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Contribution of hydrological modeling to the water resources assessment using soil-moisture accounting model: the case of the wadi Taria (Macta basin, NW Algeria)

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ABSTRACT

This study concerned the contribution of HMS soil-moisture accounting (SMA) model to the water resources assessment in the case of uncertainty regarding gauged discharges. The wadi Taria catchment in Macta basin (NW Algeria) is considered in this study. Due to public insecurity (terrorism acts) during 1990s in Algeria, the quality of gauged flow rate was affected. The SMA model was calibrated from 09/01/1975 to 08/31/1975, and has been validated from 09/01/1985 to 08/31/1990 on a daily continuous time scale. The model results indicate that overall estimation of Taria streamflow during the calibration and validation periods is good and therefore may be accepted for correcting the wrong discharge data. For the calibration period, the model performance was very good with a percentage error in volume (PEV) = 4.76%, Nash–Sutcliffe efficiency (NSE) = 0.90, coefficient of determination R^2 = 0.90 and index of agreement d = 0.97. Similarly, the model performance for the validation period ranges from very good to good with PEV = 1.3%, NSE = 0.66, R^2 = 0.67 and d = 0.89. The wrong measured flow data collected from 09/01/1990 to 08/31/1998 underestimate annual flow volume with over 20% compared with the model results. This study ended-up optimistic result for the rainfall-runoff modeling. The SMA model can be used to simulate the rainfall-runoff process in the Macta basin.

Keywords: Wadi Taria catchment; NW Algeria; Rainfall-runoff modeling; HEC-HMS; SMA model; Model performance; Water resources assessment

1. Introduction

The reliable hydrological data and hydrometric information are needed to assess and predict the evolution of water resources thus to optimally and sustainably manage water resources for the country's various economic sectors (domestic, industrial and agricultural). The above all is due to the importance of climate variability, marked by the recurrence of drought, the potential impacts of climate change and the increasing impacts of population pressure on water resources [1,2].

The runoff time series of the wadis, especially those of the Macta watersheds (Western Algeria, Mediterranean Basin – Southern Region), are often incomplete, discontinuous, short and therefore difficult to exploit for reliable water resources assessment and correct hydrological analysis of the water balance [3,4].

Unfortunately, during the decade of the 1990s, the National Agency for Hydraulic Resources (ANRH), due to fear and public insecurity (terrorism acts), had difficulties in ensuring proper hydrological and hydrometric monitoring, mainly the periodic and correct gauging of the main wadis of the Macta watersheds (Taria, Saida, Mekerra, etc.) and their tributaries [3]. Since then, there has also been a reduction in the number of hydrometric monitoring gauges, but now,

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this is generally due to a lack of human, institutional and financial resources.

A hydrological model of precipitation is a numerical tool representing the rainfall-runoff relationship at the watershed scale. The aim is to simulate river flows from precipitation observations on the watershed, by transforming time series describing the hydroclimatology of the watershed (input to the hydrological model, such as evapotranspiration [ETP]) in a series of flows (output of the hydrological model).

The choice of the type of model to be used depends generally on the objective of the modeling and on the availability of input data. The objectives of hydrological modeling are varied and can be listed as follows:

- Simulation of flows for water resources assessment (in the case of deficiencies in flows or incorrect gauges, this allows filling gaps, correcting aberrant flows and extending the times series of runoff from those of rainfall).
- Real-time forecasting of flows (in particular for floods or low flows forecasting).
- Predetermination of flood flows (flood frequency values) for dimensioning of flood protection structures.
- Determination of the impacts of hydraulic infrastructures (dams, land use, etc.) on the hydrological regime of wadis.

Numerous hydrological models have been developed since 1960s. At present there are more than a hundred. According to a number of comparative studies carried out since 1975 (work which began with the inter-comparative review of the World Meteorological Organization, WMO, in 1975) [5–10], it does not emerge of net trend: if some models are, on average, better performing than others, none is systematic. In addition, each model reflects the diversity of approaches that can be considered for modeling the behavior of a watershed. All current models fail to reproduce reality fairly well, so modelers are looking for alternative methods to improve the performance of their simulations. This is particularly true in the case of ungauged catchment areas (watershed where there is no flow measurement and therefore no possibility of parameter optimization), for which model simulations are always ambiguous.

Mehreb et al. [11] have analyzed 140 hydrological studies conducted in the Mediterranean basin, including the southern region. The results show a clear tendency for reduced water resources, as well as, very heterogeneous watershed responses over time and space, reflecting the limitations of hydrological modeling and the great uncertainties of forecasts. And, because few models have been developed to solve these problems, further studies are needed to improve knowledge of Mediterranean hydrological characteristics, considering regional specificities.

There is clearly no simple solution to the problem of uncertainty in hydrologic modeling. That uncertainty arises from lack of knowledge about model inputs, model structures and the observations utilized to evaluate models [12,13]. If rainfall observations are generally presented with fewer errors (because of the simpler measurement technique), errors in runoff measurements are more significant, with 10% maximum uncertainty limit recommended by WMO [14]. In addition to the random errors, there are errors caused by improperly calibrated equipment, or improper use of the equipment, so that a systematic error is introduced. But this error rise when the most of flow discharge observations are derived by applying the rating curve methods [15–17].

The objective of this research work concerns the first point, mentioned above. Since rainfall times series are more numerous, more complete and precise, with fewer missing values, rainfall-runoff modeling should be one of the solutions to restore missing gauging data and/or to correct aberrant data. The aim of the rainfall-runoff modeling is therefore to simulate and then extend, as far as possible, the daily time step runoff series, using the continuous rainfall-runoff hydrological model, soil-moisture accounting (SMA), tool of hydrologic engineering center-hydrologic modeling system (HEC-HMS) modeling system [18]. SMA is a lumped conceptual model that allows continuous river flow simulation and a number of model parameters are estimated using geographic information system (GIS) techniques. This type of hydrological model generates a continuous record of runoff from records of rainfall data and other climatic variables. Continuous simulation models take into account hydrological processes that are neglected in single-event flood models. The choice of the SMA model among many others is linked to the various considered hydrological processes, including, ETP, canopy interception, depression storage, percolation, shallow subsurface flow and snowmelt [18,19].

HEC-HMS has been successfully applied in many catchments worldwide and numerous studies have analyzed the use of the HMS SMA model to simulate runoff successfully in different basins around the world, including semiarid regions [19–27]. However, few studies have reported a long-term hydrological simulation in the Algerian basins; these are essentially global models used, especially in the monthly time scale, such as LoiEau [28], GR2 [29], and other models of the family of GR (Génie rural) hydrological models at Irstea [30], formerly Cemagref [4,31–34]. Benkaci and Dechemi [35] have examined four rainfall-runoff models applied on a daily time step and tested in the Cheffia basin (north-eastern Algeria). Two categories of models have been used, conceptual models (GR3 and CREC models) and "black-box" models (ARMAX and neuro-fuzzy models). It was deduced the need for the introduction of a second data, soil moisture, to improve this model. The results obtained with the added soil moisture are better than those obtained by the GR3 and CREC models only.

Once the model is chosen, it is necessary to evaluate its capacity to present the reality. This is most often done by comparing the results of the model with the observations. This is a very delicate step.

2. Materials and methods

2.1. Study area

The selected Taria catchment for the present study is located in the Macta basin, in the North of Western Algeria (Fig. 1). It is a tributary of wadi Hammam. It drains, at the discharge measurement station on the wadi at Taria village, an area of 1,365 km^2 and lies within the geographical coordinates of 0°06′ to 0°34′ E longitudes and 34°41′ to 35°14′ N latitudes. For morphometric analysis of Taria catchment the SRTM DEM 30 m has been used. The digitization of dendritic drainage pattern is carried out in QGIS and Aquaveo WMS (community free edition) softwares (Table 1).

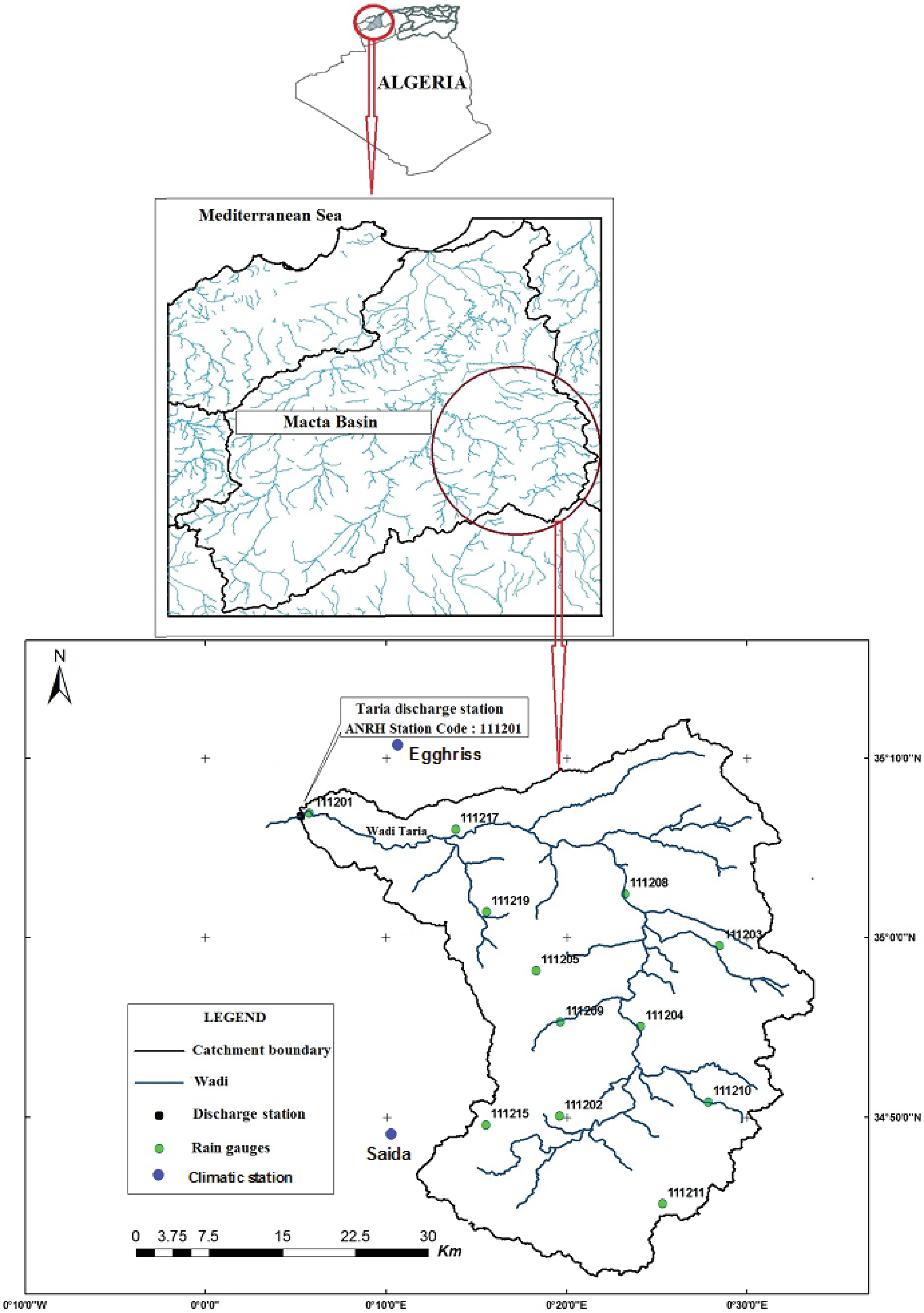

Fig. 1. Study area of the wadi Taria catchment in Macta basin (north western Algeria).

Low drainage density (0.58 km/km^2) indicates that the area has a gentle-flat slope, low rainfall and permeable bedrock, associated with widely spaced streams due to the presence of less resistant surface materials with very high sediment rate [36]. The relief ratio of the Taria catchment is low, which is characteristic features of less resistant rocks.

2.2. Data collection

2.2.1. GIS data

The maps such as topographical, soil type, soil permeability, land slope and land use/pattern were extracted for the Taria catchment using ANRH maps [3] and GIS model

Table 1
Some characteristics of Taria drainage basin

Discharge station	Taria
Wadi	Taria
Area (km^2)	1,365
P (km)	283
Kc	2.14
L (km)	131
B (km)	10.4
Dd (km/km^2)	*0.58*
Ds (m)	125
Ig (m/m)	0.004

Note: *P*, Basin perimeter; Kc, Gravelius' compactness coefficient; *L* and *B*, length and width of equivalent rectangular basin, respectively; Dd, drainage density; Ds, basin relief; Ig, relief ratio.

which is used to create the basin model input for HEC-HMS. The maximum soil storage map edited by Padoun [37] for the northern Algeria was also used to determine the total soil storage for the whole Taria catchment.

2.2.2. Rainfall-runoff

Rainfall data, at 12 rain gauges distributed over the study area, were analyzed for the period from 1975 to 1998. The rainfall data were collected from the ANRH and National Meteorological Center (ONM). Most rain gauges were stopped working after 1998 or with much missing data after that date. Note that missing data, for the considered period (1975–1998), were very few, representing only 2.5% on average for the whole set of rain gauges. Missing rainfall data at each station were estimated using data from surrounding stations and linear relationships. Thiessen polygon technique [38] for the interpolation of the daily rainfall was followed to obtain spatial rainfall estimates for the catchment, over the period 1975–1998. The rain gauges cover the whole basin, where five gauges are situated in the central zone of basin representing 36% of basin area. The rest of rain gauges are distributed in the lower zone (four gauges with 38% of area) and higher zone (three gauges with 26% of area) of the basin (Fig. 2). This uniform spatial distribution of the rain gauges considers the orographic effects on precipitation.

Daily discharge rate is observed at the outlet Taria station. The discharge data were collected from the ANRH for the same period (1975–1998). The flow measurement technique based on the conventional velocity-area method is commonly used by the ANRH. The velocity-area method consists of measuring the velocity of water at a number of verticals in the cross-section. The flow is obtained by summing the products of the velocity and corresponding area in the cross-section. This flow measurement technique becomes cost-inefficient, time-consuming and labor-intensive. And since the accessibility to the Taria hydrometric station, under the conditions of terrorism acts during 1990s in Algeria, the flow measurements can be incorrectly carried out and therefore imprecise. Thus, data for 1990s decade are considered suspicious and require correction using rainfall-runoff modeling.

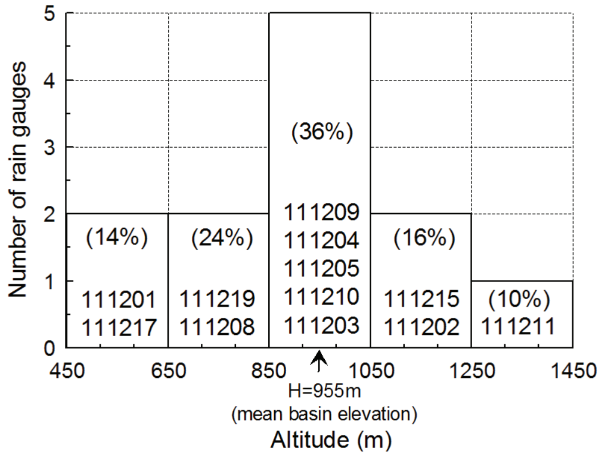

Fig. 2. Distribution of rain gauges with altitude 111211 = rain gauge code; (10%) = total Thiessen weighting coefficient.

2.2.3. Evapotranspiration

Potential or reference ETP is not measured directly, but rather computed from meteorological data. The ETP data were estimated for the entire catchment using a simple Oudin's temperature-based equation [39]. This is useful for regions with limited data where only temperature data are available. Daily temperature data were acquired from the ONM, at two meteorological stations, Saida and Egghriss (Fig. 1), with more correct and continuous temperature datasets.

2.2.4. Soils

The soils data were obtained from the European Soil Data Centre (ESDAC) [40] and from the soil maps of northern Algeria edited by Durant [41]. The studied catchment is comprised essentially of two major types of soils. The calcic cambisols are first predominant soils. These soils occur in dry and semidry regions. The soil has a good mineral reserve and its suitability depends essentially on texture, which determines retention capacity. The second predominant type of soils is the calcaric fluvisols, azonal soils in alluvial deposits, occurred essentially in the valleys. Total impervious surface for Taria catchment is estimated as 6.88%. Fixed as invariable, this percentage impervious surface dataset was clipped to the Taria catchment.

2.3. The SMA model

2.3.1. Model description

The SMA model takes into account ETP and percolation between precipitation, as well as infiltration and other losses during precipitation. Like other models, SMA is a model that can be used over long periods in alternating wet and dry conditions. The SMA model simulates the movement of water across the different elements of a watershed. Based on precipitation and ETP data, it calculates surface runoff, infiltration, evaporation and deep percolation. For this, different hydrological physical processes such as canopy interception, surface storage in depressions, infiltration, soil storage, percolation and groundwater storage in aquifers must be considered. The SMA procedure is diagrammed in the HEC-HMS technical reference manual [18] and is reproduced below (Fig. 3). There are 5 storage zones simulated and 12 parameters are required to characterize the canopy, surface, soil and groundwater storage units. Fleming and Neary [20] introduced several techniques to acquire these parameters using GIS, streamflow analysis and model calibration. For the simulation of the movement of water through the different storage zones, the following parameters, such as the maximum capacity (in mm), storage initial condition (in %) of each storage zone and maximum infiltration rate (in mm/h) are necessary [20].

2.3.2. Computation methods

In this research study, runoff was modeled using SMA model, streamflow hydrograph by Clark Unit Hydrograph technique, baseflow with linear reservoir method. The following computation methods were applied to the Taria catchment.

The loss method allows computing basin surface runoff, groundwater flow, total evaporation, as well as deep percolation out of the basin. The SMA model converts rainfall hyetograph into excess rainfall. For canopy and surface losses, the simple canopy and simple surface methods are considered [42].

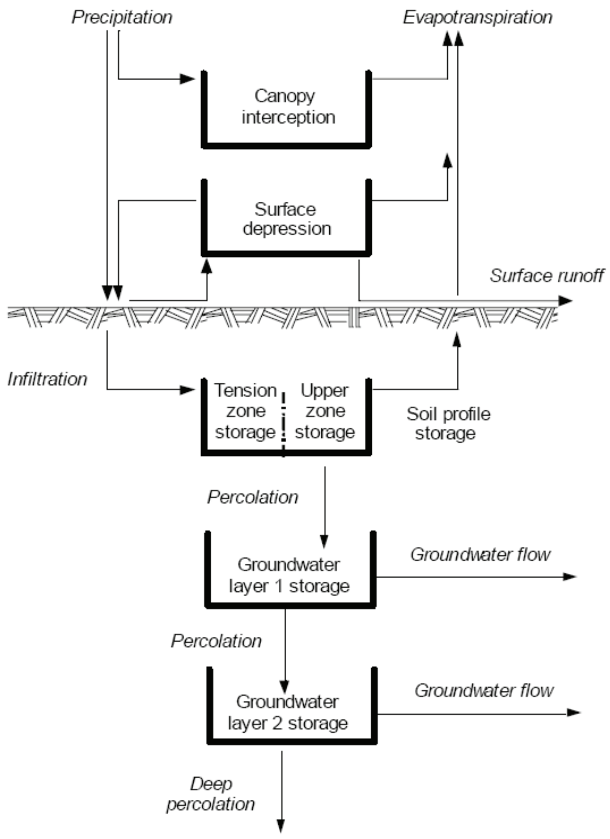

Fig. 3. Schematic diagram of HEC-HMS soil-moisture accounting (SMA) model.

Initial conditions were set to typical values for 1st September (end of summer season and the beginning of hydrological year): 0% filled for canopy storage, surface storage, soil storage, groundwater layer 1 storage and groundwater layer 2 storage. Canopy interception storage, surface depression storage, maximum infiltration rate, soil storage, tension zone storage and soil zone percolation rate parameters were estimated using land use, land cover and soil information and the maps edited by ANRH-GTZ [3] and by Padoun [37] for the northern Algeria, as derived from Tables 2 and 3. Tension storage was derived from SPAW software by determining the field capacity of the soil based on different soil texture values.

Transform method for the runoff generation allows specifying how to convert excess rainfall into direct runoff. The Clark Unit Hydrograph technique is a synthetic hydrograph method, that is, the user is not required to develop a unit hydrograph through the analysis of past observed hydrographs. The parameters required for the Clark Unit Hydrograph transform method are time of concentration (TOC) and the storage coefficient. The TOC is obtained from the GIS processing of the basin and the storage coefficient was evaluated by calibration.

Baseflow method performs subsurface flow calculation. The linear reservoir baseflow method was considered due to its simplicity and suitability for the SMA approach and was used to simulate continuously the recession of baseflow after a storm event. Additionally, the adapted module of linear reservoir is suitable and recommended with the SMA model [18]. Infiltration computed by loss method is connected as the inflow to the linear reservoir. The GW1 and GW2 storage coefficient

Table 2
Surface depression storage [20,43]

Description	Slope (%)	Surface storage (mm)
Paved impervious areas	NA	3.18–6.35
Steep, smooth slopes	>30	1.02
Moderate to gentle slopes	5–30	6.35–12.70
Flat, furrowed land	0–5	50.8

Table 3
Hydrologic median soil properties classified by soil texture [44]

Soil texture	Total porosity (cm^3/cm^3)	Saturated hydraulic conductivity (cm/h)
Sand	0.437	21.00
Loamy sand	0.437	6.11
Sandy loam	0.453	2.59
Loam	0.463	1.32
Silt loam	0.501	0.68
Sandy clay loam	0.398	0.43
Clay loam	0.464	0.23
Silty clay loam	0.471	0.15
Sandy clay	0.430	0.12
Silty clay	0.479	0.09
Clay	0.475	0.06

and storage depths were estimated by streamflow recession analysis of historic streamflow accurate measurements [45,46].

2.4. Model evaluation

A model is considered credible when it can reliably computed streamflow as compared with observed streamflow. Model evaluation can be achieved by analyzing the efficiency index, that is, the goodness of fit. To better analyze the obtained results, four best known criteria were used in the optimization (Table 4).

Each criterion admits its advantages and disadvantages. The percentage error in volume (PEV) value measures the deviation between the computed and the observed volume of flow; the model tends to minimize differences in the volume between the compared hydrographs. The NSE criterion is very commonly used and has been recommended by ASCE [53] and Legates and McCabe [49]. But this criterion leads to an overestimation of the model performance during peak flows and an underestimation during low flows. The R^2 criterion estimates the combined dispersion against the single dispersion of the observed and computed flow. According to Krause et al. [54], the fact that only the dispersion is accounted is one of the main disadvantages of R^2, if considered alone. However, for a good agreement the intercept a, on which R^2 is based, should be close to zero and the gradient b should be close to one. The index of agreement (d) was developed by Willmott [50] as a standardized measure of the degree of model prediction error and varies between 0 and 1. Like the criterion NSE, the index of agreement d, with the mean square error in the numerator, is also very sensitive to peak flows and insensitive for low flows.

3. Results and discussion

The input data (rainfall, runoff and ETP) were divided into two periods, one for calibration and one for validation. The calibration period extends from 09/01/1975 to 08/31/1985. This period with correct ANRH's discharge monitoring was considered suitable for calibration. The validation period extends from 09/01/1985 to 08/31/1990.

Three periods (calibration, validation and period of concern, 1990–1998) were used in this study characterizing, approximately, the three phases of hydrologic regime of the Taria wadi: high water, freshet and low water. The hydrologic regime of the Taria wadi depends closely to the regime of precipitation (Table 5). The calibration period is characterized by low hydraulicity due to low mean yearly precipitation amount. The validation period, with a lower percentage of rainless days, represents the high hydraulicity of hydrologic regime of the wadi with high mean yearly precipitation amount, and the period of concern, from 09/01/90 to 08/31/1998, characterize the intermediate mean yearly precipitation amount on the basin. The mean yearly precipitation for whole precipitation data is equal to 265 mm.

In the present study, a combination of manual and automated calibration techniques known as trial optimization in HEC-HMS was used to obtain optimum parameter values that give the best fit between observed and computed flow volumes values [42]. The model was calibrated for the identified sensitive parameters to improve the agreement between the computed and observed data. A sensitivity analysis shows that soil storage had the highest effect on the simulated streamflow, followed by tension storage. Note that soil storage was identified as a sensitive parameter by Fleming

Table 4
List of criteria used to compare computed (Qc) vs. observed (Qo) runoff

ID	Criteria	Equation	Performance [51,52]			
			VG	G	S	U
1	Percentage error in simulated volume (PEV)	$\mathrm{PEV}(\%) = 100\dfrac{V_o - V_c}{V_o}$ (Source: [47])	<±10	±(10–15)	±(15–25)	>±25
2	Nash–Sutcliffe efficiency, NSE (coefficient of efficiency)	$\mathrm{NSE} = 1 - \dfrac{\sum_{i=1}^{n}\left(Q_{o,i} - Q_{c,i}\right)^2}{\sum_{i=1}^{n}\left(Q_{o,i} - \overline{Q}_o\right)^2}$ (Source: [48])	0.75–1.00	0.65–0.75	0.50–0.65	<0.50
3	Coefficient of determination, R^2 (the square of the Pearson's product-moment correlation coefficient)	$R^2 = \left[\dfrac{\sum_{i=1}^{n}\left(Q_{o,i} - \overline{Q}_o\right)\left(Q_{c,i} - \overline{Q}_c\right)}{\sqrt{\sum_{i=1}^{n}\left(Q_{o,i} - \overline{Q}_o\right)^2}\sqrt{\sum_{i=1}^{n}\left(Q_{c,i} - \overline{Q}_c\right)^2}}\right]^2$ (Source: [49])	0.75–1.00	0.65–0.75	0.50–0.65	<0.50
4	Index of agreement, d	$d = 1 - \dfrac{\sum_{i=1}^{n}\left(Q_{o,i} - Q_{c,i}\right)^2}{\sum_{i=1}^{n}\left(\left\lvert Q_{c,i} - \overline{Q}_o\right\rvert + \left\lvert Q_{o,i} - \overline{Q}_o\right\rvert\right)^2}$ (Source: [50])	0.90–1.00	0.75–0.90	0.50–0.75	<0.50

Note: Vo, observed volume; Vc, computed volume; VG, very good; G, good; S, satisfactory; U, unsatisfactory.

Table 5
Hydroclimatic characteristics of the simulation periods

	Volume unit in mm/d			Volume unit in mm/year	Rainless and zero-flow days	
	Maximum	Average	Minimum		Days	%
Calibration (09/01/75 to 08/31/85: 10 years)						
Precipitations	95	0.55	0.0	201	3,198	87.5
ETP (temperature in °C)	4.31 (32.4)	1.95 (17.3)	0.10 (2.9)	712	–	–
Observed runoff	6.34	0.038	0.0	13.85	369	10.1
Validation (09/01/85 to 08/31/90: 5 years)						
Precipitations	87.2	0.94	0.0	343	1,510	82.7
ETP (temperature in °C)	4.87 (32.1)	2.04 (17.9)	0.53 (5.6)	745	–	–
Observed runoff	3.89	0.065	0.0	23.54	172	9.4
Period of concern (09/01/90 to 08/31/98: 8 years)						
Precipitations	84.2	0.81	0.0	296	2,576	88.2
ETP (temperature in °C)	4.33 (32.3)	1.96 (17.5)	0.09 (2.8)	715	–	–
Observed runoff[a]	8.11	0.044	0.0	15.97	–	–

[a]Uncertain data.

and Neary [20], Bashar and Zaki [21], Ayka [55], Roy et al. [56] and Singh and Jain [52].

The following SMA calibrated inputs parameters are recommended for general use in Taria catchment (Table 6). At the end of the calibration process, manually, the above listed four known criteria (Table 7) were used to measure how the model fits the real hydrologic system.

The hydrographs of observed and computed daily and cumulative runoff at the outlet of the Taria catchment over 10 years calibration period are depicted in Fig. 4, showing that the observed and computed runoff for calibration period are in close match. Fig. 5 depicts the comparison between computed and observed runoff depths lying on both sides of 1:1 line, which shows that there is no consistent overestimation or underestimation. Due to the low hydraulicity of the Taria basin during the calibration period, most of the points are grouped in the lower corner of the graph, which represents the low discharge rate during this period. Flood flow events are the least frequent.

However, these calibrated inputs parameters represent average conditions for the Taria catchment, so different inputs might be appropriate for specific locations in the catchment with atypical soils or surface conditions.

The hydrographs of observed and computed daily and cumulative runoff at the outlet of the Taria catchment over 5 years validation period are depicted in Fig. 6, showing that the observed and computed runoff for validation period are in close match. Fig. 7 depicts the comparison between computed and observed runoff discharges. The majority of the points lie on both sides of 1:1 line and it can be noticed that, in some cases, computed peaks are underestimated, while for whole validation data, error in volume is reduced, indicating very good model performance (Table 7). According to Table 4, the model performance shows upgrade to very good model for whole datasets (Table 7). Despite the great different hydraulicity during the two periods of calibration (low hydraulicity) and validation (high hydraulicity), the performance of the model is very acceptable allowing the more accurate correction of flow datasets of the years with hydrometric suspicious data, that is, 1990s decade.

The values of PEV, NSE, R^2 and d obtained during calibration are 4.76%, 0.90, 0.90 and 0.97, respectively. Similarly during validation of the model, the model

Table 6
Optimized values of SMA model parameters

Parameters	Minimum limit	Maximum limit	Optimized value
Maximum infiltration, mm/h	0.01	500	3.52
Impervious area, %	0.001	100	6.88
Soil storage, mm	0.01	1,500	220
Tension storage, mm	0.01	1,500	90
Soil percolation, mm/h	0.01	500	1.4
GW1 storage, mm	0.01	1,500	65
GW1 percolation, mm/h	0.01	500	0.30
GW1 coefficient, h	0.01	10000	1,110
GW2 storage, mm	0.01	1,500	150
GW2 percolation, mm/h	0.01	500	0.15
GW2 coefficient, h	0.01	10,000	1,560
Canopy maximum storage, mm	0.01	1,500	1.0
Surface maximum storage, mm	0.01	1,500	26.5
Clark TOC, h	0	1,000	15
Clark storage coefficient, h	0.01	1,000	18.5
Linear baseflow GW1 initial, m^3/s	0	100,000	0.20
Linear baseflow GW1 coefficient, h	0	10,000	3,900

evaluation criteria for PEV, NSE, R^2 and d were found to be 1.16%, 0.66, 0.67 and 0.89, respectively. The PEV for the model is small. The high values of the Nash–Sutcliffe efficiency (NSE) model, R^2 and index of agreement d (between 0.66 and 0.97) indicate close agreement between observed and computed runoff. The intercept and the gradient for the criterion R^2 are then close to zero and one, respectively [54]. For the validation period the model performed well in terms of PEV, with lowest value. This criterion gives a very good agreement when we are interested to the volume of flow in given period for the water resources assessment and water balance studies. The NSE score was 0.66. Model results consistently underestimated flows relative to the measured flow for some high rainfall-runoff events. This may be a result of uncertainty in the rating curve for the streamflow gage. The rating curve (denoted as $Q(H)$) is a standard way to continuously estimate discharge Q combined with a continuous series of observed water stage H. In the natural channels this relationship is non-unique (hysteresis effect). Unfortunately, the area-velocity method is impracticable in the field to obtain continuous or frequent measurements, essentially for high flow, when it is impossible to use a current meter, because excessive velocity and depth. To extrapolate rating curve in high flood events within an associated period of validity, a simple method, based on the power $Q(H)$ relationship is used at the ANRH office, in Algeria. This is the simplest technique that does not take into account specific hydraulic conditions during floods, so, additional uncertainties will apply. Few percentage of discharge data is gauged (approximately 10%); mostly they are obtained by rating curve extrapolation. Because the flash floods events occurred in the Mediterranean basin are difficult to anticipate and measure, so they induce large uncertainties in the estimate discharge. This method of extrapolation increases the errors of

Table 7
Performance criteria of the model for the calibration and validation periods

Performance criterion	Calibration	Validation
PEV (%)	4.76 (VG)	1.16 (VG)
NSE	0.90 (VG)	0.66 (G)
R^2	0.90 (VG) (intercept, a = 0.019; gradient, b = 0.92)	0.67 (G) (intercept, a = –0.179; gradient, b = 0.93)
d	0.97 (VG)	0.89 (G)

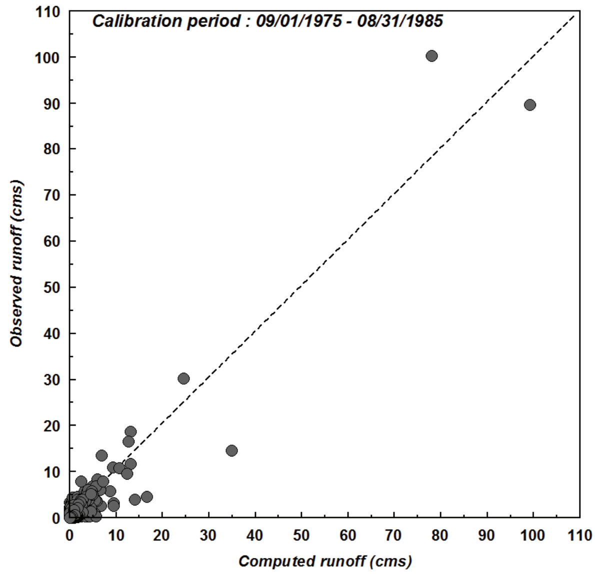

Fig. 5. Comparison between observed and computed runoff for the calibration period.

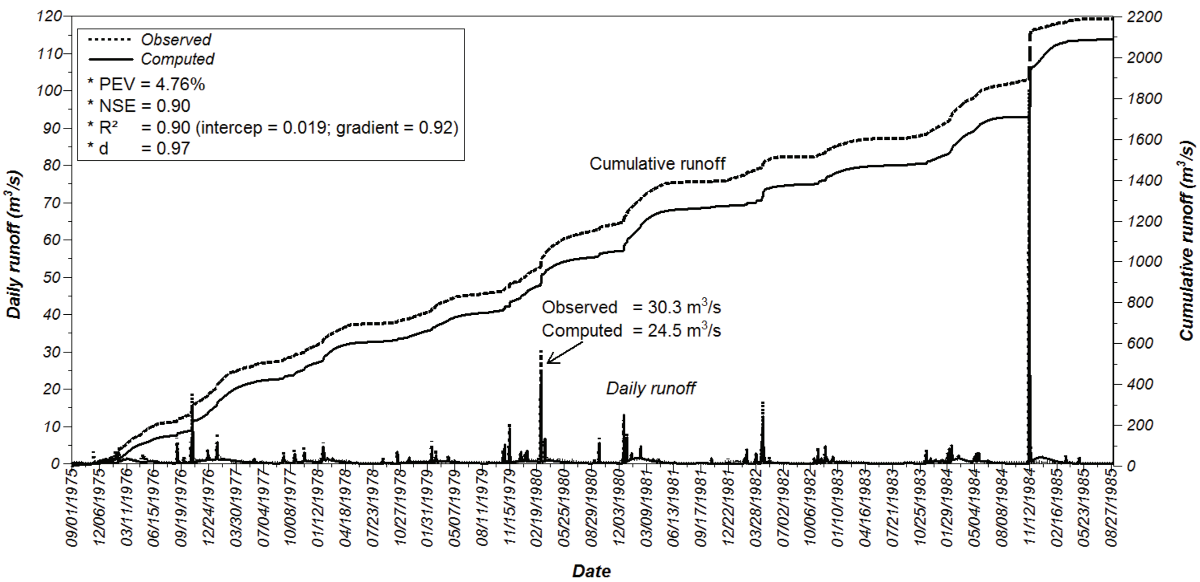

Fig. 4. Hydrographs of observed and computed HMS SMA daily and cumulative runoff in the Taria catchment in period of calibration, from 09/01/1975 to 08/31/1985.

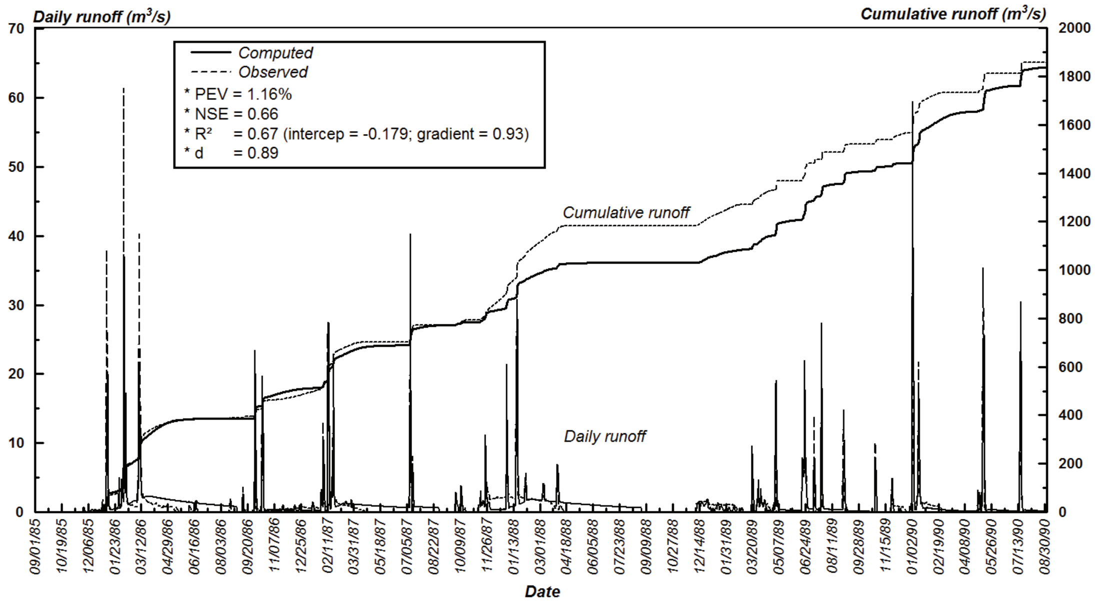

Fig. 6. Hydrographs of observed and computed HMS SMA daily and cumulative runoff in the Taria catchment in period of validation, from 09/01/1985 to 08/31/1990.

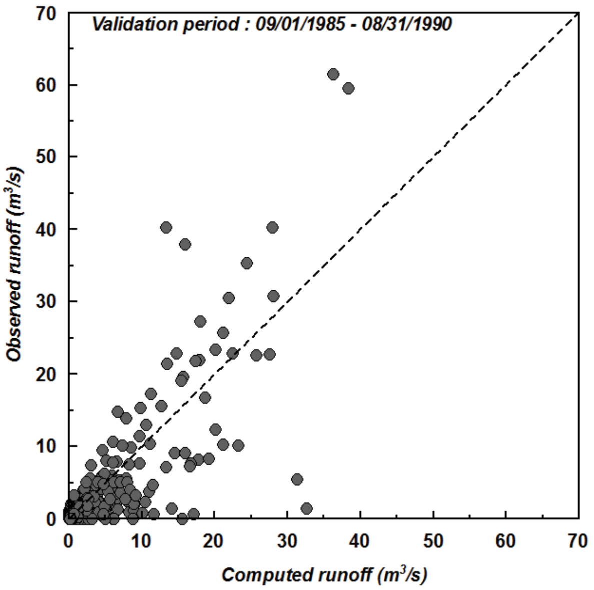

Fig. 7. Comparison between observed and computed runoff for the validation period.

the obtained flow due to the rating curve uncertainty in high flow domain, out the measured range [15]. For instance, Di Baldassarre and Montanari [16] investigated the rating curve uncertainty and concluded that may include errors of up to 25% of estimates in the extrapolation range. We recommend to investigate these uncertainties in discharge measures and estimates by using different rating curve extrapolation methods based on hydraulic 2D models before to include them in the hydrological models.

Uncertainties are also related to the SMA model. The SMA model takes into account the average daily discharge while the largest amount of runoff drained by the basin occurs during periods of flash floods that last for only a few hours for each flood event (approximately 80% of the total annual volume, including baseflow). Therefore, the number of days without runoff is important (around 10% on average, Table 5). Daily flow data do not show and explain this intraday variability in the flow and in the flash changes occurring in surface depressions, soil and subsoil that induce extreme spatial and temporal variability of model parameters. This situation is shown in Fig. 7 where the calibrated model parameters with the very good calibration performance induce less efficiency for the validation period. This situation is also shown in Figs. 4 and 6 where the cumulative curves show an almost constant difference for the calibration period (Fig. 4) and these curves overlap for the first part of the validation period (until year 87) and differs with variable error for the second part of the validation period (Fig. 6). This began with the drought period (from the year 88 to the year 89) with very few flood events. This situation is also shown for the calibration period (Fig. 4) with few flood events.

These errors in model simulation have different sources, such as errors in rainfall-runoff data, inadequate space-time representation of hydroclimatic data (rainfall, runoff and ETP) and of features of the drainage basin (slopes and soils parameters). In the temporal context, to reduce these errors, a monthly or even 10-d estimate of model parameters is required to account for this large variability in soil and subsoil hydrological conditions, in this semiarid region. In the spatial context, the catchment must to be subdividing in subcatchments to well capture this spatial variability of drainage basin features conditions (such as azonal soils, slopes, etc.) and consequently of the infiltration losses. But, because insufficient density of hydrometric monitoring network, this is not achievable.

Thus, the results indicate that overall estimation of wadi Taria streamflow by the SMA model during the

Table 8
Observed and computed annual mean of wadi Taria total flow runoff volume for the periods of calibration, validation and incorrect hydrometric data

Period	Annual total flow (×10^6 m^3)		
	Observation	SMA model	Difference (PEV, %)
1975–1985 (period of calibration)	18.90	18.00	4.76
1985–1990 (period of validation)	32.13	31.75	1.16
1990–1998 (period of incorrect runoff measures)	21.80	26.33	–20.78

calibration and validation periods is good and therefore may be accepted for further analysis, that is, correcting the wrong discharge data.

Recalling one of the main objectives of the hydrological modeling of this study (water resources assessment), the catchment runoff volumes from the model results were analyzed for the periods of calibration (1975–1985) and validation (1985–1990) and for the period with incorrect discharge data (1990–1998). Table 8 show that, if the difference in total annual mean volume, between observed and computed runoff, is acceptable for the first two periods of hydrologic modeling, due to the more accurate measured flow, conversely the period with incorrect data show a very important difference in volume compared with the model results, with over 20% underestimated runoff. Since the period of doubtful data (1990–1998) is a period with intermediate (near average) hydrological regime between the two calibration and validation periods, we can estimate approximately the volume runoff average contribution of the Taria wadi by considering the average of these two periods, which is estimated, from the observation data (supposedly more reliable), equal to 25.52 MCM (million cubic meters). This estimate, although approximate, is comparable with that obtained by the SMA model (26.33 MCM). So we can say that the SMA model, despite the insufficiencies related to the various uncertainties, discussed above, allow to correct the discharge suspicious data, and to conduct correctly water resources assessment programs to assist understanding of the impact of past and present water management practices and climate changes.

4. Conclusions

The SMA model was calibrated for the identified sensitive parameters to improve the agreement between the computed and observed runoff data. Thus, both manual and automated calibration methods were used for this study. The model generated similar results to measured data for the calibration period (09/01/1975 to 08/31/1985). Four performance metrics were utilized. The model performance was very good for all metrics. The NSE score, a key metric for hydrologic model calibration, was 0.90. The model also performed well for the validation period (09/01/1985 to 08/31/1990). Performance was very good for one metric and good for three metrics. The wrong measured flow data collected during the period from 09/01/1990 to 08/31/1998 underestimate annual total flow with over 20% compared with the model results. The model can help to save time and money to get runoff data or correct them in the case of aberrant runoff measures, such as in the case of wadi Taria catchment. In addition, it can help to simulate runoff in ungauged basins where there is no hydrometric stations.

Despite the difficulties and uncertainties associated with the acquisition of streamflow data to perform water resources assessment projects, this study ended-up optimistic result for the rainfall-runoff modeling. In general, the SMA model can therefore be used to simulate the rainfall-runoff process in the Macta basin.

References

[1] A. Hamlat, M. Errih, A. Guidoum, Simulation of water resources management scenarios in western Algeria watersheds using WEAP model, Arabian J. Geosci., 6 (2012) 2225–2236.
[2] Y. Elmeddahi, A. Issaadi, H. Mahmoudi, M.T. Abbes, M.F.A. Goosen, Effect of climate change on water resources of the Algerian Middle Cheliff basin, Desal. Wat. Treat., 52 (2014) 2073–2081.
[3] ANRH-GTZ, Etude de synthèse sur les ressources en eaux de surface de l'Algérie du Nord (cartes annexées), ANRH Publications, Alger, 2003.
[4] D. Baahmed, L. Oudin, M. Errih, Current runoff variations in the Macta catchment (Algeria): is climate the sole factor? Hydrol. Sci. J., 60 (2015) 1331–1339.
[5] WMO, Intercomparison of Conceptual Models Used in Operational Hydrological Forecasting, Operational Hydrology Report n° 7, WMO n° 429, World Meteorological Organization, Geneva, Switzerland, 1975.
[6] C. Perrin, Vers une amélioration d'un modèle global pluie-débit au travers d'une approche comparative, Doctorat Thesis, INPH, Grenoble, 2000, 530 pp.
[7] C. Perrin, C. Michel, V. Andréassian, Does a large number of parameters enhance model performance? Comparative assessment of common catchment model structures on 429 catchments, J. Hydrol., 242 (2001) 275–301.
[8] C. Perrin, C. Michel, V. Andréassian, Improvement of a parsimonious model for streamflow simulation, J. Hydrol., 279 (2003) 275–289.
[9] K. Dzubakova, Rainfall-runoff modelling: its development, classification and possible applications, Acta Geog. Univ. Comenianae, 54 (2010) 173–181.
[10] K.J. Beven, Rainfall-Runoff Modelling: The Primer, 2nd ed., Wiley-Blackwell, 2012, 488 pp.
[11] M. Mehreb, R. Moussa, C. Abdallah, F. Colin, C. Perrin, N. Baghdadi, Hydrological response characteristics of Mediterranean catchments at different time scales: a meta-analysis, Hydrol. Sci. J., 61 (2016) 2520–2539.
[12] K.J. Beven, R. Alcock, Modelling everything everywhere: a new approach to decision making for water management under uncertainty, Freshwater Biol., 56 (2012) 124–132.
[13] K.J. Beven, P. Smith, Concepts of information content and likelihood in parameter calibration for hydrological simulation models, J. Hydrol. Eng., 20 (2014) A4014010.
[14] WMO, Guide to Hydrological Practices, Data Acquisition and Processing, Analysis, Forecasting and Other Applications, WMO n°168, 5th ed., 1994, 735 pp.
[15] M. Errih, A. Berbar, M. Benaicha, Tarage et extrapolation des stations hydrométriques des petits bassins versants de l'Algérie septentrionale, Proceedings of the XXIV IAHR Congress, Madrid CEDEX, Vol. A, Study of Streams and Watersheds of High Hydraulic Irregularity, 1991, pp. 211–221.
[16] G. Di Baldassarre, A. Montanari, Uncertainty in river discharge observations: a quantitative analysis, Hydrol. Earth Syst. Sci., 13 (2009) 913–921.

[17] J.F. Martinez Plata, E.A. Dominguez Calle, H.G. Riviera, Uncertainty regarding instantaneous discharge obtained from stage-discharge rating curves built with low density discharge measurements, Ing. Invest., 32 (2012) 30–35.
[18] USACE, Hydrologic Modeling System (HEC-HMS) – Technical Reference Manual, Hydrologic Engineering Center, Davis, California, USA, 2000, 138 pp.
[19] B.M. McEnroe, Guidelines for Continuous Simulation of Streamflow in Johnson County, Kansas, with HEC-HMS, Johnson County Publics Works and Infrastructure, Report, Kansas, USA, 2010, 35 pp.
[20] M. Fleming, V. Neary, Continuous hydrologic modeling study with the hydrologic modeling system, ASCE J. Hydrol. Eng., 9 (2004) 175–183.
[21] K.E. Bashar, A.F. Zaki, SMA Based Continuous Hydrologic Simulation of the Blue Nile, A Paper Published in the International Conference of UNESCO Flanders FUST FRIEND/NILE Project Towards a Better Cooperation, Sharm El-Sheikh, Egypt, 2005.
[22] Z. Yusop, C.L. Chanand, A. Katimon, Runoff characteristics and application of HEC-HMS for modelling stormflow hydrograph in an oil palm catchment, Water Sci. Technol., 56 (2007) 41–48.
[23] M.A.M. Razi, J. Ariffin, W. Tahir, N.A.M. Arish, Flood estimation studies using Hydrologic Modelling System (HEC-HMS) for Johor River Malaysia, J. Appl. Sci., 10 (2010) 930–939.
[24] A. Majidi, K. Shahedi, Simulation of rainfall-runoff process using Green-Ampt Method and HEC-HMS Model (Case Study: Abnama Watershed, Iran), Int. J. Hydraul. Eng., 1 (2012) 5–9.
[25] M.K. Yener, A.U. Sorman, A.A. Sorman, A. Sensoy, T. Gezgin, Modeling Studies with HEC-HMS and Runoff Scenarios in Yuvacik Basin, Turkiye, International Congress on River Basin Management, 2012, pp. 621–634.
[26] D. Halwatura, M.M.M. Najjim, Application of the HEC-HMS model for runoff simulation in a tropical catchment, Environ. Modell. Software, 46 (2013) 155–162.
[27] M.M.G.T. De Silva, S.B. Weerakoon, S. Herath, Modeling of event and continuous flow hydrographs with HEC-HMS: case study in the Kelani River Basin, Sri Lanka, J. Hydrol. Eng., 19 (2014) 800–806.
[28] J. Lavabre, J.-P. Cambon, N. Folton, Z. Makhlouf, C. Michel, Loieau: un logiciel pour l'estimation régionale de la ressource en eau, Application à la détermination des débits de référence de la région méditerranéenne française, Ing. EAT, 12 (1997) 59–66.
[29] S.C. Mouelhi, C. Michel, C. Perrin, V. Andréassian, Stepwise development of a two-parameter monthly water balance model, J. Hydrol., 318 (2006) 200–214.
[30] P. Griset, Du Cemagref à Irstea, un engagement pour la recherche environnementale, Ed. Quae, 2011, 153 pp.
[31] A. Dakiche, Contribution à l'étude des régimes hydrologiques des bassins de la Tafna: Evaluation du bilan des ressources en eau superficielle, Mémoire de Magister, USTO, Département d'Hydraulique, Laboratoire HYDRE, 2005, 152 pp.
[32] R. Bouanani, K. Baba-Hamed, A. Bouanani, Utilisation d'un modèle global pour la modélisation pluie-débit: cas du bassin d'Oued Sikkak (NW algérien), Rev. Nat. Technol., C, 9 (2013) 61–66.
[33] M. Kabouya, Modélisation pluie-débit au pas de temps mensuel et annuel en Algérie septentrionale, Doctorat Thesis, Paris-Sud-Orsay University, 1990, 347 pp.
[34] M. Kabouya, C. Michel, 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 (1991) 569–587.
[35] A.T. Benkaci, N. Dechemi, Modélisation pluie-débit journalière par des modèles conceptuels et à boite noire; test d'un modèle neuroflou/Daily rainfall-runoff modelling using conceptual and black box models; testing a neuro-fuzzy model, Hydrol. Sci. J., 49 (2004) 919–930.
[36] E.-A. Chérif, M. Errih, H.M. Chérif, Modélisation statistique du transport solide du bassin versant de l'Oued Mekerra (Algérie) en zone semi-aride méditerranéenne/Statistical modelling of the solid transport in the wadi Mekerra basin (Algeria) in the Mediterranean semi-arid zone, Hydrol. Sci. J., 54 (2009) 338–348.
[37] N.N. Padoun, Water balance of the northern Algeria territory in: 'Forecasting and computing of River hydrologic characteristics' (in Russian: a Vodnom balancy territoriy severnava Algira – 'Prognozy y rachioty guidrologuitcheskykh kharacteristic rek'), Ukrainian Hydrometeorological Research Intitute, 145 (1975) 122–129.
[38] A.H. Thiessen, District No. 10, Great Basin, Monthly Weather Review, 39 (1911) 1248–1248.
[39] L. Oudin, F. Hervieu, C. Michel, C. Perrin, V. Andréassian, F. Anctil, C. Loumagne, Which potential evapotranspiration input for a lumped rainfall–runoff model? Part 2 – towards a simple and efficient potential evapotranspiration model for rainfall-runoff modelling, J. Hydrol., 303 (2005) 290–306.
[40] O. Dewitte, A. Jones, O. Spaargaren, H. Breuning-Madsen, M. Brossard, A. Dampha, J. Deckers, T. Gallali, S. Hallett, R. Jones, M. Kilasara, P. Le Roux, E. Michaeli, L. Montanarella, L. Thiombiano, E. Van Ranst, M. Yemefack, R. Zougmore, Harmonisation of the soil map of Africa at the continental scale, Geoderma, 211–212 (2013) 138–153.
[41] J.H. Durant, Les sols d'Algérie, SES, Pédologie n°2, Alger, 1954, 244 pp.
[42] USACE, Hydrologic Modeling System HEC-HMS, User's Manual, Hydraulic Engineering Center, Davis, California, USA, 2010, 306 pp.
[43] T. Bennett, Development and Application of a Continuous Soil Moisture Accounting Algorithm for the Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS), M.S. Thesis, Department of Civil and Environmental Engineering, University of California, Davis, 1998.
[44] W.J. Rawls, D.L. Brakensiek, K.E. Saxton, Estimation of soil water properties, Trans. ASAE, 25 (1982) 1316–1328.
[45] R.K. Linsley, M.A. Kohler, J.L.H. Paulhus, Hydrology for Engineers, McGraw-Hill, New York, 1958.
[46] G.H. Leavesley, R.W. Lichty, B.M. Troutman, L.G. Saindon, Precipitation-Runoff Modeling System: User's Manual, United States Department of the Interior Geological Survey, Denver, 1983.
[47] K. Paik, J.H. Kim, H.S. Kim, D.R. Lee, A conceptual rainfall-runoff model considering seasonal variation, Hydrol. Processes, 19 (2005) 3837–3850.
[48] J.E. Nash, J.V. Sutcliffe, River flow forecasting through conceptual models, Part I: a discussion of principles, J. Hydrol., 10 (1970) 282–290.
[49] D.R. Legates, G.J. McCabe Jr., Evaluating the use of "goodness-of-fit" measures in hydrologic and hydroclimatic model validation, Water Resour. Res., 35 (1999) 233–241.
[50] C.J. Willmott, On the Evaluation of Model Performance in Physical Geography, G.L. Gaile, C.J. Willmott, Eds., Spatial Statistics and Models, Vol. 40, Springer, Netherlands, 1984, pp. 443–460.
[51] D.N. Moriasi, J.G. Arnold, M.W. Van Liew, R.L. Binger, R.D. Harmel, T. Veith, Model evaluation guidelines for systematic quantification of accuracy in watershed simulations, Trans. ASABE, 50 (2007) 885–900.
[52] W.R. Singh, M.K. Jain, Continuous hydrological modeling using soil moisture accounting algorithm in Vamsadhara river basin, India, J. Water Res. Hyd. Eng., 4 (2015) 398–408.
[53] ASCE, Criteria for evaluation of watershed models, J. Irrig. Drain. Eng., 119 (1993) 429–442.
[54] P. Krause, D.P. Boyle, F. Base, Comparison of different efficiency criteria for hydrological model assessment, Adv. Geosci., 5 (2005) 89–97.
[55] A. Ayka, Hydrological Models Comparison for Estimation of Floods in the Abaya-Chamo Sub-Basin, A Thesis Presented to the School of Graduate Studies Civil Engineering Department of the Addis Ababa University, 2008.
[56] D. Roy, S. Begam, S. Ghosh, S. Jana, Calibration and validation of HEC-HMS model for a river basin in eastern India, ARPN J. Eng. Appl. Sci., 8 (2013) 40–56.