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THE USE OF THE HEC-HMS MODEL TO IMPROVE REGIONALIZED HYDROLOGICAL MODELING AND ITS APPLICATION TO THE CHELIFF BASIN, ALGERIA

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ABSTRACT

Hydrological modeling is an effective tool for predicting the hydrological response of watersheds in order to develop appropriate water resource management strategies. Various modeling techniques are available to simulate rainfall-runoff processes in ungauged basins, including regionalization of hydrologic model parameters. Regionalization by spatial proximity (SP) and physical similarity (PS) were chosen for this study to be used with Hydrologic Modeling System (HEC-HMS), which is semi-distributed hydrological model, to evaluate the performance of the model in simulating sub-basin flows as well as the applicability of averaging methods in the case of ungauged sub-basins. Eight sub-basins belonging to the large Cheliff watershed were selected using available data from the period 2007 to 2012. In order to perform a controlled regionalization, one of the eight sub-basins (Wadi Tikzal) was assumed to be ungauged, and five sub-basins were selected to be donors by the (SP) regionalization method and five others by the (PS) regionalization. The results were compared to the original gauged sub-basin series. The performance analysis was carried out through the Nash-Sutclife Efficiency (NSE), the coefficient of determination (R^2) and the root mean squared error (RMSE). The results of the simulation are generally satisfactory for wadi Tikzal sub-basin. The model adequately simulated the flows in the other sub-basins, during both calibration and validation phases. The results obtained showed that the regionalization methods used in this study, with the arithmetic mean and the inverse distance weighting (IDW), yielded good results with NSE and R^2 values exceeding 0.75 and RMSE values were close to 0.20. The arithmetic mean gave higher results compared to the IDW method, the mean of NSE between the two methods is 0.68 for the arithmetic mean and 0.65 for IDW, and R^2 of 0.69 for the arithmetic mean and 0.65 for IDW. The obtained results demonstrate that the regionalization by spatial proximity and physical similarity, using the HEC-HMS hydrological model can be effectively used to predict streamflow in ungauged watersheds, leading to effective water resources management, which enriches the literature regarding the flows regionalization, averaging methods and HEC-HMS performance, in ungauged sub-basins and especially in the northern Algerian region.

Keywords: Arithmetic mean; Cheliff basin; HEC-HMS; Inverse distance weighting; Physical similarity; Regionalization; Spatial proximity.

1 INTRODUCTION

Researchers face a major challenge in dealing with streamflow simulation at ungauged basins due to non-existence of calibration data. Streamflow regionalization, also known as streamflow prediction in ungauged catchments, is an indispensable tool in watershed management, infrastructure control and water availability for multiple uses [1]. Indeed, many regions of the world do not have flow data to calibrate simulation model's parameters due to high operational costs of stations or large gaps in data records. In addition, changes in watershed characteristics as a result of urbanization make flow forecasting in ungauged basins a challenging task in hydrology [2]. Hence, the concept of regionalization is applied in hydrological modeling such that runoff time series in the ungauged catchment are predicted by the use of the hydrological model parameters calibrated in the gauged catchment(s), called donor(s) [3].

Among many modeling techniques available for simulating rainfall-runoff processes in ungauged basins, the method of predicting runoff in ungauged basins by transferring information from gauged basins (donors) to ungauged ones that is known as the regionalization of hydrological model parameters is one of the most powerful techniques to predict flows [4, 5]. In general, regionalization methods fall into three main categories; similarity-based methods, regression-based methods and hydrological signature methods. The similarity-based methods are categorized into spatial proximity methods and physical similarity methods. The spatial proximity methods assume that geographically close watersheds have similar hydrological behavior [6] where the level of proximity is typically measured though the Euclidean distance. The physical similarity methods, on the other hand, consider that watersheds with similar physical characteristics respond to a precipitation event in a hydrologically similar way [7, 8, 9]. The normalized distance between two points in an N-dimensional space defines similarity, such that each dimension represents a sub-basin descriptor, such as elevation, soil type and land use. The egression-based methods relate the model parameters to the physical and climatic characteristics of the watershed by regression functions and assume that the relationship is transferable from gauged to ungauged basins [10]. Finally, the hydrological signature methods consider the hydrological signatures of watersheds which are represented by static indicators such as average streamflow, flood frequency etc., and dynamic indicators such as baseflow index, flow change rate etc [11].

There have been numerous studies conducted previously on ungauged watershed predictions and particularly since the launch of the Predictions in Ungauged Basins (PUB) initiative by the International Association of Hydrological Sciences in 2003. These studies multiply and extend to several regions of the world. Many studies have applied and compared regionalization methods for various regions in combination with a wide range of hydrological models [12, 13, 14]. Several techniques were applied in different regions, and thus many conclusions were drawn claiming that studies in specific regions and the choice of certain hydrological models influence the performance of regionalization methods e.g. [12, 15, 16, 17, 18, 19, 20]. For both spatial proximity and physical similarity methods, it was proven by many authors that regionalization using multiple donors could lead to significantly improved results compared to using a single donor [7, 18]. To average the generated hydrographs, there are many implementations of multi-donor averaging, but the two most commonly known approaches are the arithmetic average and inverse distance weighting (IDW) methods. Various studies have applied the HEC-HMS model for different purposes in several Algerian watersheds with specific soil and climatic conditions. Derdour et al [21] used the HEC-HMS hydrological model to predict surface runoff in a semi-arid area in the Ksour Mountains of Ain Sefra, southwestern Algeria. Mokhtari et al [22] predicted the hydrological response of the Wadi Cheliff-Ghrib watershed to climate and land use change scenarios by applying the HEC-HMS model. Allali et al [23] conducted a comparative study of two approaches, using the SCS unit hydrograph and CLARK unit hydrograph transformation methods of the HEC-HMS model to simulate the peak flow and surface runoff in the Ouahrane basin. In addition, Haddad [24] applied the HEC-HMS model to the Oued El Hachem watershed for modeling extreme rainfall-runoff events.

On the other hand, and despite the problem of availability of data in several Algerian basins due to a large number of the lack or poor quality of data, there are few research studies dealing with the regionalization methods. For example, Zamoum et al [25] used the GR2M model to provide continuous monthly streamflow information in ungauged catchments in northern Algeria by using two classification techniques: principal component analysis (PCA) and self-organizing maps (SOM). Ammari et al [26] used a simple entropy-based method for discharge simulations in gauged and ungauged river sites in the coastal Algerian watershed.

Based on this premise, streamflow prediction in ungauged basins is especially challenging and no previous study was conducted in the Cheliff basin, with an area of about 44000 km^2 drained by the cheliff river which is considered the most important river in Algeria and extends over 700 km. To this end and given the importance of regionalization in the region of Algeria and to enrich the literature by a study of regionalization in this semi-arid zone, this present study aims to employ two methods of the regionalization, by spatial proximity and by physical similarity, using the arithmetic mean and the inverse distance weighting (IDW) approaches to obtain the flows in the ungauged sub-basin from multi-donor. The HEC-HMS hydrological model was used for the transfer of flows from five gauged sub-basins in Cheliff basin (Northern Algeria) to a pseudo ungauged sub-basin. The obtained results were compared with the real flow series of the pseudo ungauged sub-basin to test the effectiveness of the implemented approach.

2 STUDY AREA

Located in northern Algeria, the Cheliff basin is circumscribed within the chains of the Atlas Tellien parallel to the Mediterranean coast. It consists of three parts (upper and middle cheliff with 10930 km^2, lower cheliff and the mina of 13150 km^2 and the upstream Boughzoul with 19990 km^2). It is located between 0°12' and 3°87' East meridians and between 33°91' and 36°58' North latitudes. It covers three sub-regions, Cheliff upstream of Boughzoul, Upper and Middle Cheliff and Lower Cheliff and Mina. It is limited to the north by the Mediterranean Sea, to the south by the high plains, to the east by the Algiers basin and to the west by the Oran basin. The precipitation in the basin is highly variable with a decreasing trend in the north-south and east-west directions [27]. The eight sub-basins studied within this study are located in the Upper and Middle Cheliff of elongated shape and very dense hydrographic flow (Figure 1).

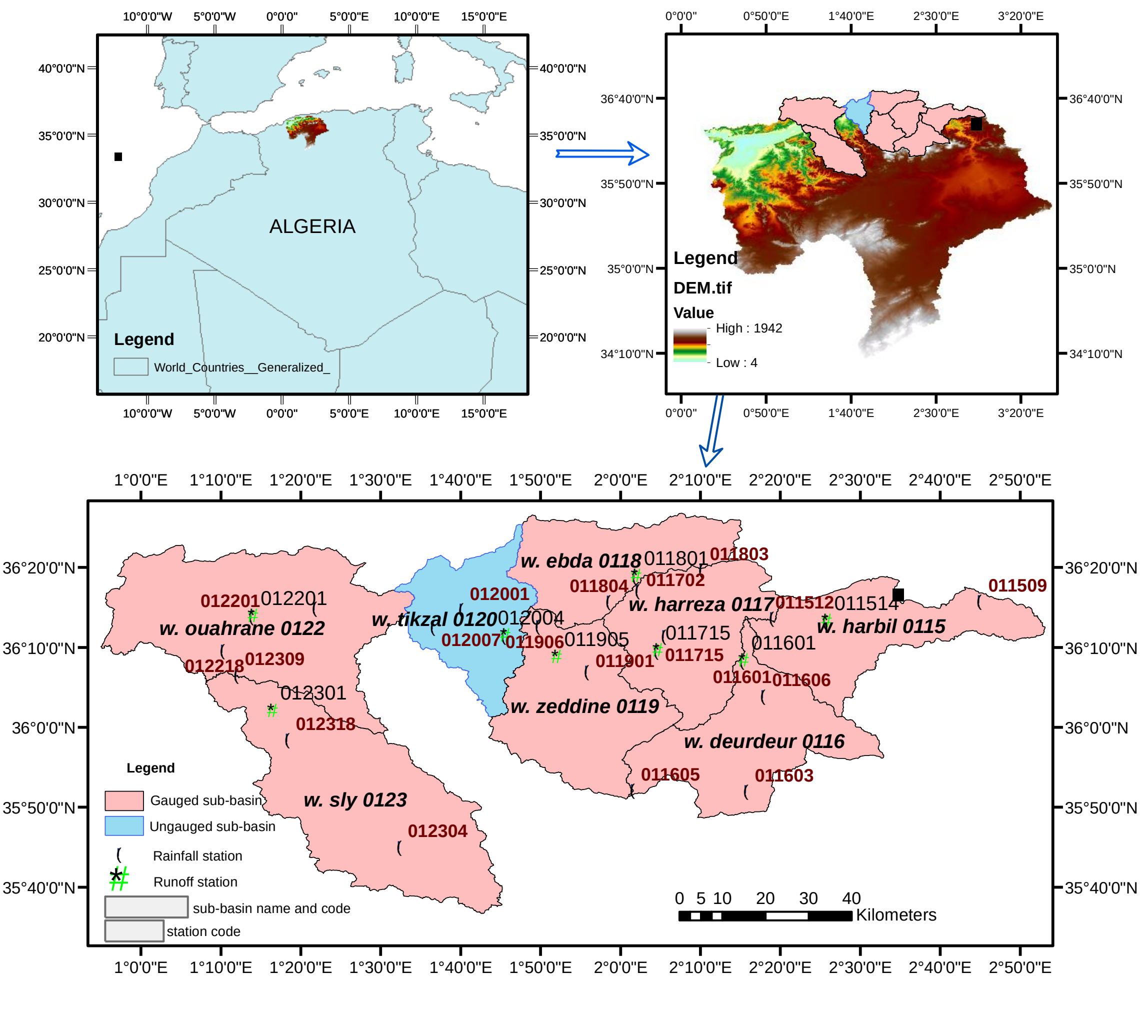

__Figure 1.__ Location of the study area and studied sub-basins

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3 DATA AND METHODOLOGY

3.1 Data

The period from 2007 to 2012 was chosen so as to have a duration covering all the stations with the smallest gaps present in the series of the region, we therefore chose 26 stations while trying to maintain geographical distribution throughout the study area.

Table 1. *Characteristics of the stations used (Source ANRH, Algeria)*

Sub-basin	Station Code	Station Type	Station name	X (m)	Y (m)	Z (m)
W. Harbil	011509	Rainfall	Medea secteur	478010.84	4013328.66	935
	011512	Rainfall	Ain Sultan	439017.34	4009581.38	285
	011514	Rainfall/Runoff	Djenane B-Ouadah	449021.74	4008687.01	336
W. Deurdeur	011601	Rainfall/Runoff	Marabout Blanc	433426.31	3999655.06	358
	011603	Rainfall	Bordj Elamir AEK	433951.74	3969592.79	1074
	011606	Rainfall	Sidi Mokerfi	437321.24	3991601.55	447
W. Harreza	011702	Rainfall	Arib cheliff	413954.07	4016184.92	246
	011715	Rainfall/Runoff	El ababsa	417311.00	4002046.94	320
	011718	Rainfall	Harreza BGE	418805.93	4005515.18	312
W. Ebda	011801	Rainfall/Runoff	Arib Ebda	413449.57	4019401.08	280
	011803	Rainfall	Sidi Medjahed	425903.56	4020829.64	850
	011804	Rainfall	Ain Defla	408451.47	4013695.89	271
W. Zeddine	011605	Rainfall	Thniet el had	412557.08	3969995.72	1162
	011901	Rainfall	El touaibia	404261.20	3997469.23	376
	011905	Runoff	Bir ouled tahar	392159.37	4010104.75	331
	011906	Rainfall	Rouina mines	395150.25	4008085.03	343
W. Tikzal	012001	Rainfall	El abadia	380853.85	4012119.23	158
	012004	Rainfall/Runoff	Tikzal	388770.83	4005865.68	215
	012007	Rainfall	Bir saf saf	375186.60	4008237.86	166
W. Ouahrane	012201	Rainfall/Runoff	Ouled fares	341490.70	4011118.12	116
	012218	Rainfall	Domaine si tayeb	335957.07	4003437.22	84
	012221	Rainfall	Medjadja	353419.22	4012948.51	188
W. Sly	012301	Runoff	Ouled Ben AEK	344798.05	3989147.23	260
	012304	Rainfall	Souk El had	368456.80	3957438.33	550
	012309	Rainfall	Oued Sly	338434.90	3997733.37	95
	012318	Rainfall	Sidi Yakoub BGE	347745.10	3982598.30	272

3.2 Methodology

The eight sub-basins studied are located in the upper and middle cheliff part of north-west Algeria, whose areas vary from 592 to 1432 km^2. These are Oued Ouhrane (code 0122), Oued Sly (code 0123), Oued Deurdeur (code 0116), Oued Ebda (code 0118), Oued Harbil (code 0115), Oued Harreza (code 0117), Oued Tikzal (code 0120), Oued Zeddine (code 0119). These sub-basins all discharge towards wadi Cheliff. This region is characterized by a semi-arid to arid climate.

The study was designed as three steps. In the first step, the calibration of the model was made for all sub-basins in the study area. The flow series and model parameters were then estimated. The flow series and model parameters are estimated by optimization trials where the peak weighted RMSE objective function available in HEC-HMS was chosen. After that, a group-based watershed classification was conducted before regionalization, in that it defined homogeneous areas with common characteristics. Then, the regionalized flows were obtained from five donor sub-basins to the target, using two methods: spatial proximity and physical similarity. Later the hydrograph averaging concept by regionalizing the parameters of the donor sub-basin and transferring them to the target sub-basin, or by obtaining a hydrograph directly by averaging the regionalized parameters from the donor sub-basins to the target sub-basin (parameter averaging) was performed. Afterwards, the Arithmetic Mean and the Inverse Distance Weighting IDW methods were applied to estimate streamflow in the ungauged basin. After that, a comparison was made between the gauged sub-basin and the regionalized one. The flowchart given in Figure 2 illustrates the three steps carried out. Figure 3 gives hydrological modeling process used in flow series estimation.

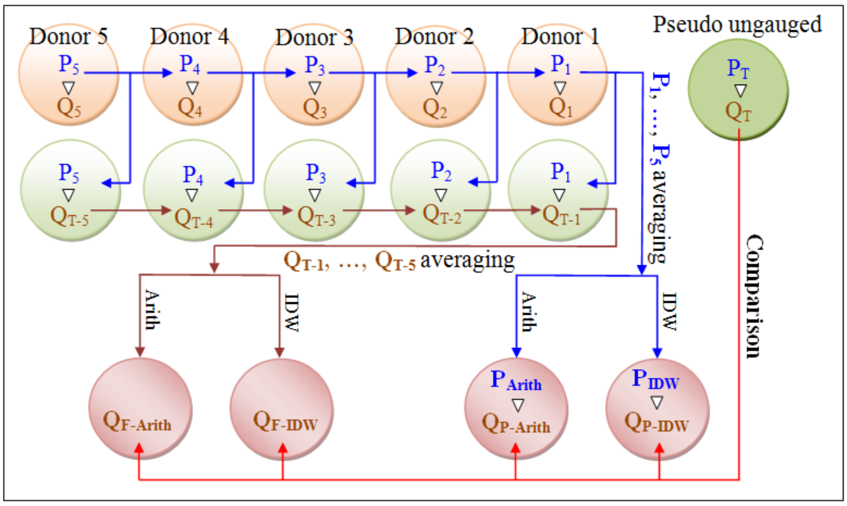

Figure 2. *Overall flowchart of the regionalization procedure: Wadi Tikzal is the receiver sub-basin. (P_1 to P_5) and (Q_1 to Q_5) are the model parameters and the flows series of the donor sub-basins. Q_{T-1} to Q_{T-5} are the flows series of the receiver sub-basin using the model parameters of the donor sub-basins*

3.3 HEC-HMS model description

The HEC-HMS model created by the United State Army Corps for Engineers (USACE) is used to model the flows for the selected sub-basins. It belongs to the category of physically based distributed models designed to simulate the rainfall-runoff processes. HEC-HMS can be used to simulate a single watershed or multiple hydrologically connected watersheds in humid, tropical, subtropical and arid zones. The HEC-HMS model requires multiple inputs as digital elevation model (DEM), soil type, land use and weather data [23, 28]. The area of the basin and many hydrological elements like junctions and sinks needs to be defined to the model. For the loss method, the deficit and constant method was chosen and the SCS unit hydrograph was selected for the transform method. For the baseflow method, the recession baseflow approach was used in this study. The deficit and constant loss method takes into account continuous changes in moisture content. It is used in combination with canopy and surface methods, the first will extract water from the ground by the potential evapotranspiration calculated in the meteorological model, and the second will retain water on the soil surface.

The Soil Conservation Service (SCS) unit hydrograph method allows a curvilinear unit hydrograph to be defined, where the percentage of unit runoff that occurs before peak flow is defined. It estimates the Unit Hydrograph peak discharge U_p (Eq. 1) and the time of peak T_p (Eq. 2).

$$U_p = C\frac{A}{T_p} \qquad (1)$$

$$T_p = \frac{\Delta t}{2} + t_{lag} \qquad (2)$$

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where U_p is the unit hydrograph peak, A is the watershed area, C=2.08 is the conversion constant, T_p is the time of the peak, Δt is the excess precipitation duration, t_{lag} is the basin lag and is equal to 60% of the time of concentration T_c.

After an event, the channel flow recedes exponentially and the recession baseflow method approximates this typical behavior observed in watersheds. This method is used for both event and continuous simulation.

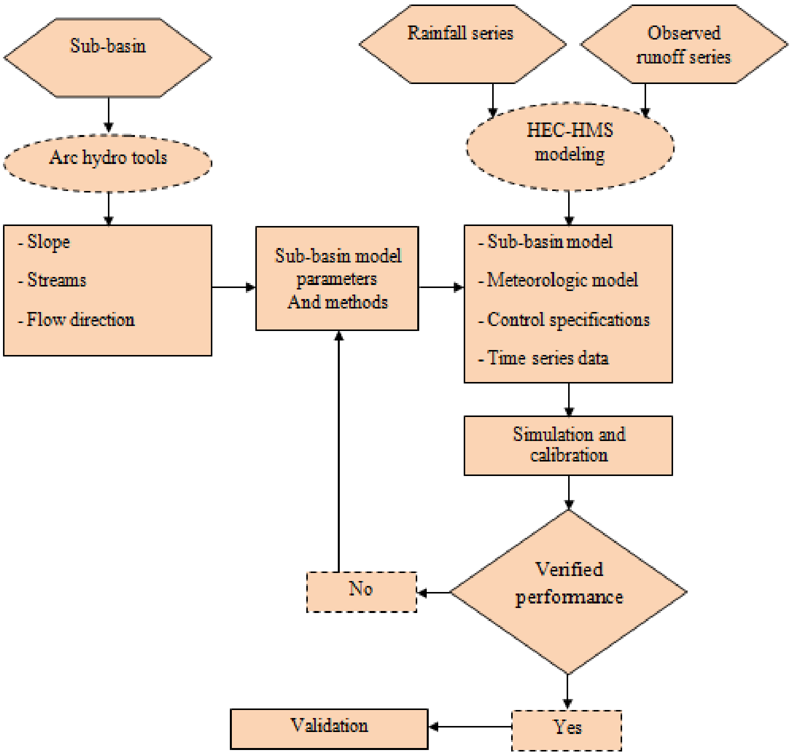

Figure 3. *Hydrological modeling process*

For the spatial proximity, the Euclidean distance between the sub-basin's centroids was calculated using the equation 3.

$$d = \sqrt{(X_G - X_U)^2 + (Y_G - Y_U)^2} \qquad (3)$$

where d is the distance between the centroids and (X_G, Y_G) and (X_U, Y_U), which correspond to the coordinates of the centroids of the gauged and ungauged watersheds [13].

The similar sub-basins are defined on the basis of the calculation of a similarity index θ, which can be calculated using the formula given in equation 4 [29].

$$\theta = \sum_{i=1}^{K} \frac{|CD_i^G - CD_i^U|}{\Delta CD_i} \qquad (4)$$

where CD_i are the values of the descriptor i for a gauged basin (G) and the ungauged basin (U), k is the number of physical descriptors taken into account, and ΔCD_i is the range of values available for the physical descriptor (i), that is the maximum value minus the minimum value. The smallest similarity index indicates the most similarity to the donor basin [13].

The morphological descriptors used for this study were given in Table 2.

Table 2. *The morphological descriptors used in this study*

Descriptor	Symbol	Unit
Sub-basin surface	A	km^2
Minimum altitude	Z_{min}	M
Maximum altitude	Z_{max}	M
Specific elevation	D_S	M
Compactness index	K_G	-
Overall slope index	I_g	m/km
Length of the equivalent rectangle	L	Km
Equivalent rectangle width	L	Km
Average precipitation	Pmean	mm
Maximum precipitation	Pmax	mm
Minimum precipitation	Pmin	mm

The objective Peak-Weighted RMSE function was used to improve the quality of the optimized parameters. These parameters are shown in Table 3.

Table 3. *Parameters calibrated for each sub-basin*

N°	Parameters	Unit
1	Deficit and Constant-Constant rate	mm/hr
2	Deficit and Constant-Initial Deficit	Mm
3	Deficit and Constant-Maximum Deficit	Mm
4	SCS Unit Hydrograph-Lag time	Min
5	Simple canopy-Initial Storage	%
6	Simple canopy-Max Storage	Mm
7	Simple surface-Initial Storage	%
8	Simple surface-Max Storage	Mm
9	Recession-Initial discharge	M^3/s
10	Recession-Ratio to peak	-
11	Recession-Recession Constant	-

3.4 Performance criteria analysis

To evaluate the performance of the hydrological model, three criteria were used: the Nash-Sutcliffe Efficiency (NSE), the coefficient of determination (R^2) and the root mean square error (RMSE). The NSE (Eq. 5) was used in many studies to evaluate the performance of hydrological models. A value of NSE=1 indicates a perfect fit between simulated and observed data [30].

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}\left(Q_{obs,i} - Q_{sim,i}\right)^2}{\sum_{i=1}^{n}\left(Q_{obs,i} - \overline{Q_{obs}}\right)^2}\right] \tag{5}$$

where $Q_{obs,i}$ is the observed discharge, $Q_{sim,i}$ is the simulated discharge, $\overline{Q_{obs}}$ is the mean observed discharge.

The coefficient of determination R^2 (Eq. 6) is used to determine the fit of the simulated data to the observed data.

$$R^2 = \left[\frac{\left[\sum_{i=1}^{n}\left(Q_{obs,i} - \overline{Q_{obs}}\right) x \left(Q_{sim,i} - \overline{Q_{sim}}\right)\right]^2}{\sqrt{\sum_{i=1}^{n}\left(Q_{obs,i} - \overline{Q_{obs}}\right)^2} x \sqrt{\sum_{i=1}^{n}\left(Q_{sim,i} - \overline{Q_{sim}}\right)^2}}\right]^2 \tag{6}$$

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where $Q_{obs,i}$ and $Q_{sim,i}$ are the observed and simulated discharge, respectively. $\overline{Q_{obs}}$ and $\overline{Q_{sim}}$ are the mean observed and the mean simulated discharge, respectively.

The RMSE (Eq. 7) is used to compute the mean magnitude of the error between the observed and the simulated values based on squared differences, in which the largest deviations contribute the most. RMSE=0 indicates a perfect fit between the simulated and the observed data.

$$RMSE = \left[\frac{\sum_{i=1}^{n}\left(Q_{obs,}-Q_{sim,i}\right)^2}{N}\right]^{1/2} \quad (7)$$

where $Q_{obs,i}$ is the observed discharge, $Q_{sim,i}$ is the simulated discharge, N is the number of data points that have been observed.

4 RESULTS AND DISCUSSIONS

The results obtained will be discussed taking into account the values of the performance criteria for calibration and validation as well as the quality of the streamflow series results transferred from the donor sub-basins to the receiving sub-basin. A comparison with previous studies will be made.

4.1 Calibration and validation of the HEC-HMS model for all sub-basins

The main objective of the rainfall-runoff modeling step by the HEC-HMS model for all the sub-basins is to verify the applicability of this model in this zone and therefore to ensure that the regionalization study can be performed. The optimized parameters, their values, and the simulation results (calibration and validation) of the HEC-HMS model for all basins are presented in Tables 4 and 5, respectively.

Table 4. *Parameters calibrated values for each sub-basin (P1 to P5 and PT)*

Parameters	W. Harreza	W. Ouahrane	W. Zeddine	W. Tikzal	W. Deurdeur	W. Harbil	W. Ebda	W. Sly
1	5.44	6.56	4.49	5.26	5.02	5.9	5.15	5.84
2	1.19	2.44	1.17	0.83	1.07	1.16	0.83	1.05
3	1.2	10.05	2.17	2.44	1.62	1.51	1.07	1.12
4	1100	1700	1800	1800	2000	2000	1832	1600
5	0.1	4.23	0.59	0.4	0.048	0.23	0.28	0.26
6	0.08	16.85	0.61	0.23	0.92	0.22	0.31	0.9
7	0.07	2.31	0.39	0.21	0.6	0.18	0.23	0.46
8	1.13	6.07	0.85	0.7	1.42	1.2	1.24	1.39
9	0.2	0.2	0.3	0.1	0.1	0.3	0.3	0.3
10	0.1	0.5	0.8	0.7	0.9	0.8	0.8	0.8
11	0.4	0.6	0.2	0.5	0.1	0.1	0.6	0.3

Table 5. *Results of efficiency coefficients of all sub-basins modeling*

Efficiency coefficients		W. Harreza	W. Ouahrane	W. Zeddine	W. Tikzal	W. Deurdeur	W. Harbil	W. Ebda	W. Sly
Calibration Phase	NSE	0.71	0.79	0.64	0.61	0.61	0.63	0.62	0.65
	R^2	0.71	0.79	0.64	0.60	0.61	0.65	0.63	0.66
	RMSE	0.50	0.50	0.60	0.60	0.60	0.60	0.60	0.60
Validation Phase	NSE	0.77	0.73	0.67	0.77	0.61	0.63	0.63	0.64
	R^2	0.76	0.74	0.67	0.76	0.61	0.63	0.64	0.64
	RMSE	0.50	0.50	0.60	0.50	0.60	0.60	0.60	0.60

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The results show several performance rates for the eight sub-basins from satisfactory to good results with good values of the averages of the coefficients. Nash-Sutcliffe criterion was calculated as 0.66 in the calibration phase and 0.68 for the validation phase whereas R^2 was found to be 0.66 in the calibration phase and 0.68 for the validation phase. The RMSE values were 0.58 in calibration phase and 0.56 in the validation phase. The maximum of the NSE coefficient is recorded for wadi Ouahrane with 0.79 in the calibration phase and for wadi Tikzal with 0.77 in the validation phase. Better values were recorded for the three coefficients in the validation phase than in the calibration phase, due to the quality of the data which is good in the validation period, then the calibration period has some estimated values of discharges, however there is good consistency between the series of precipitation and the series of discharges in the validation phase. This implies that the HEC-HMS model can be well calibrated for this region and for the set of sub-basins chosen, and that shows its capability to reproduce streamflows. Consequently, the second step of the study, which is the regionalization of the parameters for the ungauged sub-basin, can be carried out. These results in calibration stage are in agreement with several studies on the region, such as [23] and [24]. In addition to that, these results are in harmony with other studies worldwide, such as [31, 32].

The hydrographs of observed and simulated streamflow for all sub-basins are shown in Figures 4 and 5 for the calibration and validation phases, respectively. To assess the performance of the model more precisely, a critique can be used on each phase of the hydrograph, as the rising part, the descending part, the base flow and the peak flows. The figures show that the model reproduces the shape of the observed hydrographs in a satisfactory manner. The simulated peak flows are underestimated by the model for both calibration and validation stage. The average value of precipitation from the rainfall stations used could have given an underestimate of the simulated hydrographs. HEC-HMS does not consider the slope as a parameter, this could have led to a higher peak in the hydrograph. There is no important delay in the simulation of the rising or the descending parts of all the hydrographs, this can be explained by the good quantification of the interception losses by the model and the good optimization of the lag time.

To begin the process of regionalizing the parameters of the HEC-HMS hydrological model from the donor sub-basins to the receiving sub-basin, we proceeded to classify the donor sub-basins by the two similarity methods (SP and PS). Table 6 gives the classification of the sub-basins for the two similarity methods. The sub-basin with the smallest index (d), for the spatial proximity and the smallest index (θ), for the physical similarity, is judged to be the most similar to the receiver sub-basin.

Table 6. *Classification of the sub-basins for the similarity*

Class	Spatial proximity		Physical similarity	
	Sub-bassins	**Distance from receiver sub-basin centroid (d) (km)**	**Sub-bassins**	**Physical similarity index Θ**
1	W. Zeddine	28.43	W. Harbil	2.33
2	W. Ebda	29.55	W. Ebda	3.72
3	W. Ouahrane	44.01	W. Deurdeur	3.78
4	W. Harreza	46.09	W. Zeddine	4.42
5	W. sly	46.80	W. Ouahrane	4.53
6	W. Deurdeur	58.84	W. Harreza	4.85
7	W. Harbil	65.38	W. sly	5.73

The spatially closest basins were selected by calculating the Euclidean distance between their centroids and the receiver sub-basin centroid and allowed us to classify the sub-basins in order. Geographically, the closest basin to the ungauged basin (Tikzal sub-basin) is the Zeddine sub-basin and the farthest sub-basin is the Harbil sub-basin. The sub-basins taken into consideration for this method are the sub-basins of oued Zeddine, oued Ebda, oued Ouahrane, oued Harreza and oued Sly. To determine the sub-basins similar to the receiving sub-basins by physical similarity, the coefficient θ is calculated so that the most similar basin is the one with the lowest θ. The five most physically similar sub-basins taken for this part of the study are the sub-basins of oued Harbil, oued Ebda, oued Deurdeur, oued Zeddine and oued Ouahrane.

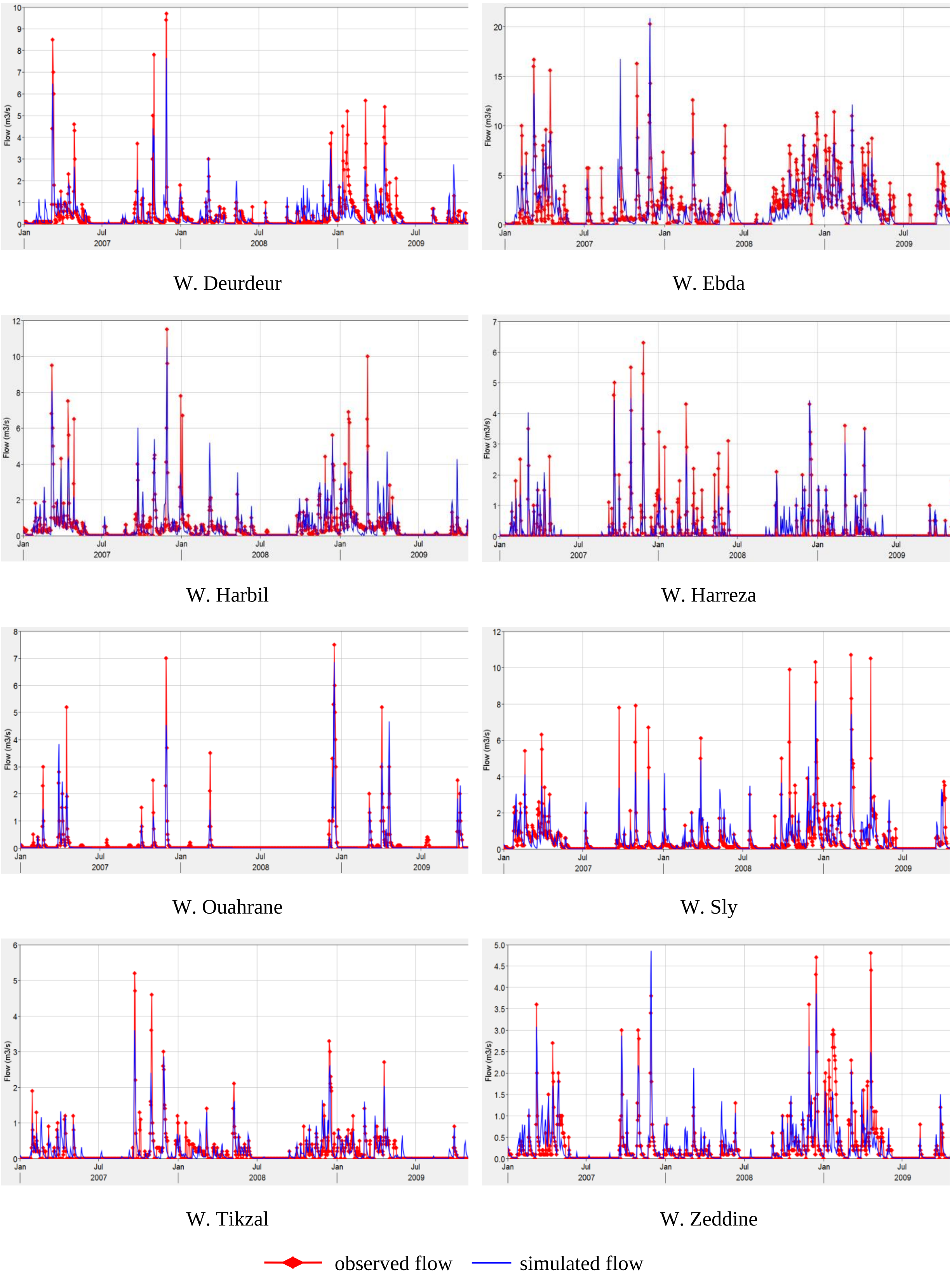

Figure 4. *Observed and simulated flows off all sub-basins for the calibration phase*

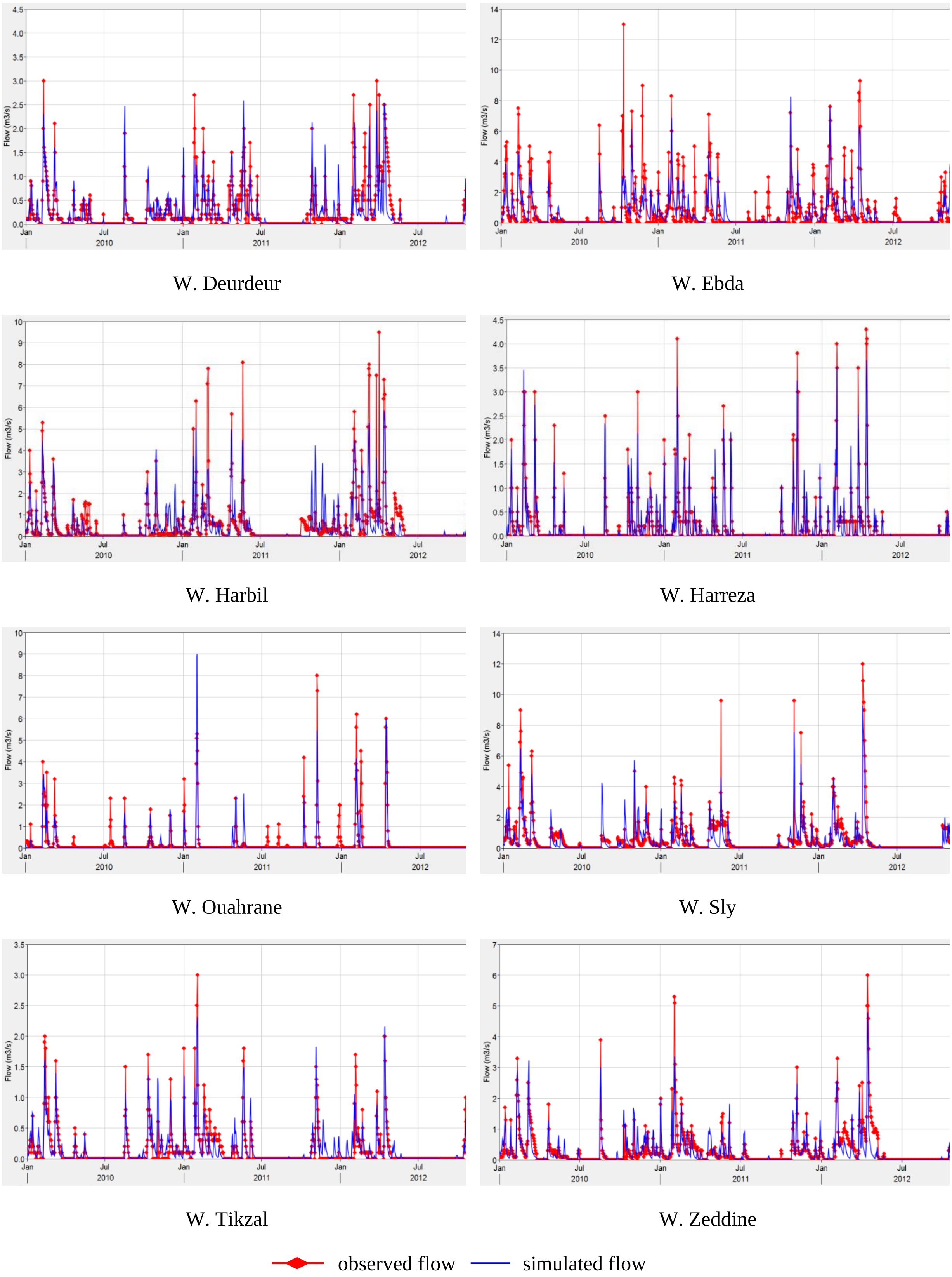

Figure 5. *Observed and simulated flows off all sub-basins for the validation phase*

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4.2 Regionalization

For the second step of this study, the results of the comparison between the series of simulated flows and the observed flows of the target sub-basin are given in Tables 7 and 8.

4.2.1 Hydrograph averaging

The physical similarity regionalization method (PS) performed better than the spatial proximity method (SP). In the calibration and validation phases (Table 7), the (PS) method yielded the highest NSE values of 0.60 to 0.61/0.75 to 0.76, respectively, and the lowest NSE values of 0.58 to 0.61/0.74 to 0.75, recorded in the (SP) method for the two phases respectively. Overall, the comparison between the averaging techniques based on the mean performance indicators values revealed that the arithmetic mean gave higher results compared to the IDW method (Table 7 and Figure 6). The best fit is observed especially for the RMSE values (0.30 vs. 0.31 and 0.47 vs. 0.30 for the calibration phase and 0.16 vs. 0.17 and 0.16 vs. 0.32 for the validation phase) in the (SP) and (PS) methods consecutively.

Table 7. *Simulation results of the regionalized flows (Hydrograph averaging step)*

Efficiency coefficients		**Spatial proximity**		**Physical similarity**	
		$\mathbf{Q_{F\text{-}IDW}}$	$\mathbf{Q_{F\text{-}Arith}}$	$\mathbf{Q_{F\text{-}IDW}}$	$\mathbf{Q_{F\text{-}Arith}}$
Calibration Phase	NSE	0.58	0.61	0.60	0.61
	R^2	0.60	0.61	0.60	0.61
	RMSE	0.31	0.30	0.47	0.30
Validation Phase	NSE	0.74	0.75	0.76	0.75
	R^2	0.76	0.76	0.76	0.76
	RMSE	0.17	0.16	0.32	0.16

Figure 6 gives the NSE results for the comparison between the simulated flows $Q_{F\text{-}IDW}$ and the observed flows Q_T, and between the simulated flows $Q_{F\text{-}Arith}$ and the observed flows Q_T.

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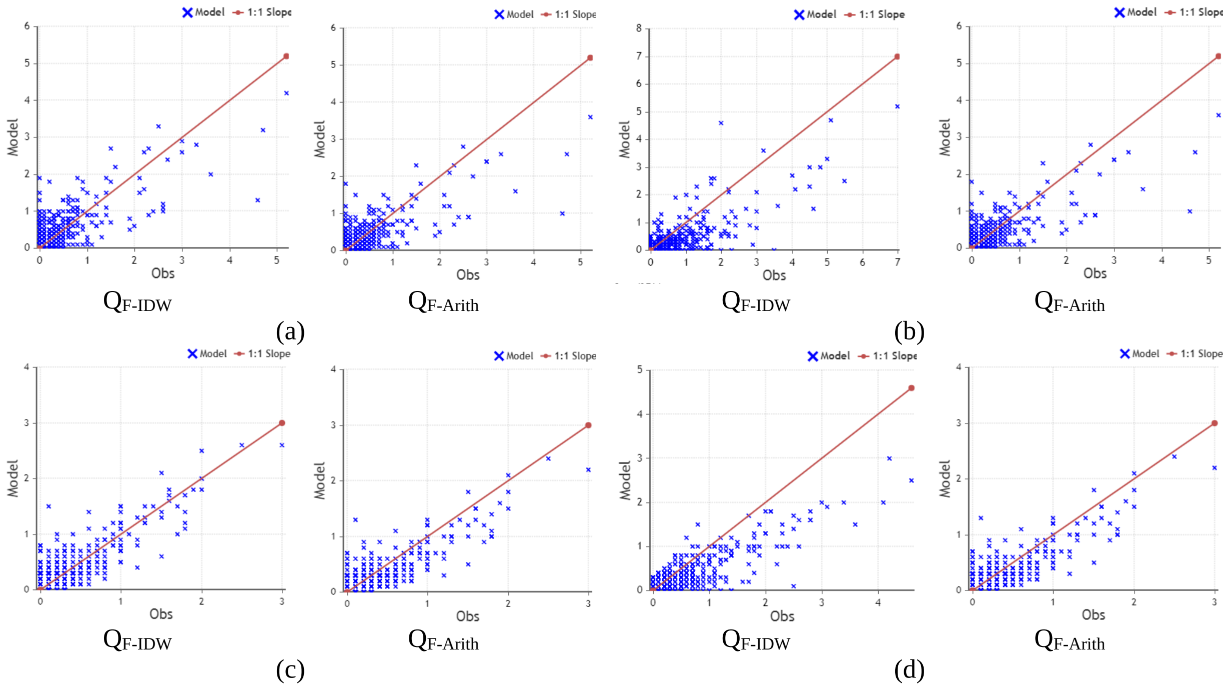

Figure 6. *Nash Sutcliffe Efficiency results for the comparison between the simulated flows ($Q_{F\text{-}IDW}$ and $Q_{F\text{-}Arith}$) and the observed flows Q_T. (a) Spatial proximity (Calibration phase). (b) Physical similarity (Calibration phase). (c) Spatial proximity (Validation phase). (d) Physical similarity (Validation phase)*

4.2.2 Parameter averaging

In this step, the spatial proximity regionalization method (SP) performed better than the physical similarity method (PS). The average NSE, R2 and RMSE values are slightly higher in (SP) than in the regionalization method (PS). High numerical performance is obtained using both approaches with the highest R^2 and NSE (0.61/0.61 and 0.77/0.75, and 0.61/0.60 and 0.75/75) and lowest RMSE (0.30/0.16 and 0.30/0.17), respectively, in the (PS) and (SP) methods and the calibration and validation phase (Table 8). These results are in agreement with Merz and Blöschl [15] study. The comparison between the averaging methods based on the mean performance indicators values, revealed that the arithmetic mean gave higher results compared to the IDW method (Table 8 and Figure 7). The best fit is observed especially for the RMSE values (0.30 vs. 0.30 and 0.30 vs. 0.34 for the calibration phase and 0.17 vs. 0.17 and 0.16 vs. 0.19 for the validation phase) in the (SP) and (PS) methods consecutively.

Table 8. *Simulation results of the regionalized flows (Parameters averaging step)*

Efficiency coefficients		Spatial proximity		Physical similarity	
		$Q_{P\text{-}IDW}$	$Q_{P\text{-}Arith}$	$Q_{P\text{-}IDW}$	$Q_{P\text{-}Arith}$
Calibration Phase	NSE	0.58	0.60	0.49	0.61
	R^2	0.59	0.61	0.49	0.61
	RMSE	0.30	0.30	0.34	0.30
Validation Phase	NSE	0.75	0.73	0.66	0.75
	R^2	0.75	0.75	0.66	0.77
	RMSE	0.17	0.17	0.19	0.16

Figure 7 gives the NSE results for the comparison between the simulated flows $Q_{P\text{-}IDW}$ and the observed flows Q_T, and between the simulated flows $Q_{P\text{-}Arith}$ and the observed flows Q_T.

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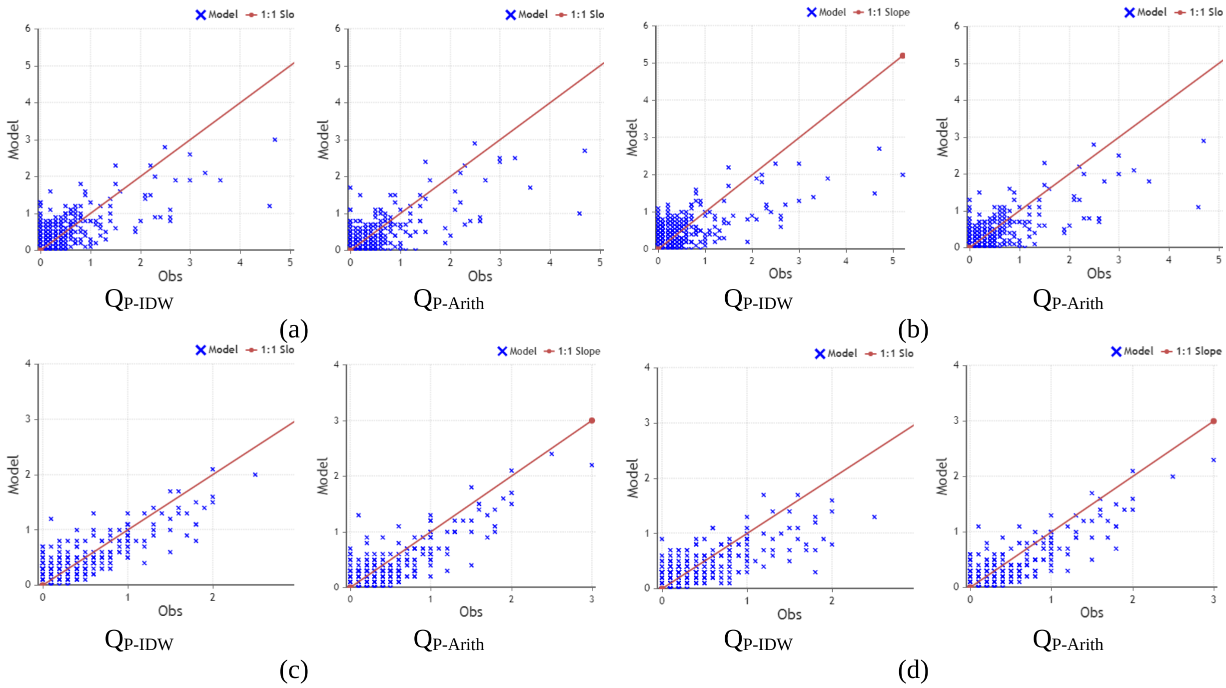

Figure 7. *Nash Sutcliffe Efficiency results for the comparison between the simulated ($Q_{P\text{-}IDW}$ and $Q_{P\text{-}Arith}$) flows and the observed flows Q_T. (a) Spatial proximity (Calibration phase). (b) Physical similarity (Calibration phase). (c) Spatial proximity (Validation phase). (d) Physical similarity (Validation phase)*

All the regionalization methods used gave regionalized flows very close to those observed and highlighted the efficiency of the approach used. A comparison of our results with those reported in other studies highlighted the efficiency of the methods used. For example, Oudin et al [7] studied 913 watersheds in France and found that spatial proximity provides the best regionalization solution, the regression approach is the least satisfactory, the physical similarity approach is intermediary. Based on 34 studies carried out in the literature covering 3874 watersheds by Parajka et al [16], the results obtained show that the spatial proximity and physical similarity methods are globally more efficient than the regression method. While the physical similarity method was found to be more effective than spatial proximity methods and regression methods in a study conducted by Yang et al [14] in over 100 watersheds in Norway. These results are similar to those obtained in our study.

5 CONCLUSION

To develop appropriate strategies for the management of water resources and to participate in the field of the regionalization of the parameters of the hydrological models and the prediction of the flows in the ungauged sub-basins which poses a problem in the stations of the Cheliff basin, we carried out this study for the regionalization of the parameters of the physically based distributed model (HEC-HMS), in the upper and middle Cheliff region. Precipitation and discharge series have been chosen and processed that cover all the sub-basins selected from the available data from the period 2007 to 2012.

The physical similarity regionalization method gave better results compared to the method of spatial proximity when averaging the hydrographs obtained from the transfer of the model parameters of the donor sub-basins. This is reflected in the average NSE, R^2 and RMSE values, which are higher in the physical regionalization method than in the spatial regionalization method. The spatial proximity regionalization method gave better results compared to the method of physical similarity in the case of obtaining the hydrograph of the ungauged sub-basin directly by the parameters resulting from the average of the donor sub-basins parameters. The NSE and R^2 values exceeded 0.75 in the validation phase for both methods, while the low RMSE values (0.16) indicate a good fit of the observed and regionalized series.

The results of this study are good for use in liquid flow modeling by optimizing the parameters affecting the output results. The resulting HEC-HMS model is very sensitive to lag time and the percentage of impervious land in the loss method. In order to predict surface runoff, the HEC-HMS hydrological model was applied to watersheds and can be applied to other watersheds with similar hydrometeorological and land use characteristics. It is concluded that the HEC-HMS model can be used to predict the future impacts like climate change on basin flows. It is concluded that it is used to simulate runoff in ungauged watersheds and the application of basin flow modeling using HEC-HMS is useful for flood forecasting, water management and sustainable development.

Based on the methodology outlined in this study, the proposed approach would have performed better if other conditions had been introduced, such as the effect of the land use change, the effect of climate change. Improving the accuracy of the prevision can take place by taking into account several input parameters and the boundary conditions of the temperature of the evapotranspiration and slope, as well as the introduction of more basin descriptors for the regionalization of the hydrological model parameters.

REFERENCES

[1] QI, W., J. CHEN, L. LI, C. XU, J. LI, Y. XIANG & S. ZHANG. A framework to regionalize conceptual model parameters for global hydrological modeling. *Hydrology and Earth System Sciences Discussions*. 2020, pp. 1–28. DOI: 10.5194/hess-2020-127

[2] BELARBI, H., B. TOUAIBIA, N. BOUMECHRA, S. AMIAR & N. BAGHLI. Sécheresse et modification de la relation pluie–débit: cas du bassin versant de l’Oued Sebdou (Algérie Occidentale) [Drought and modification of the rainfall–runoff relation: case of Wadi Sebdou basin (western Algeria)]. *Hydrological Sciences Journal*. 2017, vol. 62(1), pp. 124–136. ISSN: 0262-6667. DOI: 10.1080/02626667.2015.1112394

[3] GUO, Y., Y. ZHANG, L. ZHANG & Z. WANG. Regionalization of hydrological modeling for predicting streamflow in ungauged catchments: A comprehensive review. *Wiley Interdisciplinary Reviews: Water*. 2021, vol. 8(1), e1487. ISSN 2049-1948. DOI: 10.1002/wat2.1487

[4] ROJAS-SERNA, C., L. LEBECHEREL, C. PERRIN, V. ANDRÉASSIAN & L. OUDIN. How should a rainfall-runoff model be parameterized in an almost ungauged catchment? A methodology tested on 609 catchments. *Water Resources Research*. 2016, vol. 52(6), pp. 4765–4784. ISSN 0043-1397. DOI: 10.1002/2015WR018549

[5] RAZAVI, T. & P. COULIBALY. Streamflow prediction in ungauged basins: review of regionalization methods. *Journal of Hydrologic Engineering*. 2013, vol. 18(8), pp. 958–975. ISSN 1084-0699. DOI: 10.1061/(ASCE)HE.1943-5584.0000690

[6] VANDEWIELE, G.L., C.-Y. XU & W. HUYBRECHTS. Regionalisation of physically-based water balance models in Belgium. Application to ungauged catchments. *Water Resources Management*. 1991, vol. 5, pp. 199–208. ISSN 0920-4741. DOI: 10.1007/BF00421989

[7] OUDIN, L., V. ANDRÉASSIAN, C. PERRIN, C. MICHEL & N. LE MOINE. Spatial proximity, physical similarity, regression and ungaged catchments: A comparison of regionalization approaches based on 913 French catchments. *Water Resources Research*. 2008, vol. 44(3). ISSN 0043-1397. DOI: 10.1029/2007WR006240

[8] HE, Y., A. BÁRDOSSY & E. ZEHE. A review of regionalisation for continuous streamflow simulation. *Hydrology and Earth System Sciences*. 2011, vol. 15(11), pp. 3539–3553. ISSN 1607-7938. DOI: 10.5194/hess-15-3539-2011

[9] BECK, H.E., A.I.J.M. VAN DIJK, A. DE ROO, D.G. MIRALLES, T.R. MCVICAR, J. SCHELLEKENS & L.A. BRUIJNZEEL. Global-scale regionalization of hydrologic model parameters. *Water Resources Research*. 2016, vol. 52(5), pp. 3599–3622. ISSN 0043-1397. DOI: 10.1002/2015WR018247

[10] YOUNG, A.R., V. KELLER & J. GRIFFITHS. Predicting low flows in ungauged basins: a hydrological response unit approach to continuous simulation. In: DEMUTH, S., A. GUSTARD, E. PLANOS, F. SCATENA & E. SERVAT (eds.). *Climate Variability and Change – Hydrological Impacts. Proceedings of the Fifth FRIEND World Conference: November 2006, Havana, Cuba*. IAHS Publications, no. 308, 2006, pp. 134–138. ISBN 978-1-90150278-7. Available at: https://iahs.info/uploads/dms/13649.28-134-138-17-308-Young.pdf

[11] ZHANG, Y., F.H.S. CHIEW, M. LI & D. POST. Predicting runoff signatures using regression and hydrological modeling approaches. *Water Resources Research*. 2018, vol. 54(10), pp. 7859–7878. ISSN 0043-1397. DOI: 10.1029/2018WR023325

[12] SALINAS, J.L., G. LAAHA, M. ROGGER, J. PARAJKA, A. VIGLIONE, M. SIVAPALAN & G. BLÖSCHL. Comparative assessment of predictions in ungauged basins – Part 2: Flood and low flow studies. *Hydrology and Earth System Sciences*. 2013, vol. 17(7), pp. 2637–2652. ISSN 1607-7938. DOI: 10.5194/hess-17-2637-2013
[13] BRETON-DUFOUR, M. *Étude de méthodes de régionalisation des paramètres des modèles hydrologiques et application à un bassin versant non-jaugé au Mexique [Study of methods for regionalising hydrological model parameters and application to an ungauged catchment in Mexico]*. Montréal, 2017. Doctoral thesis. Université du Quebec, École de technologie supérieure.
[14] YANG, X., J. MAGNUSSON, J. RIZZI & C.-Y. XU. Runoff prediction in ungauged catchments in Norway: comparison of regionalization approaches. *Hydrology Research*. 2018, vol. 49(2), pp. 487–505. ISSN 1998-9563. DOI: 10.2166/nh.2017.071
[15] MERZ, R & G. BLÖSCHL. Regionalisation of catchment model parameters. *Journal of Hydrology*. 2004, vol. 287(1–4), pp. 95–123. ISSN 0022-1694. DOI: 10.1016/j.jhydrol.2003.09.028
[16] PARAJKA, J., A. VIGLIONE, M. ROGGER, J.L. SALINAS, M. SIVAPALAN & G. BLÖSCHL. Comparative assessment of predictions in ungauged basins – Part 1: Runoff-hydrograph studies. *Hydrology and Earth System Sciences*. 2013, vol. 17(5), pp. 1783–1795. ISSN: 1607-7938. DOI: 10.5194/hess-17-1783-2013
[17] REICHL, J.P.C., A.W. WESTERN, N.R. MCINTYRE & F.H.S. CHIEW. Optimization of a similarity measure for estimating ungauged streamflow. *Water Resources Research*. 2009, vol. 45(10). ISSN 0043-1397. DOI: 10.1029/2008WR007248
[18] SAMUEL, J., P. COULIBALY & R.A. METCALFE. Estimation of continuous streamflow in Ontario ungauged basins: Comparison of regionalization methods. *Journal of Hydrologic Engineering*. 2011, vol. 16(5), pp. 447–459. ISSN 1084-0699. DOI: 10.1061/(ASCE)HE.1943-5584.0000338
[19] VIGLIONE, A., J. PARAJKA, M. ROGGER, J.L. SALINAS, G. LAAHA, M. SIVAPALAN & G. BLÖSCHL. Comparative assessment of predictions in ungauged basins – Part 3: Runoff signatures in Austria. *Hydrology and Earth System Sciences*. 2013, vol. 17(6), pp. 2263–2279. ISSN 1607-7938. DOI: 10.5194/hess-17-2263-2013
[20] POOL, S., D. VIVIROLI & J. SEIBERT. Value of a limited number of discharge observations for improving regionalization: A large-sample study across the United States. *Water Resources Research*. 2019, vol. 55(1), pp. 363–377. ISSN 0043-1397. DOI: 10.1029/2018WR023855
[21] DERDOUR, A., A. BOUANANI & K. BABAHAMED. Modelling rainfall runoff relations using HEC-HMS in a semi-arid region: Case study in Ain Sefra watershed, Ksour Mountains (SW Algeria). *Journal of Water and Land Development*. 2018, no. 36 (I–III), pp. 45–55. ISSN 1429–7426. DOI: 10.2478/jwld-2018-0005
[22] MOKHTARI, E.H., B. REMINI & S.A. HAMOUDI. Modelling of the rain-flow by hydrological modelling software system HEC-HMS-watershed's case of wadi Cheliff-Ghrib, Algeria. *Journal of Water and Land Development*. 2016, no. 30 (VII–IX), pp. 87–100. ISSN 1429–7426. DOI: 10.1515/jwld-2016-0025
[23] ALLALI, H., Y. ELMEDDAHI, D.-E. MOUDJEBER, H. MAHMOUDI & M.F.A. GOOSEN. Utilizing hydrograph transform methods and a hydrologic modeling system in rainfall-runoff simulation of a semi-arid watershed in Algeria in north-west Africa. *Desalination and Water Treatment*. 2022, vol. 255, pp. 220–228. ISSN 1944-3994. DOI: 10.5004/dwt.2022.28344
[24] HADDAD, A. Extreme Rainfall-Runo Events Modeling Using HEC-HMS Model for Oued El Hachem Watershed, Northern Algeria. *Archives of Hydro-Engineering and Environmental Mechanics*. 2022, vol. 69(1), pp. 45–57. ISSN 2300-8687. DOI: 10.2478/heem-2022-0004
[25] ZAMOUM, S. & D. SOUAG-GAMANE. Monthly streamflow estimation in ungauged catchments of northern Algeria using regionalization of conceptual model parameters. *Arabian Journal of Geosciences*. 2019, vol. 12(11), pp. 1–14. ISSN 1866-7511. DOI: 10.1007/s12517-019-4487-9
[26] AMMARI, A., T. MORAMARCO & M. MEDDI. A simple entropy-based method for discharges measurements in gauged and ungauged river sites: the case study of coastal Algerian rivers. *Bulletin de l'Institut Scientifique, Section Sciences de la Terre, Rabat*. 2017, no. 39, pp. 35–44. ISSN 1114-6834. Available at: http://www.israbat.ac.ma/wp-content/uploads/2017/10/Ammari_et_al_final_Octobre2017.pdf
[27] ELMEDDAHI, Y., H. MAHMOUDI, A. ISSAADI, M.F.A. GOOSEN & R. RAGAB. Evaluating the effects of climate change and variability on water resources: A case study of the Cheliff Basin in Algeria. *American Journal of Engineering and Applied Sciences*. 2016, vol. 9(4), pp. 835–845. ISSN 1941-7020. DOI: 10.3844/ajeassp.2016.835.845
[28] IBRAHIM-BATHIS, K. & S.A. AHMED. Rainfall-runoff modelling of Doddahalla watershed—an application of HEC-HMS and SCN-CN in ungauged agricultural watershed. *Arabian Journal of Geosciences*. 2016, vol. 9(3), art. no. 170. ISSN 1866-7511. DOI: 10.1007/s12517-015-2228-2

[29] BURN, D.H. & D.B. BOORMAN. Estimation of hydrological parameters at ungauged catchments. *Journal of Hydrology*. 1993, vol. 143(3–4), pp. 429–454. ISSN 0022-1694. DOI: 10.1016/0022-1694(93)90203-L
[30] NASH, J.E. & J.V. SUTCLIFFE. River flow forecasting through conceptual models part I – A discussion of principles. *Journal of Hydrology*. 1970, vol. 10(3), pp. 282–290. ISSN 0022-1694. DOI: 10.1016/0022-1694(70)90255-6
[31] HALWATURA, D. & M.M.M. NAJIM. Application of the HEC-HMS model for runoff simulation in a tropical catchment. *Environmental Modelling & Software*. 2013, vol. 46, pp. 155–162. ISSN 1364-8152. DOI: 10.1016/j.envsoft.2013.03.006
[32] AZMAT, M., M.U. QAMAR, S. AHMED, E. HUSSAIN & M. UMAIR. Application of HEC-HMS for the event and continuous simulation in high altitude scarcely-gauged catchment under changing climate. *European water*. 2017, no. 57, pp. 77–84. ISSN 1105-7580. Available at: https://www.ewra.net/ew/pdf/EW_2017_57_11.pdf