catchment area to use rationally water resources and to fight natural disasters linked to extreme phenomena (floods and low-water levels), thanks to advances made in the fields of computer technology, data processing and geographic information systems (GIS). Distributed hydrologic models use an increasingly comprehensive description of a catchment area and of the hydrologic cycle. The user of a hydrologic model must specify the parameters of the model so that it is able to correctly simulate the behavior of a catchment area [1]. From the observations made by quantifying the rain that has fallen, one reproduces the runoff response of the basin. The transformation of rainfall into runoff remains a complex problem, but requires for simple use, a limited number of parameters. Conceptual modeling enables to limit the number of parameters to be used in the model, but renounces a detailed knowledge of the different hydrologic phenomena [2].

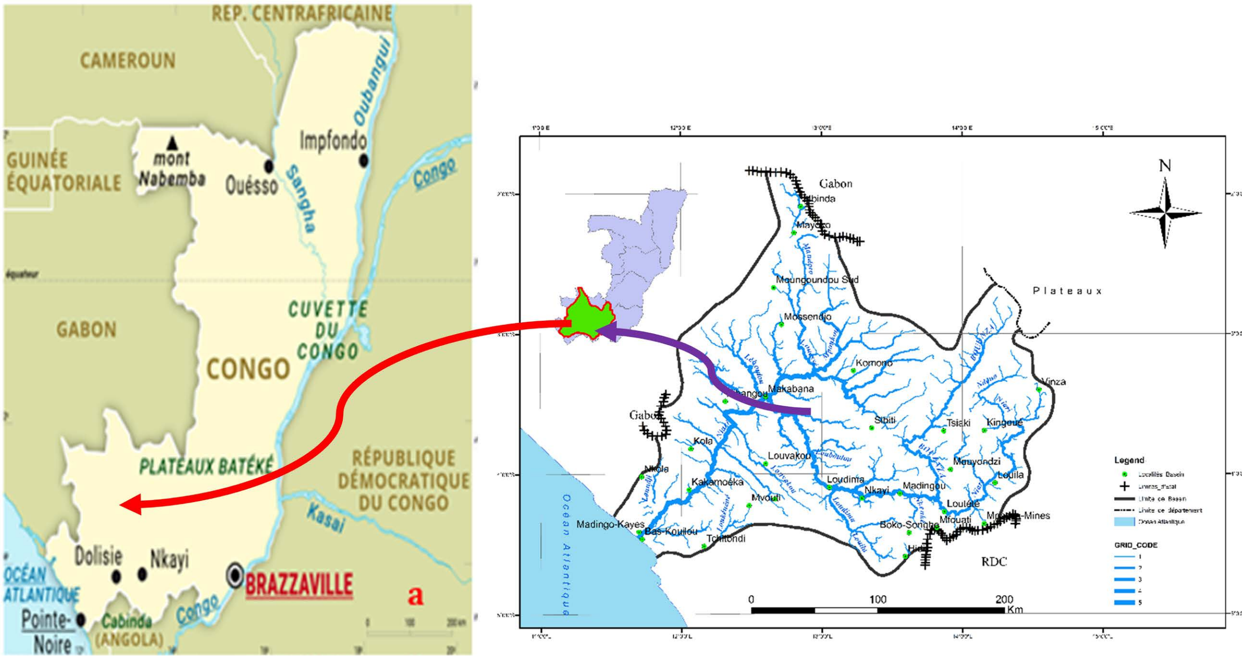
Rainfall-runoff models are powerful tools, although they can always be improved, enabling to answer the needs of water resources management and forecasting of their evolution. From real time data or precipitation forecasts, they are able to evaluate runoff and its evolution at a given point in a river [3]. The main objective of this study is to determine the calibration and validation parameters of the GR2M model applied to the hydrologic data of the Kouilou-Niari basin, at monthly time steps, estimating subsequently its performance and robustness.

2. Materials and Methods

2.1. Materials

2.1.1. Study Area

The study area is a catchment area located in southwestern Republic of Congo (**Figure 1(a)** and **Figure 1(b)**). The Kouilou-Niari basin is located between the parallels 2˚ and 5˚ south and the meridians 11˚45' and 15˚ east, has 690 km long, an average flow of 930 m^3/s and drains an area of approximately 60,000 km^2. Its hydrologic regime corresponds to the humid tropical regime with long periods of high water, also called bimodal regime. The longitudinal profile of the Kouilou-Niari basin starts from N'douo locality at an altitude of z = 650 m up to the



(a) (b)

Figure 1. Map of the location of the study zone, (a) map of Repblic of Congo (b) map of the Kouilou-Niari basin [4].

exit of the Mayombe massif, specifically at Magne locality where the tide is already felt. The slope practically vanishes at the mouth of the river on the Atlantic ocean at Madingou-Kayes locality at altitude z = 0 m (**Figure 2**). From a morphological point of view, the Kouilou-Niari basin is elongated in shape, with a moderate relief type, which justifies the high peak flows at the outlet. The impact of the relief on the hydrogeological characteristics of the basin is significant. Overall, the relief of the Kouilou-Niari basin is relatively homogenous, it is linked to geological nature of the soil and is not generally very rugged. The altitudes, which are generally important enough, reach 700 m at its peaks from the region of plateaux in the north, to that of a peneplain of less than 80 m of altitude in the south towards the Atlantic ocean. The highest peak in the basin is at Biyamba I locality, with nearly 1000 m above sea level.

The geology of the Kouilou-Niari basin is linked to the nature of the soil and to the importance of rainfall. The entire northern part of the basin, has a crystalline and well-watered soil, and is covered by tropical forest. This strong plant cover helps to strongly dampen the rise in water level. The Mayombe massif is also covered by forest. It soil is impermeable, and offers few obstacles to runoff, floods can be very violent. This geology is essentially made up of schisto-limestone formations from the Upper Precambrian, marly limestones, of the Bouenza and sand of the Batéké plateau. It is covered with a clay-sandy to sandy-clay soil, generaly with medium permeability (**Figure 3**). The hydrographic network is clear and very dense. The discontinuity of the plant cover favours superficial runoff, irregularity of flows and genesis of strong water levels, especially on steeply sloping land where the soils are very sensitive to direct runoff [5].

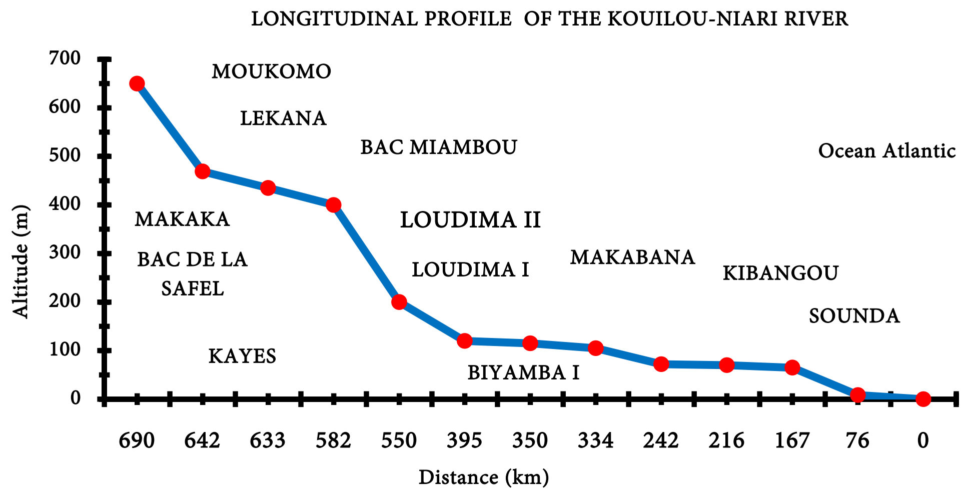


Figure 2. Longitudinal profile of the Kouilou-Niari river [4].

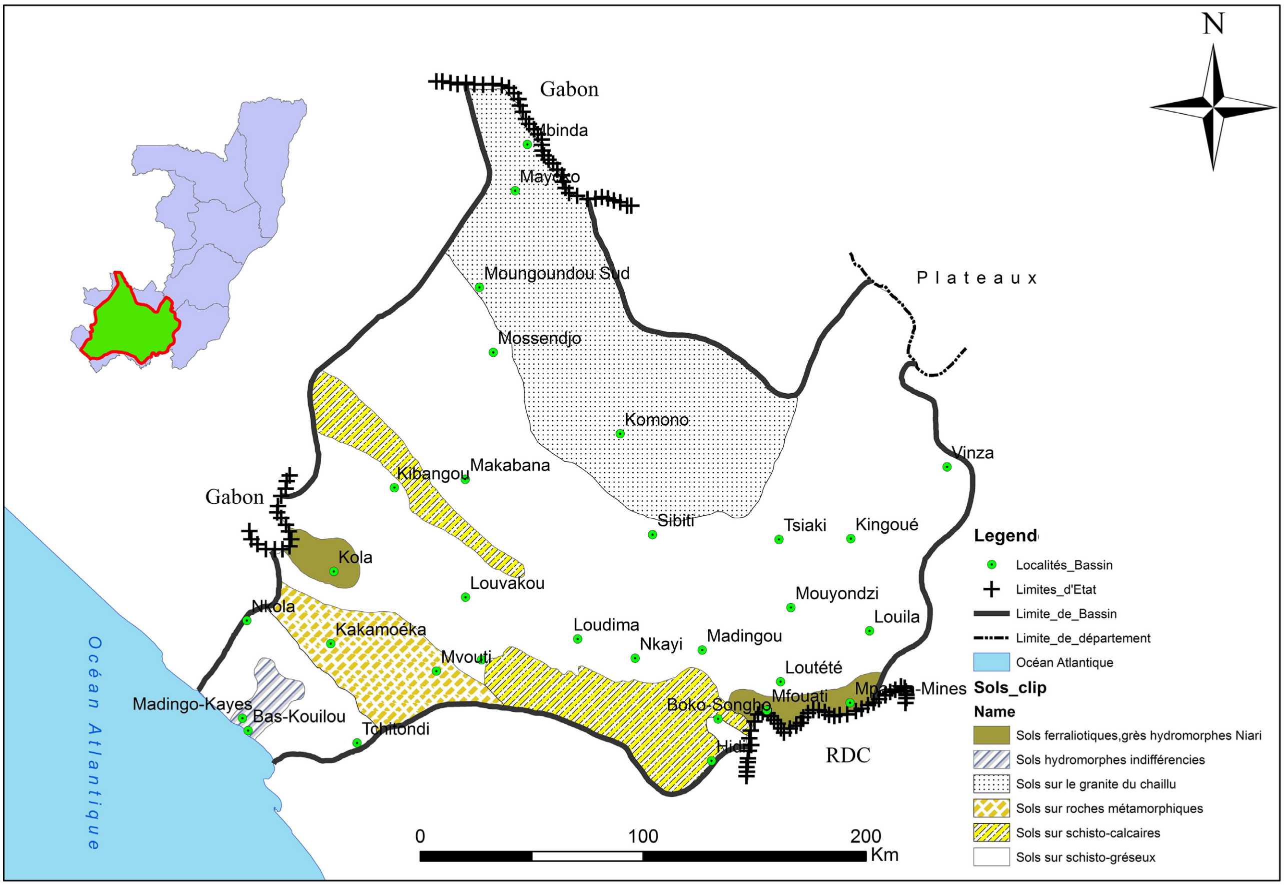


Figure 3. Soil map of the Kouilou-Niari basin.

The forest vegetation attenuates the runoff of this very watered part of the basin. Sedimentary lands occupy the central and southern parts of the basin. More recent rocks are superimposed on limestone formations: micaceous feldespathic sandstones, often reddish, belonging to the so-called schisto-sandostone series. They are sometimes surmounted by sandy-clay to clay-sandy ferralitic soils, generally not very permeable, giving rise to important runoffs. The great variety of rocks in the basin causes very significant variations in the regime of the various tributaries of the Kouilou-Niari rivers. This influence is all the stronger since, in the equatorial regime where the rains are relatively little concentrated in time, the runoff is particularly sensitive to the geological nature of the soils.

The study area belongs to the humid tropical domain and extends over different micro climates ranging from the savannah region in the north to the forest area in the south. The greatest or the least abundance of precipitations and its seasonal distributions constitute the characteristics determining different climatic zones. Indeed, rain is the most predominant climatic parameter which, therefore, is used for the definition of climatic regimes [6].

One notes, four climatic periods in the Kouilou-Niari basin, distributed as follow: small dry season (January-February: JF); big rainy season (March-April-May: MAM); great dry season (June-July-August-September: JJAS) and small rainy season (October-November-December: OND).

2.1.2. Hydro Climatological Data

The climatologic data are mainly at monthly time step and come from two sources: the meteorological services of the National Civil Aviation Agency (ANAC), and the Climatic Research Unit of University of East Anglia (CRU.UEA). The hydrometric data at monthly time step come from hydrometric stations in the Kouilou-Niari basin managed by the hydrologic service of ORSTOM (Tchicaya [7], Molinier, Thebe and Thiebaux [8]).

Due to the closure of all hydrological stations of this catchment area since the year 1983, the data received and processed are those that are available over the period 1950-1982 corresponding to a hydrologic cycle of more than thirty years. In the study area, the monthly rainfall distribution is bimodal, with two maxima occuring in December and in April with proportions fluctuating between 34.63 and 38.89% of the annual total. The basin flows increase from north to south, with a flow between 31.3 and 930.4 m^3/s, with an average of 425.4 m^3/s, its specific flow rate is 0.01691 $m^3/s/km^2$ at Sounda hydrological station in the Kouilou river.

2.1.3. Analysis of Hydroclimatic Parameters

The Kouilou-Niari basin is subject to different climatic factors such as air temperature, relative air humidity, winds, etc. The unequal and changing distribution of these variables is at the origin of the diversity of climates. To this, one must add the disparities and geographic shifts which qualify the regularity of climate [9]. The analysis of hydroclimatic variables is based on data of six selected stations (Moukomo, Lekana, Makaka, Loudima I, Makabana and Sounda):

- temperatures: over the entire basin, the average annual temperature, over the period 1952-1982, is 24.3˚C, the highest is 28.4˚C and was recorded in march 1969 at Pointe-Noire, and the lower is 19.8˚C in June 1954 at Mouyondzi;
- relative humidity: the monthly relative humidity of the basin varies between 88.1% in December and 72.9% in October with an average of 81.2%. It is

greater than 80% in forest zones and 70% elsewhere with a low rate of seasonal variation around 4%;

- sunshines: the average annual sunshine does not exceed 2000 hours across the country (around 1900 hours in Brazzaville and 1600 hours in Pointe-Noire). It is weak because of the heavy cloudiness. Diffuse radiation is always high and contributes to 60% of the global radiation estimated at 540 calories per cm^2 per day [7];
- evaporation: the average annual evapotranspiration calculated by the Thornthwaite method fluctuates between 1445.2 and 1184.1 mm per year respectively with an average of 1294.2 mm per year [10];
- rainfall: the average annual rainfall is 1655.1 mm per year. The maximum rainfall of 2144.0 mm per year was recorded at Sibiti and the minimum of 550.8 mm per year in Pointe-Noire. Seasonal rainfalls are essentially concentrated during the seasons MAM and OND;
- flowing water: the average annual water level flowing over the Kouilou-Niari basin is estimated at 631.4 mm. The maximum value is 1223.2 mm at Biyamba I hydrological station and the minimum is 106.8 mm at Loudima II hydrological station.

The monthly and annual variations of rainfall in the Kouilou-Niari basin (**Figure 4** and **Figure 5**) show that rainfalls are more concentrated between November and May (wet period) than between June and October (dry period).

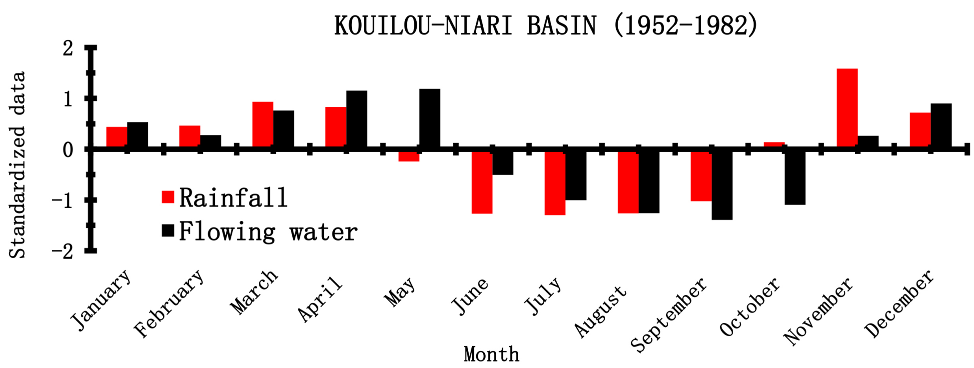


Figure 4. Monthly evolution of rainfall and flowing water of Kouilou-Niari basin [4].

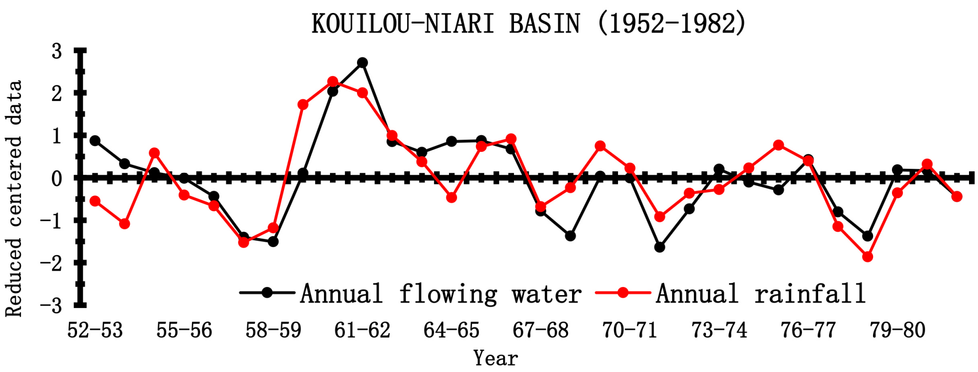


Figure 5. Interannual evolution of rainfall and flowing water of Kouilou-Niari basin.

2.2. Methods

The methodology used for the calibration and validation study of the GR2M model in the Kouilou-Niari basin is subdivised into three parts: 1) collection of hydroclimatic data, it comes from two sources. Six hydrological stations were selected in the period 1952-1982; 2) processing of data received from the various stations, based on mathematical formulas and 3) hydrologic modeling of the cathment area using the GR2M model. The data were subjected to various classical statistical analysis. These analyses enable to characterize the pluviometric and hydrologic behaviour of the basin.

- **Hydrologic modeling with the GR2M model**

The hydrologic model used for this study is widely described in several works [11]-[16]. The hydrologic modeling at monthly time step of the Kouilou-Niari basin has been possible by using the global conceptual model GR2M. This model uses two optimization parameters (X_1 and X_2): X_1 represents the production store capacity and X_2 represents the underground exchange coefficient. This is a model with two stores: a soil store known as the production store and a routing store with a capacity set at 60 mm (**Figure 6**). The adjustment parameters are the maximum capacity of the soil store (free parameter) as well as the underground exchange parameter representing another loss than evapotranspiration (ETP). The model uses as input data, rainfall, ETP and flow rates converted into flowing water, and provides as output data, the simulated flow rates expressed in mm. The version used here is that presented by Mouelhi, Michel, Perrin, and Andreassian [17]. A diagram of the model structure is given in **Figure 6**, where

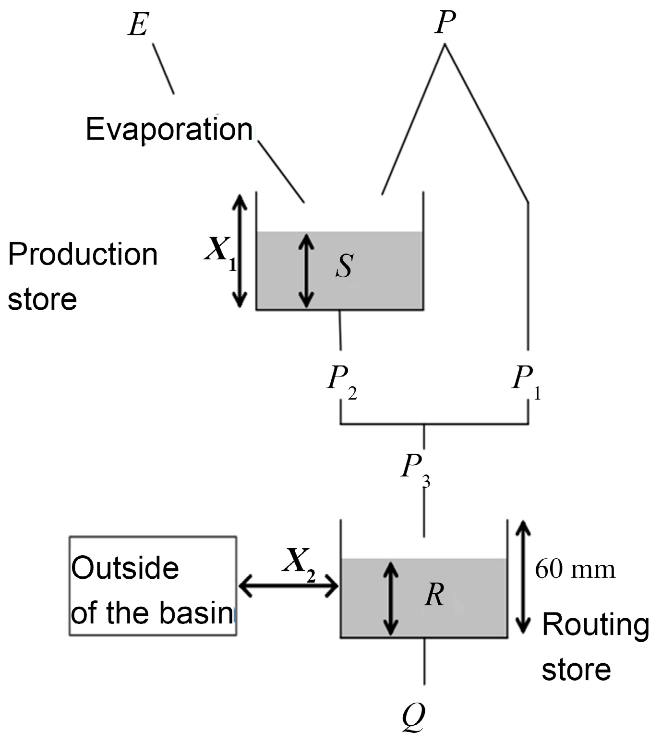


Figure 6. Conceptual diagram of GR2M model [17].

P is the monthly rainfall and E is the potential monthly evapotranspiration or ETP for the same calendar month.

- **Validation criteria**

The best known and most optimized criterion for rainfall-runoff modeling is the Nash-Sutcliffe criterion (1970) [18], defined by Equation (1) which is written below,

$$\text{Nash} = 100\left[1 - \frac{\sum_{i=1}^{n}\left(Q_{obs,i} - Q_{calc,i}\right)^2}{\sum_{i=1}^{n}\left(Q_{obs,i} - \overline{Q_{obs}}\right)^2}\right] \quad (1)$$

where $Q_{obs,i}$, $Q_{calc,i}$ and $\overline{Q_{obs}}$ are respectively the observed flow rate and the simulated flow rate at i station, and the average observed flow rate in the catchment area.

The validation of the model is checked by comparing the calculated flow rates with those observed through a quality criterion (Nash criterion). To take into account some particular values of the flows, this criterion has been calculated by using the square root of flows to attenuate the importance of the flood flows, or by using the logarithm for the low flow rates. In practice, the model is better estimated when its objective function is closed to 100%. The performance of the model can be estimated according to the values taken by the Nash criterion [19]: Nash ≥ 90%, the model is excellent; 80% ≤ Nash ≤ 90%, the model is very satisfactory; 60% ≤ Nash ≤ 80%, the model is satisfactory and Nash ≤ 60%, the model is bad.

3. Results and Discussion

3.1. Results

Anlysis and interpretation of the results on hydrologic modeling with the GR2M model in the Kouilou-Niari basin are made by using graphical representations, in order to better calibrate and validate the model. To carry out this study, the Kouilou-Niari basin has been divided into three hydrologic zones: north zone (N'douo sub-basin), central zone (Niari sub-basin) and south zone (Kouilou sub-basin). In general, the hydrologic regimes of the rivers in the basin are closely related to the rainfall regimes.

The application of the GR2M model in the Kouilou-Niari basin concerns the monthly data for the period 1952-1982. The calibration and validation periods are fixed (**Table 1**). The calibration of the model is carried out by proceeding manually to the changes of the values of the parameters X_1 and X_2 respectively from 6 and 1, and several times until to obtain the optimal values of the quality criterion of Nash-Sutcliffe, of determination coefficient R^2 and of correlation coefficient R between the simulated and observed flow rates. The calibration and validation results obtained with the GR2M model, as well as those of the Nash criterian, are given in **Table 1** and shown in **Figure 7**.

The correlation coefficients (between simulated flow rates and observed flow rates) are obtained with the ETP data calculated by the Thornthwaite method

Table 1. Calibration and validation of the GR2M model in the Kouilou-Niari basin (1952-1982).

Hydrologc unit	Length of calibration and validation phase (month)		Calibration parameters				Validation parameters			
	Calibration phase	Validation phase	Incoming model		Outgoing model		Nash Criteria			
			X_1	X_2	X_1	X_2	Rising (Q)	River module $\sqrt{Q}$	Low water $\ln(Q)$	Assessment
Moukomo	01/1952-06/1954 (30 month)	07/1954-06/1957 (36 month)	6.00	1.00	8.76	1.01	75.8	77.7	78.1	100.2
Lekana			6.00	1.00	8.87	1.10	62.1	64.7	65.5	100.0
N'douo sub-basin			**6.00**	**1.00**	**8.66**	**0.98**	**76.3**	**78.8**	**79.8**	**100.1**
Makaka			6.00	1.00	8.96	1.29	45.9	49.0	50.6	99.4
Loudima			6.00	1.00	8.79	1.09	65.8	68.3	67.7	100.6
Makabana			6.00	1.00	8.69	1.02	74.6	76.6	77.4	99.9
Niari sub-basin			**6.00**	**1.00**	**8.26**	**1.08**	**80.6**	**83.1**	**84.4**	**99.7**
Sounda			6.00	1.00	8.67	1.04	60.5	68.2	72.6	99.7
Kouilou sub-basin			**6.00**	**1.00**	**8.67**	**1.04**	**60.5**	**68.2**	**72.6**	**99.7**
Kouilou-Niari basin	Ditto (sub-basins)		**6.00**	**1.00**	**8.46**	**1.04**	**80.5**	**83.3**	**84.9**	**99.8**

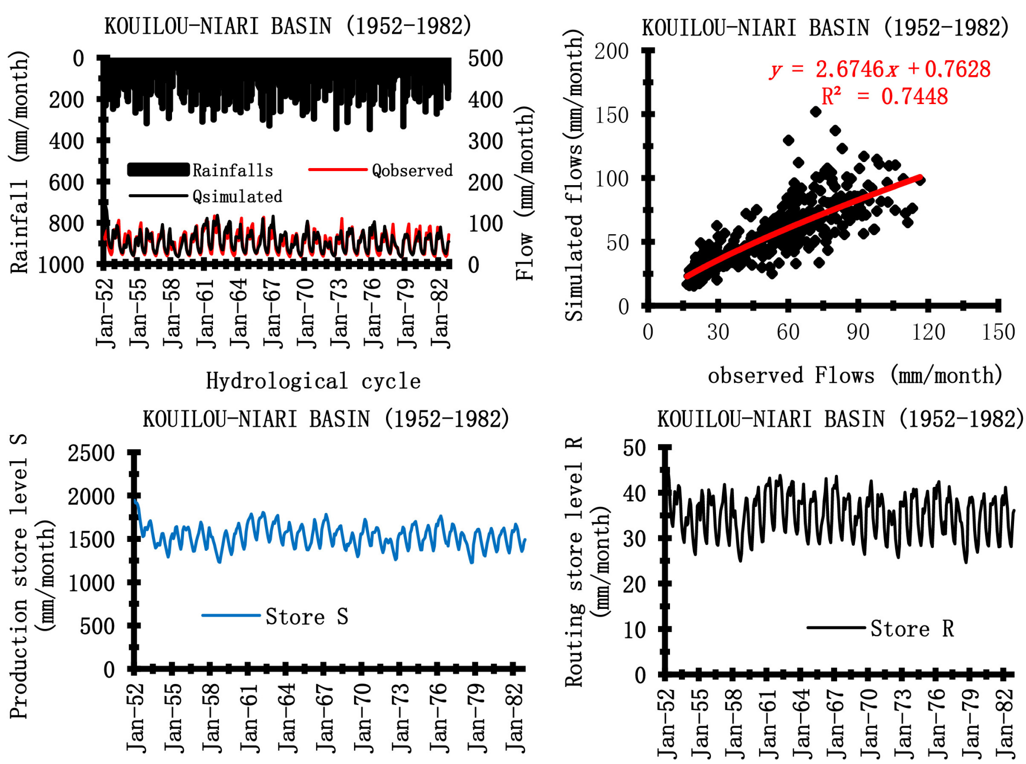


Figure 7. Calibration of GRM model with rainfalls of Kouilou-Niari with Thornthwaite ETP.

[10]. The correlations in the calibration phase and in the validation phase give significant values (**Figure 8** and **Figure 9**, and **Table 2**). Rainfall-runoff modeling using the GR2M model, gives satisfactory results in the N'douo sub-basin and in the Kouilou sub-basin and very satisfactory results in the Niari sub-basin. One notes that in the whole of the Kouilou-Niari basin these results are very satisfactory (**Table 1**).

The results shown in **Tables 1-3** and in **Figures 7-9**: $X_1 = 8.46$; $X_2 = 1.04$; Nash = 84.9%; R = 0.5798 (in calibration phase) and R = 0.9240 (in validation phase), and the good superposition of the curves (simulated flow rates and observed flow rates) for the Kouilou-Niari basin (**Figure 7**), allow to say that the model is well calibrated. For the validation phase, data on rainfalls, ETP and flow rates (expressed in flowing water) corresponding to the period after calibration phase, and which have not been used during this phase, are introduced. The calculations are made by using the values of the parameters X_1 and X_2 optimized during the calibration phase.

Table 2. Variations of correlation and determination coefficients in calibration phase and validation phase of the GR2M model in Kouilou-Niari basin (1952-1982).

Basin	Sub Basin	River	Station	Coefficient R^2 et R	Calibration Phase	Validation Phase
Kouilou-Niari	N'douo	N'douo	Moukomo	R^2	0.4855	0.8108
				R	0.6968	0.9004
		Mpoukou	Lekana	R^2	0.4977	0.6726
				R	0.7055	0.8201
		N'douo sub-basin		R^2	0.4048	0.8108
				R	**0.6362**	**0.9004**
	Niari	Bouenza	Makaka	R^2	0.1839	0.5121
				R	0.4288	0.7156
		Niari	Loudima	R^2	0.1376	0.7392
				R	0.3709	0.8598
		Louéssé	Makabana	R^2	0.2889	0.7810
				R	0.5375	0.8837
		Niari sub-basin		R^2	0.3907	0.8455
				R	**0.6251**	**0.9195**
	Kouilou	Kouilou	Sounda	R^2	0.1768	0.6792
				R	0.4205	0.8241
		Kouilou sub-basin		R^2	0.1768	0.6792
				R	**0.4205**	**0.8241**
Kouilou-Niari Basin				R^2	0.3362	0.8538
				R	**0.5798**	**0.9240**

(R^2): determination coefficient and (R): correlation coefficient.

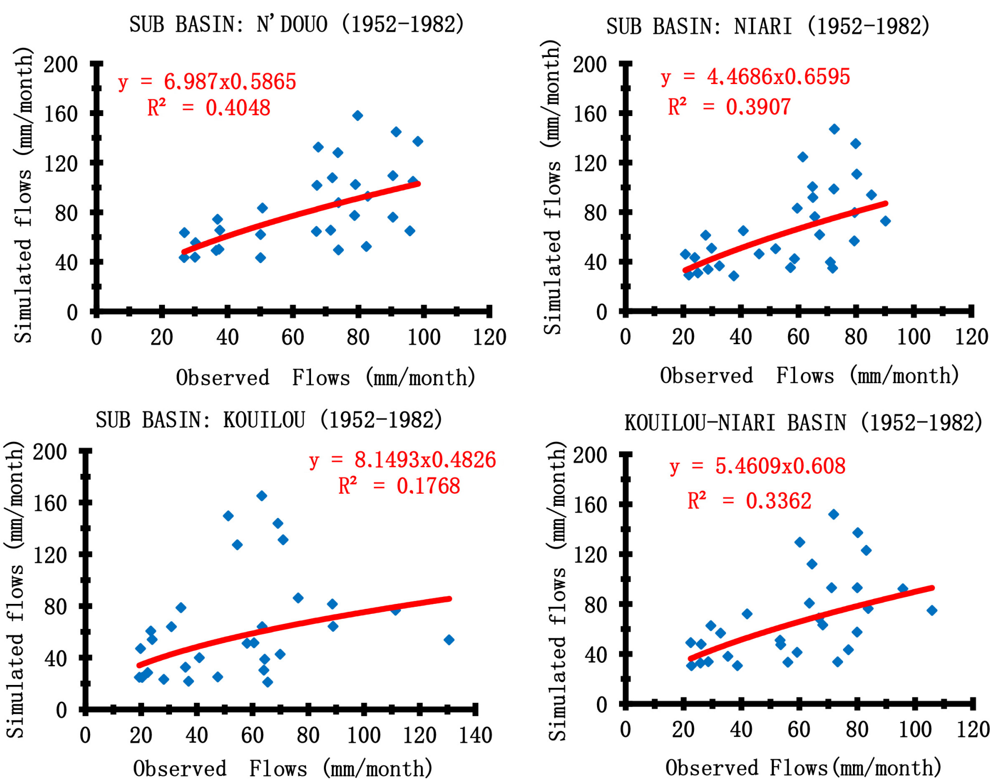


Figure 8. Calibration of the GR2M model with Thornthwaite ETP in Kouilou-Niari basin.

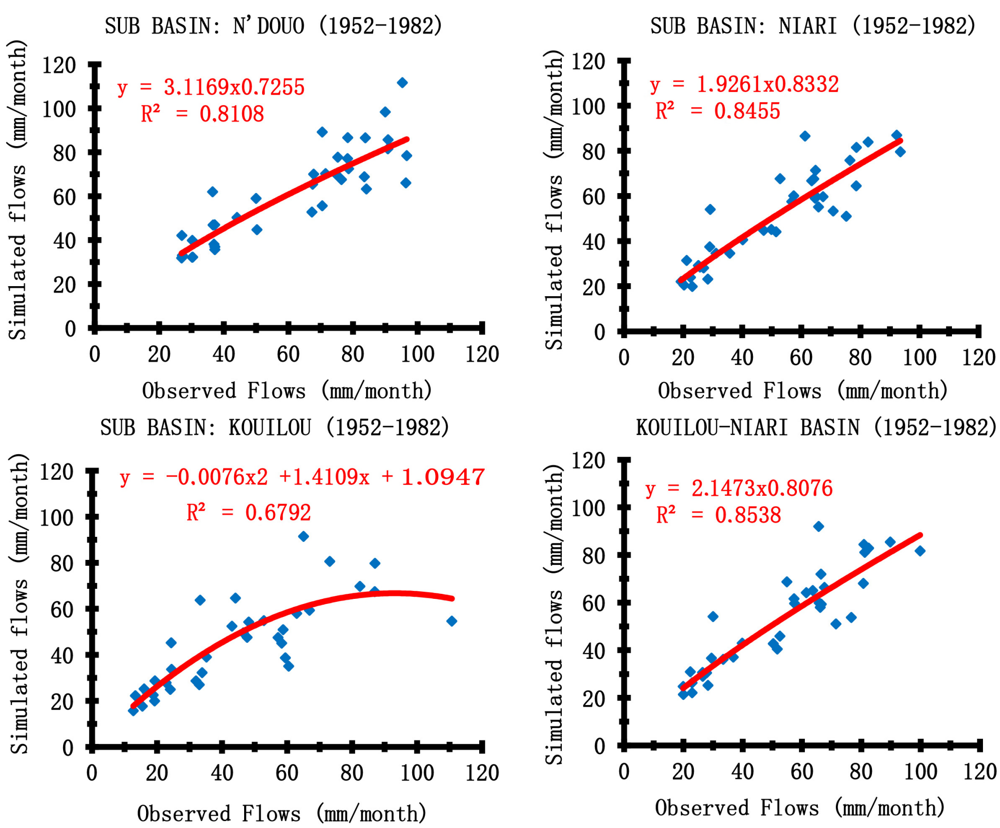


Figure 9. Validation of the GR2M model with Thornthwaite ETP in Kouilou-Niari basin.

Table 3. Filling rates of production and routing stores of the GR2M model in Kouilou-Niari Basin (1952-1982).

Basin	Sub-basin	Rivers	Station	Production store (S) (mm)	Routing store (R) (mm)
Kouilou-Niari	N'douo	N'douo	Moukomo	2273.5	35.9
		Mpoukou	Lekana	2644.5	39.1
		N'douo sub-basin		**2252.2**	**37.6**
	Niari	Bouenza	Makaka	2700.9	39.5
		Niari	Loudima I	2186.9	33.9
		Louéssé	Makabana	2172.6	35.8
		Niari sub-basin		**1475.5**	**35.2**
	Kouilou	Kouilou	Sounda	1966.4	32.7
		Kouilou sub-basin		**1966.4**	**32.7**
Kouilou-Niari Basin				**1770.9**	**35.2**

The flows calculated with the model are then compared with the flows observed by simple correlation (Figure 8 and Figure 9). With some correlation coefficients of 0.5798 in the calibration phase and 0.9240 in the validation phase, the results in the validation phase confirm the good performance of the model. The calibration of the GR2M model seems to be satisfactory throughout the Kouilou-Niari basin (Table 1). The filling rate of the production store (S) is very high (Figure 7), it varies between 1966.4 mm at Sounda station and 2700.9 mm at Makaka station. It is moderate over the entire basin and fluctuates between 1475.5 mm in Niari and 2252.2 mm in N'douo sub-basins. Furthermore, evolution of the filling rate of the routing store (R) remains stable enough and varies around 32.7 mm at Sounda station and 39.5 mm at Makaka station (Table 3).

3.2. Discussion of Results

The results obtained during this study have been possible only after a deep study of two hydrologic variables (rainfall and runoff) and by subdividing the catchment area into three hydrologic units as indicated above. The study concerns essentially the calibration and validation of the GR2M model by highlighting the performance and robustness of the model. The graphical representations show the evolutions of rainfall and flowing water (flow rates) over a hydrologic cycle of more than thirty years (1952-1982). By comparing the different values of Nash criteria obtained, one notices that the highest value corresponds to the criteria calculated with the logarithm of the flow rates (Table 1). These results show that the GR2M model reproduces better low flows than high flows (floods) in the Kouilou-Niari basin. This model has been previously tested in several basins around the world, including those in Africa. The study made by Mouelhi [20] gave satisfactory results in terms of performance. The performances obtained in the Kouilou-Niari basin have the same orders of magnitude as those obtained by Mouelhi [20]. Indeed, the Nash criteria values obtained are greater than 80%, like those obtained by Kouassi [11] in the N'zi Bandama basin in Ivory Coast, with performances ranging between 66% and 80%. This model has also been used in several similar works in West and Central Africa [21] [22] [23]. Ouédraogo [21] has applied it to the Iradougou basin in Niger, Ardoin [22] has also applied it in Ivory Coast in the Sassandra basin. The results obtained by Ardoin [23], show that in the calibration phase, the performances fluctuate between 62 and 90.2% with an average of 83.4%, and in the validation phase, they vary between 21.1% and 83.4% with an average of 55.5%. Performances are more satisfactory in calibration phase in Sassandra basin than in N'zi basin. On the other hand, they are more satisfactory in N'zi basin than in Sassandra basin in validation phase. In addition, with the results obtained by Amiar, Bouanani, and Baba-hamed [13] in the Oued Touil basin in Algeria and those obtained by Bouanani, Baba-hamed and Bouanani [15] in the Oued Sikkak basin in Algeria, the present study shows that the GR2M model is reliable in Central Africa.

Throughout the Kouilou-Niari basin, the Nash criteria values obtained in the sub-basins fluctuate between 72.6% and 84.4% with an average of 78.93%. In the stations, these values have an average of 68.65% and vary between 50.6 and 78.1%. These values are greater than 80% over the entire Kouilou-Niari basin (**Table 1**). In the validation phase, it is noted that the Nash criterion deteriorates in the north and in the south of the basin. The average of this criterion at the stations and in sub-basins varies between 66.73% and 76.03%. The performance results obtained in the Kouilou-Niari basin have the same order as those obtained in other basins in West and Central Africa, and in the Maghreb [11] [12] [13] [14] [15]. One can also observe that the results obtained by Medane [14] and by Gherissi [24], in the basins of Oued Boumessaoud and Oued Lakhdar in Algeria, have some values of the Nash-Sutcliffe criterion, as well as those of the correlation coefficients, greater than 60% in validation phase as in this study.

4. Conclusions

The rainfall-runoff modeling in the Kouilou-Niari basin with the GR2M model, at monthly time scale, presents satisfactory results. The performances obtained in validation phase reach 82.9%. These results demonstrate the performance and robustness of this model in the Kouilou-Niari basin. The parameters of the model, for the Kouilou-Niari basin, have been determined. The Sounda station downstream from the basin controls its characteristics at the catchment outlet. Historical data are very difficult to obtain. They are not always in the desired quantity and quality. Optimization by the GR2M model has given satisfactory values of the quality criteria (Nash). The validation phase has given very good results, confirming the good calibration of the model in this basin located in the humid tropical climate zone in the heart of Africa.

The performance and robustness results obtained for this model indicate the good adaptation of the GR2M model in this basin. Despite the satisfactory results obtained, the modeling has some weakness for long chronological time series applications. In fact, inadequacy of rainfall recording stations, well dispatch on the whole basin, has an influence on the quality of input data of model, and consequently on the quality of calibration and validation results. So, extreme phenomena modeling (rising of water level) remains difficult if not impossible. For that a good knowledge of these phenomena in study area needs sometimes a good hydrometric network, where available observation time series would be long and reliable to enable a good estimate of incoming and outgoing average flows in the catchment area.

At the end of this study, one can conclude that the applying of GR2M model with the chronologic time series of the Kouilou-Niari basin, has given satisfactory results. Assuming that climate change, anthropogenic activities and geomorphological transformations in this catchment area do not seriously affect the model parameters optimised for the period 1952-1982, one plans, in the absence of recent hydrological data, to use the calibration obtained here for short- and medium-term studies of this very important catchment area in the socio-economic activities of the Republic of Congo.

Acknowledgements

We would like to thank the Meteorology Service of the National Agency of Civil Aviation (ANAC) for providing us with the climatic data, and the Hydrological Service of the National Institute for Research in Exact and Natural Sciences (IRSEN) for providing us with the hydrometric data used in this work.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Duan, Q., Gupta, H.V., Sorooshian, S., Rousseau. A.N. and Turcotte, R. (2003) Calibration of Watershed Models. Water Science and Application 6. American Geophysical Union, Washington DC. https://doi.org/10.1029/WS006

[2] Haziza, E. (2003) Modélisation mensuelle pluie-débit/apports de la spatialisation cas des données de sols. Master Thesis, Montpellier II University, Montpellier.

[3] Plantier, M. (2003) Prise en compte de caractéristiques physiques du bassin versant pour la comparaison des approches globale et semi distribuée en modélisation pluie-débit. Master Thesis, Louis Pasteur University, Strasbourg.

[4] Ngoma Mvoundou, C., Tathy, C., Nkounkou Tomodiatounga, D., Elenga, R.G., Moukandi Nkaya, G.D. and Mabiala, B. (2018) Evaluation of the Impacts of the Climate Changes on the Hydrologic Network of the Kouilou-Niari Basin in the South-West of Congo Brazzaville. *Journal of Water Resources and Ocean Science*, **7**, 28-41. https://doi.org/10.11648/j.wros.20180703.12

[5] Sekina, A. (2014) Modélisation Pluie-Débit: Outil de prévision des crues le mieux adapte par le modèle hydrologique. Master Thesis, Abou Bekr Belkaid University,

Tlemcen.

[6] Pardé, M. (1967) Régimes hydrologiques de l'Afrique Noire à l'ouest du Congo, de J. Rodier [compte-rendu]. *Annales de Géographie*, **413**, 109-113.

[7] Tchicaya, J.A. (1994) Etude Hydrogéologique du bassin du Kouilou-Niari. Master Thesis, Louis Pasteur University, Strasbourg.

[8] Molinier, M., Thebe, B. and Thiebaux, J.P. (1981) Données Hydrologiques en République Populaire du Congo. Office de la Recherche Scientifique et Technique Outre-Mer, Centre de Brazzaville, Brazzaville.

[9] Tardy, Y. (1986) Le cycle de l'eau: climats, paléoclimats et géochimie globale. Edition Masson, Paris.

[10] Balouta Ngoma, F., Tathy, C. and Niere, R.R. (2019) Comparative Study of Some Estimation Motheds of Evapotranspiration in the Tropical Zone: Case of the Region of Pointe-Noire (Congo). *International Research Journal of Environmental Sciences*, **8**, 39-52.

[11] Kouassi, A.M. (2007) Identification of Trending in Rainfall-Runoff Relationship and Groundwater Discharge in a Hydroclimatic Variability Context: Case Study of the N'zi (Bandama) Catchment in Ivory Coast. *European Journal of Scientific Research*, **16**, 412-425.

[12] Soussou, S., Masseck, B., Badji, A.M., Malanda-Nimy, E.N., Ansoumana, B., Kuruma, M., Mariko, A., Bamba, F., Dacosta, H., Malou, R., Barry, A., Kane, A., Mme Fall, A.N. and Hamadoun, S. (2011) Calage et validation des modèles hydrologiques GR4J et GR2M sur le bassin du Bafing en amont du Bafing Makana: Vers l'étude de l'impact du climat sur les ressources en eau de la retenue du Manantali. *Proceedings of the* 6*ième* *édition, journées scientifiques* 2*iE*, Ouagadougou, 4-8 April 2011.

[13] Amiar, S., Bouanani, A. and Baba-hamed, K. (2015) Modélisation pluie-débit: Calage et validation des modèles hydrologiques GR1A, GR2M et GR4J sur le bassin d'Oued Touil (Cheliff amont de Boughzoul, Algerie). *Proceedings of the Conférence Internationale FRIEND/UNESCO/Programme Hydrologique International sur l'Hydrologie des Grands Bassins Africains*, Hammamet, 26-30 October 2015, 1-10.

[14] Medane, K. (2012) Hydrologie et modélisation pluie-débit: Cas du bassin versant de l'Oued Boumessaoud (Tafna NW algérien). Master Thesis, Abou Bekr Belkaid University, Tlemcen.

[15] Bouanani, R., Baba-Hamed, K. and Bouanani, A. (2013) Utilisation d'un modèle global pour la modélisation pluie-débit: Cas du bassin d'Oued Sikkak (NW Algérie). *Nature et Technologie*, *C-Sciences de l'Environnement*, **9**, 61-66.

[16] Kouame, K.F., Kouassi, A.M., N'guessan, B.T.M., Kouao, J.M., Lasm, T. and Saley, M.B. (2013) Analysis of Trends in the Rainfall-Runoff Relation in the Context of Climate Change: Case of the N'zo-Sassandra Watershed (Western Côte d'Ivoire). *International Journal of Innovation and Applied Studies*, **2**, 92-103.

[17] Mouelhi, S., Michel, C., Perrin, C. and Andreassian, V. (2006) Stepwise Development of a Two-Parameter Monthly Water Balance Model. *Journal of Hydrology*, **318**, 200-214. https://doi.org/10.1016/j.jhydrol.2005.06.014

[18] Nash, J.E. and Sutcliffe, J.V. (1970) River Flow Forecasting through Conceptual Models Part I—A Discussion of Principles. *Journal of Hydrology*, **10**, 282-290. https://doi.org/10.1016/0022-1694(70)90255-6

[19] Koffi, Y.B., Lasm, T., Ayral, P.A., Anne, J., Kouassi, A.M., Assidjo, E. and Biemi, J. (2007) Optimization of Multi-Layers Perceptrons Models with Algorithms of First and Second Order. Application to the Modelling of Rainfall-Rainoff Relation in Bandama Blanc Catchment (North of Ivory Coast). *European Journal of Scientific*

Research, **17**, 13-328.

[20] Mouelhi, S. (2003) Vers une chaîne cohérente de modèles pluie-débit conceptuels globaux aux pas de temps pluriannuel, annuel, mensuel et journalier. Ph.D. Thesis, ENGREF, Cemagref, Antony.

[21] Ouedraogo, M. (2001) Contribution à l'étude de l'impact de la variabilité climatique sur les ressources en eau en Afrique de l'Ouest. Analyse des conséquences d'une sécheresse persistante: normes hydrologiques et modélisation régionale. Ph.D. Thesis, Montpellier II University, Montpellier.

[22] Ardoin, B.S. (2004) Variabilité hydro-climatique et impacts sur les ressources en eau de grands bassins hydrographiques en zone soudano-sahélien. Ph.D. Thesis, Montpellier II University, Montpellier.

[23] Sighomnou, D. (2004) Analyse et redéfinition des régimes climatiques et hydrologiques du Cameroun: perspectives d'évolution des ressources en eau. Ph.D. Thesis, Yaoundé 1 University, Yaoundé.

[24] Gherissi, R. (2012) Hydrologie et modélisation pluie-débit: cas du bassin versant de l'Oued Lakhdar (Ex Chouly) Tafna-Nw Algerien. Master Thesis, Abou Bekr Belkaid University, Tlemcen.