IMPROVING THE ACCURACY OF HYDROLOGICAL MODELING USING SNOW WATER EQUIVALENT (SWE) DURING SPRING FLOODING IN THE MOROCCAN HIGH ATLAS

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Abstract : The present study aims to evaluate the performance of a hydrological model to simulate the runoff process during spring floods in order to identify the impact and the contribution of snowmelt based on snow water equivalent (SWE) in the Moroccan High Atlas watersheds. For this purpose, a seasonal analysis was performed to select the flood events that reproduce this phenomenon over the period from 2011 to 2018. To this end, the calibration has been done by forcing the model with snow water equivalent (SWE) data. Based on the Nash-Sutcliffe efficiency coefficients (NSE), and Relative Root Mean Square Error (RMSE), the results indicate that the model provide an overall acceptable representation of the snow cover dynamics.

Keywords: Snow water equivalent, Hydrological modeling, Runoff, Micromet ERA5.

AMÉLIORER LA PRÉCISION DE LA MODÉLISATION HYDROLOGIQUE À L'AIDE DE L'ÉQUIVALENT EAU DE NEIGE (SWE) LORS DES INONDATIONS PRINTANIÈRES DANS LE HAUT ATLAS MAROCAIN

Résumé : La performance d'un modèle hydrologique pour simuler le ruissellement est évaluée afin d'identifier l'impact et la contribution de la fonte des neiges dans les bassins versants du Haut Atlas marocain lors des crues printanières. Une analyse saisonnière a été réalisée pour sélectionner les événements de crue reproduisant ce phénomène entre 2011 et 2018. La calibration a été faite en forçant le modèle avec des données d'équivalent en eau de la neige (SWE). Basés sur les coefficients d'efficacité de Nash-Sutcliffe (NSE) et l'erreur quadratique moyenne relative (RMSE), les résultats indiquent que le modèle fournit une bonne représentation de la dynamique de la couverture neigeuse.

Mots-Clés : Équivalent en eau de la neige, modélisation hydrologique, ruissellement, Micromet ERA5.

Introduction

Water is the most precious natural resource in the Mediterranean regions, suffering from a pronounced water shortage (Yucel et al., 2015), and this is even truer in the semi-arid regions of the Moroccan High Atlas watersheds, such as the Zat basin. Mountain snowfall in this basin serves as a natural reservoir to store precipitation during cold season and transform it into runoff that feeds rivers in spring and summer. Therefore, understanding the synchronization processes of snowmelt and river runoff is essential for water resource management. Snowmelt is an important resource for many aspects of hydrology, including water supply, and flood management. Due to its contribution to the hydrological cycle, it is important to simulate and forecast snowmelt runoff using hydrological models. The model (HEC-HMS) was chosen for this purpose. The applied methodology consists in simulating flows using daily meteorological data estimated by the MicroMet ERA5, to produce daily runoff, then comparing the simulated runoff to the daily observed discharge data measured at the Taferiat station located downstream of the Zat basin during the 2011-2018 period. Two methods were used to simulate snowmelt in this basin, namely energy balance methods resulting in-good results and temperature index methods resulting in non-significant results. Indeed, the energy balance method calculates the amount of snowmelt based on the remaining energy differences in an energy balance at the snow-air interface, while the temperature index method uses the air temperature as the only index of energy exchange at the snow surface (Anderson, 2006). These studies highlighted the importance of snowmelt to the hydrological regime of the Zat River, which is characterized by mountainous and rugged topography, spatially and temporally sparse, inconsistent, frequently with poor quality measured data (Maidment et al., 2015). Moreover, the snow regime in the Zat catchment is largely undocumented, although this catchment has a greater importance in terms of water resources than its neighboring Ghdat watershed. However, a distributed energy-balance model "Snow Model" was used to simulate the snowpack evolution. A key asset of Snow Model is MicroMet (meteorological data interpolation), which spatially interpolates the meteorological forcing data over the study area.

The objectives of this study are (1) to analyze the spatio-temporal variability of the snow water equivalent in the Zat watershed. (2) To evaluate the performance of HEC-HMS hydrological model to simulate the runoff process during spring floods using snow component. (3) To quantify and evaluate the importance of snowmelt contribution in the hydrological regime.

1. Study area

Zat watershed is a sub-basin of the Tensift catchment, it is also an Atlas tributary located on the left bank of Tensift River situated in the Moroccan High Atlas Mountains (Mount Toubkal, the highest mountain in North Africa). It is drained by the Zat River, which measures 89 km, the slopes are often very steep with an average of 19%, and it covers a total area of about 520 km² (Figure 1). The topography of the catchment area varies from 3777 m to 756 m at Taferiat station (Benkirane et al., 2020). This basin experiences a Mediterranean climate. Therefore, the catchment is sparsely vegetated, except for the valleys' bottoms. The study region is subject to frequent flash floods due to the topographical effect which it favors the quick runoff of snow melt and rainfall. The Zat River regime at Taferiat station is slightly dominated by the snowmelt contribution with a maximum discharge in April (Baba et al., 2021).

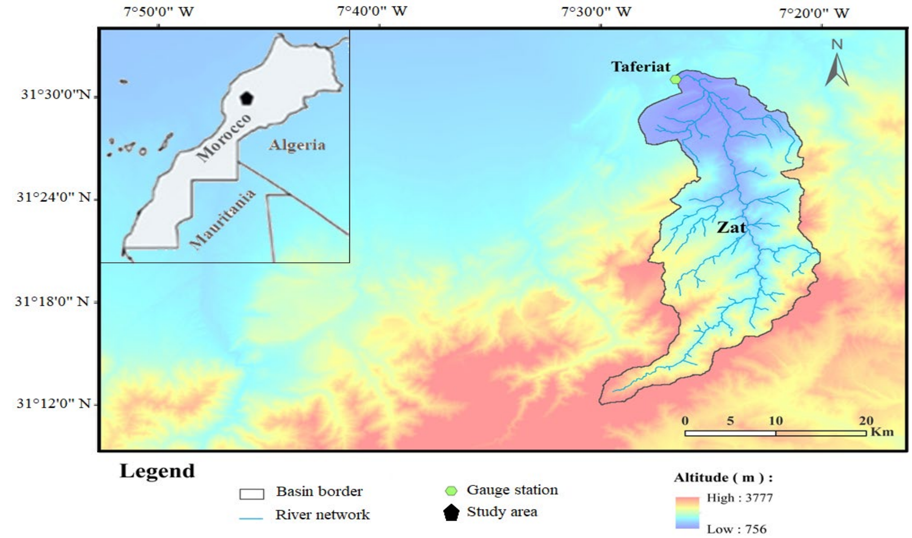

figure 1. The geographical location of the Zat basin.

2. Data, Hydrological model and Methodology

2.1. Data

The terrain pre-processing starts with the reconditioning of Digital Elevation Model (DEM). DEM tiles of resolution is approximately 30 m. It was downloaded from the United States Geological Survey (USGS). This DEM was clipped along the border of the basin using the polygon shapefile of the county downloaded from ESRI (Figure 1).

10-min river discharge data have been used from Taferiat River gauge (756 m, Figure 1) from the Tensift basin agency from 2011 to 2018. A python algorithm has been developed to convert the 10 min time step data into daily data. Noticing that flood events used in this study were selected during the melt season from January to June.

The SnowModel, is a spatially distributed, that accounts for meteorological forcing, topography, and vegetation cover. SnowModel combines six sub-models: MicroMet (Liston and Elder, 2006a, 2006b) is a spatially distributed meteorological forcing condition from AWS observations. EnBal is a distributed energy balance model which simulates energy and water fluxes from the MicroMet outputs (Liston 1995); SnowPack simulates snow depth, snow density, and snow water equivalent (Liston and Mernild, 2012).

2.2. HEC-HMS Model

The Hydrologic Engineering Center- Hydrologic Modelling System (HEC-HMS) model was developed by the US Army Corps of Engineers. This model was designed to simulate hydrologic processes in watershed systems to handle the water balance equation for event-based or continuous hydrologic modeling (Joshi et al., 2019).The HEC-HMS model is divided into four major input components: such as the watershed model, the weather model, the data manager, and the control manager (Bhuiyan et al., 2017).It is widely used for simulating precipitation and runoff for a wide range of geographical areas by considering important parameters such as various losses, base flow, direct runoff, river routing and reservoir components (USACE-US, 2017). The HEC-HMS model is a conceptual hydrological model potentially able to perform spatio-temporal simulations of rainfall-flow relationships across a watersheds (Gebre, 2015). Overall, HEC-HMS has been successfully applied in watershed modeling of several river basins. In Morocco, there are several studies on HEC-HMS application for example (Werren et al., 2016; Brirhet and Benaabidate, 2016; Benkirane et al., 2020). The method used in this paper includes SCS-CN (Soil Conservation Service) Curve Number, Clark Unit Hydrograph, and Baseflow Recession, which are necessary to determine the hydrologic loss rate, runoff transformation, and base flow rates. The calibration process was performed using the observed flow data at the outlet of the basin. There are a total of 16 parameters in the selected methods of the basin and the meteorological component in HEC-HMS.

2.3. Methodology

Firstly, the meteorological, hydrological, and geological data were previously analyzed (Benkirane et al., 2020). In addition; the DEM of the basin was pre-processed (a. DEM reconditioning b. Fill sinks c. Flow direction d. Flow Accumulation e. Stream definition f. Stream segmentation g. Watershed grid delineation h. Watershed Polygon Processing I. Drainage Line Treatment and j. Adjoint Watershed Processing. The study area is converted into a shapefile, in order to be implemented in the HEC-HMS model). The basin and stream properties were defined using HEC-GeoHMS to generate HMS model files. This was imported into the HEC-HMS software, where all parameters for the basin, meteorology, and control specification components were entered and calibrated from the database over 2011 to 2018. Many parameters were individually and manually adjusted (max-min) and the model was run with the reasonable ranges specified for the most sensitive parameters. Finally, the model was evaluated using statistical indices such as NSE, and RMSE.

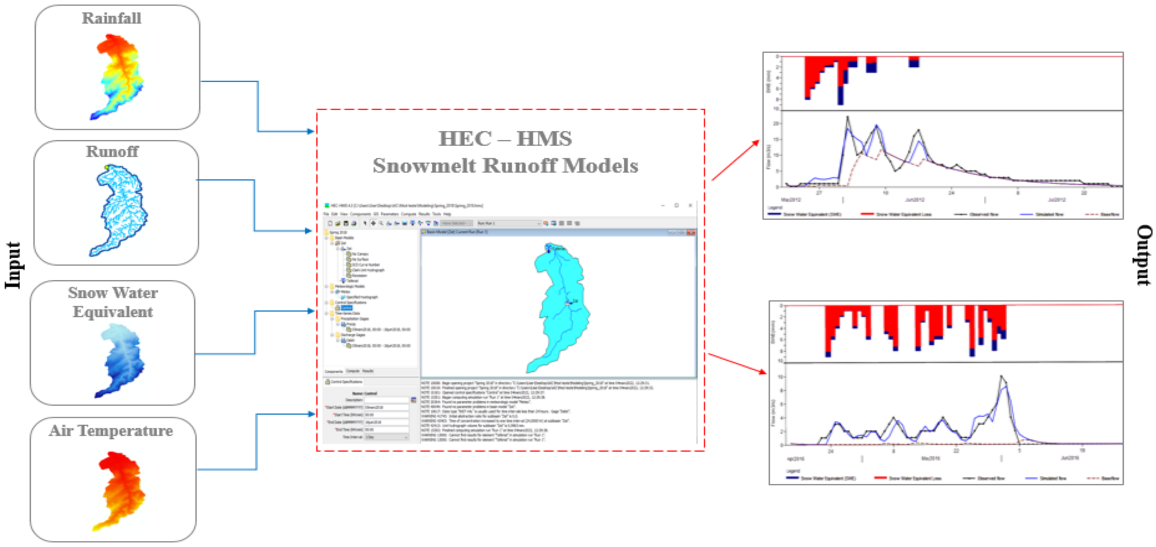

figure 2. Schematic representation of the calibration process of HEC-HMS based hydrologic models.

A manual calibration of the parameters was performed in this study due to the unpredictable behavior of the basin and the lack of data at the Taferiat measuring station. The manual calibration starts with an appropriate estimation of the initial parameters to run the model on a daily scale over a period from 2011 to 2018. The calibration was conducted using the gauging station recordings to simulate the flow on HEC-HMS. After running the simulation, the simulated results were compared to the observed data.

3. Results

The Zat watershed is a dynamic snow basin due to its topography and elevation. To model the process of snowmelt transformation into runoff. SWE simulations were performed; in general, the model reasonably simulated the snowmelt runoff in the Zat basin (Figure 3 and 4) between 2011 and 2016. Consequently, the model failed to correctly simulate the snowmelt runoff from 2017 to 2018 due to the occurrence of precipitation events, which led to an overestimation of the streamflow during the spring season of 2018. However, based on the comparison of the simulated flow curve to the observed flow curve, the model was able to produce a reasonable simulation of snowmelt runoff in the watershed. Thus, the obtained NSEs were greater than 0.85 for the majority of snow events; indeed, two representative events were selected for this paper.

A visual assessment of Figures 3 & 4 shows that the simulated flow curves are well reproduced compared to the observed flow curves for both events. The modeled results were used to test the performance of the model to simulate snowmelt runoff. Therefore, a comparison was made for the model performance using two performance criteria (Table 1). The adopted methodology provided better modeled results compared to alternative approaches we previously used.

Figures 3and 4 demonstrate an underestimation of the flow during some peak flows due to the permeability of the soil at the medium elevation (1800m). On the other hand, the rise and recession curves were well reproduced for both events, and the volumes were respected. The NSE coefficient attained 90% and an RMSE value of 0.3 during 2012 event while an NSE of 86.5% and an RMSE of 0.4 were obtained for 2016 event.

Noticing that the Curve Number, percent impervious surface, snowmelt temperature, and the runoff coefficient were the most sensitive parameters in the snowmelt methods applied for this watershed.

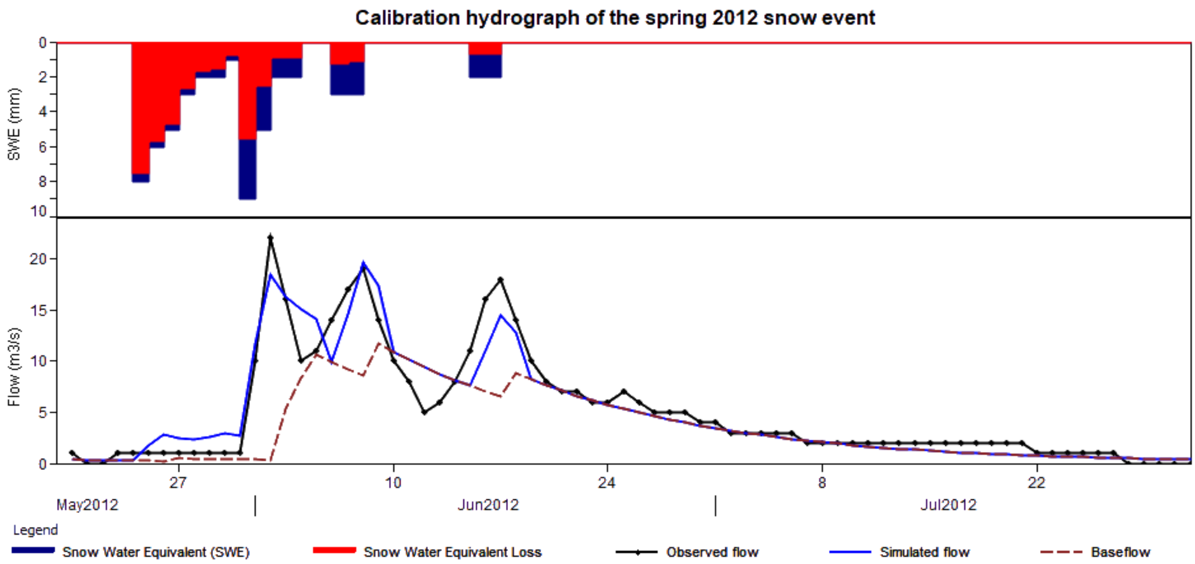

figure 3. Calibration result of the spring 2012 snowmelt event illustrating the SWE simulated flow and the observed flow at the Taferiat station.

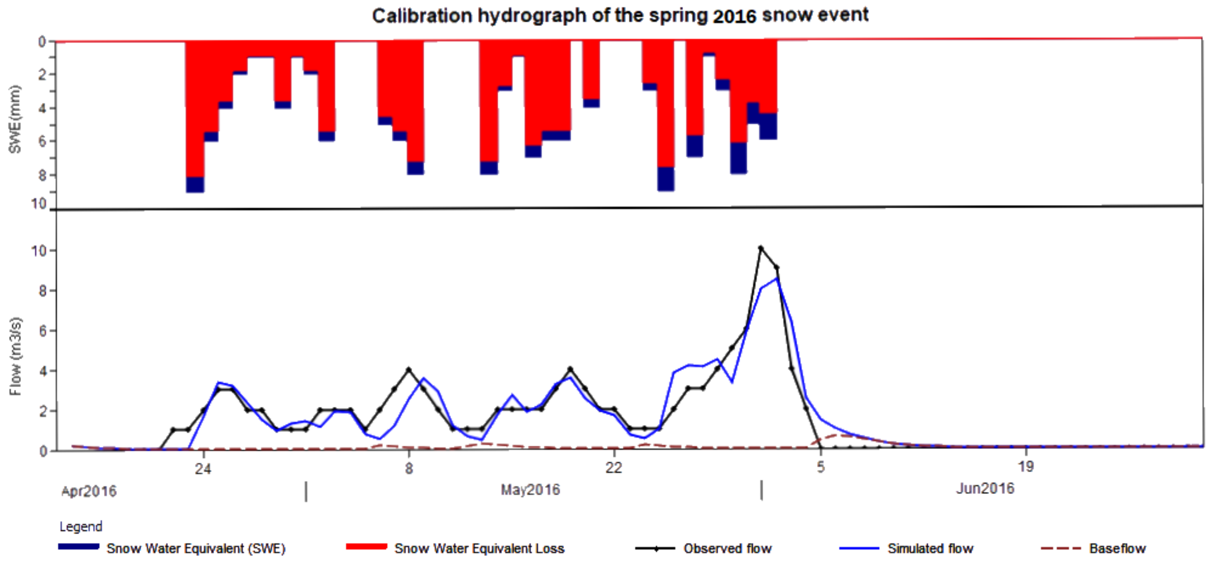

figure 4. Calibration result of the spring 2016 snowmelt event illustrating the SWE simulated flow and the observed flow at the Taferiat station.

Table 1. Calibration results of spring events

Events	Observed volume	Simulated volume	RMSE	NSE
Spring 2012	61.39	59.99	0.3	**90%**
Spring 2016	18.94	18.9	0.4	**86.50%**

Indeed, by examining the performance results (table 1), it can be seen that the obtained NSE and RMSE provides good performance considering different aspects of the hydrographs (i.e., raise curve, recession curve, volumes and peak flows).

Conclusion

The main objective of this study isto evaluate the ability of the HEC-HMS model to simulate daily flows in mountainous watershed where data are scarce. This study preprocessed the basin characterization with the GIS-based program HEC-GeoHMS, and created basin and meteorological models. The resulting outputs were used as inputs for the hydrological simulation. The HEC-HMS conceptual model was successfully calibrated for the Zat basin on a daily time scale between 2011 and 2018. The sensitivity analysis of the model reveals that Curve Number, Percentage of Impervious Surface, Snowmelt Temperature, and Runoff Coefficient are the most sensitive parameters of the model. The Nash-Sutcliffe efficiency criterion value were between 90% for the 2012 event and 86.50% for the 2016 event, which demonstrates a good model adjustment with a slight underestimation. However, it is evident that the model underestimated the flow during calibration. This is attributed to three main criteria, namely climatic factors, geological factors and topographical factors. This led to an underestimation of flow in the spring. These modeled results have a great impact on predicting runoff from snow-melt watersheds, which may have significant implications for flood forecasting. Based on the overall evaluation, it can be concluded that the used methodology can be applied to model the runoff flow rate due to snowmelt.

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