Modelling of the annual mode of the small rivers of high plateaus of Madagascar for Micro Hydroelectric power plant

Rija N. Randrianarivony [1(*)], Philippe Lauret [2], Zely A. Randriamanantany [1],
Jean Claude Gatina [2]

[1 (*)] IME – Institut pour la Maîtrise de l'Energie (IME), BP 566 University of Antananarivo
+2613204 08475, email: nirinarija@yahoo.fr, ime@univ-antananarivo.mg,
[2] LPBS –Laboratoire de Physique du Bâtiment et des Systèmes (LPBS), Université de La Réunion
BP 7151, 15 avenue René Cassin, 97715 Saint-Denis, France

ABSTRACT

The exploitation of New and Renewable Energy is a priority for the implementation of the policy of Decentralized Rural Electrification (DRE). The high plateau and the East slope of Madagascar abound in potentiality for the installation of micro and pico hydroelectric power plant. Unfortunately the lack of hydrological data penalizes the development of this choice. The modeling of the annual mode of the small rivers is then necessary to allow the reliability of the feasibility studies relatively short for the size of these power stations. The database of the 'Autorité pour la Protection contre les Inondations de la Plaine d'Antananarivo' (APIPA) are used during modeling with the Artificial Neural Networks (ANN). The global model obtained is parsimonious and ended in satisfactory results allowing the reconstitution of the annual mode of the small rivers with weak hydrological data.

Keywords: rainfall-runoff models, catchments, Artificial Neural Network, Micro Hydraulic Power station

INTRODUCTION

According to the National Balance of Energy, wood is still by far the source most used in Madagascar. This is the reflection of the geographical distribution of the population and also the fact that the energy consumption is primarily domestic. To date only less than 20 % of Malagasy households have access to electricity **[1]**.
By taking into account the climate change in the choice of the energy system, the systems with new and renewable energies are prioritized.
The Ministry for Energy and the Mines identified nearly 300 sites whose combined annual power is approximately 7.000 MW and which can produce 60.000 GWh of electricity. However the power currently installed does not exceed 250 MW on all the territory all sources confused, that represents only the 3% of the potential power. The six provinces of Madagascar are equipped with hydraulic resources. 30 sites can develop a power beyond 50MW, 70 sites between 1 and 5 MW, and 200 sites are in the interval of potential power lower than 100 kW.
The sites of power less than 50kW are much more numerous and meet the needs for the Communes or rural localities for Madagascar. The conference of Lome and that of Katmandou in 1979 raised the possibility of feeding a hundred dwellings with power of 30 kW **[2]**.
The MCH are exploited in a durable way, and then the data of long durations are appreciated and solicited. The goal of this paper is to highlight the capacity of the ANN to model the interannual daily medium flows of the rivers with very few data recorded on site.

THE ARTIFICIAL NEURAL NETWORK (ANN)

One finds various introductions on the ANN into the literature, but it is significant to reiterate its inspiration by the biological neuron [**3**]. The formal neuron is represented in the most convenient way with the *figure 1a*. The inputs of the neuron are the variables on which the neuron operates, and the output is the value of the activation function *f* often sigmoid.

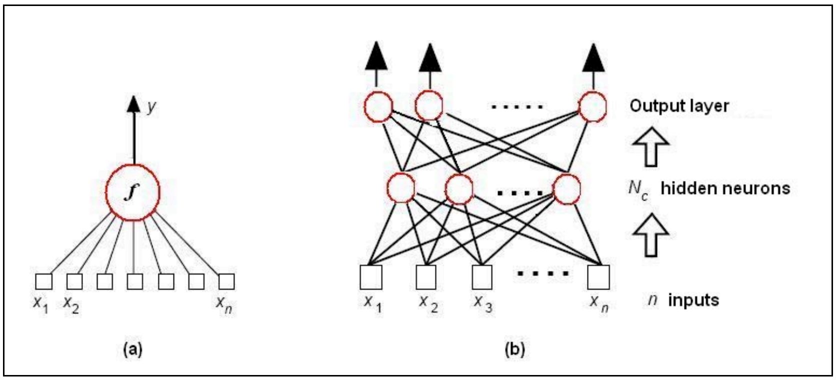

Figure 1. The formal neuron and the Multi-Layer Network

The parameters are attached to the entries of the neuron; the output of the neuron is a nonlinear function of a combination of the inputs x_i with the w_i which are often called under the name of "weight". The potential v most frequently used take the form of (1), in which the term w_0 is called "bias":

$$f(\nu) = f\left(w_0 + \sum_{i=1}^{n} w_i x_i\right) \qquad (1)$$

A neuron fulfils simply a nonlinear parameterized function, of its input variables. The advantage of the neurons lies in the properties which result from their association in networks, i.e. of the composition of the nonlinear functions fulfilled by each neuron. The interest of the use of the ANN in hydrology is its capacity to reflect the non linearity inherent in the relation rainfall-runoff without entering the process (black box). It is an interesting property to consider only the weather parameters.

There are several types of structure of ANN. To model the annual mode of the rivers, we choose the structure of the Multi-Layer Perceptron (MLP) (*Figure 1b*). A traditional phase of training consists in allotting initial values to the whole of the weights and bias, and minimizing then a quadratic function error using the training data set and an algorithm of training derived from method of rétropropagation of the error **[4]**.
One presents at the neuronal model a whole of values in input, which values at output are associated. After several passages on the training data set, the network learns the relation existing between the variables from input and the variable of output. Once the training is finished, the network is, a priori, able to generalize, i.e. to give correct outputs when other unseen inputs are introduced to him during the test.
To appreciate the performances of the models, one called upon the R^2 criterion defined by **[5].**

$$R^2 = 1 - F^2 / F_0^2 = 1 - \frac{\sum_{i=1}^{n}\left(Q_{obs,i} - Q_{calc,i}\right)^2}{\sum_{i=1}^{n}\left(Q_{obs,i} - \overline{Q_{obs}}\right)^2} \qquad (2)$$

This variable criterion in the interval] - ∞, 1] has the advantage of being easy to interpret. It estimates the improvement of adjustment which one obtains by using the model to simulate the flows compared to a model “zero” (reference model) which would give over all the period considered a constant flow equal to the medium flow. The computer code is developed under Matlab with the Netlab Toolbox **[6]**.

DATA AND STUDY AREA

The database used is obtained with the contribution of the service of the hydrology of Madagascar by the means of the Authority for Protection against the Floods of the Plain of Antananarivo (APIPA), the organization which undertakes of the prevention of the flood in the basin of Ikopa. These data cover the years 2001 to 2004.
The APIPA has equipment of advertisement of raw which is composed of 18 sites measuring automatic of rain and/or of flow in the catchments area of Ikopa upstream of Bevomanga (4 300 km²). What interests us are the affluent upstream which are in the basins smaller and lower than 300 km² for an adjustment of the Pico or micro hydroelectric production.

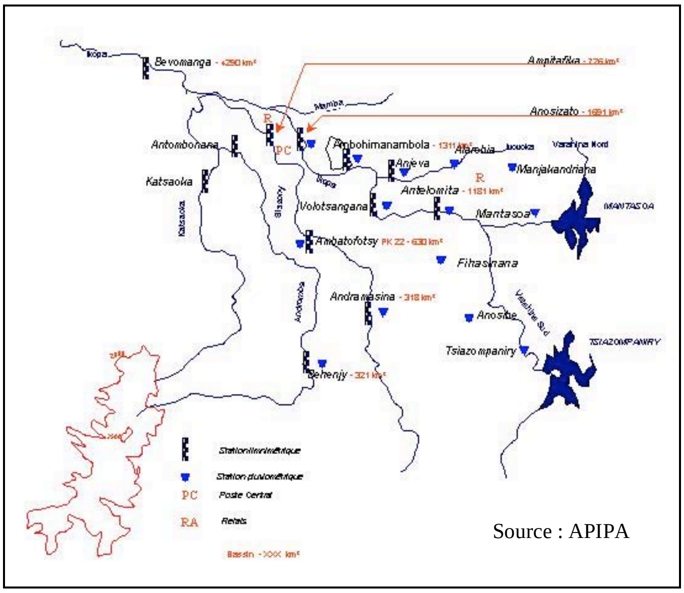

Figure2: Network of flood warning of Antananarivo

Only stations equipped at the same time with measurements the rain and flow or limnimetric height which interests us for our rainfall-runoff modelling. Thus the five stations with knowing Ambohimanambola, Anjeva, Volotsangana, Andramasina and Ambatofotsy are retained. The first three stations are on three basins different from Ikopa and the two last on the same course from Sisaony.
The hourly data available are converted into daily data. We took the limnimetric height only at a fixed hour of the day because of the recommendation in hydrology [**7]** and the rainfall collected during the earlier 24 hours. The highlands and Eastern slope of Madagascar represent similarities in term of geology and pluviometry [**8]**, which justifies the choice of the area of study.

RESULTS AND DISCUSSIONS

The models are fixed for a test base which is complete for 365 days of the year. The minimum criterion of Nash observed is 0.53. This result is obtained at the station of Anjeva during the year 2003 (*Figure 3c*). For the station of Ambohimanambola this criterion is 0.85. This low performance for Anjeva is caused by the existence of the extraordinary peaks in the neighbourhoods of 340th day that we still see on *the Figure 3c* in spite of the calculation of the average between 2002 and 2003.

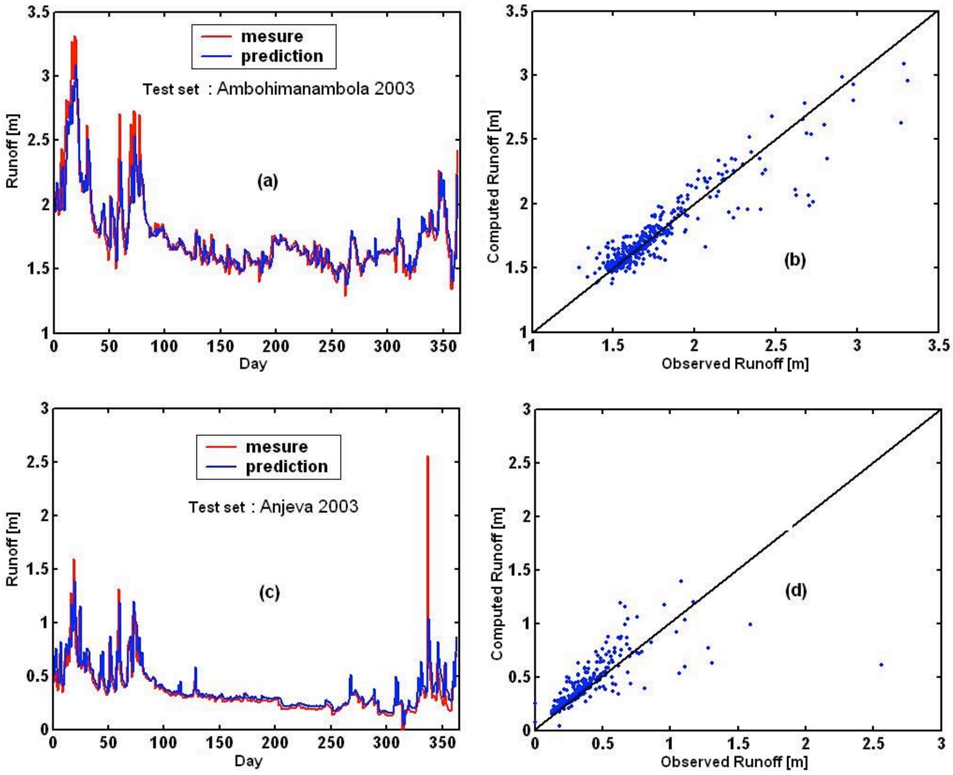

Figure 3. Mode during the year 2003 for the station of Anjeva and Ambohimanambola, output errors

Figure 4 shows the results of forecast with rainfall mean data between 2002 and 2003 and only the data of 30 days measurement. Then the test base is supplemented progressively in height of river predicted with the average of the rainfall records for two years. The predicted height of the river is then supposed to be the daily average height during the considered period of two years.

The criteria of Nash recorded on Anjeva and Ambohimanambola are respectively 0,10 and 0,46. It is about the presentation of extreme results recorded on the level of two basins. The fall of the performance is foreseeable but these results obtained shows that the models represent the annual mode of the rivers absolutely better than the annual medium flow.

The presence of the seasonality is always marked in all the cases. The fluctuation of the curves is due to the fact that the prediction is dictated by the rainfall. Pluviometry always presents jumps even if the mean were carried out. The two years average does not manage to smooth pluviometry.

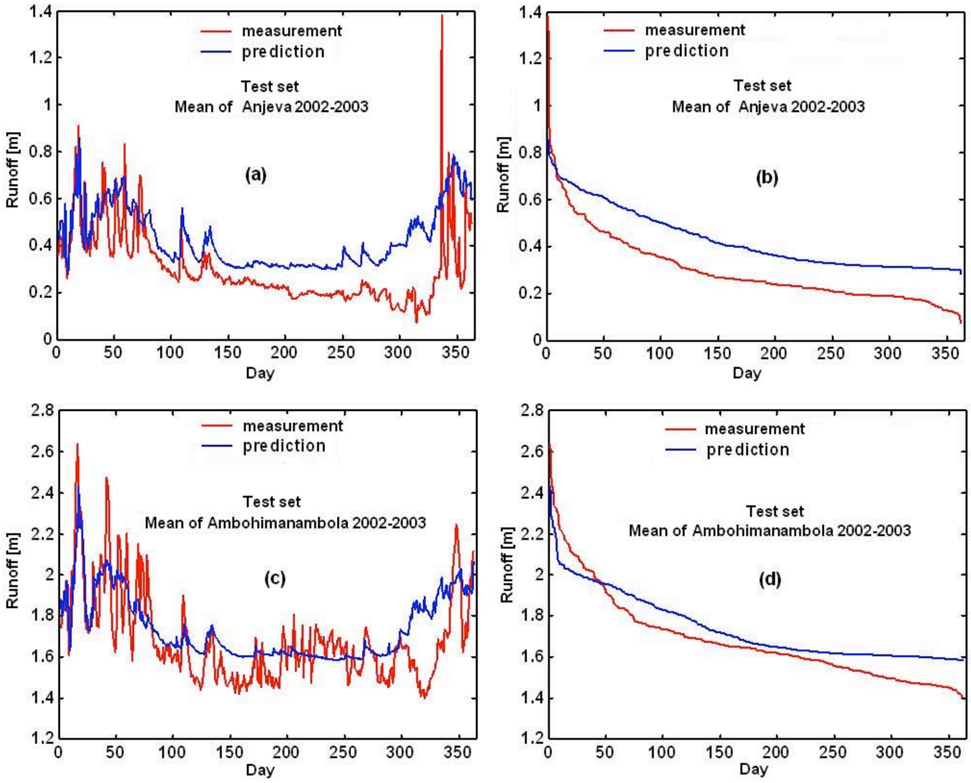

Figure 4. Daily average height during 2002-2003 for the station of Anjeva and Ambohimanambola; classified heights

For exploitation in hydroelectric conversion, the load curve classified is definite like the curve giving the history of the daily medium flows of a site, classified according to the percentage of the time when the flow is equal to or higher than this flow, is proposed. The relation between the flow and the height of water is purely algebraic that it is allowed to us to directly use the latter (*Figure 4.b,* d).

CONCLUSION

Also one can conclude that with the rainfall data and some height or flow recorded on site, the ANN shows its capacity to reproduce the annual mode of small rivers in our area study. That represents an enormous profit for the rapid evaluation of their hydroelectric potential.
According to our findings the two years average is not enough to smooth the curves. But already over the two years, the exploitation of the curves heights classified for the evaluation in hydroelectric potential is more reassuring in term of efficiency compared to the very simple use of minimum flow of low water level of the year of measurement. Indeed the minimum flow changes according to whether the year is surplus or overdrawn in pluviometry. Whereas according to the curves, the assured height of river during 300 days is closer to the prediction than the minimal height. The existence of the rainfall records of several years gives more insurance to the curve classified heights obtained by the model.

REFERENCES

[1] Ministère des Finances et de l’Economie /INSTAT/UE, 2006, Enquête Périodique auprès des ménages 2004,Appui à la mise en place d’un système national intégré de suivi de la pauvreté.

[2] Monition, L., Le Nir, M., Roux, J., 1981.Les Micro Centrales Hydroélectriques. Edition Masson, Paris, 188p.
[3] McCulloch, W.S., Pitts, W., 1943. A logical calculus of the ideas immanent in nervous activity. Bulletin of Mathematical Biophysics. 5, 115-133.
[4] Rumelhart, D.E., Hinton, G.E., Williams, R.J., 1986. Learning internal representations by error propagation. Parallel Distributed Processing. 1, 318–362.
[5] Nash, J.E., Sutcliffe, J.V., 1970. River flow forecasting through conceptual models. Part I—a discussion of principles. Journal of Hydrology. 10, 282–290.
[6] Nabney, I.T., 2002. Netlab: Algorithms for Pattern Recognition. Springer-Verlag, London, U.K
[7] World Meteorological Organisation, 1987. Intercomparison of Conceptual Models Used in Operational Hydrological Forecasting. Rapport d'hydrologie opérationnelle N° 7, OMM–N° 429, Genève.
[8] Chaperon, P., Danloux, J., Ferry, Luc., 1993. Fleuves et Rivières de Madagascar. Editions IRD. Paris.