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# Flood Study From the Gr2m Model in the Mono Basin at the Outlet of Athieme (South-benin)

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**Abstract**

Around the world, in particular in Benin and more precisely in the town of Athiémé, floods, caused by high floods or by the overflow of the Mono River as was the case in September 2016, cause great social and economic damage. The main objective of this work is to study the floods in the Mono basin at the Athiémé outlet thanks to the GR2M model.

The methodological approach used consisted in the collection and processing of rainfall and hydrological data over the period from 1965 to 2011. These different data are processed by descriptive statistical methods and applied in the GR2M model.

The Nash values obtained during the application of GR2M on the Mono to Athiémé, vary from 73% to 88.6% in calibration, and from 67.9% to 93.7% in validation. This study therefore made it possible to note that hydrological fluctuations are sensitive to rainfall forcing, and that rainfall variability has a great impact both on the flow and on recharge and evaporation. In addition, the GR2M model is effective in simulating floods on the Mono in Athiémé.

**Keywords**: Basin, floods, model, simulation, flow, recharge, evaporation.

## 1. Introduction

In Benin, as in many countries of Sub-Saharan Africa, water is an essential resource for any form of animal or plant life, according to (M. Boko, 1988, p. 76; IPCC (2019, p. 9). IWRM takes into account the needs of populations, environmental sustainability and the economic interest of societies, and is nowadays a great development tool, according to (D. J. kodja, 2013, p. 8). It is

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then necessary to ensure the proper use of water by IWRM, thus participating in poverty reduction, food security, better health and a better sanitation system.

The floods, according to E. E. Ago et al., (2005, p. 15); Amoussou et al., (2016, p. 2), would be caused by the abundance of rainfall in the rainy season, the overflow of rivers and the stagnation of water. Likewise, the phenomenon of flooding would be aggravated because of the releases of the Nangbéto hydroelectric dam. Thus, the villages of Athiémé such as Sèvotinou, Ahoho, Awakou, Ablomègan, Adamèetc, are often victims of floods; and this especially during the period from July to September according to (Y. E. Atiyè, 2014, p. 6).

These floods cause significant social and economic damage in the municipality according to Y. E. Atiyè (2014, p. 52). Indeed, these damages range from the degradation of the physical environment to the destruction of houses, fields, the blocking of economic activities and the appearance of water diseases such as cholera, malaria according to D. J. Kodja, (2018, p. 18). To these are added the loss of human life sometimes. Moreover, the floods cause the loss of thousands of hectares of food crops and cash crops in the town of Athiémé (Amoussou, 2010, p. 282). Therefore, E. Amoussou, (2010, p. 283), finds that this phenomenon is recurrent in Benin and particularly in the town of Athiémé. For proof, some municipalities in the North have been victims of the damage caused by the overflow of the Niger River in this year 2016. In addition, last September, some villages in the town of Athiémé also suffered great damage following the overflow of the Mono river.

Considering all of the above, it is essential to ask yourself a few questions. Indeed, what characterizes the hydro-rainfall variability in the Mono basin in Athiémé? Is the GR2M model effective in simulating floods in the Mono basin at the Athiémé outlet? These are all concerns to which this work will try to find approaches to solutions.

### *1.1. Area of study*

The Mono basin forms a border between Togo and Benin for its last 100 kilometers, but its mouth is entirely in Benin territory. In the upper Mono basin, the presence of metamorphic rocks is much more noticeable. But in the lower valley, there are rather sedimentary formations, and the alluvial plain is bordered on both banks by plateaus of barre land, which are themselves crossed from East to West by the depression of the Tchis and the Cado. The climate is tropical in the north of the basin, but equatorial towards the south. Figure 1 shows the geographical location of the Mono in Athieme.

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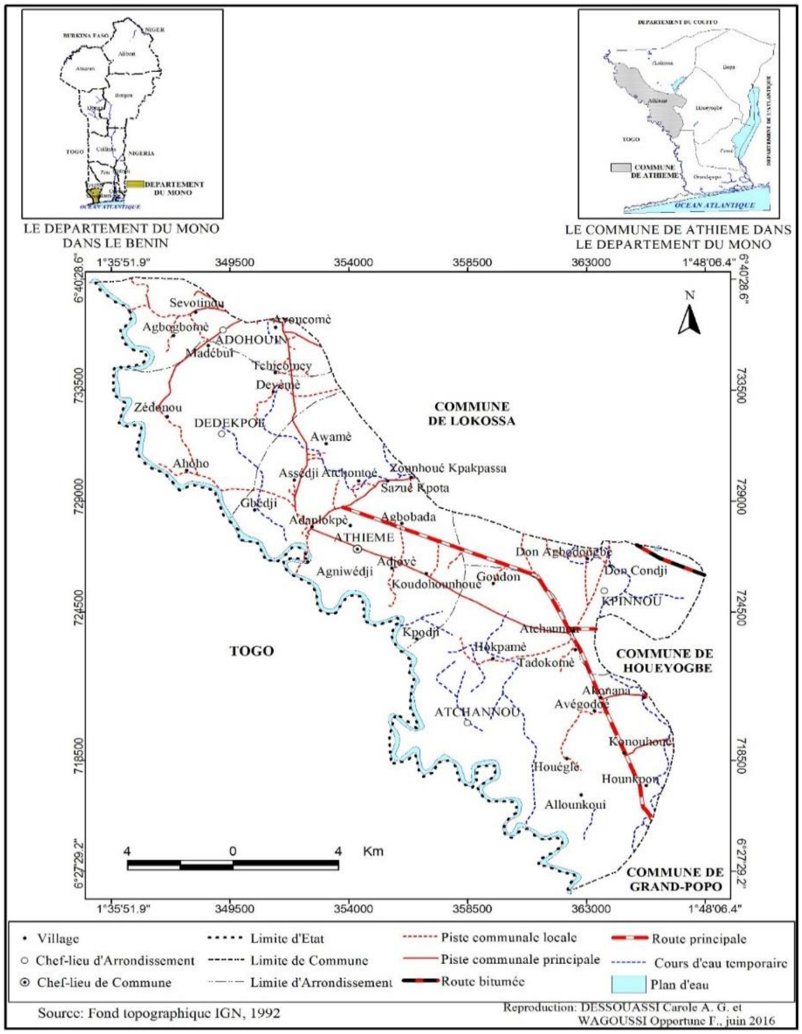


**Figure 1:** Geographical location of the Beninese portion of the Mono to Athiémé watershed

## 2. Data and methods

### *2.1. Data collected*

In order to better understand the research topic and to have a broader view on the methodology to be adopted, scientific documents as well as old works concerning our theme were exploited. Climatological and hydrometric data were then collected. Indeed, at Météo-Benin, monthly FTE data were collected from 1965 to 2014, and those of minimum and maximum temperatures from 1952 to 2015, on the Cotonou-Aéroport station, then monthly rainfall data on the Athiémé station from 1921 to 2013, on that of Aplahoué from 1946 to 2012, on that of Grand-Popo from 1946 to 2013, and on the Bopa stations, Dogbo and Ouidah from 1965 to 2011. According to information obtained from ASECNA, the Athiémé station, created in 1921, was moved in 1973 to Lokossa, where it did not really start providing information until 1979. But in 2009, it started working again in Athiémé. Finally, at the DG-Eau, the monthly flow data of the Mono in Athiémé from

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1944 to 2011 were collected. In order to be able to retain a homogeneous period, we chose a common period ranging from 1965 to 2011, i.e. 47 years of data. Table 1 presents the characteristics of the measuring stations.

**Table 1:** Presentation of the stations

| **STATIONS CLIMATOLOGICAL** | | | | |
|---|---|---|---|---|
| **Station names** | **Latitude** | **Longitude** | **Altitude (m)** | **Type of stations** |
| Aplahoué | 06° 55’ | 01° 41’ | 153 | Rainfall |
| Athiémé | 06° 34’ | 01° 40’ | 11 | Rainfall |
| Grand-Popo | 06° 17’ | 01° 49’ | 5 | Rainfall |
| **HYDROLOGICAL STATION** | | | | |
| **Station names** | **Latitude** | **Longitude** | **Altitude (m)** | **Area (km$^2$)** |
| Athiémé | 06° 34’ | 01° 40’ | 8,2 | 21475 |

**Source:** (Weather-Benin and General Directorate of Water, 2016)

Figure 2 shows the rainfall network of the Mono basin in Athiémé.

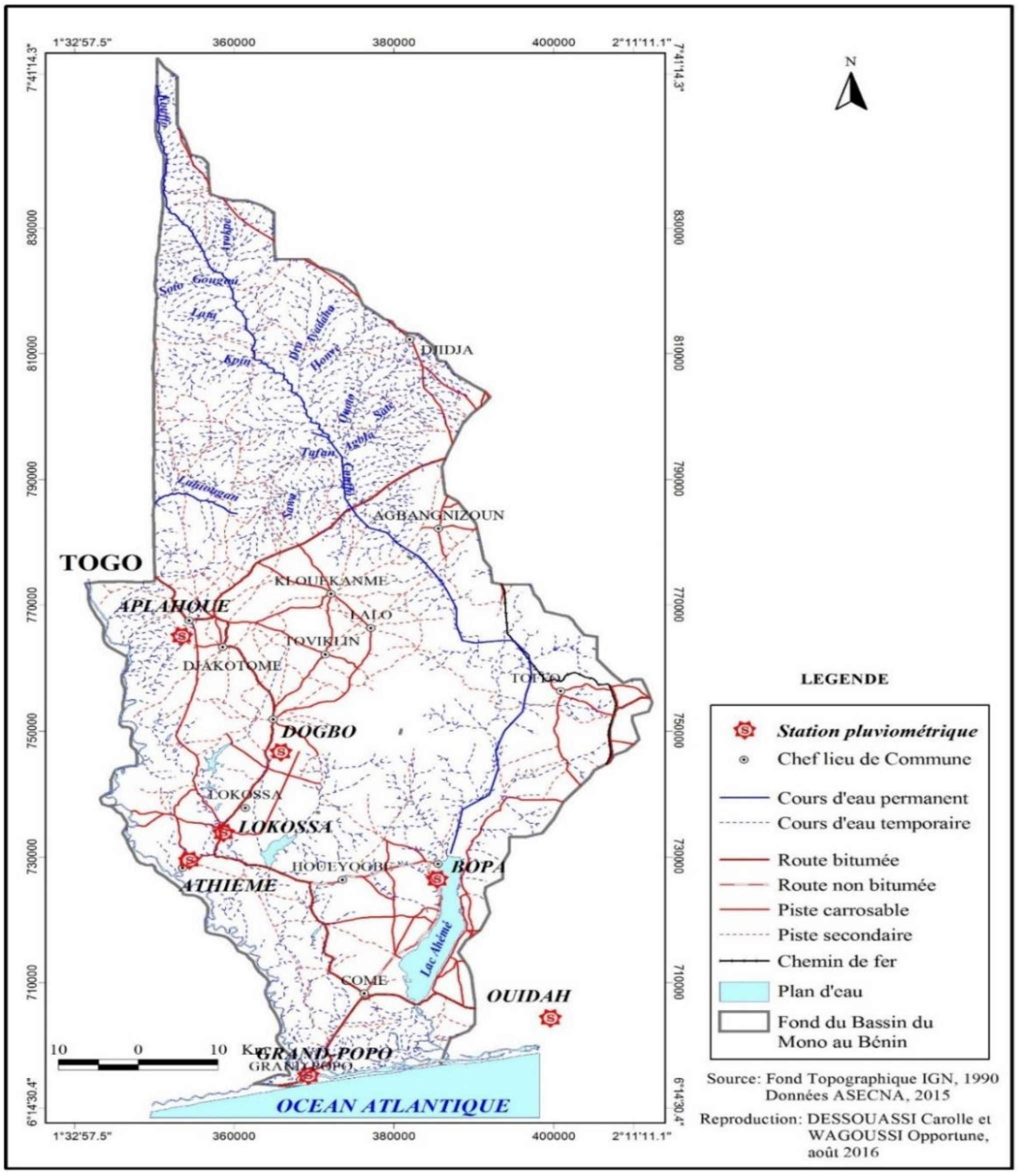


**Figure 2:** Rainfall network of the Mono basin in Athiémé

### *2.2. Methods of data processing*

#### 2.2.1. Description, operation and usefulness of the GR2M model

According to E. W. Vissin (2007), the GR2M model is a global conceptual and empirical model that was developed by MICHEL du CEMAGREF in 1983. It requires only two parameters X1 (soil water retention capacity) and X2 (underground exchange coefficient). It has two tanks: a ground tank which regulates the production function and which is characterized by its maximum capacity X1, and a gravity water tank which regulates the transfer function characterized by X2. As input data, we have the area of the basin in km2, the monthly rainfall data (P) in mm, those of

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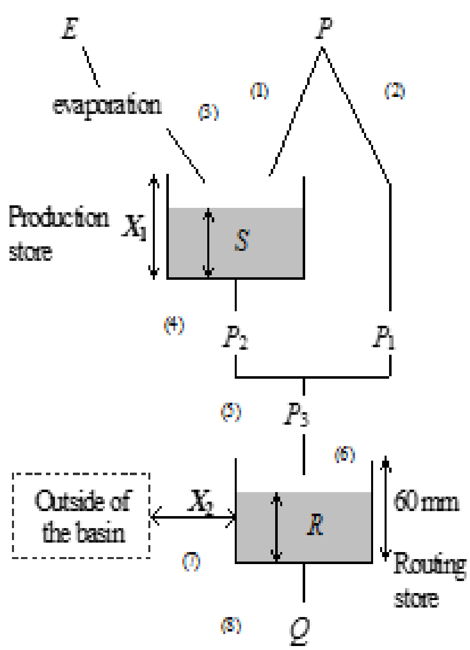
potential evapotranspiration (E) in mm, initial values of the filling rates of the production reservoir (X1). The estimated data are those of the flow rate at the outlet (Q). This model is very useful, because it makes it possible to verify its effectiveness in the simulation of monthly flows. In addition, thanks to its reliability, many have had to use it during their research work.

2.2.2. Description of the model structure

Figure 3 shows the diagram of the operation of the GR2M model.




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

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

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

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

(5) $P_3 = P_1 + P_2$

(6) $R_1 = R + P_3$

(7) $R_2 = X_2 R_1$

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

**Figure 3:** Operation of the GR2M model
**Source:** S. Mouelhi et al., (2006, p. 7)

The version of the model used in this work is that made by S. Mouelhi et al., updated in 2006. This model has a production function that is based on a soil moisture monitoring tank, very similar to the one existing in the GR4J model. 1.2.3.Utilisation du modèle

2.2.3. Method of calibration/validation of the model

To calibrate and validate the GR2M model, sub-periods of two years were used. Thus, the calibration subperiods obtained are: 1965 – 1966, 1969 – 1970, 1973 – 1974, 1977 – 1978, 1981 – 1982, 1985 – 1986, 1989 – 1990, 1993 – 1994, 1997 – 1998, 2001 – 2002 and 2005 – 2006. The validation ones are therefore: 1967 – 1968, 1971 – 1972, 1975 – 1976, 1979 – 1980, 1983 – 1984, 1987 – 1988, 1991 – 1992, 1995 – 1996, 1999 – 2000, 2003 – 2004 and 2007 – 2008.

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In order to test the effectiveness of the model, we will first have to determine the parameters by optimizing a quality criterion of the flows generated by these models. Thus, the total period has been divided into small calibration and validation sub-periods of two years each. With a view to optimizing the parameters of the models, the criterion function chosen is that proposed by Nash and Sutcliffe (1970). Nash is defined by :

$$Nash(Q) = 100\left[1 - \frac{\sum_i \left(Q^i_{obs} - Q^i_{cal}\right)^2}{\sum_i \left(Q^i_{obs} - Q^i_{moy}\right)^2}\right] \text{in } \%$$

with: $Q^i_{obs}$ observed monthly or daily flow, $Q^i_{cal}$ calculated monthly or daily flow, Q_average^i observed monthly or daily average flow.

A characteristic feature of this "Nash" criterion is to give a preponderant importance to periods of high water. To have a criterion giving a greater weight to the periods of low water, we used a logarithmic transformation on the flows :

$$Nash(\ln(Q)) = 100\left[1 - \frac{\sum_i \left(\ln\left(Q^i_{obs}\right) - \ln\left(Q^i_{cal}\right)\right)^2}{\sum_i \left(\ln\left(Q^i_{obs}\right) - \ln\left(Q^i_{moy}\right)\right)^2}\right] \text{in } \%$$

2.2.4. Evolution of the calibration parameters/validation of the model

The GR2M model is an empirical model. Its parameters X1 (capacity of the production reservoir) and X2 (coefficient of underground exchanges) must therefore not be interpreted taking into account the physical characteristics of the sub-watersheds. In order to study their evolution, the analysis of their temporal and spatial fluctuations in calibration will be made in order to identify their variation interval over the study period 1965 – 2011.

After the optimization thanks to the solver function of the Excel sheet, the parameters X1 and X2 giving more performance and robustness to the model have been retained. The correlation between these two parameters is made in order to see if there is a significant link between them. The analysis of the "Nash" values made it possible to highlight the ability of the GR2M model to simulate the flows of the basin. The study of the variability of the Nash values optimized over the selected subperiods is also carried out.

2.2.5. Methods for analyzing the results

The methods of studies adopted in this work to study the climate and the hydrological regime are essentially statistical. They made it possible to analyze the organization of the geographical space in terms of rainfall and hydrology, to highlight the links existing between these different

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parameters and the surface conditions. Several software programs such as XLSTAT, GR2M and Excel have also been used to process the data. Indeed, the GR2M software was chosen because of its integration into Excel, its ability to analyze the hydrological functioning and reproduce that of the flows of a watershed, as well as because of its ease of use. As for the XLSTAT software, it was chosen because it is accessible, compatible with Excel, powerful, complete and very easy to use. Moreover, it has made it possible to fill in the gaps present in the data series. Thanks to these data processing tools, the results have been obtained which are presented in the following chapter.

## 3. Results and discussion

### *3.1. Presentation of the optimized values in calibration and validation*

Tables 2 and 3 present the values optimized respectively for calibration and validation for a time step of 2 years over the entire study period.

**Table 2:** Optimized calibration values for a time step of 2 years from 1965 to 2011

| **Subperiods** | $Nash(\ln(Q))$ | | | |
|---|---|---|---|---|
| | **X1** | **X2** | **Nash** | **Balance sheet** |
| **65-66** | 6,5 | 0,51 | 83,4 | 27,2 |
| **69-70** | 6,6 | 0,48 | 73 | 64,4 |
| **73-74** | 6,59 | 0,36 | 81,5 | 68,9 |
| **77-78** | 6,63 | 0,46 | 88,6 | 58,8 |
| **81-82** | 6,78 | 0,38 | 82,7 | 97,1 |
| **85-86** | 6,29 | 0,51 | 86,6 | 75,3 |
| **89-90** | 4,22 | 0,54 | 86 | 125,7 |
| **93-94** | 6,1 | 0,54 | 87,8 | 62,8 |
| **97-98** | 6,26 | 0,7 | 85,9 | 43,2 |
| **01-02** | 5,91 | 0,66 | 80,9 | 184,8 |
| **05-06** | 6,18 | 0,66 | 86,6 | 72,5 |

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**Table 3:** Values obtained in validation for a time step of 2 years from 1965 to 2011

| **Sous-périodes** | $Nash(\ln(Q))$ | | | |
|---|---|---|---|---|
| | **X1** | **X2** | **Nash** | **Balance sheet** |
| **67-68** | 6,5 | 0,51 | 82,8 | 150,6 |
| **71-72** | 6,6 | 0,48 | 93,7 | 150,7 |
| **75-76** | 6,59 | 0,36 | 73,7 | 16,5 |
| **79-80** | 6,63 | 0,46 | 83,7 | 29,8 |
| **83-84** | 6,78 | 0,38 | 75,9 | 50,5 |
| **87-88** | 6,29 | 0,51 | 87,3 | 87,9 |
| **91-92** | 4,22 | 0,54 | 72,9 | 445,4 |
| **95-96** | 6,1 | 0,54 | 73,2 | 47,4 |
| **99-00** | 6,26 | 0,7 | 79,6 | 12,2 |
| **03-04** | 5,91 | 0,66 | 67,9 | 531,9 |
| **07-08** | 6,18 | 0,66 | 87,3 | 194 |

The minimum, average and maximum values are therefore grouped in Table 4.

**Table 4:** Values obtained by calibration and validation over the overall period 1965 – 2011

| **Values** | **X1** | | **X2** | | $Nash(\ln(Q))$ | |
|---|---|---|---|---|---|---|
| | **Cal.** | **Val.** | **Cal.** | **Val.** | **Cal.** | **Val.** |
| Minimum | 4,22 | 4,22 | 0,36 | 0,36 | 73 | 67,9 |
| Averages | 6,19 | 6,19 | 0,53 | 0,53 | 83,91 | 79,82 |
| Maximum | 6,78 | 6,78 | 0,7 | 0,7 | 88,6 | 93,7 |

The analysis of Table VII reveals that the Nash values vary from 73% to 88.6% in calibration, and from 67.9% to 93.7% in validation. On average, the Nash is 83.91% in calibration and 79.82% in validation. These optimized Nash values (in calibration as well as in validation) on the Mono to Athiémé watershed illustrate well the efficiency of the GR2M model which is thus efficient in the simulation of high water flows. It is also noted that the Nash values are clearly higher than 67%. The analysis of the correlation between the two parameters of the GR2M model has been made.

*3.2. Variation of the correlation coefficients according to the GR2M model*

Table 5 presents the values of the correlation coefficient existing between the various parameters of the GR2M model.

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**Table 5:** Correlation between the different parameters of the GR2M

| | X1 | X2 |
|---|---|---|
| X1 | 1 | 0,72 |
| X2 | 0,72 | 1 |

The analysis of Table 5 shows that the correlation coefficient between the parameters X 1 and X 2 of the model is 72%. This result attests that there is a good relationship between the two parameters. It is then important to test the effectiveness of the GR2M model in simulating the flow of floods on the Mono basin in Athiémé, by analyzing the simulation of average flows relative to the effectiveness of the model in simulating high water flows.

### *3.3. Calibration and validation of the GR2M model on the Mono basin in Athiémé*

Two sub-periods have been selected to present the graphs obtained for calibration and validation. The choice was made taking into account the best value obtained for the Nash in validation. Thus, the subperiods 1977-1978 and 1979-1980 were retained for the dry period, while the subperiods 2005 -2006 and 2007-2008 were retained for the wet period. Figure 4 shows the dynamics of the flow rates observed and simulated after optimization on the wet subperiods during calibration and validation on the Mono at Athiémé.

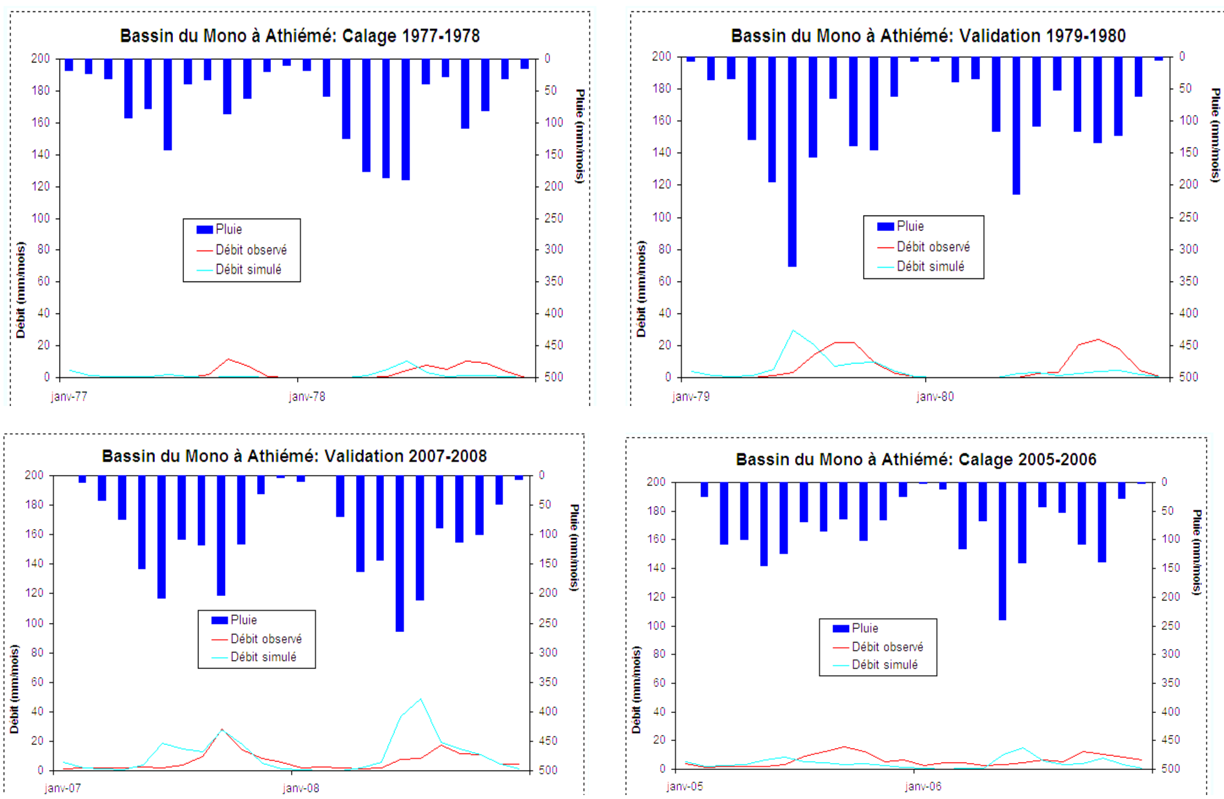


**Figure 4:** Variability of rains and flows observed and simulated in Athiémé

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The analysis of Figure 4 shows that the observed flow rates and those simulated do not have completely the same appearance. The maximum is obtained sometimes at the level of the observed flow rates, sometimes at the level of those simulated. A shift is thus observed between the maxima of the simulated flow rates and those of the observed flow rates. This could be due to the response time of the watershed to rainy events from Mono to Athiémé. By comparing the evolution of the flows and that of the rains, we notice that there is a harmony, that is to say that the flows evolve almost at the rate of the rainfall and their maximum is reached in rainy season. It should also be noted that the various adjustments made have all been validated. Figure 5 shows the correlation between the observed and simulated flow rates.

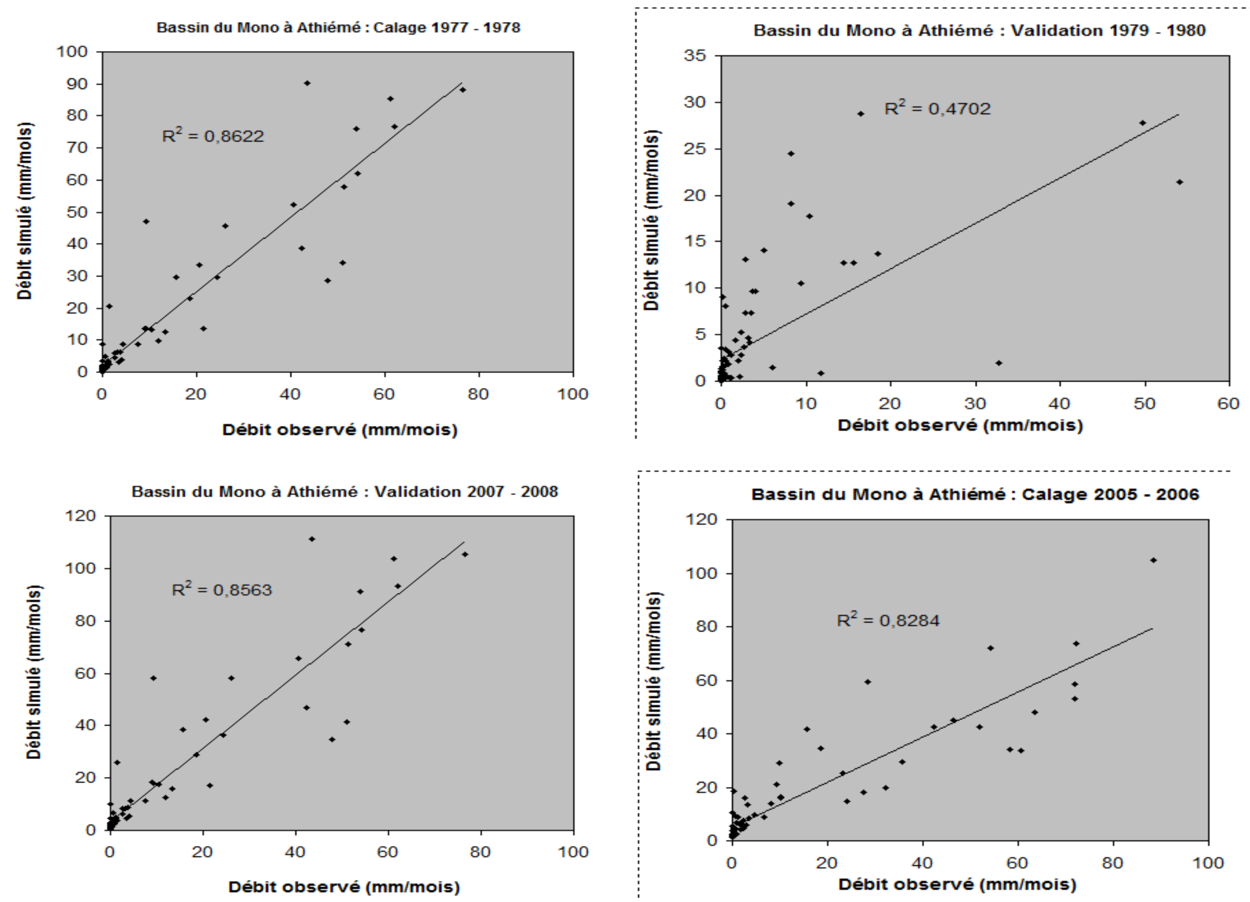


**Figure 5:** Correlation of observed and simulated flow rates in calibration and validation

The analysis of Fig. 5 shows that the correlation coefficients between the observed and simulated flow rates are significant. Indeed, the correlation coefficient is 0.86 over the 1977 - 1978 subperiod and 0.83 over the 2005 - 2006 subperiod in calibration. In validation, it is 0.47 over the subperiod 1979 – 1980 and 0.86 over the subperiod 2007 – 2008. These high values of the correlation coefficient confirm the robustness.

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*3.4. Discussion of the results*

The hydro-pluviometric functioning of the Mono basin in Athiémé is characterized by two subperiods of rainfall increase: 1965 - 1968 and 1987 – 2011, then a subperiod of rainfall recession: 1969 – 1986. According to the results, the dynamics of the flow is linked to the rain which is justified by the strong correlation between these two parameters. To better estimate the flow rates of the Mono in Athiémé, it was necessary to apply the GR2M model on the study basin thanks to its easy use.

The results from the application of the GR2M model on the basin have been very acceptable. Indeed, the Nash values vary from 73% to 88.6% in calibration, then from 67.9% to 93.7% in validation. This makes it possible to say that the GR2M is effective in simulating the flow of high water. Which confirms the results of previous studies carried out by (M. Le Lay, 2002, p. 9), (E. W. Vissin, 2007, p. 262), (D. J. Kodja, 2013, p. 58) and (E. Amoussou, 2010, 283) who also had to test the effectiveness of the GR2M model for the simulation of flows on the OHHVO, the analysis of the Nash criterion applied to average flows in the sub-basins from Niger to Benin, on flood forecasting on the Zou basin in Atchérigbé, then the study of floods on the Mono watershed in Athiémé with the GR2M model.

In conclusion, not only physical factors influence the flow dynamics, but also the simulated flows are much more sensitive to variations in rainfall and FTE data. Therefore, the results of this study are in line with those of other previous studies conducted by the IPCC, 2007, p. 8).

**Conclusion**

The GR2M model was tested on the Mono basin in Athiémé. The variation of the Nash values in calibration as in validation was therefore observed. The calibration and validation were done over the global period, but by choosing sub-periods of 2 years each. The optimized values of the Nash (in calibration as well as in validation) on the Mono to Athiémé watershed illustrate well the efficiency of the GR2M model which is thus efficient in the simulation of high water flows. Therefore, the flows evolve almost at the rate of rainfall and their maximum is reached in rainy season. In addition, not only physical factors influence the flow dynamics, but also the simulated flows are more sensitive to variations in rainfall and FTE data. The GR2M model is therefore effective in simulating floods on the Mono basin in Athiémé. The second hypothesis is also verified.

This study was therefore limited to Athiémé. The wish is that other subsequent studies are made and take into account many Mono stations. Indeed, this will allow us to have a better knowledge of floods and their frequency of occurrence in order to take adequate precautions. Thus, the damage caused by these natural hazards will be limited. That the next studies therefore take into account the physical hydrodynamic parameters of the soil in order to interpret the beginning and the end of the seasons, which could improve the efficiency of the GR2M model on the basin.

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