GIS preprocessing for rainfall-runoff modeling using HEC-HMS in Nekkor watershed (Al-Hoceima, Northern Morocco)

Yassine El Yousfi[1,*], *Mahjoub* Himi[1,2], *Hossain* El Ouarghi[1], *Mourad* Aqnouy[3], *Said* Benyoussef[4], *Hicham* Gueddari[5], *Hanane* Ait Hmeid[5], *Abdennabi* Alitane[6], *Mohamed* Chahban[5], *Soukaina* Bourdan[7], *Ouassila* Riouchi[5], *Ngadi* Hamza[5], *Ayoub* Tahiri[8]

[1] Research Team : Water and Environment Management, Laboratory of Applied Sciences (LSA), National School of Applied Sciences Al Hoceima, Abdelmalek Essaadi University, 93030 Tetouan, Morocco.

[2] Faculty of Geology, University of Barcelona, Marti I Franques, S/N, 08028 Barcelona, Spain.

[3] Moulay Ismaïl University of Meknes, Faculty of Sciences and Techniques, Applied Geology Research Laboratory. Applied Geology and Remote Sensing Research Team, B.P:509, Boutalamine 52000, Errachidia, Morocco.

[4] Research team: Biology, Environment and Health, Department of Biology, Errachidia Faculty of Science and Technology, University of Moulay Ismaïl, 50000 Meknes, Morocco.

[5] OLMAN BPGE Laboratory, Multidisciplinary Faculty of Nador, Mohamed First University, 60000 Oujda, Morocco.

[6] Research Team: Water Sciences and Environment Engineering, Laboratory of geological engineering, Department of geology, Faculty of Sciences, Moulay Ismail University, 50000 Meknes, Morocco.

[7] Loukkos Hydraulic Basin Agency, 93000 Tetouan, Morocco.

[8] Materials, Membranes and Processes of Separation, Department of Chemistry, Faculty of Sciences, Moulay Ismaïl University, Zitoune PB, Meknes 11201, Morocco.

Abstract. All Discharge data are among the most critical factors that must be considered when evaluating the management of water resources in a watershed. Simulation of rainfall-runoff is therefore an important element in assessing the impacts of serious flooding. In the present study, rainfall-runoff in the Nekkor watershed in Al Hoceima province was simulated using GIS, remote sensing and the Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) model. The applicability, capacity and suitability of this model for rainfall runoff in the watershed were examined. The watershed parameters were generated using (HEC-GeoHMS) and ArcGIS. The model was calibrated using a daily data set that occurred in the watershed between 2003 and 2007, the validation period was from 2009 to 2012. Model performance was evaluated using a variety of different statistical indices to study the response and impact of rainfall-runoff. Model parameters were changed and calibration was performed using the Soil Conservation Service Curve Number loss method. Consistent and satisfactory performance in terms of peak discharge, total flood volume, timing of peak discharge and overall hydrograph adjustment effect was found. The determination coefficient (R^2) for the validation period reached 0.73 versus 0.71 for the calibration period. The root mean square error (RMSE) is within the acceptable range. The relative bias (RE) demonstrates an overestimation in the calibration period and an underestimation in the validation period in the peak flows. These results will help decision makers to better manage water resources in this watershed and mitigate flood risks.

1 Introduction

Rainfall and runoff are major constituents of the hydrologic cycle. Hydrological models are now widely used to simulate the spatiotemporal variability of water flows. A flood is characterized by abnormally elevated water levels that extend beyond the channel or the channel bank [1]. Therefore, a few catchments have enough continuous hydrologic measurements for accurate water resource evaluations [2,3]. It is important to know the volume of runoff in a given watershed for the efficient planning and management of durable water resource projects. Present and future water associated challenges are place and time-specific, such can differ

* Corresponding author: yassine.elyousfi@etu.uae.ac.ma

depending on the impact of floods, glacier dynamics, or prolonged and longer droughts, among other things [4,5]. However, data analysis and quantification are essentially the most complicated and time-consuming [6].

HEC-HMS (Hydrologic Engineering Center e Hydrologic Modeling System) model was developed by the US Army Corps of Engineers [7] that could be used for different hydrological simulations [8]. The HEC-HMS model is among the hydrological models that requires few input data and provides a robust output [9]. It has been largely used due to its capability to simulate flooding in both long and short term events as well as its very simplicity to use. Several previous studies have indicated the capability of the HEC-HMS model in simulating floods and continuous events [10,11]. Although, the HEC-HMS model is currently used in this research for reasons of availability and performance through adopting the SCS-CN approach [12]. The SCS-CN method is one of the methods that has been evaluated in different regions, it is frequently used to simulate flood flow in Mediterranean regions [13,14,15,16]. In watershed scale CN parameter represents land use, soil, antecedent soil moisture, and hydrological conditions. It can be estimated using observed precipitation data or using the percentage given by SCS table [17].

The Nekkor watershed is chosen as the study zone in this investigation and the parameters of the basin (base flow and infiltration) are calibrated with data of rainfall and runoff of the watershed, which are collected by two rainfall stations and two runoff stations for the period 2003-2007, and the period of 2009-2012. The objective of this research is to simulate rainfall-runoff in the Nekkor watershed in Al Hoceima province using GIS, (HEC-HMS) model and the SCS-CN as a hydrological method. Moreover the applicability, capacity and suitability of this model for rainfall runoff in the watershed were examined through different performance criteria.

2 Methodology

2.1 Study area

The study area is located in the province of Al Hoceima, in northeastern part of Morocco, The watershed's location is between 34° 43.99′ to 35° 8.02′ north latitude and 4° 3.64′ to 3° 38.58′ west longitude (Figure 1), and covers an area of 780 square kilometers. Altitudes in the Nekkor watershed range from 82 to 1969 m. The climate is typically Mediterranean with a trend towards semi-arid. It is usually hot and dry in summer and cold and wet in winter. The climatology of the Nekkor watershed is characterized by irregular rainfall, as well as a significant evapotranspiration potential. The average annual precipitation ranges from 286.4 mm to 311.5 mm among the different stations contained in the basin, but the average interannual rainfall of the basin is estimated to be 340 mm [18], the main river length is estimated to be 70 km. The overall slope index is 20.7 m km^{-1} throughout the watershed [19], on the left bank, this index is higher than on the right bank [20]. The average slope in the plain is about 0.75% and in the riverbed is 2.3%. The long-term sustainability of the Nekkor River is maintained by important springs in Ain Hamra, which are located upstream of the basin, its average annual flow has lowered as a result of the installation of a dam that cut out the natural surface flow of the river in the plain.

The lithology of the watershed area is composed of impermeable formations, generally Miocene marls, flysch quartzites, and Schistose Marls. It is also surrounded by the limestone dorsal of the Bokoya Massif in the northwest, the lower Miocene sandstones of Jbel Kouine in the south, schistosand flysch in the southeast, the Jurassic shales of Jbel Azrou Akechar's Liasic hard limestone formations in the southwest, and to the North-East, towards the Nekor accident, there is mainly a Triassic gypsiferous olistostrome, as well as the formations of shales, limestones and marlstones of the Cretaceous [21,22]. The area around Nekkor River reports permeabilities between 3.10^{-4} m/s and $1.3.10^{-3}$ m/s.

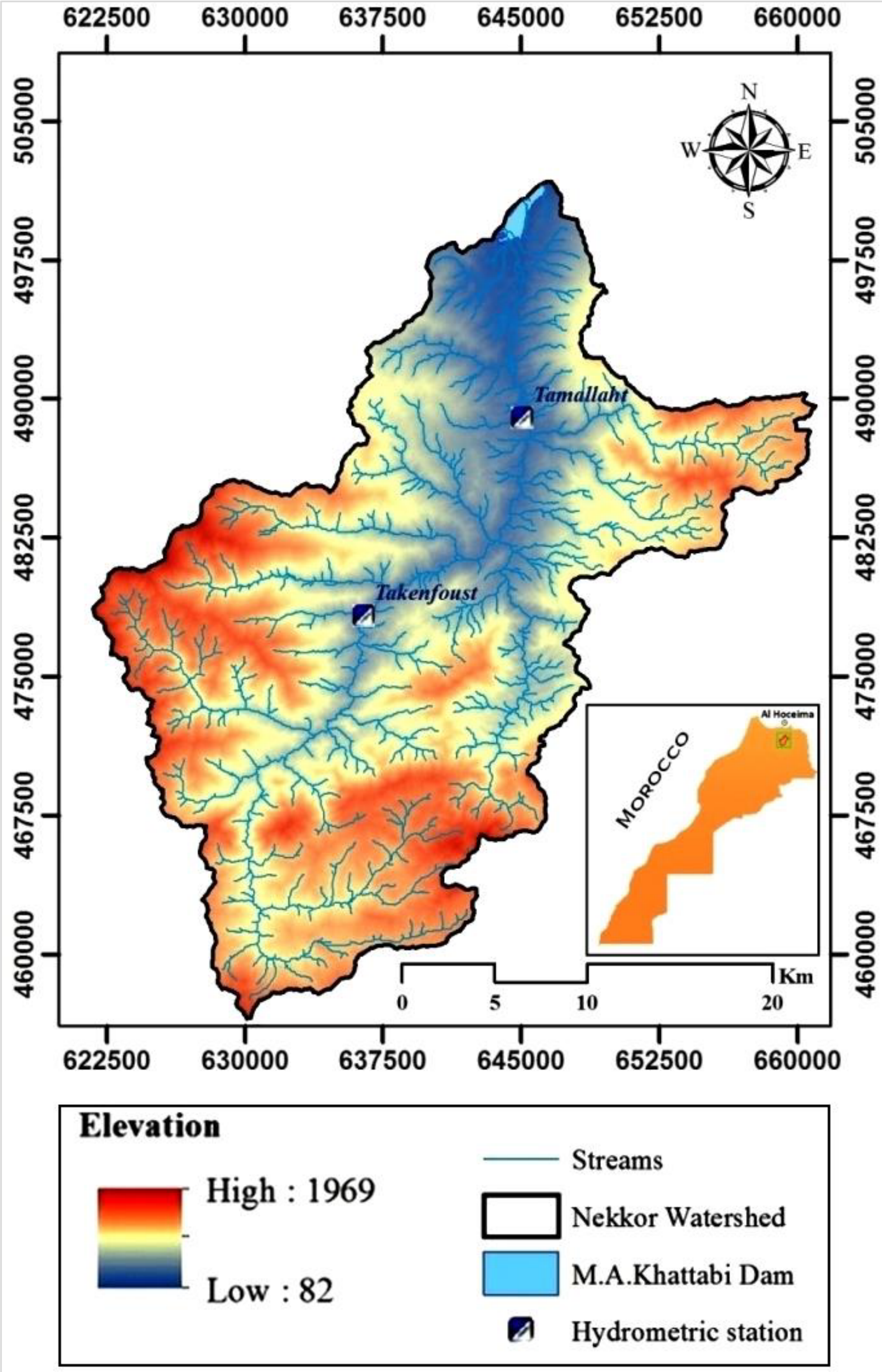

Fig. 1. The drainage network in the watershed and the location of gauging stations for the flow in the study area.

2.2 Data acquisition

The available data used in the present research was collected from the Hydraulic Basin Agency of Lokkous (ABHL) and only data on climate is derived from the Global Weather Data as shown in Table 1. For the years (2003-2012), daily precipitation was collected at two stations Tamellaht and Takenfoust. The ABHL provided as evaporation data.

ABHL also offered daily flow data for the seven years (2003-2007) and (2009-2012) at Tamellaht and Takenfoust gauging stations.

Table 1. Spatial and temporal data.

Type of data	Description	Source
Map of topography	Model of Digital Elevation (DEM) With a resolution of 30 meters	
Map of land use	Classification of land uses (2003)	
Map of the soil	Types of soil (2003)	Hydraulic Basin Agency of Lokkous
Spatial data	Source Basin, river, sub-basins, discharge, 2 rainfall station.	
Hydromet data	Daily precipitation, Water level, Discharge, (2003-2007) and (2009-2012)	
Climate data	Humidity, temperature, etc. (2003-2007) and (2009-2012)	Global Weather Data

2.3 Data map generation

The preparation of the spatial data was performed using the ArcGIS 10.5 program package. The data maps required as input for flow assessment were generated. Based on the digitized maps, the total area of the watershed, the area covered by each type of land use and the stream lengths were calculated.

The Nekkor watershed was digitized according to the distribution of rainfall measurement stations for the calibration and validation process of the model within the main watershed (Figure 2).

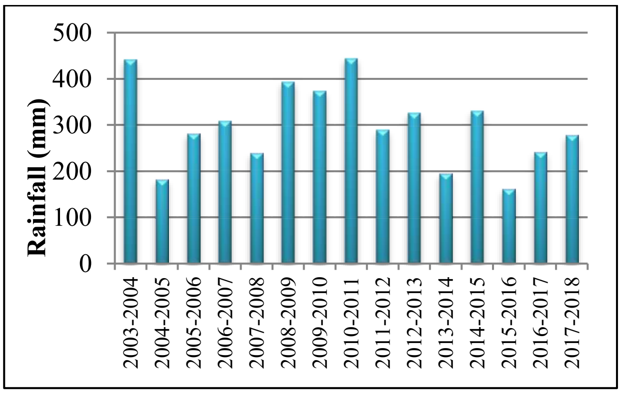

Fig. 2. Annual variations of precipitation in Nekkor watershed.

2.4. Flow chart

Different hydrological models can be used to estimate the amount of direct runoff that should be generated by a specific rainfall event in a basin. Models might be basic or complicated, and they all require various input data.

The Soil Conservation Service (SCS) technique is the one of these models that is most frequently used to estimate direct rainfall-runoff [13,14,15,16].

Figure 3 illustrates the process flow for runoff estimation through using SCS-CN method and its application in GIS.

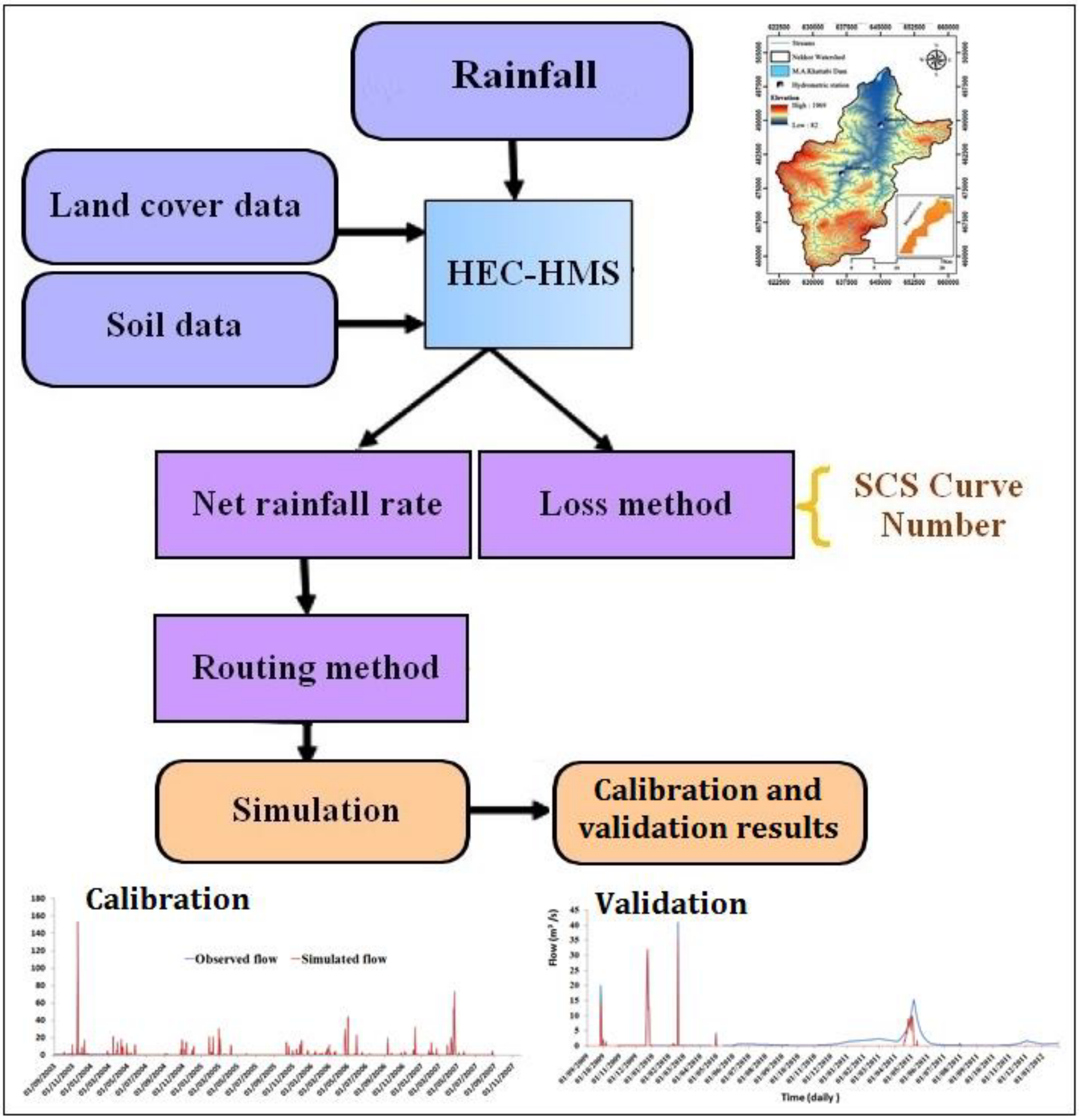

Fig. 3. Methodological Flowchart.

2.5. Model application and calibration

Daily stream flows were calculated by implementing the HEC-HMS 4.8 model and the data maps prepared were applied in the model to simulate Nekkor watershed runoff.

Sub-basins models are created using HEC-GeoHMS and a DEM data. HEC-GeoHMS effectively delimits the upstream limit of the watershed and sub-basin preliminary contours when a watershed outlet is delineated.

The flood hydrograph measured was generated from the rainfall and flow data. In contrast, the flow discharge is provided by Automatic Water Level Registration (AWLR), based on the equation of the rating curve.

In addition, this unit includes several methods of choice, like Soil Conservation Service Unit Hydrograph [23].

GeoHMS develops a basin model which can be integrated into HEC-HMS, as well as a database table of field-estimated parameters and many other data layers including land use and soil databases.

The following investigations are necessary for the hydrological modeling of the watersheds area, daily precipitation data, catchment land use patterns, monthly evaporation data, constant rate, daily river discharge data, initial deficit, impermeability, storage coefficient, peaking coefficient, standard lag, base flow, time of concentration, and curve number.

The CN was calculated according to the SCS-CN approach by integrating the land use and soil hydrology group [24].

The values were determined by taking into account the predominant soil type in the study area.

2.6. SCS Curve Number loss method

Among other loss methods, SCS loss method was specifically chosen for event-based simulation research.

The Soil Conservation Service Curve Number loss method was applied, this approach is efficient to use because it only involves two input data with CN and the impermeable zone.

For progressive losses, the SCS CN approach combines the curve number procedure. The CN was calculated by taking the average of the various land uses in the research region. The following equation to determine the weighted curve number (WCN).

$$WCN = \frac{\sum_{i=1}^{n} \mathrm{CN_i} \times \mathrm{A_i}}{\sum_{i=1}^{n} \mathrm{A_i}}$$

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

The approach was primarily aimed at determining the total infiltration throughout a storm. The program calculates rainfall increments within a storm by recomputation of the volume of infiltration after each period. The difference in volume across two adjacent periods represents the infiltration within each period.

The SCS CN approach involves the percentage of land use in the watershed and sub-watershed and the catchment area's elevation.

CN allows the runoff depth to be estimated from rainfall depth, given the value of the potential maximum retention S.

This potential maximum retention mainly represents infiltration occurring after runoff has started. This infiltration is controlled by the rate of infiltration at the soil surface, or by the rate of transmission in the soil profile, or by the water-storage capacity of the profile, whichever is the limiting factor.

Precipitation excess is appraised using the SCS CN model based on soil cover, antecedent moisture content, land use, and cumulative precipitation [7], by applying the following formula:

In which Pe denotes the accumulated precipitation excess at time t; Ia is the initial abstraction; is the potential maximum retention; P represents the accumulated precipitation at time t. The SCS established an imperial relationship with I_a and S as $I_\alpha = \lambda S$, with λ=0.2 and the equation represents as follows:

$$\mathrm{P_e} = \frac{(\mathrm{P} - 0.2\mathrm{S})^2}{\mathrm{P} + 0.8\mathrm{S}}$$

Where S is associated with the curve number CN as:

$$\mathrm{S} = \frac{(1000)^2}{\mathrm{CN}} - 10$$

Consequently, the method of transformation involves the identification of a lag time as an input. SCS has the ability to develop a relationship of lag time (Tlag) and time of concentration (Tc). The duration of concentration might be assumed using subbasin characteristics such as reach length and topography.

$$\mathrm{T_{lag}} = 0.6Tc$$

Were S is the slope in % and L is the length of the reach in feet.

$$\mathrm{T_c} = 0.0078 \times \left(\frac{L^{0.77}}{S^{0.385}}\right)$$

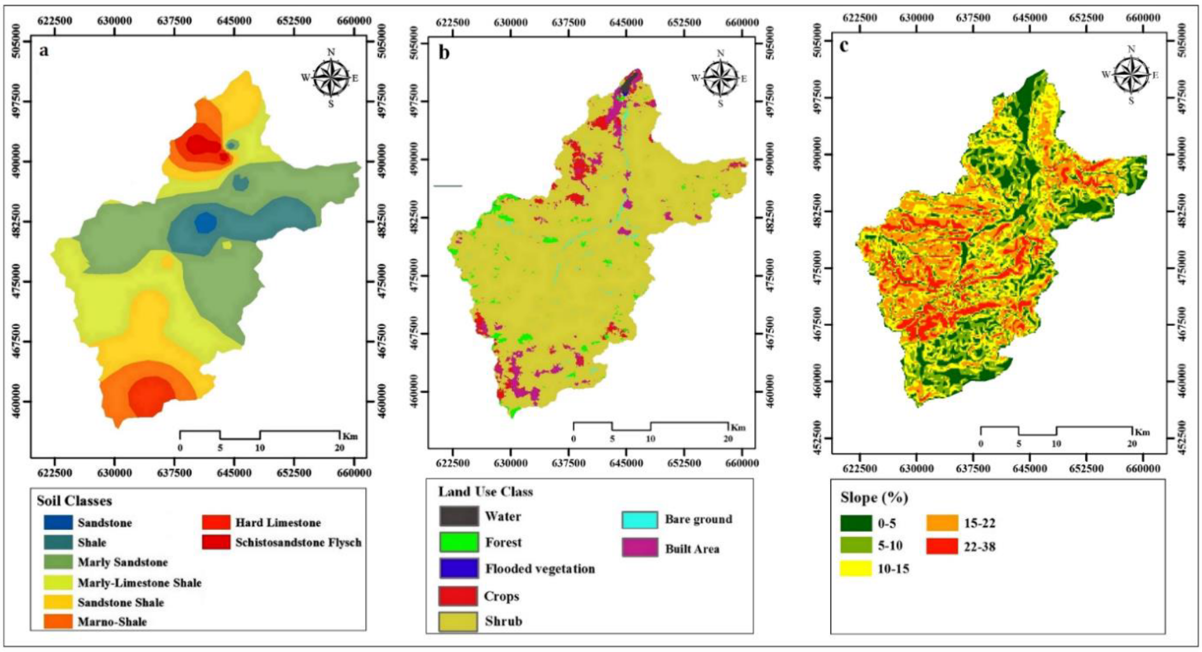

Fig. 4. The obtained parameters in Hec-Geo HMS and ArcGis, a. Soil maps, b. Land use map, c. Slope map.

2.7 Clark unit hydrograph

HEC-HMS provides transformation tools, a number of different processing methods are provided by HEC-HMS. The Clark Unit Hydrograph and Snyder Unit Hydrograph methods, which have been successfully applied to simulate flooding in the Moroccan watershed [11,25,26,27,28]. In this study, direct runoff was transformed into Clark unit hydrograph. An illustration of a synthetic unit hydrograph method becomes a Clark unit hydrograph [29]. This implies that the user is not liable [30] for developing a unit hydrograph by analyzing past. Alternatively, a program-implemented time versus area curve is employed to generate the translation hydrograph deriving from a precipitation burst. In order to account for the storage attenuation across the sub-basin, the generated hydrograph is routed through a linear reservoir.

3 Results and discussion

3.1 Calibration and validation

Model performance was evaluated using a variety of different statistical indices to study the response and impact of rainfall-runoff. Model parameters were changed and model calibration was performed using the Soil Conservation Service Curve Number loss method and the Clark unit hydrograph transfer method. Consistent and satisfactory performance in terms of peak discharge, total flood volume, timing of peak discharge and overall hydrograph adjustment effect was found.

The observed and simulated hydrographs for both the calibration and validation period present nearly similar shapes and trends (Figure 5). Based on the hydrograph analysis, overestimates and underestimates of the simulated flows can be seen during the two simulation periods, we notice it especially in periods of heavy rainfall.

Several physical parameters were taken into account during calibration in this study. We claimed that the CN represents the impact of both soil type and LULC upon the watershed response toward hydrological parameters as indicated by Tassew et al. [31].

The CN parameter value could greatly influence runoff generation [32] and it is directly proportional to runoff generation. Consequently, a low CN value indicates a low runoff coefficient, while a high value denotes a high runoff coefficient. The curve number (CN) technique is currently applied to assess the runoff in the Nekkor watershed in Morocco.

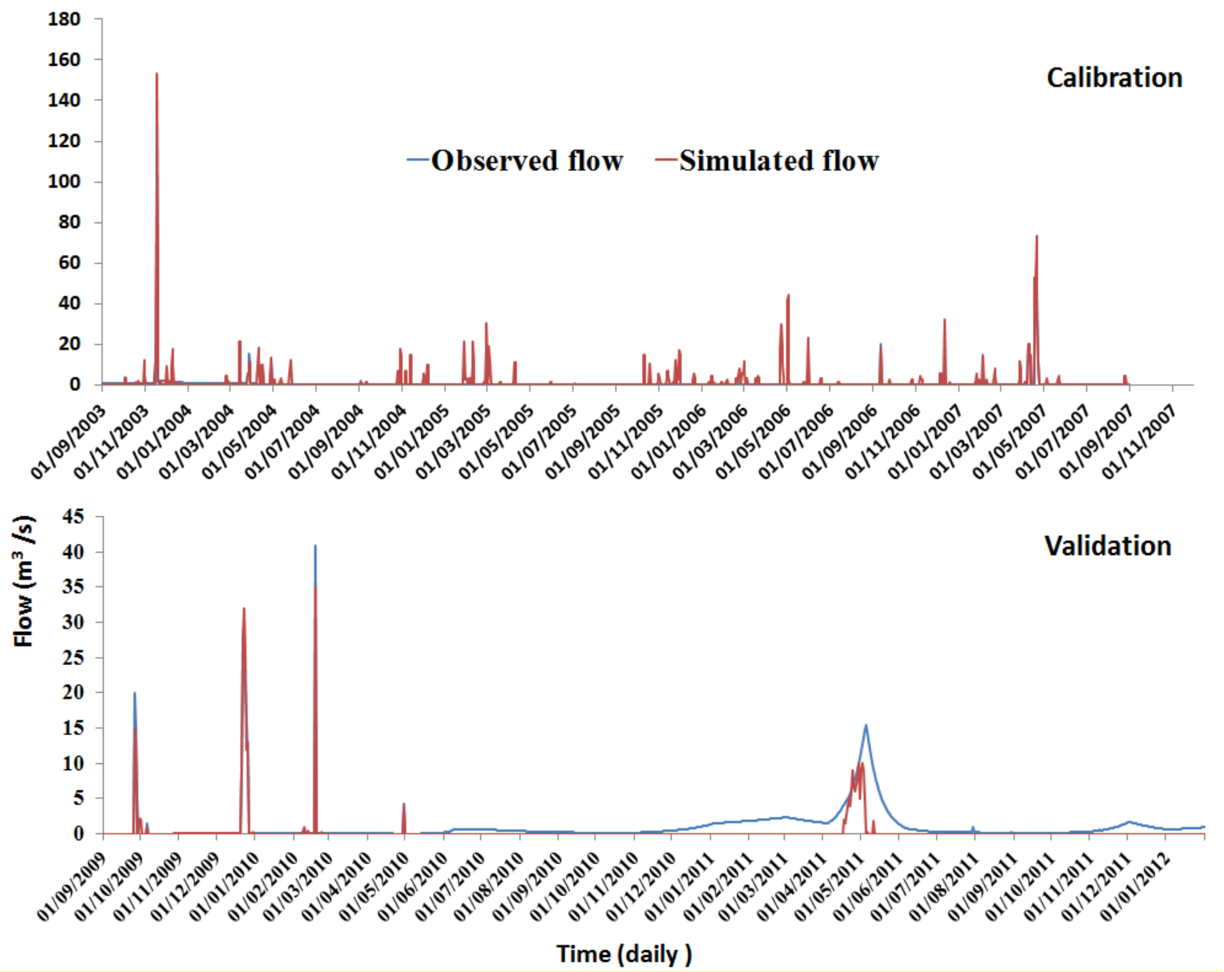

Fig. 5. Hydrograph of simulated and observed flow during calibration and validation period.

The average CN in the watershed was 80 suggesting a high flow and less infiltration within the basin. The obtained results established evidence that the hydrological model has the potential to support the watershed integrated management system [33]. In this study, the SCS-CN method of the HEC-HMS model was able to provide a simulation Rainfall-Runoff for normal and wet soil moisture conditions.

3.2. Model performance assessment

As the results show, the model accurately predicted the peak flow rate based on the available historical records data. The performance criteria values during the calibration period were as follows: R^2 = 0.71, Pbias = 85.9 and Rmse = 4.00, R^2 shows that the applied statistical error tests were found to be in an acceptable range. A number of researchers in Morocco [11,25,26,27,34,35] have find a good fit, certain of them with an R^2 value greater than 0.70. The Percent Bias coefficient (Pbias) for the calibration reached 85.9 % whish demonstrates a large overestimation in this period. Rmse indicated inappropriate results during calibration. The performance criteria values during the validation period were as follows: R^2 = 0.73, Pbias = -61.6% and RMSE = 1.48. The improvement of the R^2 and Rmse results during the validation period shows that the model is able to represent the hydrological functioning in the Nekkor watershed. In validation Pbias = -61.6% demonstrates a large underestimation in this period.

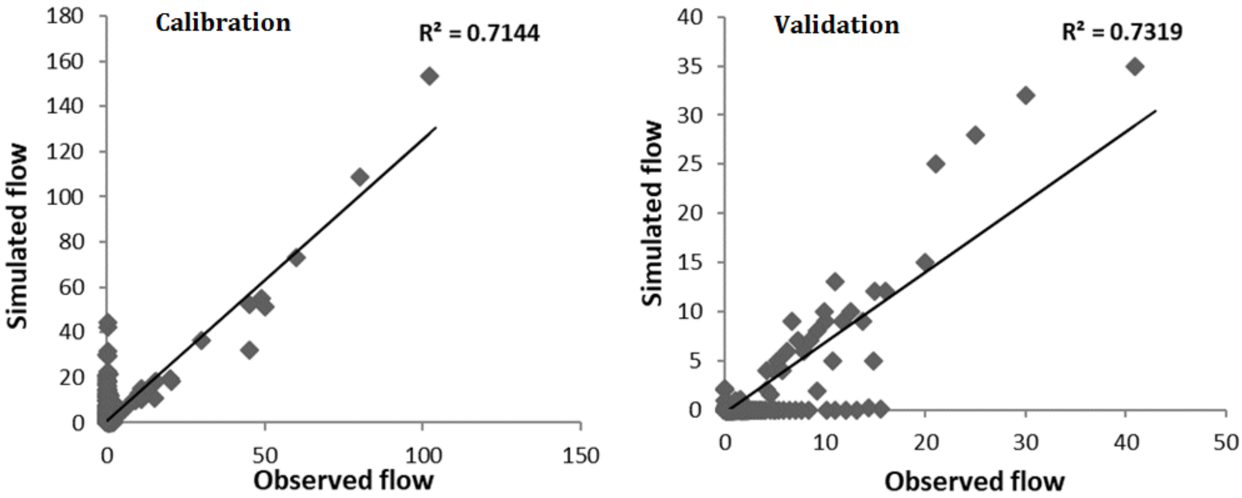

Fig. 6. The Scatter plot of observed and simulated flow in calibration and validation periods.

An increased CN value indicates a higher runoff, while a CN value of 100 indicates that all the rain will run off as runoff. The CN value for this watershed was spatially varied, with 35 for the forested area and a peak value of 99 for the waterbodies area with an average of 80. The CN approach provides a more flexible, as well as site-specific method for selecting appropriate design values for runoff estimation in this study.

The need to use accurate CN forecasts to predict watershed runoff was emphasized. Because the CN method was developed by the U.S. Department of Agriculture and the NRCS, its application to a Mediterranean watershed is challenging because it is derived from a temperate regime. Studies conducted not only in Mediterranean regions but also in temperate regions with varying climatic conditions have encountered difficulties when using the CN method.

Normally, CNs for different land use patterns are taken from standard CN tables (Sonbol et al., 2005), which may sometimes not provide accurate results due to the range of climatic conditions.

The transform approach Clark unit hydrograph seems to be the good method for modeling direct runoff in this watershed, further application of this approach should be encouraged to confirm its suitability for northern Moroccan watersheds. Considering the results of the calibration and validation phase, the volume and timing of the runoff was fairly accurate. This demonstrates that the HEC-HMS 4.8 model is suitable for simulate Nekkor flows. Although the structure of the HEC-HMS 4.8 model is simple, it is a powerful tool for rainfall-runoff simulation.

4 Conclusion

In this study we simulate rainfall-runoff of the Nekkor watershed in Al Hoceima province using GIS, (HEC-HMS) model and the SCS-CN as a hydrological method. Moreover the applicability, capacity and suitability of this model for rainfall runoff in the watershed were examined through different performance criteria. Results show that SCS Curve Number loss method and the Clark unit hydrograph transform approach in HEC-HMS 4.8 can be reliably used to simulate Nekkor flows.

The HEC-HMS model accurately predicted peak flow based on available historical rainfall data. It was noted that curve number, initial abstraction, and lag time were the primary parameters affecting runoff generation. The determination coefficient (R^2) for the validation period reached 0.73 versus 0.71 for the calibration period. The root mean square error (RMSE) is within the acceptable range.

The relative bias (RE) demonstrates an overestimation in the calibration period and an underestimation in the validation period in the peak flows. Although the structure of HEC-HMS is simple, it is a powerful tool for storm runoff. More advanced implementation of

HEC-HMS should be promoted to confirm its applicability to Moroccan watersheds. These results will help decision makers to better manage water resources in this watershed and mitigate flood risk. To accomplish this, it is recommended that gauging stations that measure precipitation and discharge on an hourly basis be installed, then the application of the HEC-HMS model on an hourly basis will reduce the risk of flooding in the downstream part of the Nekkor watershed.

5 Acknowledgement

The authors would like to thank the Loukkos Watershed Agency of Tetouan for providing us the basic data. We thank the Research Team Water and Environment Management at National School of Applied Sciences Al Hoceima and National Center for Scientific and Technical Research (CNRST) for supporting this research.

References

1. M. Al-Zahrani, A. Al-Areeq, H.O. Sharif, Estimating urban flooding potential near the outlet of an arid catchment in Saudi Arabia. Geomatics, Natural Hazards and Risk, 8(2), 672-688, (2017), https://doi.org/10.1080/19475705.2016.1255668
2. A. Wale, T.H.M. Rientjes, A.S.M. Gieske, H.A. Getachew, *Hydrol. process.* **23**(26), 3682-3693, (2009), https://doi.org/10.1002/hyp.7284
3. A. Randrianasolo, M.H. Ramos, V. Andréassian, *Adv. Geosci.* ***29***, 1-11, (2011), https://doi.org/10.5194/adgeo-29-1-2011
4. K. Basnet, U. Baniya, S. Karki, Oodbodhan: A Journal of TUTA, Pashchimanchal Campus, **5**(5), 41-49, (2018).
5. S. Khadka, K. Basnet, Storm water management of barahi chowk area, lakeside, pokhara, nepal using swmm. *In 2nd International Conference on Eng. Technol.* **2**(1), 320-325, (2019),
6. C. Cahyono, W.K. Adidarma, *Model. Earth Syst. Environ.* ***5***(4), 1705-1722, (2019), https://doi.org/10.1007/s40808-019-00625-8
7. A.D. Feldman, Hydrologic modeling system HEC-HMS: technical reference manual. US Army Corps of Engineers, Hydrologic Engineering Center, (2000).
8. W. A. Scharffenberg, M.J. Fleming, *Hydrologic modeling system HEC-HMS: user's manual*. US Army Corps of Engineers, Hydrologic Engineering Center, (2006). .
9. V. Ramesh, Application of the HEC-HMS model for runoff simulation in the Krishna basin, (2017). https://doi.org/10.13140/RG.2.2.13326.05448
10. K. Sok, C. Oeurng, Application of HEC-HMS model to assess streamflow and water resources availability in Stung Sangker catchment of Mekong'Tonle Sap lake basin in Cambodia (2016), https://doi.org/10.20944/preprints201612.0136.v1
11. M. Aqnouy, J.E.S. El Messari, A. Bouadila, I. Bouizrou, M.R.A. Mansour, *Int. J. Innov. Appl. Stud.* ***24***(4), 1773-1781, (2018)
12. R. Meenu, S. Rehana, P.P. Mujumdar, *Hydrol. Process.* **27**(11), 1572-1589, (2013), https://doi.org/10.1002/hyp.9220
13. Y. Tramblay, C. Bouvier, C. Martin, J. F. Didon-Lescot, D. Todorovik, J. M. Domergue, Assessment of initial soil moisture conditions for event-based rainfall–runoff modelling. J. Hydrol. **387**(3-4), 176-187, (2010), https://doi.org/10.1016/j.jhydrol.2010.04.006
14. D.A. Zema, A. Labate, D. Martino, S. M. Zimbone, Land Degrad. Dev. **28**(1), 294-308, (2017), https://doi.org/10.1002/ldr.2591
15. A. Kastridis, C. Kirkenidis, M. Sapountzis, Hydrol. Process. **34**(25), 4920-4939, (2020), https://doi.org/10.1002/hyp.13913
16. T. Saouabe, E. M. El Khalki, M.E.M. Saidi, A. Najmi, A. Hadri, S. Rachidi,... Y. Tramblay, Evaluation of the GPM-IMERG precipitation product for flood modeling in a semi-arid mountainous basin in Morocco. Water, **12**(9), 2516, (2020), https://doi.org/10.3390/w12092516
17. N. USDA, National engineering handbook. Hydrology Section, **4**, 4-10, (1972)/
18. M., Amil, Bassin versant du Nekor: recherche des zones sources d'envasement de la retenue du barrage MBA el Khettabi (Maroc*)* (Doctoral dissertation, Université Cheikh Anta Diop, Dakar, SN), (1992)/
19. N. Arrebei, M. Sabir, M. Naimi, M. Chikhaoui, D. Raclot, *Rev. Mar. Sci. Agron. Vét.*, *7*(7), 313-322, (2019)/
20. A. Lahlou, Envasement du barrage Mohamed Ben Abdelkrim Al Khattabi. Hydrology in Mamountious II. Artificial reservoir water and slopes. Proceeding of tow Lausane symposium, August. *IAHS publication*, (194), 243-252, (1990).
21. S. Benyoussef, M. Arabi, H. El Ouarghi, M. Ghalit, Y. El Yousfi, M. Azirar, A. Ait Boughrous, *J. Water Land Dev*. **52** (I–III), 245–250, (2022), https://doi.org/10.24425/jwld.2022.140395

22. Y. El Yousfi, M. Himi, H. El Ouarghi, M. Elgettafi, S. Benyoussef, H. Gueddari,... A. Alitane, *Groundw. Sustain. Dev.* **19**, 100818, (2022), https://doi.org/10.1016/j.gsd.2022.100818
23. E. Suhartanto, Panduan HEC-HMS dan Aplikasinya di Bidang Teknik Sumber Daya Air. *CV Citra, Malang,* (2008).
24. D.S. Krisnayanti, W. Bunganaen, J.H. Frans, Y.A. Seran, D. Legono, *Civ. Eng. J.* **7**(6), 1070-1083, (2021), https://doi.org/10.28991/cej-2021-03091711
25. M. Aqnouy, J.E.S. El Messari, H. Ismail, A. Bouadila, J.G. Moreno Navarro, B. Loubna, M.R.A. Mansour, *J. Ecol. Eng*. **20**(4), 104-113, (2019), https://doi.org/10.12911/22998993102794
26. M. Aqnouy, J.E.S. El Messari, A. Bouadila, A. Morabbi, L. Benaabidate, M. O. Al-Djazouli, *Ecol. Eng. Environ. Technol*. 2021; **22**(1), 9–23, (2021), https://doi.org/10.12912/27197050/132098
27. I. Bouizrou, N. Chahinian, J.L. Perrin, R. Müller, N. Rais, *J. Hydrol. Reg. Stud.* **34**, 100800, (2021), https://doi.org/10.1016/j.ejrh.2021.100800
28. M. Ouaba, E.M. El Khalki, M.E. Saidi, M.J.B Alam, *Environ. Earth Sci.* **6**(2), 541-556, (2022), https://doi.org/10.1007/s41748-022-00296-z
29. D.W. Kull, A.D. Feldman, *J. Hydrol.* Eng. **3**(1), 9-19, (1998), http://dx.doi.org/10.1061/(ASCE)1084-0699(1998)3:1(9)
30. Scharffenberg W. Hydrologic Modeling System HEC-HMS User's Manual. U.S. Army Corps of Engineers, *Institute for Water Resources, Hydrol. Engineering Center* (CEIWR-HEC), (2016).
31. B.G. Tassew, M.A. Belete, K. Miegel, *Hydrol*. **6**(1), 21, (2019), http://dx.doi.org/10.3390/HYDROLOGY6010021
32. M. Lal, S.K. Mishra, A. Pandey, R.P. Pandey, P.K. Meena, A. Chaudhary,... Y. Kumar, *Hydrogeol. J.* **25**(1), 151-167, (2017), http://dx.doi.org/10.1007/s10040-016-1460-5
33. K. Chadli, *Model Earth Syst Environ*, **2**, 1-10, (2016), http://dx.doi.org/10.1007/s40808-016-0105-y
34. A., Bouadila, L., Benaabidate, I., Bouizrou, M. Aqnouy, *J. Ecol. Eng.* **20**(6), (2019), http://dx.doi.org/10.12911/22998993/109458
35. A. Alitane, A. Essahlaoui, A. Van Griensven, E.A. Yimer, N. Essahlaoui, M. Mohajane,... A. Van Rompaey, *Sustainability*, **14**(17), 10848, (2022), https://doi.org/10.3390/su141710848