



Contribution to the Rain-Flow Modelization in IKOPA Watershed; Antananarivo Madagascar

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Abstract: *The studies concern the use of the rain-flow modelization at the daily scale applied to a watershed of Ikopa using a tank global model: the Genie Rural « GR » model. The model « GR4J » is used to simulate the transformation of the rain into flow on the natural basin which the input parameters are the precipitation and ETP. After verifying the performance of the model, the calibration phase and the obtained adjustment validity from the calibration give the acceptable results with the rain data of the Ambohimambola station (for the GR4J). These results indicate that the model takes into account the different exchanges (atmosphere and underground) and the storage capacity.*

Keywords: *Hydrology, Watershed, Modelization, Rain-flow, Model, GR4J.*

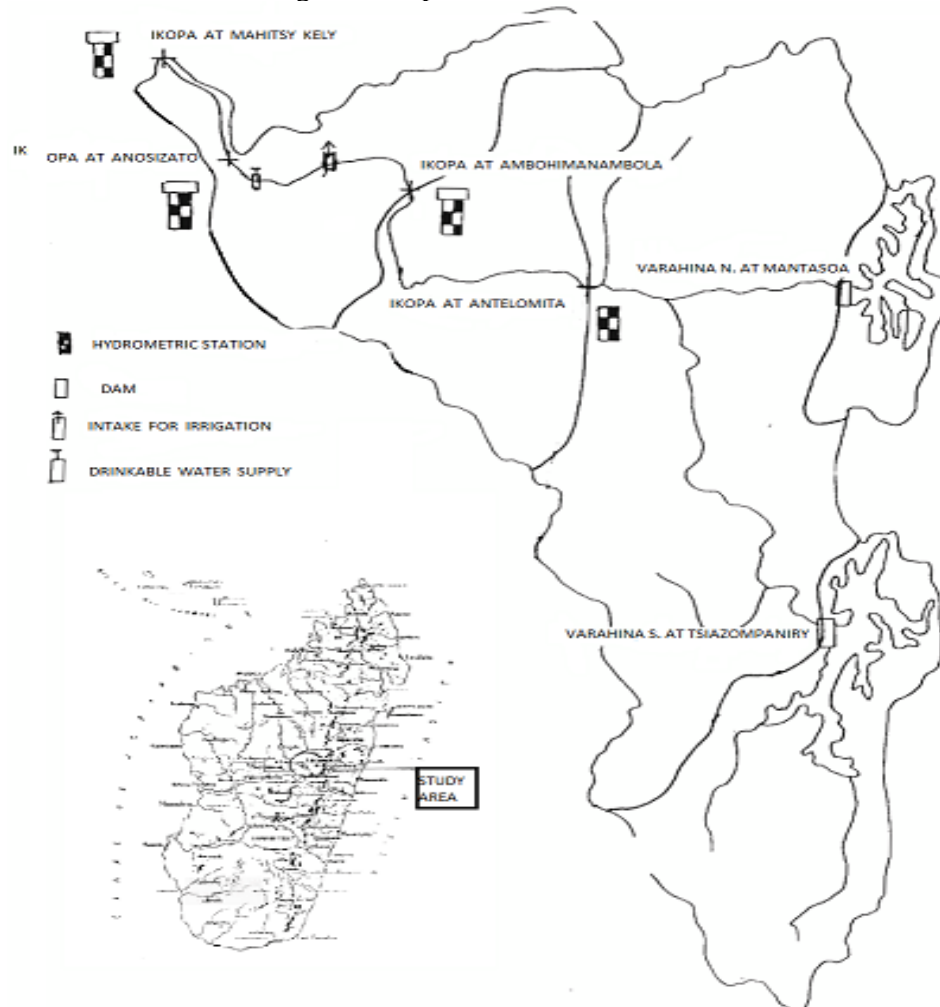
I. Introduction

Since the flood in 1959, many materials damages have been noticed in Antananarivo. So, it's necessary to take into account the risk in order to propose a flood modeling method applicable in the studied area. To solve the problem, a reservoir dam is one of the physical tools of water management. The presence of the reservoir dam leads a significant number of modifications into the natural hydrological cycle and, in particular, into the relation between the rain and the flows. Thus the objective is to propose an applicable modelization model facing the flood risk in order to integrate into a reliable and explicit ways within the structure of a simple and effective rain-flow model. In this case, the digital rain-flow model is used from the data in real time or of precipitations forecasts. The model can evaluate the flows on the watershed and its evolution in a point of a water stream for the reservoir dam management of global approach. Thus, many parameters are analyzed in order to suggest a methodology for the flood forecasting by estimating the performance and the sturdiness of the model. The adopted approaches based on, at the same time, the tools which are used in many countries, and the adapted modelization methods to the geographical and climatic contexts in Analamanga region for the Ikopa basin. This approach is the empirical model with continuous process called appreciable GR4J for its qualities of use, simplicity, effectiveness and thrift. It is about a daily model with four adjustable parameters [Perrin, 2002].

II. Study zone

Ikopa is one of the most important rivers in Madagascar by its considerable energetic potential and by its flow (exceptional intensity about 980 m³/s during the flood in 1959). The Basin of Ikopa belongs to the basins of the Highlands of Madagascar and is located in the South East of Antananarivo city, Analamanga Region. With its altitude of 1250m, its geographical co-ordinates are as follows: latitude of 18°51'S and longitude of 47°27'E. The average altitude is 1400m and the peaks of the basin, 1500m in the North and 1700m in the South; and the Varahina-North and the Varahina-South are the principal tributaries which constitute the water division line between the two slopes of the island, (fig. N°: 1).

Figure 1: Ikopa watershed localization



III. Data and methods

A. Hydrological parameters

The reservoir dam ensures the support of the flow of low water and the flood capping which are partially emptied before the rainy season. During the dry season, the flow is regulated, so the hydrological analysis leans on the data at the rainfall station of Ambohimananambola.

- The examination of the series of precipitations for the period (2001/2005) has revealed an annual rainfall average of 1388mm. Note that the rainy season begins in November until February which is the most abundant month.
- The maximum and the minimum annual average temperatures are respectively 26°C and 10°C.
- The dominant wind in our region of study is of South – East direction with a maximum average speed of 6 m/s in August.
- The average evapotranspiration is calculated by the method of Penman because it gives the best estimation of the ETP and for the application of the Genie Rural model.

B. Model structure and model GR4J operation

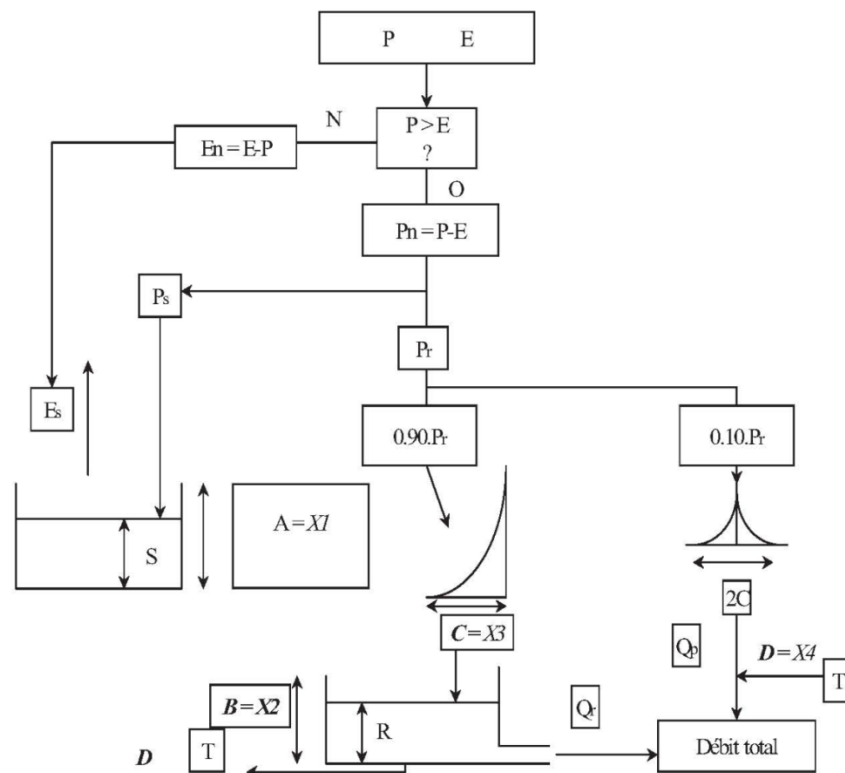
a – Model structure

The models GR are hydrological models of the Genie Ruural which are developed by the Antony CEMAGREF. These models belong to the family of the conceptual models with tanks. The model structure is based on the association of a production function and of a routing function.

b - Diagram of the model

The model rain – daily output GR4J (Genie Rural model with 4 daily parameters) is a global rain-flow model with four parameters making it possible to reproduce from data of rain of potential evapotranspiration the response in flow of catchment area. This model knew several versions, proposed successively by Edijatno and Michel (1989); Edijatno (1991); Nascimiento (1995); Edijatno and Al (1999); Perrin (2000) ; Perrin (2002)and Perrin and Al (2003)which is schematized on the figure below.

Figure n° 2: Structural diagram of the Model GR4J



GR4J is a total empirical hydrological model with four parameters which allow to reproduce from the rain data, flows, evapotranspiration as well as the watershed area. These parameters are required.

c - Principle and operation of the model

The principle of the method is based on the hydrological procedure of the “flood routing” i.e. the difference between the inflow and the outflow is equal to the variation of the stored volume during a small interval of time. This model works with various steps of time and is relatively simple to use. It uses four parameters of modelization as well as two tanks which allow to reproduce from the rain data, the potential evapotranspiration and the watershed flow response. Functions of production, routing and exchange allow to simulate the hydrological behavior of the basin. The parameters are determined by a calibration in order to minimize the differences between the observed and calculated series. From the level of the routing reservoir, the flow of the tank will form a part of the total flow to the outlet and the term underground exchange which will influence the quantity of outgoing water of the hydro gram to the outlet that gives the flow component.

f - Criteria choices of evaluation in control

The model validation is necessary to check evaluation criteria of the simulation quality which principle is to compare the simulated and observed flows. In this case, the numerical criteria are used to evaluate the performances of the model, a calibration procedure – cross control (Klemes1986). For the performance criteria, it's necessary to evaluate the following criteria:

- The criterion of Nash and Sutcliffe (1970) is the most used in hydrology which allows to judge the quality of representation of the set of flows; its formula is as follows:

$$Nash = 1 - \frac{\sum_{i=1}^n (Q_{Obs.i} - Q_{Calc.i})^2}{\sum_{i=1}^n (Q_{Obs.i} - \overline{Q_{Obs}})^2}$$

With $Q_{Obs.i}$: Observed flows with the step of time i,
 $Q_{Calc.i}$: Simulated flows with the step of time i,
 $\overline{Q_{Obs}}$: Average of the observed flows over the period,
n : Total number of steps of time of the study period.

- The balance sheet criterion of Nash serves to check the model operation; it's given by the following formula :

$$Nash = 1 - \left| \frac{\sum_{i=1}^n Q_{Cal.i}}{\sum_{i=1}^n Q_{Obs.i}} - \frac{\sum_{i=1}^n Q_{Obs.i}}{\sum_{i=1}^n Q_{Cal.i}} \right|$$

In general, the Nash criterion is a bad quality when its value is low (<70%), acceptable when it is higher than 70%, perfect when it is equal to 100%.

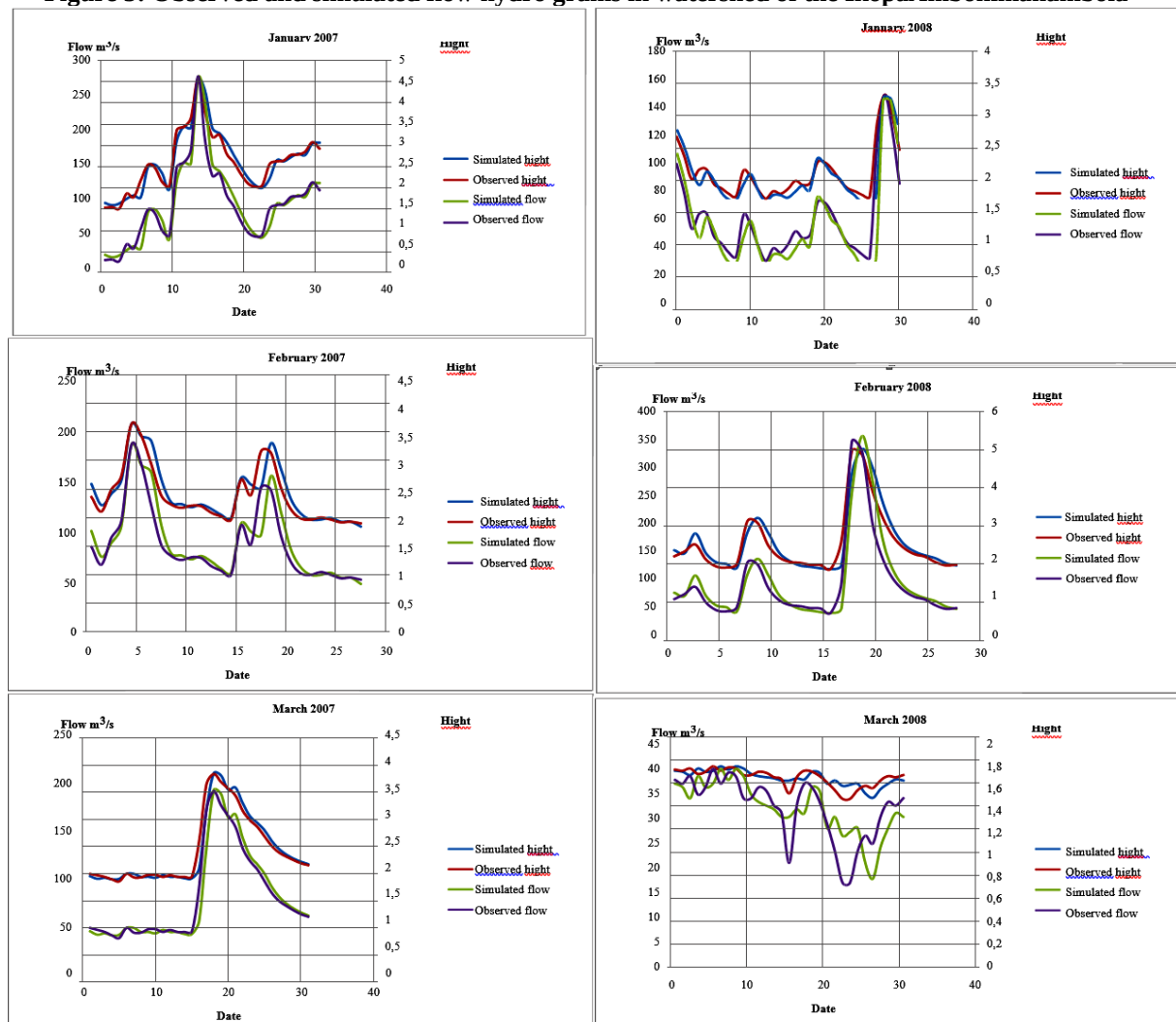
C. Methodology

The GR4J model, hydrological model or rain-flow, consists in calculating the flow at the time step in the watershed in response to the precipitations and evapotranspirations of the considered basin. To modelize the daily flow, the whole equations are used to the input model allowing, from weather entries (rain, potential transpiration evaporated (ETP), temperature...), to simulate an outlet flow. In order to study the quality of hydrological simulation by a total modelization rain-flow, the simulation is then evaluated in validation by the criteria of Nash. To carry out that, 04 years data are exploited (rain, evapotranspiration and flow), from 2001 to 2005, at the time step.

IV. Obtained results with the model

The results of the hydro grams of the simulated and observed flows on the basin of Ikopa are presented on the figure 3.

Figure 3: Observed and simulated flow hydro grams in watershed of the IkopaAmbohimambola



According to the observation found on the diagram in 2007, the pluviometry in Analamanga Region during February and January can characterize the rainy period, shorter, but very intense which causes big flood involving the dikes ruptures. The abundant rainfall causes risks of flood and inundation which correspond to an approximately flow of 350 m³/s. So, the rise of water further to a strong pluviometry is probably noted and the

low area in the study area (IVè district, Tanjombato, Soavina, AnosizatoAndrefana) can be threatened considering the value of the noted flood flow. If the flood of these zones worsens, the propagated of the risings of Ikopa in the left valley bank can cause many bad impacts from Anosimahavelona to the agricultural perimeters of the Communes of Alasora and Ankaraobato.

a – Obtained results with the simulation of the initial model

With the use of the Genie Rural model GR4J, the table n° 6 below represents the modelization results of the hydrograms on the basin of Ikopa entering to the dam of Antaramanana.

Table n° 1: Modelization results

YEARS	SIMULATED VOLUME	OBSERVED VOLUME	SIMULATED QMAX	OBSERVED QMAX
2006 – 2007	5 628 000	6 373 710	270 m ³ /s	267 m ³ /s
2007 – 2008	6 359 640	7 133 490	380 m ³ /s	344 m ³ /s
2008 – 2009	4 291 350	4 235 070	175 m ³ /s	123m ³ /s
2009 – 2010	4 221 000	4 516 470	174 m ³ /s	138 m ³ /s
2010 – 2011	4 221 000	4 037 090	160 m ³ /s	113 m ³ /s
2011- 2012	3 376 800	4 769 730	180 m ³ /s	153 m ³ /s

b– Retained results to the calibration and in the performance control

The results of the models performances evaluations on each station are presented in the table below.

Table n° 2: Obtained results with the initial model

STATION	Water stream	Retained results with the chock		I. Selected results in control with the performance	
		NASH(Q)	BIILAN	NASH(Q)	BIILAN
Ambohimambola	Ikopa	87.7	98.5	83.8	93.4
Anjeva	Ikopa	82.7	97.1	79.6	90.1
Alarobia	Ikopa	81.1	98.1	77.7	91.2
Antelomita	Ikopa	85.2	98.1	82.7	89.4
Volotsangana	Ikopa	84.8	97.4	70.1	88.9
Mantaoa	Varahina Nord	81.8	97.9	74.3	91.7
Tsiazompaniry	VarahinaSud	64.5	92.6	57.7	88.5

The obtained results in general are acceptable and improve globally when we go towards the downstream, but in particular, the results on the Ambohimambola station are rather better than those obtained on the other rivers because they are due to the significant number of the wastreams of Ikopa (Antelomota, Anjeva and Volotsangana) and to their irregular mode. Moreover in calibration, the performances of each criterion of evaluation are optimal.

V. Summary

In this study, a reliable and strong rain-flow model represents the hydrological response of watershed can be proposed: GR4J (*Perrin version et al. 2003*). The mathematical formulations of the model corresponding in terms of numbers of parameters (four) and to the production function of transfer which represent the generation process of the flows were gathered. We have tested the sensitivity of the model compared to each parameter as we have tested the observed couple data rain-flows in order to understand its operation. Since the obtained performances in calibration as in validation are in general higher than 70% whereas the results with the calibration on the objective function Q, and the obtained results after validation allow to note that the elaborated rain-flow modelization using the GR4J model presents very acceptable results for the average rains of IKopa. The results show the performance and the strength of GR4J model in the watershed of IKopa. In addition, the rain-flow models allow to simulate the output for a given point of a water stream on the corresponding watershed. In order to improve the risk management of flood on the level of Antaramanana dam, this modelization allows also to simulate the flows for various volumes of releases to the dam. The dam management would be improved, allowing at the same time to maximize the tank filling and to minimize the risks of overflow and flood downstream .Finally, we can conclude that the results from the application of the Genie Rural model to the data of the watershed of Ikopa are very satisfying for the daily used step of time.

VI. References

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