International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:12, No:1, 2018

Hydrological Modeling of Watersheds Using the Only Corresponding Competitor Method: The Case of M'Zab Basin, South East Algeria

Oulad Naoui Noureddine, Cherif ELAmine, Djehiche Abdelkader

***Abstract*—**Water resources management includes several disciplines; the modeling of rainfall-runoff relationship is the most important discipline to prevent natural risks. There are several models to study rainfall-runoff relationship in watersheds. However, the majority of these models are not applicable in all basins of the world. In this study, a new stochastic method called The Only Corresponding Competitor method (OCC) was used for the hydrological modeling of M'ZAB Watershed (South East of Algeria) to adapt a few empirical models for any hydrological regime. The results obtained allow to authorize a certain number of visions, in which it would be interesting to experiment with hydrological models that improve collectively or separately the data of a catchment by the OCC method.

***Keywords*—**Empirical model, modeling, OCC, rainfall-runoff relationship.

I. Introduction

MODELING that can provide a holistic understanding of the technology at a fundamental level are of great necessity. Compared to experimental research and development, followed by commercialization of the technology, modeling studies are at a relatively rudimentary state [1]. Hydrological modeling is important for watershed management as hydrology is the driving force behind many processes occurring on the watershed [2]. Rainfall-runoff models are standard tools for hydrologic analysis. These models are used for applications such as water resources studies and flood forecasting [3]. Physically, these models based on mathematical representations of physical phenomena [4], [5]. Knowledge of the hydrologic behavior of a watershed is essential for the management of that watershed and the related water resources. It is also required for the construction of models that are capable of predicting the watershed's outflow hydrograph. Such a model has been developed for small nonhomogeneous anisotropic basins [6]. In terms of landscape properties, watersheds present a wide range of heterogeneity, and the spatial variation in climate data is complex. Therefore, the homogenization of hydroclimatic data facilitates the understanding of the hydrological behavior of watersheds in different axes. [7] Conceptual rainfall-runoff (CRR) models have become widely used for flood forecasting as the demand for timely and accurate forecasts has increased. The dominant processes at the sub-basin scale contribute to the overall hydrological response at the watershed scale. These processes are described in detail and precisely by hydrological models. [8].

To obtain reliable predictions the most important problem for all models is the requirement a certain degree of calibration. [3], [9], [10], in which process the model parameters are adjusted (manually or automatically) until the observed and simulated watershed responses match as closely as possible [11], [12]. The OCC method is an approach to solving complex optimization problems because of their better performance compared to other tools. In this study, this method has been successfully applied to the study the hydrological behavior of the basin from its first test to control the adaptation of the empirical formulas used in Algeria. This method is applied to the M'Zab basin through Ghardaïa Province (Wilaya) (south-eastern region of Algeria). To generalize the use of this approach, several tests on the majority of watersheds of the world become necessary.

Oulad Naoui Noureddine and Djehiche Abdelkader are with the University Ammar Telidj-Laghouat, Algeria (phone: (+213) 29.93.17.91, fax: (+213) 29.93.26.98, e-mail: noure_hydraulique@yahoo.fr, djehichea@yahoo.fr).

Cherif ELAmine is with the University of Science and Technology of Oran Mohamed Boudiaf - BP. 1505, El M'Naouer Oran, Algeria (phone: (+213) 41.56.03.29, fax: (+213) 56.03.01, e-mail: cherif_ea@yahoo.fr).

II. Materials and Methods

A. The OCC Method

The OCC method is a stochastic optimization method based on the mechanism of random selection of individuals and of a solidarity phenomenon. This method starts randomly by an initial population of individuals in such a way that they lead in a competition during succession of iterations called simulations. Between the simulations, individuals submit methods of calculation of the minimum error in such a way that these methods will transform the population to favor the emergence of better individuals. The performance of individuals is evaluated through the objective function, and in the resulting total population (the common individual), all individuals allowed to survive are designated to create a new Population of S individuals. The loop is rotated, and a selection phase is recommenced for re-evaluation, a translation phase of individuals to the OCC and so on. For the method of the OCC, a stop criterion makes it possible to leave the loop; it is the cloud condensation of individuals which translates by graphical representation of objective function variation during the simulations (Fig. 1).

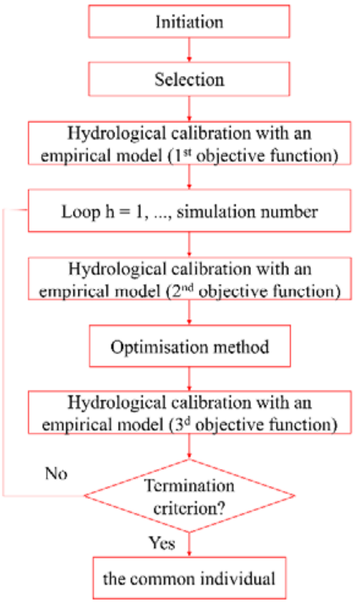

Fig. 1 Operation of the OCC method

B. Empirical Models

Many pre-determination tools are empirical models, these models based on a very schematic representation of the functioning of a watershed. The predetermination of the exact values of the projected flows in the absence of the hydrometric data is based on the empirical models. There are several formulas that calculate the projected flows rates, which are distinguished as: the formula of Mallet-Gauthier (Q / MG), Sokolovsky of the formula (Q / SOK), the formula Giandotti (Q / GIA), the formula for Possenti (Q / MW), ((1)-(4)).

$$Q/MG = 2.K.\log\left(1 + 20.P_{moy}\right)\frac{S}{\sqrt{L}}.\sqrt{1 + 4.\log(T) - \log(S)} \quad (1)$$

$$Q/SOK = \frac{0{,}28.(P_t - H_0).\alpha p\%.F.S}{T_c} \quad (2)$$

$$Q/GIA = \frac{C.S.(H_{moy} - H_{min})^{\frac{1}{2}}}{4.(S)^{\frac{1}{2}} + 1{,}5.L}.P_t \quad (3)$$

$$Q/PO = \frac{\mu.Pj_{max}.S}{L_p} \quad (4)$$

where Q/MG the flow value is estimated by using the formula Mallet -Gautier; Q/SOK the flow value is estimated by using the formula Sokolovsky; Q/GIA the flow value is estimated by using the formula Giandotti; Q/PO the flow value is estimated by using the formula Possenti.

III. Study Area

A. Presentation of the Study Area

The M'Zab basin is a part of the northern Sahara which covers an area of 600 000 km^2. An area of 1653.65 km^2 and a main thalweg of 38.8 kilometers characterizes the M'Zab basin, which has an average annual rainfall of 130.15 mm. M'Zab basin is crossed by four valleys draining trays Dayas and Dorsal of Mozabite, its natural outlet, which is near Ourgla city.

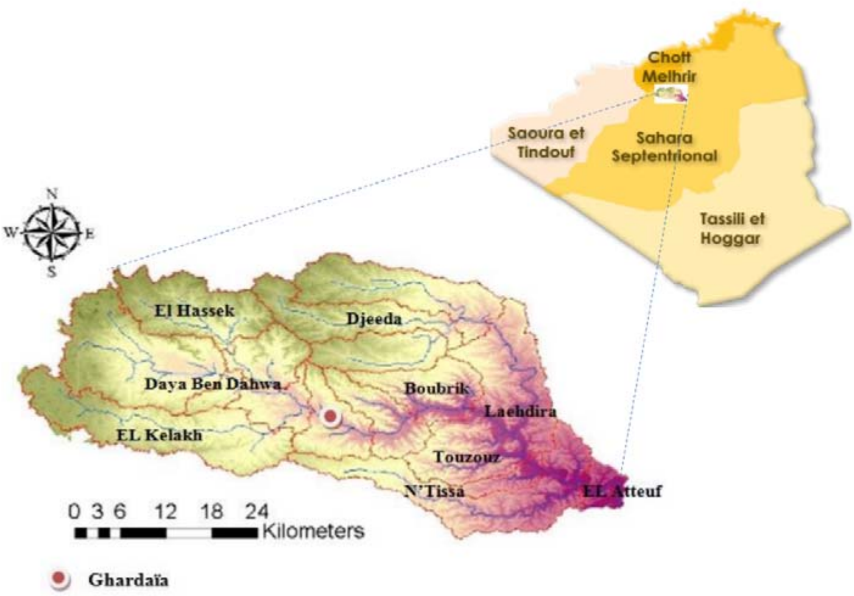

Fig. 2 Study area with the delineated sub-basins in the M'Zab Basin

B. Floods of October 1st, 2008

In the majority of cases, meteorology is the main factor in the genesis of floods. In general, these floods are caused by widespread rainy periods (rainy storms) that are long (several hours, and even several days) or spontaneous; only twenty minutes sufficed for the heavy rains of October 1st 2008 to cause the death of more than 34 people and turn into ruins the M'Zab valley in Ghardaïa (Fig. 3), which was totally inundated by muddy water. [13]

Fig. 3 Ghardaïa: floods of October 1st, 2008

After four years of drought, and more precisely, on Monday September 29th, 2008, a strong accumulation of rains continued gradually on Tuesday with an average intensity. The day of disaster October 1st, 2008, unfortunately corresponded with Eid (the end of the Muslim month of fasting) with 150 mm of rain falling in one hour (Fig. 4).

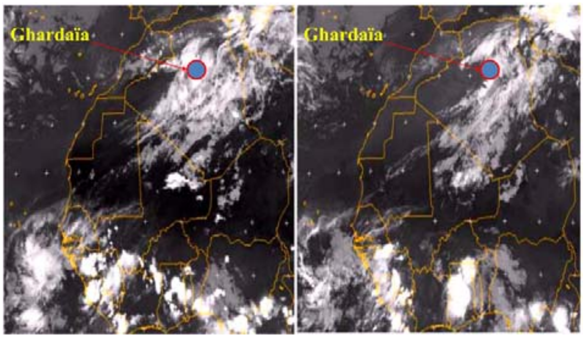

Fig. 4 Satellite images of Algeria for days September 30 and October 1 2008 [14]

The M'Zab valley is highly vulnerable to hydrological weather hazards. This is a consequence of its natural constraints and its socio-economic development. This was highlighted during the October 2008 floods which, by their damage, are among the most severe extreme hydrological events affecting this region. The role of the weather-hydrological hazard in the genesis of these floods has been amplified by human activity, in particular by uncontrolled urbanization and the development of facilities and economic activities in flood-prone areas. Events have shown that dikes are not always an effective flood protection measure. In the case of extreme weather-hydrological hazards, the frequency of their failure amplifies the effects. The lack of a flood announcement system so far explains the damage.

IV. Results and Discussion

A. Calibration, Validation and Evaluation of OCC Model

The purpose of calibration was to obtain optimal values of precipitation, discharges. The model validation involved predicting hydrographs using the optimal parameters. The predicted hydrographs were then compared to the observed hydrographs recorded at the outlet of the basin [15]-[17]. The performance of the OCC method is validated by statistical phase, validation and test parameters. The performance indicators used in this study are: Mean Square Error (MSE), Nash-Sutcliffe Coefficient of Efficiency (NSC), Root-Mean-Square Error (RMSE) and Mean Absolute Percentage Error (MAPE). These are defined as:

$$\mathrm{MSE} = \sum_{i=1}^{n}\left(\mathrm{Q_{sum}} - \mathrm{Q_{pro}}\right)^2 \quad (5)$$

$$NSC = 1 - \frac{\sum_{i=1}^{N}(Qt_i - \hat{Q}t_i)^2}{\sum_{i=1}^{N}(Qt_i - \bar{Q}t)^2} \quad (6)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Qt_i - \hat{Q}t_i)^2} \quad (7)$$

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{Qt_i - \widehat{Qt}_i}{\widehat{Qt}_i}\right| \times 100 \quad (8)$$

where Qt_i is the measured flow rate value, $\hat{Q}t_i$ is the flow calculated by the model, $\bar{Q}t$ is the measured average flow rate $\tilde{Q}t$ is the simulated mean flow rate and N is the number of data.

It is possible to compare the empirical models used, but to ensure that these models effectively model rainfall, a comparison or a validation of adaptation of the data against a reference value is essential. As such, the most suitable model is the model that gives an acceptable value (Table I), always referring to the performance indicators cited above.

TABLE I
Calibration and Validation Results for the M'ZAB Basin

	MSE	RMSE	NSC	MAPE
Ma-Gau	65.48	8.09	0.999	1.02
Sokolovsky	114.7	10.71	0.999	1.39
Possenti	11708.68	108.21	0.964	16.10
Giandotti	52.11	7.22	0.575	0.91

To test the effectiveness of the OCC technique, productivity testing tests must be carried out to obtain the right solution (minimum error). Fig. 5 shows the performance process of the OCC technique while optimizing the precipitation of a watershed for the data of the Ghardaïa station by deferent empirical models. It is evident from Table I that the values of the stability indicators give different values, taking into consideration this difference does not carry out on the convergence of the OCC technique, but gives a comparison view between empirical models. The stability indicators used in this study take minimum values with an increase in the number of simulations.

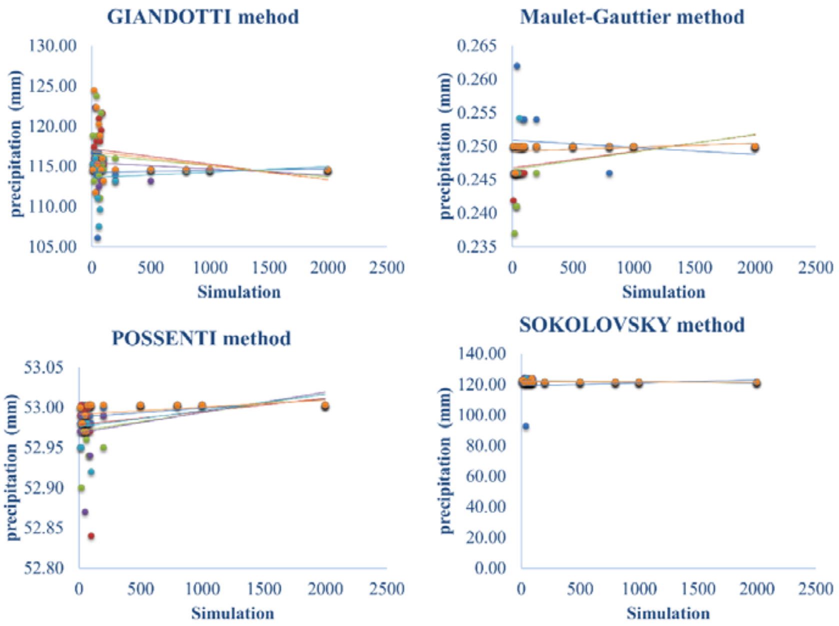

Fig. 5 Cloud along the simulation in different methods

For different types of precipitation data, (mean annual precipitation, maximum daytime precipitation and short-term precipitation) the weakly appreciated values of the objective function are more likely after more than 40 simulations (Fig. 5). A sudden increase in the value of any indicator during some simulation could be attributed to the mode effect of improving the optimization method used, which creates points in the distant neighborhood of the current point in order to maintain the diversity in the population, and thus ensures the sole competitor corresponds. In addition, the size of the population also significantly influences the performance of the OCC technique to promote the emergence of the best individual. Fig. 5 shows the effect of the population on the minimum value of the objective function for the different types of precipitation of other empirical models used.

The computation time varied according to number of simulations in the first one and population size in the second one, the desired results cannot be achieved with considerably small population sizes. If the population size is low, the diversity of a population cannot be maintained. The performance evaluation of the OCC technique developed to estimate the flood flows of a watershed shows that the value of the objective function gives the OCC with the increase in the number of simulations and the size of the population. Therefore, appropriate selection of population size and generation number is necessary to obtain sufficient results.

The results obtained show a very good ability of the model to predict the observed discharge values. The consent of the tipping points was mainly due to the accuracy of the models used in the optimization phase. We also note a considerable improvement in the dynamic performance obtained with the flood rates. This flood is optimized by an OCC with great robustness for the estimation and the optimization of the precipitations.

Fig. 6 shows an overlap between the measured and simulated flows by the OCC method. We used a single-objective calibration with the objective function (Objfun). For this, we use the OCC method as an optimization algorithm. The correct selection at optimization phase giving good agreement with the objective function, and consequently the accepted results.

In order to explore the quality of the flood flow values obtained by the OCC technique, a sensitivity analysis of the hydrological parameters of a pond were obtained for the three types of precipitation (mean annual precipitation, maximum daily precipitation and short-term precipitation) of deferent empirical models. For example, sensitivity analysis of these three types of precipitation for a catchment was performed to examine the effect of changes in individual parameters on the objective function, which allowed to indicate the quality of the parameters obtained by the OCC technique. The results of the sensitivity analysis for the various types of empirical models used in our study (M'Zab basin) are shown in Fig. 6. These results, as is evident from Fig. 6, show that a set of flood rate values was obtained by the OCC technique for different types of models, giving a minimum value of the objective function. In addition, a comparison of these results reveals that the values of mean annual precipitation, maximum daily precipitation and short-term precipitation are optimal values. Moreover, the results of these analyzes also indicated that a good agreement were found, which gave a minimal objective function.

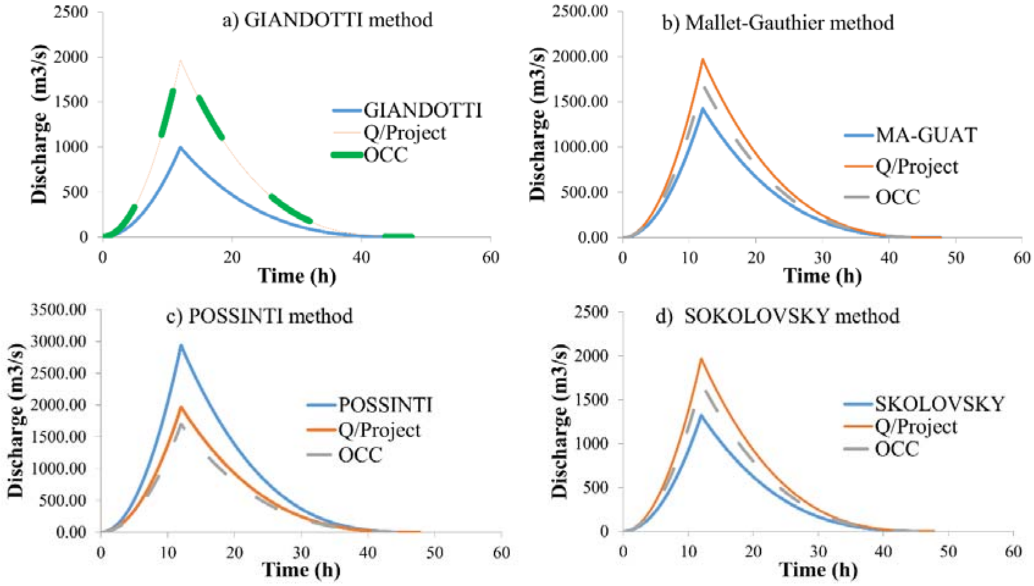

Fig. 6 Hydrographs flood; different rates calculated using different empirical models and simulated using the OCC method

V. Conclusion

The study of optimization of precipitation and their corresponding hydrological impacts using an OCC model is validated and calibrated in the study area. The evaluation of the OCC model has shown that it could be used as a tool for studying the hydrological behavior of the study area. The OCC model is recommended in decision support for water resource planning and management, as it has been found to be capable of generating quantitative data that could provide information useful to managers and decision makers to scientifically develop the projects for protection of agglomerations against natural hazards and minimizing negative environmental impacts. Hydrological analysis by the OCC model is very important for understanding the actual variation in precipitation and the control factor for the flood in an arid region. In general, the results show that the use of the OCC method in the field of hydrology is important. The appropriate management of water resources requires the estimation of the hydrological properties of watersheds for which the modeling of the rainfall-runoff relationship is the most used technique in the field of water resources management. In the present study, the efficiency of the OCC method usually ensures acceptable solutions. This method is evaluated in the estimation of the flow rates of a watershed for meteorological data in fixed duration. In this study and for the M'Zab basin, computer codes were developed to optimize three types of precipitation (annual mean precipitation, maximum daily precipitation and short-term precipitation) in a particular hydrological regime (arid zone) using the OCC method. The applicability, adequacy and robustness of the developed codes were tested using a long series of data. The project flows were compared with those obtained by the OCC method. On the basis of the results of this study, it can be said that the OCC method is an efficient and reliable technique for estimating the flood flows of watersheds, especially in the case of its first test at the M'Zab basin. The sensitivity analysis suggests that a flood rate value was obtained by the stochastic optimization technique OCC, which gave a minimum value of the objective function. The MATLAB program developed in this study can serve as a teaching and research tool. This program should also be useful for the practice of hydrologists. In conclusion, the OCC method is reliable, robust and efficient in estimating flood flows from meteorological data. With the availability of high speed and high capacity PCs to avoid the disadvantage of longer computing time, the use of the OCC technique is recommended to determine the flood flows of a watershed from meteorological data, instead of complex, difficult, cumbersome and subjective software.

References

[1] G. B. Gholikandi, M. Khosravi, "Upgrading of submerged membrane bioreactor operation with regard to soluble microbial products and mathematical modeling for optimisation of critical flux", Desalin. Water Treat, vol.39, April .2011, pp .199–208.

[2] M. Albek, U. B. Ogutveren, E. Albek, "Hydrological modeling of Seydi Suyu watershed (Turkey) with HSPF", Journal of Hydrology vol.285, sep.2003, pp. 260–271.

[3] M. Yadav, T. Wagener, H. Gupta, "Regionalization of constraints on expected watershed response behavior for improved predictions in ungauged basins", Advances in Water Resources, vol. 30, Feb.2007, pp. 1756–1774.

[4] E. Todni, "Rainfall-Runoff Modeling-Past, Present and Future", Journal of Hydrology, vol.100, Feb.1988, pp 341-352.

[5] Wheater H. S., Jakeman A. J., Beven K. J. Progress and directions in rainfall-runoff modelling. In: Jakeman AJ et al., editors. Modelling change in environmental systems. John Wiley and Sons; 1993, pp 101–32.

[6] J. De Vries, "Hydrologic Behavior of a Forested Mountain Soil in Coastal British Columbia", Water Resour. Res, vol.14, Oct. 1978, pp.935-942.

[7] J. J. McDonnell et. al, "Moving beyond heterogeneity and process complexity: A new vision for watershed hydrology", Water Resour. Res, vol. 43, July.2007, pp.1-6.

[8] K. P. Sudheer, I. Chaubey ,V. Garg and Kati W. Migliaccio, "Impact of time-scale of the calibration objective function on the performance of

watershed models", Hydrological Processes, vol.21, April.2007, pp. 3409-3419.

[9] Thorsten Wagener Æ Hoshin V. Gupta, "Model identification for hydrological forecasting under uncertainty", Stoch Environ Res Risk Assess, vol.19, Sep.2005, pp.378–387.

[10] Qingyund Uan, Soroossho Rooshiaann, D Vijai Gupta, "Effective and Efficient Global Optimization for Conceptual Rainfall-Runoff Models", Water Resour. Res, vol.28, April.1992, pp.1015-1031.

[11] M. Sivapalan et. al, "IAHS Decade on Predictions in Ungauged Basins (PUB), 2003–2012: Shaping an exciting future for the hydrological sciences", Hydrological Sciences–Journal, vol.48, Dec.2003, pp.857-880.

[12] Y. Tang, P. Reed, and T. Wagener, "How effective and efficient are multiobjective evolutionary algorithms at hydrologic model calibration?", Hydrol. Earth Syst. Sci, vol.10, March.2006, pp. 289–307.

[13] Laroussi Beloulou, "Vulnérabilité aux inondations en milieu urbain. Cas de la ville de Annaba (Nord-Est Algérien).", Badji Mokhtar-Annaba University,2008.

[14] A. Medejerab, "Les Inondations Catastrophiques Du Mois D'octobre 2008 A Ghardaïa- Algerie.", Geographia Technica, vol.4, Sep,2009, pp.331-316.

[15] Katana, S. J. S., Munyao, T. M. and Ucakuwun, E. K, "Hydrological Impacts Of Land Cover Changes In Upper Athi River Catchment, Kenya", International Journal of Current Research, vol. 5, May, 2013, pp.1187-1193.

[16] Moussaab Zakhrouf, Mohamed Chettih, Mohamed Mesbah, "Adaptive neural fuzzy inference systems for the daily flow forecast in Algerian coastal basin", Desalination and Water Treatment, vol.52, Dec2014, pp. 2131–2138.

[17] Elias Moussoulis, Ierotheos Zacharias & Nikolaos P. Nikolaidis, "Combined hydrological, rainfall–runoff, hydraulic and sediment transport modeling in Upper Acheloos River catchment" Desalination and Water Treatment, vol. 57, Sep,2016, pp.11540–11549.