International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 24 No. 4 Nov. 2018, pp. 1773-1781

http://www.ijias.issr-journals.org/

Application of hydrological model "HEC HMS" In a Mediterranean watershed (Oued Laou, Northern of Morocco)

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ABSTRACT: The model HEC-HMS 3.5 has been applied to calibrate (from 2004 to 2008) and validate (from 2009 to 2012) with a daily time step, to offer the chance for describe hydrology in a Mediterranean watershed "Oued Laou" located in northern of Morocco. We based this study on two complementary approaches; observation and trend detection in the site and hydrological simulation using the HEC HMS model, these two approaches are reinforced by remote sensing, also the geographic Information System (GIS) techniques were used to determine the geometric and hydrological parameters required to estimate the parameters of the model. The model performance measured in the output of simulation give satisfactory results with an average Nash greater than 70%. We note that the model tends to underestimate volumes as well as flood peaks. These results lead to a realistic modeling of the hydrological processes in the Laou watershed and could fill a lack of information concerning the hydrological functioning of this basin. This study shows that the hydrological model HEC-HMS 3.5 can be used to model the Laou river basin, also in other similar contexts.

KEYWORDS: Hydrological simulation, HEC HMS Model, GIS, Laou Watershed, Underestimate, Flood peaks.

1 INTRODUCTION

To reduce the flood damage consequences or low-water events affecting human health, the environment, and economic activity, it is essential to understand the hydrological functioning in order to insure a good management of water resources. Therefore, in this study a semi distributed hydrologic model has been used, for supporting the environmental planning directives with simulation and prediction models, regarding the development of regulation and planning tools around the world [1], [2], [3].

The HEC-1 hydrological model was originally developed in 1967 by Beard and other members of the Hydrology Engineering Center, along with the US Army Corps of Engineers, for simulating flood hydrographs in complex basins [4]. After that, the software platform has been developed and used in thousands of studies with the objective of hydrological simulations [5], [6], [7]. In this study, a semi distributed hydrologic model of HEC-HMS 3.5 has been used to simulate runoff of the Laou watershed. Several studies highlighted that the HEC-HMS 3.5 was able to simulate the rainfall-runoff relation in space and time in different watersheds [8], [9]. Khaddor (2016) has applied HEC-HMS model to simulate Flow River in Kalaya watershed in the North of Morocco, has obtained results indicated that the model could simulate various meteorological and hydrological processes for the flood hydrograph, as well as the estimation of runoff over years return periods [10]. Tramblay (2012) has applied rainfall-runoff modeling using HEC-HMS and GIS in two sub-basins; Mdouar and Elmakhazine in Northern Morocco and as result, the HEC-HMS could give a reliable simulation despite of decreasing of gauges stations in some of sub-basins [11]. The main aim of this study is to understand the hydrological functioning of the Laou watershed by applying the HEC HMS model for modeling rainfall-runoff.

The main aim of this study was to identify flow by simulated and observed at Laou catchment in the computer-based rainfall runoff processes. The GIS based semi-distributed model named HEC-HMS was used for this study.

2 MATERIALS AND METHODS

2.1 STUDY AREA

The Laou watershed is located in the North-western part of Morocco (fig.1), and covered an area of 940 km² and a stream length of 70 km. The flow direction is almost from the south to the north of the watershed.

The watershed water budget is linked to high winter precipitation that reaches more than 1000 mm per year in higher outcrops (fig 2). Indeed, almost half of the basin's area is with elevation above 1000 m (fig 2).The geological formations of the study area consist mainly of impermeable or low permeability facies. The limestone chain, the plains and the alluvial valleys benefit of the infiltration of rain water which make important the groundwater reservoirs in the area. The Laou watershed extended in a general NE-SW and it is inserted between two mountains to the North and South. Its climate undergoes the influence of a sub-humid Mediterranean microclimate in winter with maximum rainfall in winter and spring [12].

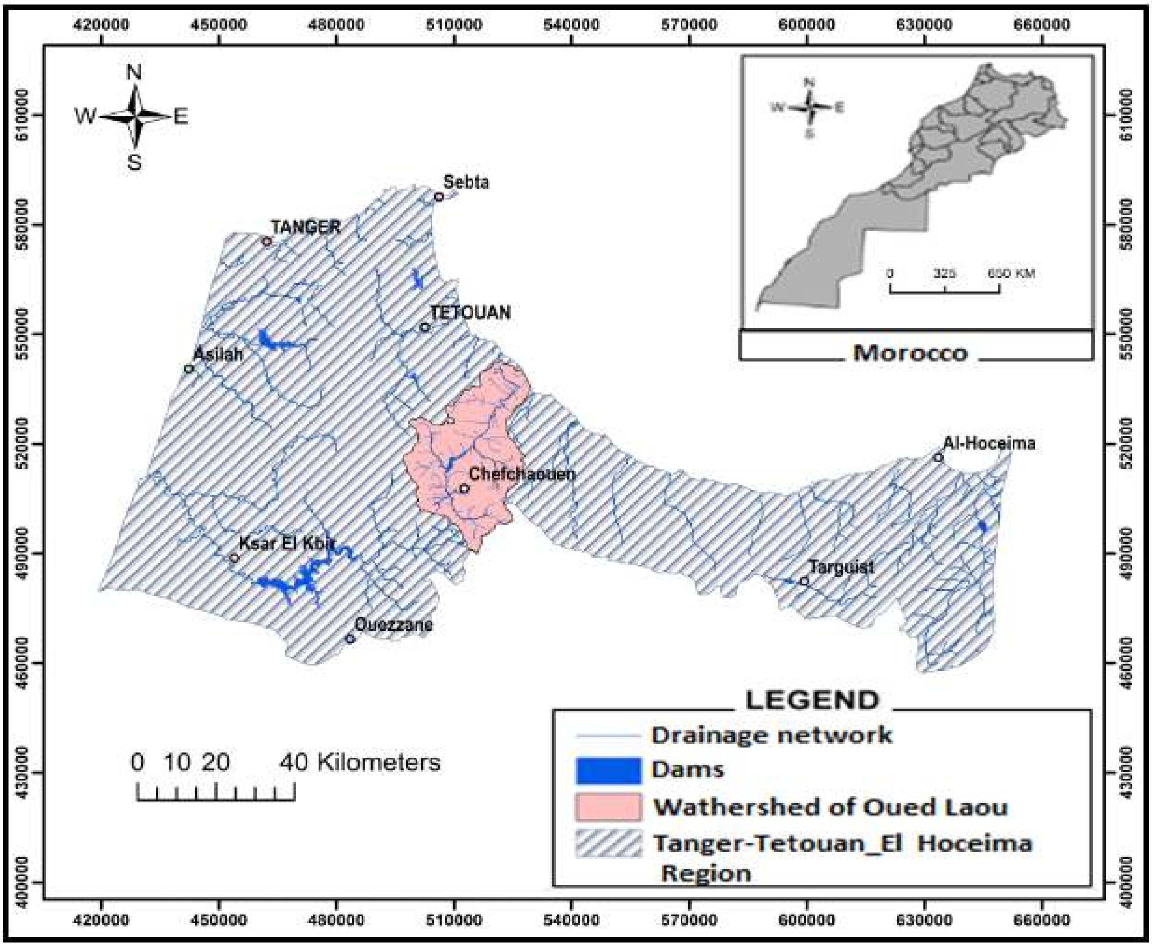

Fig. 1. Map of Morocco, location of study basin and drainage network

Hydro-climatic data used in this study correspond to a period from 2004 to 2012 and are issued from two stations:

Bab Taza; a rainfall station located upstream the Laou watershed and characterized by more abundant precipitations reaching more than 1200 mm / years.

Koudiet Kouriren; a hydrometric and rainfall station located downstream of the basin just before the plain and is characterized by a predominant drought with an annual main precipitation of 473 mm.

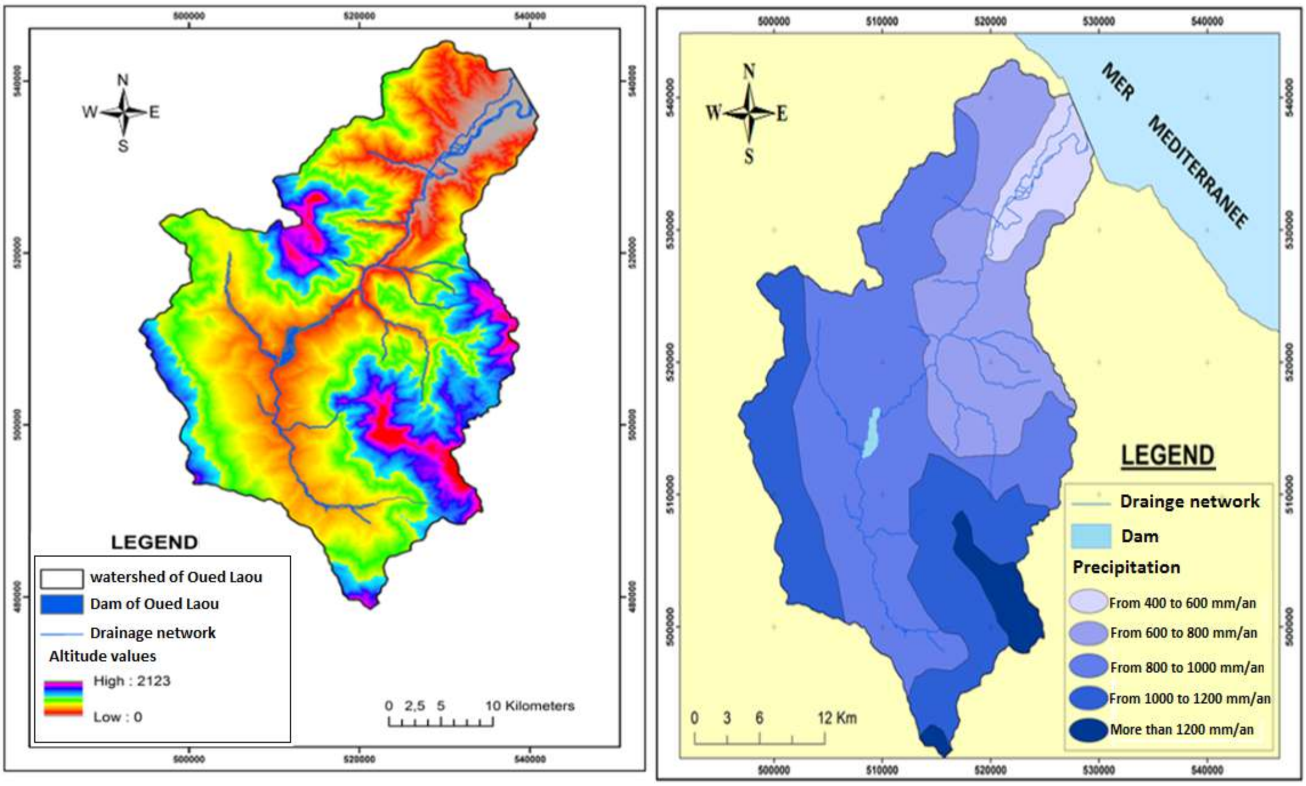

Fig. 2. Digital elevation Model (DEM), precipitation distribution map.

The Laou streams flow are fairly important during winter period, but are provided by springs during dry periods. This investigation is carried out on two field visits; 29 April 2017 and 29 August 2017 (fig 3) in the Tassikeste stream which is a tributary of Laou River

These visits revealed that this stream is characterized by an intermittent flow (absence of water in the dry season) and then, the Koudiat Kuriren gauging station does not control this tributary.

The drainage of the Laou river is also done by several superficial rivers, whose flows continue until they are downstream, which is the connection with the watercourse of the Laou river (Ouara, Farda, Talembot, Boumarouil, Tassefete). These branches of flow are fed by sources related to carbonate formations such as those of Majjou, whose average annual flow is greater than 400 l / s. The main tributaries cross mainly Cretaceous flyschs easily erodible in the absence of vegetation to retain soil; the calcareous dorsal and the Paleozoic coastal formations constituting important reliefs form an area favorable to runoff [12].

Fig. 3. Photos of the visits made; the first on 29/04/2017 and the second on 29/08/2017 in Tassikeste sub-basin

2.2 Study Method

The simulation was performed across (2004-2008) for calibrating the model and from (2009) to (2012) for validate the model. Indeed, the validation is the key criteria to test the hydrological model performance with serious independent data [13], [14]. During the validation period, we have calibrated the model without changing the parameters that we used in calibration period. The phenomenon of evaporation was excluded, while the infiltration was assumed less important given the predominance of altitudes (slopes) that favored the flow.

To run the model it was necessary to complete sub- models such as the watershed loss. For this sub-model, the used approach for the model calibration is SCS (Soil Conservation Service) curve number as a production function. Many studies have successfully used this function in a semi-arid Mediterranean context [11]. The hydraulic conductivity, initial loss, wet front suction, volumetric moisture deficit and percentage of impervious surfaces are the input parameters in loss sub-model. The values of curve number (CN) obtained for the basin was estimated and optimized.

To convert excess rainfall to runoff, the CLARK model (Mod Clark) was used and values of lag time were introduced to the model for each sub-basin. The base flow was deducted from observed hydrographs and, the monthly average flows were considered as the base flow in Koudiet Kouriren gauging station. The monthly constant parameters for the base flow method are set by calculation and manual processing of the inter-annual monthly averages, and then they are inserted manually on the platform of the HEC HMS model (Fig 4).

To run the model in continuous base, observed daily hydrographs and their respective daily hyetographs were used. These data obtained from Koudiet Kouriren hydrometric and rainfall station and Bab Taza rainfall station are used for the calibration for the period 2004-2008 and validation for 2009-2012 respectively, then the model validation was performed and simulated with optimum values and observed hydrographs were compared.

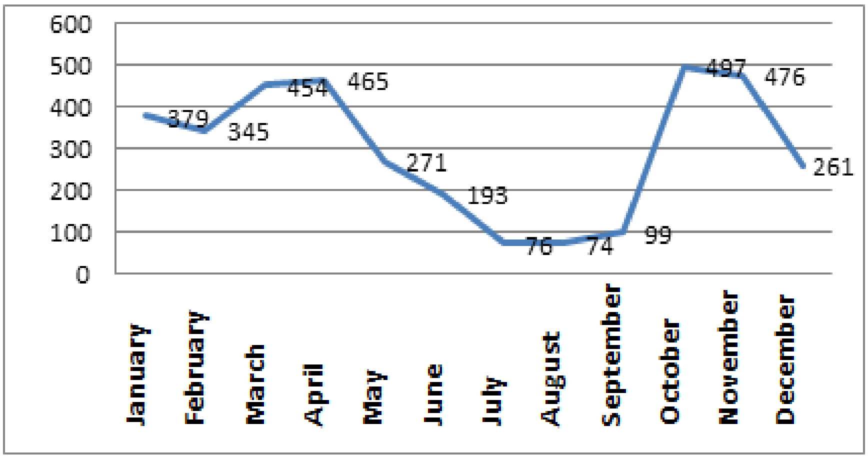

Fig. 4. Monthly average inter-annual base flow curve from 2004 to 2012.

The simulated flow rates were statistically tested, by Nash-Sutcliffe efficiency (NSE) [15], and the correlation between observed and simulated flows values, to assess the model performance.

2.3 HEC-HMS Model

The HEC1 is a developed version of HEC-HMS under windows for surface runoff simulation in watersheds. In this model, watershed is given as an interconnected system with hydrologic and hydraulic components. Several components are combined to simulate the basin processes. Each component is representative of the factors to convert precipitation to runoff within a part of the basin which is usually considered as sub-basin[16].

The daily stream owes were computed based on Soil Conservation Service (SCS). The concentration time parameter was calculated in order to be used in the model function. The literature proposes several empirical formulas for calculating the concentration time. Some are more prevalent in Morocco (table 1).

Table 1. The concentration time calculated by different equations

	Giandotti	Turrazza	Kirpich	Van Te Chow	Average
Tc (h)	8.70	8.50	6.73	5.70	7.41

The lag time is also an important hydrological parameter because it is directly related to the time of concentration [16] by the equation;

$$\mathbf{T_L} = 0{,}6\ T_c$$

Where T_L is Lag time (min).

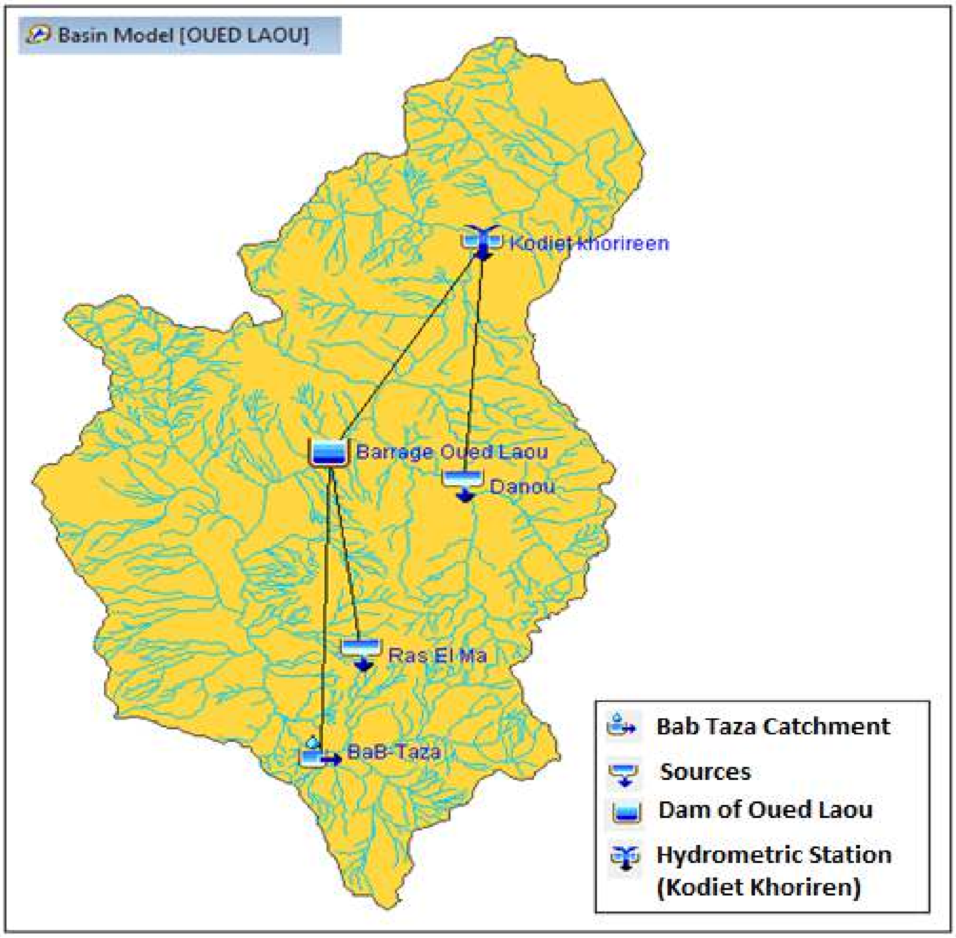

Fig. 5. Project Map on the Hydrologic Model Platform (HEC-GEOHMS).

The basin physical characteristic values (shape, area, etc.) were measured by the appropriate GIS (Arc GIS 10.3), and the Tc (concentration time) and the Lag time were calculated, based on the formulas most prevalent in Morocco. In order to reach the optimized values when the required parameters cannot be estimated precisely, the parameters are calibrated, by systematic search of the best fit between observed and simulated stream flow hydrograph. The calibrated values were determined for each sub-basin of the Laou basin in order to have the optimum parameter values after manually calibrating the model [17]. All parameters are simultaneously evaluated and corrected.

2.4 MODEL PERFORMANCE

At the end of the continuous simulation, the model performance was evaluated for both (calibration and validation) in different ways including Nash-Sutcliffe efficiency[15] and coefficient of determination (R2) [18].

- Nash-Sutcliffe efficiencies (ENS)

The validation of the model is verified by a comparison of flows calculated and observed through quality criterion. The most used criterion for the conceptual models is the Nash and Sutcliff criterion, which is expressed by the equation below;

$$\text{Nash} = 1 - \frac{\sum(\text{Qobs} - \text{Qcalc})^2}{\sum(\text{Qobs} - \text{Qm})^2}$$

Where ;

Qobs, Qcalc, Qm are respectively the observed and simulated flows over a time step and the average of the observed flows. Practically, it is estimated that the simulation is of poor quality when the Nash criterion is low (<0.5), it is acceptable when it is greater than (> 0.7), perfect when it is equal to (1).

- Coefficient of correlation (R2)

$$\mathbf{R^2}=\left[\frac{\sum(\boldsymbol{Q_{obs}} - \boldsymbol{Q_{obs}})^2 - \sum(\boldsymbol{Q_{sim}} - \boldsymbol{Q_{sim}})^2}{\sum(\boldsymbol{Q_{obs}} - \boldsymbol{Q_{obs}})^2}\right]$$

Where:

Qobs=observed discharge

Qsim=simulated discharge

obs=mean of observed discharge

sim=mean of simulated discharge

More R^2 is close to 1, more the result of simulation is close to the observation [2].

3 RESULTS AND DISCUSSION

The model used for simulating the hydrological functioning in the Laou basin (940 km²) is a semi-distributed and conceptual model, without spatialization of rain or properties of the soils. The basin is assumed presenting a rather homogeneous land use and without waterproof zones. Rugged terrain characterized by steep slopes promotes runoff and limits the importance of underground reserves[12].

The SCS production function appears to be more adopted in Laou watershed. This function is widely used because of its simplicity and the limited number of required parameters. A higher CN means more runoff where a CN of 100 means that all the rain will flow as runoff. CN's are no greater than 98, even for conventional pavements, since some small amount of rainfall will be held by the surface [1]. Therefore we have calibrate the model by adjusting the SCS CN, the best fit of CN was equal 62 that indicate the distinction of initial condition of soils in the study area as well as its found by Tramblay in the El Makhazine watershed [11] .

The model run's results indicate that using monthly constant method at base flow leads to more harmony between observed and simulated hydrographs in the Laou basin.

Clark's unit hydrograph transfer function was the most suitable for the Laou Basin. Indeed, it demonstrates its ability to simulate flow in contexts where land use and topography are complex. This result is similar of the Tramblay findings in the El Makhazine watershed [11].

In Figure 6, the daily hydrographs of the simulated and calibrated runoff for the period 01/01/2004-31/12/2008 are fitting well. Based on the calibrated parameters and values, the model is validated on a data series that did not used during calibration period, We have used the series going from (01/01/2009-31/12/2011) to validate the model, and finally the performance have improved.

Regarding the flood volumes, we note a succession of underestimation of flood volumes during the calibration and validation period. This underestimation persists despite the efforts and corrections made, which is well understood regarding the fact that the transfer function has no effect on the flood volume, but it is rather on the movement of this intervening volume. Besides, the watershed does not have enough rainfall station to properly control the inflow.

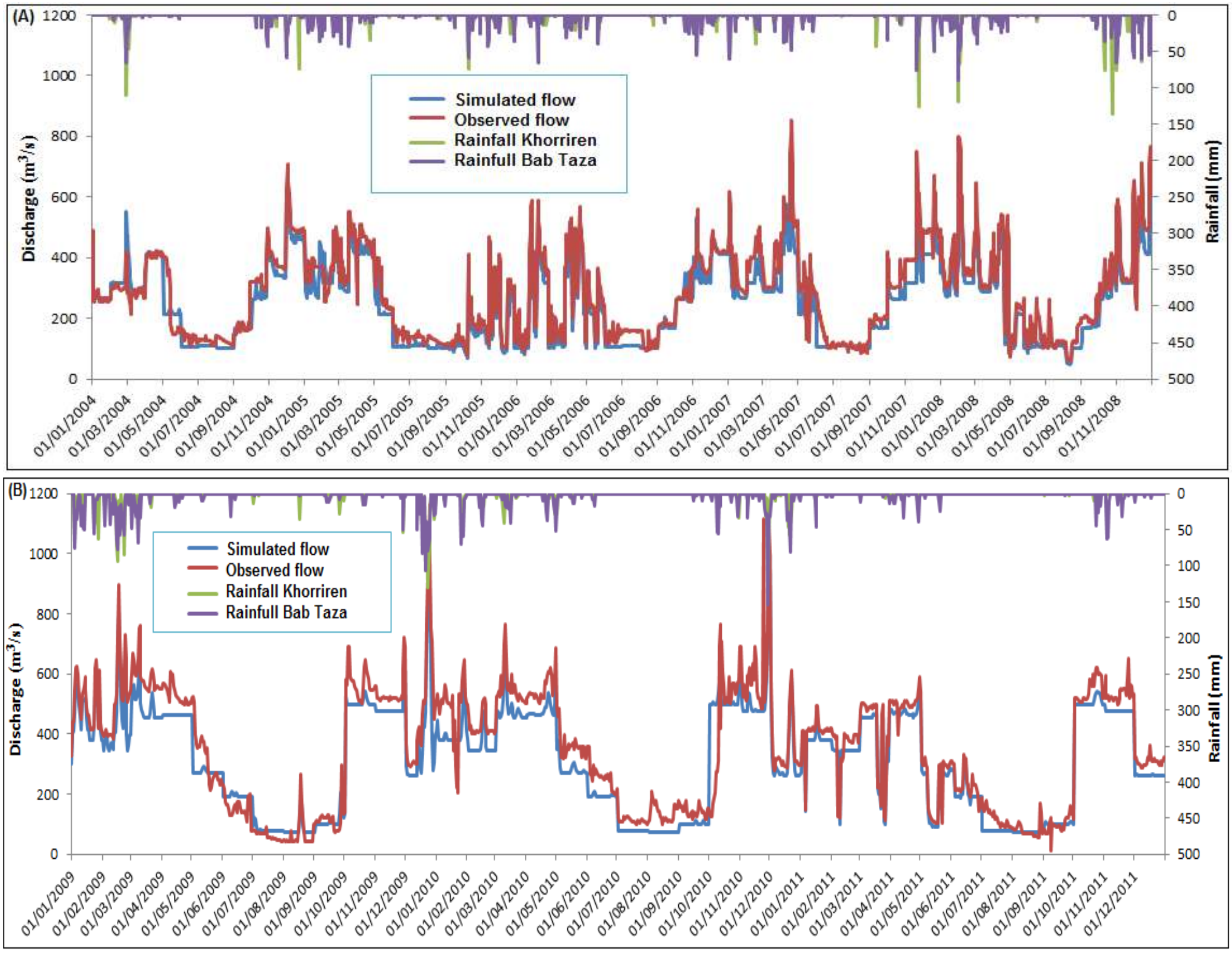

Fig. 6. Daily hydrograph comparison between simulated and observed flow for the catchments of Laou basin. A) Calibration period 2004-2008, B) Validation period (2009-2012).

The model tends to underestimate flood peaks, but it is able to correctly reproduce the basin hydrological functioning. We deduced that the model was more appropriate in the Laou watershed. This model takes into account the chronological sequence of the phenomena and the parameters of the watershed, more precisely the basic flows which are in the form of sources supplying the main watercourse.

The model performance was checked using the Nash-Sutcliffe efficiencies (ENS) (Table 2) and, as obtained result, the HEC-HMS 3.5 model reproduces satisfactorily the discharges measured at Koudiat Kuriren gauging station for the period 2004-2008, as well as the measured discharges for 2009-2012 (Table 2).

Table 2. Model performance indicator (ENS) in calibration and validation periods.

Indicateur	**Calibration period**	**Validation period**
NASH	0.72	0.83

The statistical coefficient (Coefficient of correlation R^2 (Fig 7)) supports to good fit models for the calibration (R^2= 0.92) and for validation period (R^2=0.91).

Based on the results and data confirmation, Hec Hms model can be a reliable tool for modeling the Laou river flow. Evaluation performance yields coefficient close to 1.0. Thus, the Hec Hms model can be used to predict flood levels, flow rates as well as for design purposes.

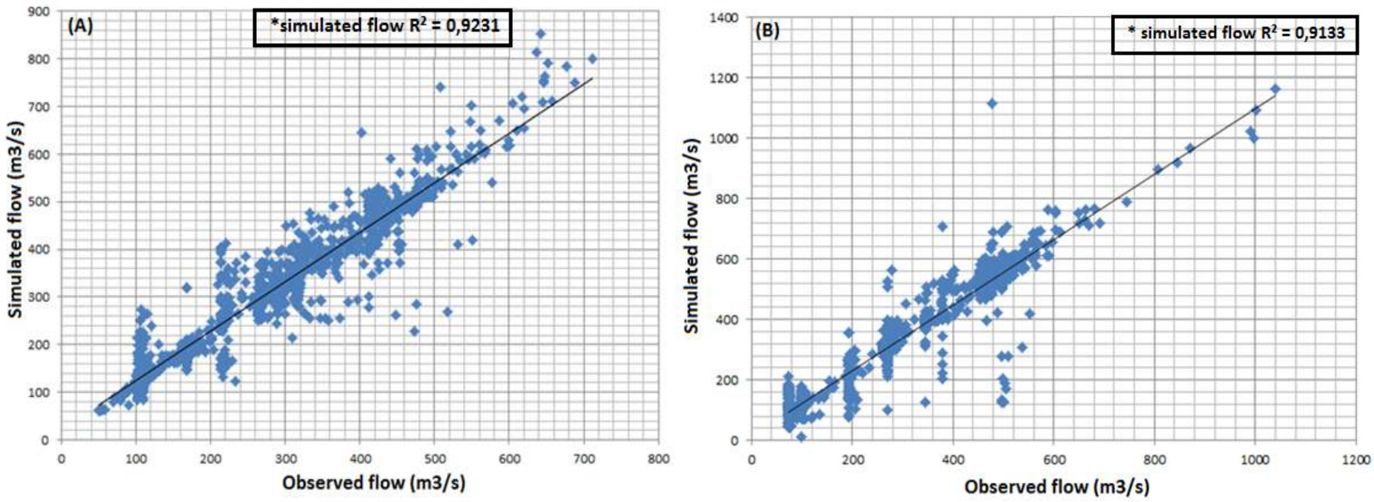

Fig. 7. Simulated versus observed flow, 5 years for calibration (A) and 3 years for validation (B)

4 CONCLUSION

The main objective of this study was to identify flow by simulated and observed at Laou catchment in the computer-based rainfall runoff processes. The GIS based semi-distributed model named HEC-HMS was used for this study. The response of model in simulating rainfall runoff was analyzed for the basin. The GIS based extension tool HEC-GEOHMS was mainly used for preparation of inputs for HEC-HMS.

Continuous simulation capabilities of Hec-Hms Model 3.5 were useful for assessing the impacts of stream development and understanding the hydrological function in the Laou River. The model demonstrates that base flow contribute in the Runoff of Laou watershed especially in the dry season.

The model provides the best performance in calibration as well as in validation that generally greater than 70%. This study highlights how these capacities could be applied to rivers in a Mediterranean watershed. The hydrological behavior of the Laou River is determined by the application of hydrological modeling on the platform of a semi-distributed and conceptual model. As far as prevention is concerned for better decision-making, the Laou Basin may have risks linked to the overflow of its tributaries, especially in winter.

Following is the specific recommendation from the analysis:

- We recommend using the platform of HEC HMS in Mediterranean watershed
- The simulated water balance demonstrates that the catchment outputs are dominated by the base flow, Then It becomes necessary to add hydrological stations in many sub-basins in the Laou watershed, and these future stations should contribute to measure the base flow in this basin.

ACKNOWLEDGMENT

A very special thanks to the scientific research team of Laboratory of Georesources and Environment, USMBA, Faculty of Sciences and Techniques, Fez – 30000, Morocco.

REFERENCES

[1] D. Halwatura and M. M. M. Najim, “Application of the HEC-HMS model for runoff simulation in a tropical catchment,” Environ. Model. Softw., vol. 46, pp. 155–162, 2013.

[2] H. Garba and I. A. Chukwujama, “Evaluating the performance of a hydrological model on River Kaduna discharge,” vol. 6, no. 1, pp. 25–29, 2016.

[3] D. Caissie, “archivee-archived,” Fish. Ocean. Gulf Reg. Ocean. Sci. Branch Diadromous Fish Sect. P.O. Box 5030, Moncton, NB, E1C 9B6, no. River discharge and channel width relationships for New Brunswick rivers, 2006.

[4] J. O. Oleyiblo and Z. Li, “Application of HEC-HMS for flood forecasting in Misai and Wan ’ an catchments in China,” Water Sci. Eng., vol. 3, no. 1, pp. 14–22, 2010.

[5] K. Cydzik and T. S. Hogue, “Modeling postfire response and recovery using the hydrologic engineering center hydrologic modeling system (HEC-HMS),” J. Am. Water Resour. Assoc., vol. 45, no. 3, pp. 702–714, 2009.

[6] M. R. Knebl, Z. Yang, K. Hutchison, and D. R. Maidment, “Regional scale flood modeling using NEXRAD rainfall , GIS , and HEC-HMS / RAS : a case study for the San Antonio River Basin Summer 2002 storm event,” vol. 75, pp. 325–336, 2005.

[7] R. Meenu, S. Rehana, and P. P. Mujumdar, “Assessment of hydrologic impacts of climate change in Tunga – Bhadra river basin , India with HEC-HMS and SDSM,” 2012.

[8] A. Asadi and F. Boustani, “Performance Evaluation of the HEC-HMS Hydrologic Model for Lumped and Semi-distributed Stormflow Simulation (Study Area : Delibajak Basin),” Am. J. Eng. Res., vol. 2, no. 11, pp. 115–121, 2013.

[9] W. Gumindoga, D. T. Rwasoka, I. Nhapi, and T. Dube, “Ungauged runoff simulation in Upper Manyame Catchment, Zimbabwe: Application of the HEC-HMS model,” Phys. Chem. Earth, vol. 100, pp. 371–382, 2017.

[10] I. Khaddor, M. Achab, and A. H. Alaoui, “Hydrological simulation (rainfall-runoff) of kalaya watershed (tangier, morocco) using geo-spatial tools,” J. Water Sci. Environ. Technol., vol. 2508, no. July, p. 9250, 2016.

[11] Y. Tramblay, “Modelisation Des Crues Dans Le Bassin Du Barrage Makhazine , Maroc,” 2012.

[12] J. Stitou, E. L. Messari, and A. Salhi, “PROJET WADI DE L ’ UNION EUROPEENNE RAPPORT DES ACTIVITES DE 2007,” 2007.

[13] J. Vaze, P. Jordan, R. Beecham, A. Frost, and G. Summerell, Guidelines for Rainfall-Runoff Modelling : Towards Best Practice Model Application, no. December. 2011.

[14] A. K. Verma, M. K. Jha, and R. K. Mahana, “Evaluation of HEC-HMS and WEPP for simulating watershed runoff using remote sensing and geographical information system,” pp. 131–144, 2010.

[15] J. E. Nash and J. V Sutcliffe, “River Flow Forecasting Through Conceptual Models Part I-a Discussion of Principles*,” J. Hydrol., vol. 10, pp. 282–290, 1970.

[16] A. Majidi and K. Shahedi, “Simulation of Rainfall-Runoff Process Using Green-Ampt Method and HEC-HMS Model (Case Study : Abnama Watershed , Iran),” vol. 1, no. 1, pp. 5–9, 2012.

[17] A. D. Feldman, “Hydrologic modeling system HEC-HMS, Technical Reference Manual,” Tech. Ref. Man., no. March, p. 145, 2000.

[18] L. Kalin and M. M. Hantush, “Hydrologic Modeling of an Eastern Pennsylvania Watershed with NEXRAD and Rain Gauge Data,” vol. 11, no. 6, pp. 555–569, 2007.