

Comparison Of Two Hydrological Models (Lumped And Distributed) Over A Pilot Area Of The Issen Watershed In The Souss Basin, Morocco

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Abstract

The present study aims to develop a hydrological model of flood forecasting to arid environment in the Issen basin (sub-chatchement of Aguenza basin) through a comparison between two conceptual hydrological models (HEC HMS) and ATHYS which is a conceptual distributed model rarely used in the Moroccan context. The aim is to measure the degree of adaptability of these models to the study area in order to generalize the selected model to the entire watershed. The obtained results from the validation phase of the two models were satisfactory, the two models were able to reproduce the hydrological behavior of the Aguenza watershed during flooding periods. Besides, this study has shown that a good distributed model can provide improvements over a global model for flood forecasting and particularly in terms of volume as in the present study case.

Keywords: Hydrology, Issen, Modeling, HEC-HMS, ATHYS

Introduction

Flood forecasting involves modeling the hydrologic response of a watershed to environmental inputs, principally precipitation and temperature. Plenty of the hydrological models are known at present, however, to find an appropriate one for the area of interest is still considered a challenged task for responsible hydrologists as main controlling mechanisms of the hydrological system often vary from place to place under scope of the spatial and temporal scales in use (Blöschl and Sivapalan, 1995; Sivakumar, 2004; 2008) *in* (Phandee et al, 2014).

Therefore, a flood forecast system must integrate components or sub-systems that estimate recent and future precipitation and temperature, simulate the hydrologic response and, provide useful information about the

resulting streamflow, stage and other impacts. Because the value of a hydrologic forecast system depends on predicting runoff conditions before they occur, it is vital that the system minimize potential delays in performing these functions and preparing the forecast output. The following discussion describes typical requirements of a forecast system, even if specific requirements may vary depending on watershed characteristics, available data and other resources.

The present study has as main aim the research of the model allowing to represent the hydrological operation of the area Issen basin (sub- Aguenza watershed) through the test and the implementation of certain hydrological models which showed their robustness and their performance with the international scale on a pilot zone of the basin, in the prospect of generalizing the retained model to all the basin.

The two chosen models for this study are HEC-HMS (Lumped Model) and Athys (Distributed Model).

The study area

The Aguenza river basin extends over an area of 648 Km² (Fig.1). The High Atlas Mountains form the Northern and Eastern boundary of the basin. The Anti-Atlas Mountains form the Southern boundary. The climate in the basin is arid to semi-arid where the largest precipitation occurs in the High Atlas outcrops.

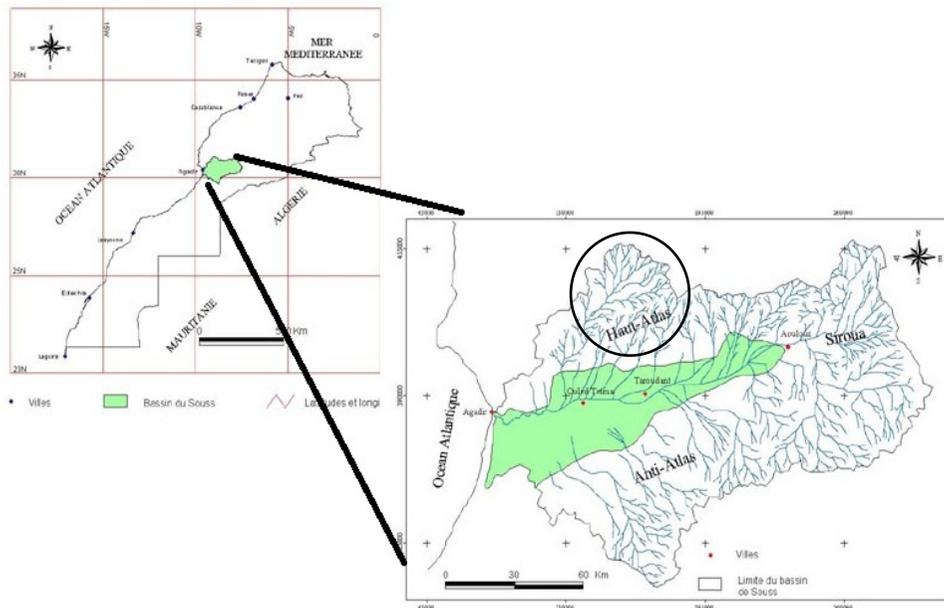


Figure1: Location of study area

The precipitation annual average in the upper elevation zones of the High Atlas Mountains ranges from 500 to 600 mm per year, 150 to 200 mm for the Anti-Atlas Mountains, with a total average for the basin of 280 mm.

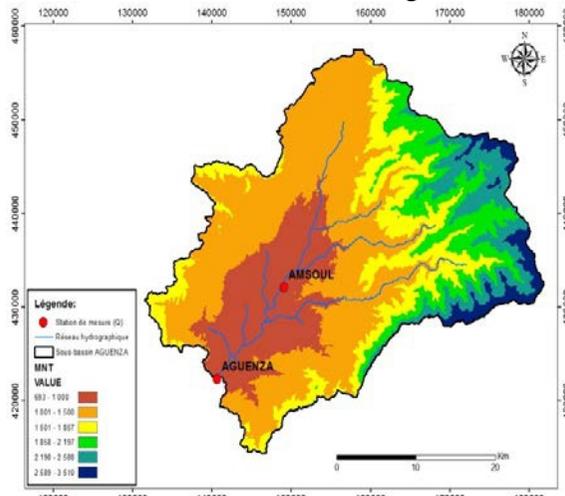


Figure2: Digital elevation Model (DEM)

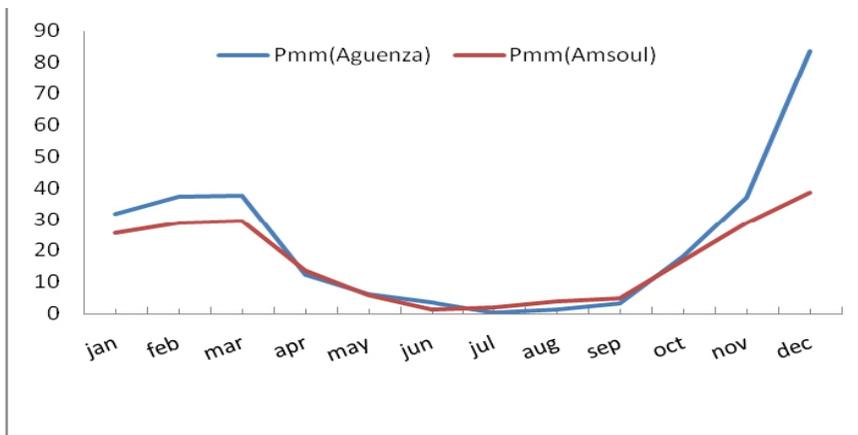


Figure 3: Monthly mean precipitation (1980–2010) at the different stations

Materials and Methods

Hydrological models simulate the conversion of rainfall (and snowmelt) depth to runoff amount. This process includes the losses due to interception of rainfall by leaf cover, infiltration of rainfall into the soil as well as the runoff timing.

In general, two distinct options are available to model the hydrological processes. The lumped model considers individual sub-basins as a single unit, whereas the distributed model sub-divides each sub-basin in smaller cells. A lumped hydrological model averages spatial characteristics

related to rainfall-runoff response for the entire area of a sub-basin being analyzed. A distributed model explicitly accounts for spatial variability using spatial datasets describing soils, vegetation, and land use. A distributed model will subdivide a sub-basin area based on a particular grid size to capture spatial and temporal variability and then route flows through the sub-basin from cell to cell. For a lumped model, a sub-basin may be subdivided into elevation zones in order to capture the variability of snow accumulation at different elevations. Figure 4 highlights the conceptual difference between lumped and distributed subdivisions for a sub-basin. In either case, sub-basins may be aggregated through routing models to form the simulation of a complete river basin.

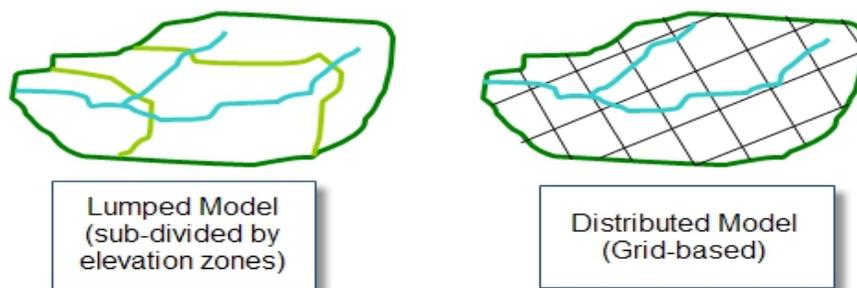


Figure 4: Lumped versus Distributed Basin

With lumped models, various parameters related to the volume and timing of hydrologic processes are calibrated to accurately simulate historical streamflow from historical precipitation and temperature observations. Distributed models rely on spatial data sets but generally also require some calibration to optimize simulations.

Some advantages of distributed models compared with lumped models include their ability to predict runoff at the un-gauged locations in the watershed, simulation of water quality parameters and, predicting impacts due to change in land use (Smith et al., 2004). Theoretically, the ability to account for spatial variability of rainfall and physical features within a basin should achieve better simulations. However, recent studies have suggested that distributed modeling approaches do not always provide improved basin outlet simulations compared to lumped conceptual models (Reed et al., 2004; Smith et al., 2004).

The general approach consisted in preselecting the models to be studied and to apply to the zone relays in gathering and preparing the necessary data while carrying out the creation of a space database under a geographical information system (GIS). An evaluation of quality of available and collected information was carried out to come to a conclusion about the data which will be taken into account in the study. Then, the list of the data

which will be generated starting from the satellite images or other layers by using the GIS was defined. The second phase related to the execution of hydrological models HEC-HMS and ATHYS on Aguenza watershed then the validation of these models. The last phase was consisted on the analysis and the interpretation of the obtained results.

Preselection of models to be applied in the study

The choice of conceptual models HEC-HMS and ATHYS is justified by several criteria which are essential for the total modeling of the catchment area of Aguenza. These elements can be summarized as follows:

▪ Approach of Preparations of the Data

The selection criteria are:

- ✓ Availability of sufficient data of daily rain in the basin for representing the space distribution of the event;
- ✓ Disponibility of data of close recording rain-gauges to represent the temporal repair of the event of rain;
- ✓ Compatibilty between the daily rain recorded in the area from recording rain-gauge and other pluviometric stations, proving that it is about a generalized event allowing to be able to apply the temporal distribution to all the basin. Indeed, for the chosen zones for the chock of the model, there is generally only one recording rain-gauge which is located downstream and not at the top of basin and its data could not represent what occurs on the upstream of the basin if it is not about a generalized event.

▪ The basic necessary information to the operation of selected models

a- Relief: Digital Elevation Model (DEM) used is the GDEM-ASTER. It has a space resolution of 30 m and it was extracted from the satellite images ASTER through the process of stereoscopy;

b- Land use : it was generated starting from Global Land Cover Map-European Space Agency (ESA) GlobalCover9;

c- Soil types: the data are extracted by combining the existing pedological map with the level of the basin (map at 1/500 000) and the database of the grounds worked out by the FAO which provides a set of information on the ground. The soil coverage that was used in the model was downloaded from the FAO Geonetwork (www.FAO.org/geonetwork) Harmonized World Soil Database (HWSD) Version 1.2 (FAO, 2012);

d- Weather data: precipitations were spatialized starting from pluviometric stations installed in the basin by using the interpolation by the method of Thiessen;

e- Flows data : this information was collected and structured in digital files starting from the database BADRE21 of the Moroccan Direction of research and planning;

f- Data processing: The preparation of the data for HEC-HMS was carried out by using the extension HEC-DSS which makes it possible to prepare all the data, diagrams and files necessary to the operation of model HEC-HMS. The version of the software used in this work is version HEC-HMS 3.5;

The preparation of the data for ATHYS model was made by using the available platform of ATHYS model with the conversion of data to the extension fts.63.

Description of hec-hms and athys models

A. HEC-HMS

The HEC-HMS platform is free and available on Internet (<http://www.hec.usace.army.mil/software/hec-hms/>) and its used for modeling rain-flow of the risings requires to consider several components of the flow; basic flow, losses and transfer of slopes flow towards downstream.

Baseflow Method

Five baseflow methods are offered by HEC-HMS. The baseflow represents the contributions from the aquifer or from interflow. For all of baseflow methods, the initial baseflow volume strongly influences the amount of baseflow that the model simulates in the method of the Recession Baseflow. This method resets after precipitation events and therefore, can be used for either event or long term simulations, but it is primarily intended for event simulation.

$$B_t = B_i R_c^t$$

Where B_i is the initial basic flow in time t_0 and R_c the constant of exponential decay. The parameters of the recession are:

1. Initial basic flow, B_i (m^3s^{-1})
2. The constant of R_c recession ($[0-1]$)
3. Threshold, T_d ($[0-1]$)

Loss method

Many studies indeed used successfully the model of losses SCS (USDA-SCS, 1985) in Mediterranean and semi-arid context (Brocca and al., 2009; Trambly and al., 2010). In addition, this model is adapted to give an account of the initial conditions of moisture of the basins slopes to the event-driven scale. The parameter CN (or S) can indeed be connected to various indicators of moisture of the grounds, measured on the ground (Huang and

al., 2007; Brocca and al., 2009; Trambly and al., 2010), resulting from models or obtained by satellite.

The SCS Curve Number Loss method calculates the incremental precipitation lost to infiltration for each time step. The parameters for the method must be derived from physical properties of the basin, including soil type and land use.

The curve number has clearly defined ranges and should not be specified with values beyond the defined ranges. This method is recommended for basins that do not have a good flow record for calibration.

$$P_e = \frac{(P - I_a)^2}{P - I_a + S}$$

Where P_e indicates the excess of precipitations, P the total of precipitations, I_a the initial losses and S the maximum potential of retention. In the SCS method, the initial losses are given by the I_a relation = $0,2S$. The potential of retention S is connected to Curve Number (CN), itself being able to be estimated by tables describing the various soil types (USDA-SCS, 1985) or by calibration with data observed data:

$$S = \frac{254400 - 254CN}{CN}$$

Transform Method

The method of the Clark unit hydrograph represents two processes; translation and attenuation. The translation is based on a synthetic histogram time-surface with a time of concentration T_c . The histogram represents the surface of the basin which contributes to the flow with the discharge system according to time. The attenuation is modelled by a linear tank. The tank represents the stock at the level of the basin, St the outgoing flow average of the tank for one period T is given by:

$$O_t = C_A I_t + C_B O_{t-1}$$

With I_t , the flow entering the reservoir at time t , C_A , C_B , of the coefficients calcld with the relation:

$$C_A = \frac{\Delta t}{S_t + 0,5\Delta t} \text{ et } C_B = 1 - C_A$$

Δt is the step of computing time, here 1 hour.

The parameters required by the method of Clark are thus:

1. The time of concentration T_c (hours)
2. The coefficient of storage St (hours)

These two parameters can be estimated by calibration when recordings of rain and flow are available.

B. ATHYS

The model of production developed by Soil Conservation Service (SCS) of the USDA (Mishra and Singh, 2003; Steenhuis and al., 1995) connect to the office plurality of the effective rain EP to the office plurality of the rough rain Pb , by the equation:

$$P_e = \frac{(P_b - I_a)^2}{(P_b - I_a) + S}$$

The parameters of adjustment of the model are I_a and S . We generally admit that I_a and S are bounded by the relation:

$$I_a = 0.2 * S$$

S , expressed in mm, can also be connected to Curve Number of the SCS by:

$$S = \frac{25400}{CN} - 254$$

In MERCEDES, one uses the expression of the coefficient of instantaneous streaming, which is written as follow (Gaume et al., 2004):

$$\left(\frac{-0.2S}{+0.8S} \right)$$

This diagram was also supplemented, in MERCEDES, by a tank ground, which level describes the evolution of stock. The tank is supplied by the water which infiltrates, and it is drained by the evaporating recovery, the percolation towards the deep and exfiltrated water. The equations of the diagram are as follows:

$$R(t) = C(t) \times i(t)$$

$$C(t) = \left(\frac{P^*(t) - 0.2S}{P^*(t) + 0.8S} \right) \left(2 - \frac{P^*(t) - 0.2S}{P^*(t) + 0.8S} \right)$$

where P^* correspond with the excess of of the rain, supply réservoir

$$f(t) = (1 - C(t)) \times i(t)$$

Draining of the tank ground

$$Vid(t) = DS.S(t)$$

The $S(t)$ désigne le niveau du réservoir sol à l'instant t :

In independent pixels mode, each pixel produces with each step of time an elementary hydrograph to the discharge system. The addition of all the elementary hydrographs, for all the pixels and all the steps of time, provides the complete hydrograph of the rising.

The elementary hydrograph is determined by a diagram of type translation/storage, dependent on:

- T_m , travel time to the discharge system of the contribution produced by the mesh, calculated according to the L_k lengths and V_k speeds relative to each K-mesh of the trajectory:

$$T_m = \sum_k \frac{l_k}{V_k} \cdot \frac{60}{dt}$$

K_m , the time of damping, appearing the variations speeds in time. Damping is simulated by a linear tank, of which capacity K_m .

The equation of the elementary hydrograph is :

$$q(t) = 0 \quad t < t_0 + T_m$$

$$q(t) = \frac{p(\Delta t)}{K_m} \cdot \exp\left(-\frac{t - (t_0 + T_m)}{K_m}\right) \cdot A \quad t < t_0 + T_m$$

Results and Discussions

Calibration consists in adjusting the numerical values assigned to model parameters to best reproduce the observed response. It is the process of choice of parameter values games. This can be done manually by a model sensitivity analysis procedure or automatically by an optimization procedure in seeking the optimum value of a given criterion function that improves consistency between observed and simulated response of the basin.

The calibration test is the standard deviation and coefficient of MSE Nash. We will use in this study a manual procedure by the sensitivity analysis primarily for all parameters of each production function and thereafter to the transfer function.

➤ Calibration of model parameters HEC-HMS

The table below shows the calibration results of HEC-HMS model parameters used for each event:

Table 1 : Calibration results of HEC-HMS model parameters

Episode	CN	Tc (h)	St (h)	NASH	Observed volume (m ³)	Observed Qp (m ³ /s)	Simulated Qp (m ³ /s)	Simulated volume (m ³)
12/26/1996	70	3	3	0.7	11736000	326	301	10836000
1/10/1996	40	3	5	0.8	8316000	220	217	8202600
12/13/1995	60	3	3	0.7	14580000	540	530	14310000
2/17/1991	64	3	3	0.8	4284000	140	142	4345200
11/9/1988	63	3	3	0.8	9450000	350	270	7290000
11/5/1988	65	3	3	0.7	1458000	81	90	1620000
10/15/1988	55	3	2	0.7	1749600	81	38.2	825120
11/4/1984	65	3	3	0.8	8640000	200	192	8294400

➤ **Calibration of model parameters ATHYS**

The calibration results of ATHYS model parameters used for each event are given in table 2:

Table 2 : Calibration results of ATHYS model parameters

Episode	Obs. Qp (m ³ /s)	Obs. Vol. (m ³)	Tb (h)	Sim. Qp (m ³ /s)	Sim. Vol. (m ³)	NASH	S	W	DS	V0	K
12/26/96	326	11736000	20	312	11232000	0.8	130	0.2	0.5	3	0.9
1/10/96	220	8316000	21	243	9185400	0.7	100	0.5	0.49	0.7	0.8
12/13/95	540	14580000	15	600	16200000	0.59	73	0.2	3	4	0.7
2/17/91	140	4284000	17	156	4773600	0.46	70	0.1	0.1	0.5	0.1
11/9/88	350	9450000	15	290	7830000	0.87	35	0.20	1	3	0.7
11/5/88	81	1458000	10	95	1710000	0.44	87	0.1	1	3	0.7
10/15/88	81	1749600	12	78	1684800	0.83	87	0.10	0.5	3	0.7
11/4/84	200	8640000	24	145	6264000	0.81	130	0.10	0.1	3	0.7

➤ **Validation phase**

The model is validated using two different approaches. Due to the limited sample size, a classical split-sample approach is tested, using the eight first events for calibration and the remaining five events for validation (Table 3).

Table 3 : validation results of HEC-HMS model parameters

Episode	CN	Tc(h)	St(h)	NASH	Observed volume (m ³)	Observed Qp (m ³ /s)	Simulated Qp (m ³ /s)	Simulated volume (m ³)
11/28/2014	70	3	3	0.6	11485800	425.4	393	10611000
12/21/2000	69	3	2	0.9	3045600	94	91	2948400
12/20/2000	90	3	3	0.5	414720	12.8	11.7	379080
12/6/1999	90	3	2	0.4	4989600	126	119	4712400
2/1/1998	72	3	3	0.7	6300000	140	135.7	6106500

➤ **Calibration of model parameters ATHYS**

The table below shows the calibration results of ATHYS model parameters used for each event:

Table 4 : validation results of ATHYS model parameters

Episode	Obs. Qp (m ³ /s)	Obs. Vol. (m ³)	Tb (h)	Sim. Qp (m ³ /s)	Sim. Vol. (m ³)	NASH	S	W	DS	V0	K
11/28/14	425.4	11485800	15	362	9774000	0.8	62	0.2	4	4	0.7
12/21/00	94	3045600	18	87	2818800	0.8	50	0.1	0.5	3	3
12/20/00	12.8	414720	18	10	324000	0.5	50	1	15	1.5	2
12/6/99	126	4989600	22	110	4356000	0.6	20	0.1	2.5	1	0.7
2/1/98	140	6300000	25	132	5940000	0.6	100	0.2	20	0.5	0.1

➤ **Evaluation simulations**

Besides the visual examination of simulated hydrographs, different metrics can be used to measure the ability of the rainfall-runoff model to reproduce the flood events. For each event, a measure commonly used in hydrology is the Nash coefficient between the measured flow rates and calculated flows Q Q_e for each time t :

$$NASH = 1 - \frac{\sum_{t=1}^n (Q_t - Q_{e_t})^2}{\sum_{t=1}^n (Q_t - \bar{Q})^2}$$

To assess the ability of the model to reproduce several episodes, one can make the mean or median of the Nash coefficient, or calculate the bias (RBIAS) and quadratic errors related (RRMSE) on volumes and pics:

$$RBIAS[\%] = \frac{1}{N} \sum_{i=1}^N \left(\frac{X_i - Y_i}{X_i} \right) \times 100$$

$$RRMSE[\%] = \sqrt{\frac{1}{N} \sum_{i=1}^N \left(\frac{X_i - Y_i}{X_i} \right)^2} \times 100$$

Wherein X and Y are the volumes or flood peaks respectively observed and measured for each episode i.

Table 5: Indicators results of ATHYS and HEC-HMS models

	Indicators			
	HEC-HMS		ATHYS	
	Calibration	Validation	Calibration	Validation
MEANS NASH	0,65	0.62	0.67	0.66
RBIAS VOLUME	9.75%	5.6%	2.1%	7.8%
RRMSE VOLUME	16.45%	3.74%	11.58%	8.58%

Conclusion

The implementation of conceptual hydrological models is a tedious work as it requires the collection of basic space-time multi-source data.

As part of this work it is to compare the performance of two hydrological models global and distributed on a pilot area of Issen basin (Aguenza watershed)

The obtained results show that the variation of the two models is not very different and, the resulting Nash coefficient is in the same range of values.

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