Statistical Comparison of nonlinear rainfall-runoff models for simulation in Africa North-West semi-arid areas

Ouafik Boulariah[1], Antonia Longobardi [2], Mohamed Meddi[1],

[1]LGEE – Ecole Nationale Supérieure d'Hydraulique de Blida B.P.31 09000 Blida Algérie

[2]Department of Civil Engineering, University of Salerno, Fisciano (SA), Italy

*corresponding author: o.boulariah@ensh.dz

Abstract

Determining the relationship between rainfall and runoff for a watershed is one of the most important problems and challenging task faced by hydrologists and engineers. Conceptual hydrological models represent most suitable tools for this purpose in case of data scarcity. In this work we set up a comparative study between two conceptual nonlinear models, the GR2M and the ABCD, applied to semi-arid catchments located in north-west of Algeria. Monthly rainfall, temperature and stream flow data are available for the period 1971-2010. Overall, in calibration, the two models perform similarly, whereas the results show that the GR2M model performed better than the ABCD in the validation phase. Such circumstance could be caused by different motivations. On one side the different number of model parameters that make the ABCD the less parsimonious approach, with four parameters to be calibrated. On the other side the inability of the ABCD model to capture and describe the groundwater processes, important for the cases study. Moreover the validation phase embeds a large drought period, started in late 1980s, which makes difficult model adaptation to different hydrological regimes.

Keywords: Statistical comparison, non-linearity, GR2M, ABCD.

1. Introduction

Much research has been conducted during the last century to address the modeling of the relation between rainfall and runoff. To simulate this relation in a hydrological catchment two essential issues have to be investigated, the hydrological knowledge of the catchment and the observed data (Tiwari and Chatterjee, 2010; Hosseini and Mahjouri, 2016). The African northwestern Region, and particularly Algeria, has experienced a decrease in mean annual precipitation as showed by Gobanova and Meddi (2007). In this aspect, the Tafna and the Oranian coastal basins represents useful and interesting case studies but they have been only sporadically investigated from their scientific perspective, especially for what concerns the relation of rainfall-runoff. In this paper, conceptual non-linear hydrological model are used to analyze the hydrological cycle for three different catchments locate in north-west of Algeria. According to Bouanani *et al*. (2017), the simulation of the transformation of rainfall-runoff in the North West of Algeria using the models developed by Cemagref GR indicates that the "reservoir models" are more reliable and indicated than a model of the "black box" type (Xiong *et al*., 2001), The same line of research has been developed by many scientists such us (Kabouya, 1990; Kabouya and Michel, 1991; Makhlouf, 1994; Makhlouf and Michel, 1994; Mouelhi, 2003; Mouelhi *et al*., 2006a). In this paper, beyond the GR model (Mouelhi, 2006) with two parameters, the ABCD model with four parameters (Thomas, 1981) is further applied, on a monthly time step. This topic was selected to know the model that more effectively simulates the monthly flows in a semi-arid climate in the western north of Algeria, based on a comparison of a various statistical index such as BIAS, RMSE, and NSE. The results of the simulations will help understand if conceptual models are suitable for this area or whether it is needed to move to other classes of hydrological model, either more physically based or purely statistical.

2. Case of study

The area of study, located at the Western North of the Algerian territory, extends on totality from the province of Tlemcen and Oran on a total surface of about 13000 km^2. The present study bases on three sub-basins, two located in the Oranian coastal area (Wadi Tlata and Wadi Mellah) and the other in the basin of the Tafna (Wadi Chouly). Their surfaces are respectively 95km^2, 720km^2 and 170km^2 and their location is illustrated in Figure 1. On the geologic plan, the Oranian coastal is characterized by a rubbing karstic formation (Benest, 1985) more than **70%** with an important permeability thus the presence of the large Sabkha of Oran (water with strong salinities) in the east of the catchment (Peron, 1883). Catchments formed by materials with an important permeability as Karst they ensure an important infiltration of surface waters (Amin *et al*., 2017). In the hydrological plan, according to (Taibi *et al*., 2017) studies of precipitation shows that in the western of Algeria mark an offset in precipitation. The Oranian

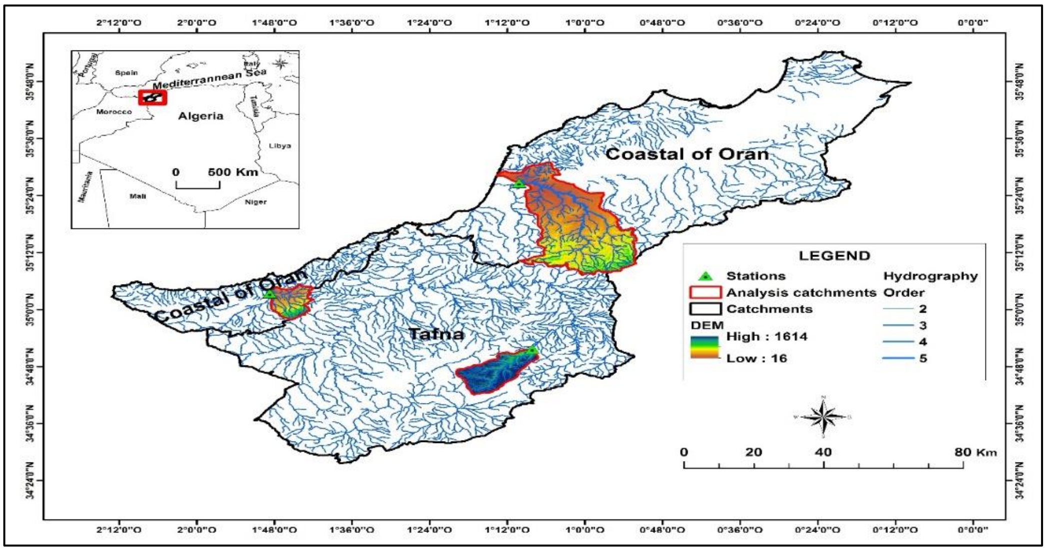

Figure 1: Location of the Study Area.

coastal is characterized by a significant decrease in rainfall since the middle of the 1970s.

3. Methodology

In this paper, due to data scarcity the class of the conceptual hydrological models has been selected. In particular the GR2M (Makhlouf and Michel, 1994), and the ABCD (Thomas, 1981) have been applied. For both models, input requires precipitation, potential evapotranspiration and runoff at the monthly scale. The number of parameters is limited to two for the GR2M and four for the ABCD. Model parameters have been estimated through a classical calibration phase and then used in a validation phase for final statistical assessment and comparison.

4. Description of models

The GR2M model knew several versions, proposed in the past by different authors (Kabouya, 1990; Kabouya and Michel, 1991; Makhlouf, 1994; Makhlouf and Michel, 1994; Mouelhi, 2003; Mouelhi *et al*., 2006a), which made it possible to improve gradually the performances of the model. We presented in this paper the version proposed by Mouelhi *et al*., (2006a) which appears the most powerful. The two free parameters of GR2M are X1, the soil moisture storage maximum capacity (mm), and X2, the water exchange term with neighboring catchments (mm).

The ABCD water balance model is a simple hydrologic model for simulating stream flow in response to precipitation and potential evapotranspiration developed by (Thomas, 1981). The model is comprised of two storage compartments: soil moisture and groundwater. The structure of the ABCD model shown detailed in (Thomas, 1981). The soil moisture gains water from precipitation and loses water to evapotranspiration (ET), surface runoff and groundwater recharge. The groundwater compartment gains water from recharge and loses water as discharge. The total streamflow is the sum of surface runoff from the soil moisture and groundwater discharge. The two parameters of the ABCD model are **a**, controls the amount of runoff and recharge that occurs when the soils are under-saturated. **b**, controls the saturation level of the soils. **c**, defines the ratio of groundwater recharge to surface runoff. **d**, controls the rate of groundwater discharge

5. Rainfall-runoff relationship simulation results

To predict the monthly runoff, we use as input the data of observed rainfall (mm) and runoff (mm). For the potential evapotranspiration, we applied for the calculated by the method of Thornthwaite (Valipour *et al*., 2017) from series of monthly average temperatures. For the calibration and the validation of each model, we used the data of the following time interval (Table 1). The way of calibration consisted to determine the optimal parameters from the different quality criteria. We held the parameters for which the quality criteria are optimal. To compare the results of each model, we applied the root mean square error (RMSE; (Hyndman and Khandakar, 2006)), bias and Nash-Sutcliffe coefficient of model efficiency (Nash and Sutcliffe, 1970).

$$RMSE = \left[\frac{1}{n} \sum_{i=1}^{n} (Q_{\mathrm{mod},i} - Q_{oss,i})^2 \right]^{1/2} \quad (1)$$

$$NSE = 1 - \frac{\sum_{i=1}^{n} (Q_{oss,i} - Q_{\mathrm{mod},i})^2}{\sum_{i=1}^{n} (Q_{oss,i} - \overline{Q}_{oss})^2} \quad (2)$$

$$BIAS(\%) = \frac{\sum_{i=1}^{n} (Q_{\mathrm{mod},i} - Q_{oss,i})}{\sum_{i=1}^{n} Q_{oss,i}} * 100 \quad (3)$$

Qobs and Qsim are respectively the values of observed and simulated runoff, Qobs is the average value of Qobs, N is the number of observations. The RMSE represent the average measurement of the error in the simulation but it does not provide any information on differences in phase. The Bias index represent the average of all the various errors and supervise if the models are over or underestimated. The coefficient of effectiveness for models of Nash- Sutcliffe, one of the indices is the most used for the evaluation of the estimated power of the hydrological models (Moriasi *et al*., 2007). Values for the calibrated parameters and indexes statistics for the calibration and validation phases are illustrated respectively in Table 2 and

Table 3. Figure 2 illustrates moreover the visual comparison between observed and modelled time series, for the GR2M approach.

Table 1: Calibration and validation periods of the model

		Calibration	validation
TAFNA	**Chouly Wadi**	1971-1988	1995-2006
Oranian Coastal	**Tlata Wadi**	1979-1989	1990-2010
	Mellah Wasi	1979-1990	1990-2011

[a] **[b]**

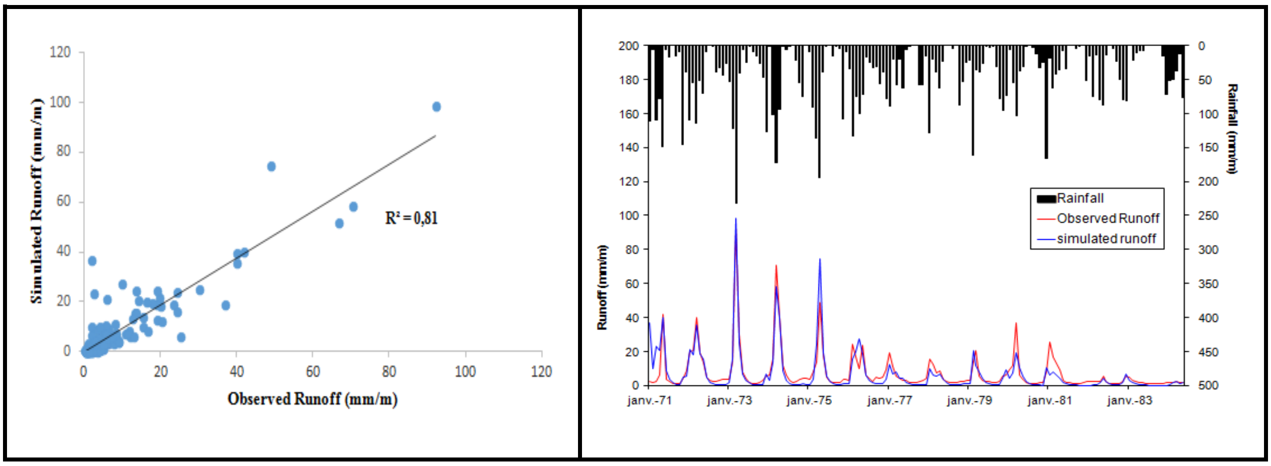

Figure 2: Results of calibration obtained by the GR2M model; (a) Display of the quality of the calibration; (b) Correlation between observed and simulated Runoff.

Table 2: Calibrated model parameters for the two consider conceptual hydrological models.

Models	**ABCD**				**GR2M**	
Basins/Parameters	**a**	**b**	**c**	**d**	**X1**	**X2**
Chouly Wadi	0,39	17,95	0,44	0	5,6	0,8
Tlata Wadi	0,35	6	0,38	0	4,53	0,55
Mellah Wadi	0,52	12,21	0,94	0	7,13	0,66

Table 3: Calibration and validation performance statistics for each model and for each modelled catchment.

		Calibration phase				**Validation phase**			
Catchment	**Model**	**RMSE**	**NSE**	**BIAS**	**R2**	**RMSE**	**NSE**	**BIAS**	**R2**
Chouly Wadi	GR2M	1,44	0,85	-16,82	0,81	0,34	0,7	16,18	0,76
	ABCD	1,38	0,9	-19,31	0,91	0,21	0,66	-8,48	0,48
Tlata Wadi	GR2M	0,016	0,84	-0,68	0,78	0,46	0,73	24,08	0,74
	ABCD	0,34	0,84	-14,37	0,85	0,14	0,65	7,51	0,7
Mellah Wadi	GR2M	0,37	0,29	-24,4	0,11	1,15	-0,1	-77,63	0,08
	ABCD	0,025	0,31	1,65	0,32	0,3	0,18	-21,45	0,06

6. Discussion and conclusion

Model performances (Table 3) during the calibration phase appear almost similar and good, with an exception for the results obtained for the Wadi Mellah, where the model calibration neither for the GR2M nor for the ABCD provided high values for the goodness-of-fit statistics. A large underestimation of the ABCD is furthermore to be highlighted for the Wadi Tlata catchment compared to the same results provided by the GR2M simulation. Models performance during the validation period appear worst but still on an acceptable standard, especially for what concerns the GR2M model, featured by the largest NSE and coefficient of determination for both the Wadi Chouly and the Wadi Tlata catchments. The worst performance of both models during the validation phase is in part due to the fact the model parameters have been adapted and are optimal for a different period but it might be also due to the long drought period embedded into the validation time interval, that affected the area from late 1980s. Calibrated parameters illustrated in Table 2 provide more insights about the different performance for the GR2M and the ABCD model. As a first point the ABCD model is the less parsimonious approach, with four parameters to be set. Such circumstance clearly makes the model less flexible and less adaptable to changes in hydrological regimes. Model parameters for the GR2M appear similar for all of the analyzed catchments. This feature is typically important in the case the model is used for regional scale prediction. The ABCD parameters are instead rather variable for the three catchments. This circumstance is probably caused by the adaptation of the different hydrological processes embedded in the model structure to the different case study. What appear quite clear is the inability of the ABCD model to capture and describe the groundwater processes (d=0), which is of particular importance for the cases study. The bad performance obtained for the Wadi Mellah is probably to be seek in the particular geological properties of the catchment for which the hydrological process included in the conceptual models do not represent probably the actual hydrological water balance. Statistical models, without either a physical or conceptual base, are advisable for this particular case.

Reference

Akognongbé A. (2008) Contribution à l'étude de la caractérisation hydropluviométrique avec le modèle GR4J sur le bassin de l'Ouémé à Savè et Atchérigbé. Mémoire de maîtrise en géographie. UAC: 79p.

Amin, M. M., Veith, T. L., Collick, A. S., Karsten, H. D., & Buda, A. R. (2017). Simulating hydrological and nonpoint source pollution processes in a karst watershed: A variable source area hydrology model evaluation. Agricultural Water Management, 180, 212-223.

Beven, K., & Wood, E. F. (1983). Catchment geomorphology and the dynamics of runoff contributing areas. Journal of Hydrology, 65(1), 139-158.

Hosseini, S. M., & Mahjouri, N. (2016). Integrating support vector regression and a geomorphologic artificial neural network for daily rainfall-runoff modeling. Applied Soft Computing, 38, 329-345.

Hyndman, R.J. and Khandakar, Y., 2006. Automatic time series for forecasting: the forecast package for R (No. 6/07). Melbourne: Department of Econometrics and Business Statistics, Monash University. https://ideas.repec.org/p/msh/ebswps/2007-6.html

Kabouya, M., 1990. Modélisation pluie-débit aux pas de temps mensuel et annuel en Algérie septentrionale. Thèse de Doctorat, Université Paris Sud Orsay, 347 pp.

Kabouya, M. et Michel, C., 1991. Estimation des ressources en eau superficielle aux pas de temps mensuel et annuel, application à un pays semi-aride. Revue des Sciences de l'Eau 4(4), 569-587.

Makhlouf, Z., 1994. Compléments sur le modèle pluie-débit GR4J et essai d'estimation de ses paramètres. Thèse de Doctorat, Université Paris XI Orsay, 426 pp.

Makhlouf Z., Michel C. (1994) A two parameter monthly water balance model for French Watersheds Journal of Hydrology. 162 299-318

M. Benest, Evolution de la plateforme de l'Ouest algérien et du Nord - Est Marocain au cours du Jurassique supérieur et au Crétacé : Stratigraphie, milieux de dépôts et dynamique sédimentaire. Thèse de Doctorat, Lab. Géol., Univ, Lyon1. Fasc. I et II, (1985) 367 p.

M.K. Tiwari, Ch. Chatterjee Development of an accurate and reliable hourly flood-forecasting model using wavelet-bootstrap-ANN (WBANN) hybrid approach J. Hydrol., 394 (2010), pp. 458–470

Moriasi, D.N., *et al.*, 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE, 50 (3), 885–900. doi:10.13031/2013.23153

Mouelhi, S. (2003). Vers une chaîne cohérente de modèles pluie-débit conceptuels globaux aux pas de temps pluriannuel, annuel, mensuel et journalier.

Mouelhi, S., Michel, C., Perrin, C. et Andreassian, V., 2006a. Linking stream flow to rainfall at the annual time step: the Manabe bucket model revisited. Journal of Hydrology 328, 283-296, doi:10.1016/j.jhydrol.2005.12.022.

Nash, J.E. and Sutcliffe, J.V., 1970. River flow forecasting through conceptual Models part I — A discussion of principles. Journal of Hydrology, 10 (3), 282–290. doi : 10.1016/0022-1694(70)90255-6

Peron, A. (1883). Description géologique de l'Algérie. Éditions Masson, Librairie de l'académie de médecine, Paris, 8.

Sherman, L. K. (1932). Streamflow from rainfall by the unit-graph method. Eng. News Record, 108, 501-505.

Taibi, S., Meddi, M., Mahé, G., & Assani, A. (2017). Relationships between atmospheric circulation indices and rainfall in Northern Algeria and comparison of observed and RCM-generated rainfall. Theoretical and Applied Climatology, 127(1-2), 241-257.

Thomas, H. A. (1981). Improved methods for national water assessment, water resource contract WR15249270, USGS unnumbered series, Harvard Water Resources Group.

Valipour, M., Sefidkouhi, M. A. G., & Raeini, M. (2017). Selecting the best model to estimate potential evapotranspiration with respect to climate change and magnitudes of extreme events. Agricultural Water Management, 180, 50-60.

Wei, C. C. (2016). Comparing single-and two-segment statistical models with a conceptual rainfall-runoff model for river streamflow prediction during typhoons. Environmental Modelling & Software, 85, 112-128.

Xiong, L., Shamseldin, A. Y., & O'connor, K. M. (2001). A non-linear combination of the forecasts of rainfall-runoff models by the first-order Takagi–Sugeno fuzzy system. Journal of hydrology, 245(1), 196-217.

Zhao *et al*, 1980 Zhao, R.J., Zhuang, Y.L., Fang, L.R., Liu, X.R., Zhang, Q.S., 1980. The Xinanjiang model. In: Hydrological Forecasting Proceedings Oxford Symposium, IAHS, pp. 351–356.