Pamukkale Univ Muh Bilim Derg, 26(6), 1015-1022, 2020

Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi

Pamukkale University Journal of Engineering Sciences

Comparison of hydrological models in upper Aras Basin

Yukarı Aras Havzasında hidrolojik modellerin karşılaştırması

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Received/Geliş Tarihi: 07.05.2019 Revision/Düzeltme Tarihi: 12.12.2019 doi: 10.5505/pajes.2019.98852
Accepted/Kabul Tarihi: 18.12.2019 Research Article/Araştırma Makalesi

Abstract

The increasing importance of water resources planning and management each day has led to a widespread use of hydrologic modeling. Especially in Turkey, where the headwaters of drainage basins are located around mountainous areas, snowmelt dominates streamflow during spring months which makes modeling applications important and necessary. In this study, two different conceptual hydrologic models (HEC-HMS and HBV) are compared during 2008-2015 water years in the mountainous headwaters of Aras Basin, located in eastern Turkey. For both models, performance on runoff using Nash-Sutcliffe Efficiency is above 0.8 and 0.7 for calibration and validation respectively. This first conceptual hydrologic modeling implementation and comparison in Aras Basin did indeed give promising results as well as suggesting to consider other variables beside streamflow.

Keywords: Hydrologic modeling, HEC-HMS, HBV, Snow water equivalent, Aras basin.

Öz

Günbegün önemi artan su kaynakları planlama ve yönetimi çalışmalarında hidrolojik modellemenin etkin kullanılması yaygınlaşmaktadır. Özellikle Türkiye'deki drenaj havzaları başlangıç bölgelerinin karlı dağlık alanlardan oluşması ve bahar aylarında karların erimesiyle birlikte akımların büyük bir bölümünün kar erimesinden meydana gelmesi bu bölgelerdeki modelleme uygulamalarını önemli ve zorunlu kılmaktadır. Bu çalışmada, Türkiye'nin doğu ve dağlık bölgesinde yer alan Aras Havzasının memba suları iki farklı kavramsal hidrolojik model (HEC-HMS ve HBV) kullanılarak 2008-2015 su yılları arasında modellenmiş ve karşılaştırılmıştır. Nash-Sutcliffe ölçütü kullanılarak performansı değerlendirilen her iki modelin akıma göre kalibrasyon başarısı 0.8 ve doğrulaması 0.7 değerlerinin üzerinde bulunmuştur. Aras Havzasında öncül bir kavramsal hidrolojik modelleme uygulaması olan bu karşılaştırma çalışmasının başarılı sayılabilecek sonuçlar verdiği ve benzer çalışmaların akımın yanı sıra başka değişkenlerin de çalışmaya dahil edilebileceğini göstermiştir.

Anahtar kelimeler: Hidrolojik modelleme, HEC-HMS, HBV, Kar su eşdeğeri, Aras havzası.

1 Introduction

Millions of people will be exposed to increasing water stress and floods with growing population and changing climate/land use patterns throughout the world in the coming decades. Hence, effective management of water resources is an increasingly important issue [1]. For prediction of land use and climate change effects on water resources, most applications of hydrological design and forecasting require the use of hydrologic models [2]. Assessments of the hydrologic impacts are required for developing strategies to cope with changing conditions, which is often approached using hydrological models in combination with climate scenarios. River flow in highlands is essential for irrigation, hydropower generation, and sustaining ecosystems that depend directly or indirectly on snow melting. Snow melt is crucial for water supply hence, it is of great concern for water management especially in mountainous basins [3].

In this study, HEC-HMS (Hydrologic Engineering Center Hydrologic Modeling System) and HBV (Hydrologiska Byrans Vattenbalansavdelning) physically based conceptual hydrological models, including continuous snow and soil moisture accounting algorithms are applied in the upper Aras River Basin, located in the mountainous eastern Turkey where optimum operation and management of water resources is a vital task. The processes of model development, parameterization, calibration and validation are described, and results of HEC-HMS and HBV models are compared with each other considering runoff and snow measurements.

Although several studies on HEC-HMS Soil Moisture Accounting (SMA) [4] modeling are practiced in different countries, this is the first study in Turkey. HEC-HMS SMA is performed to simulate and forecast streamflow in various parts of the world by many researchers [5]-[12]. In the recent years, some investigators analyzed the use of different automatic calibration methods applied to HEC-HMS [13]-[15]. Additional studies concentrated on comparing different modules of HEC-HMS with other hydrologic models such as MIKE-SHE [16], LBRM [17]-[18] and artificial neural networks [19]-[20] achieving successful results.

Hydrological modeling using HBV [21] is conducted more than 90 countries in the world [22], including Turkey, but this is the first application in Aras River Basin. Some of the studies that applied HBV model in different versions are on sensitivity and parameter uncertainty analysis [23]-[25], regionalization of model parameters [26]-[28], flood analysis [29], multi-objective calibration [30]-[35] and climate change [36]-[38].

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HBV model is also evaluated in comparison to other hydrological models such as SRM [39]-[40], VIC model [41], SWIM and artificial neural networks [42]. Until recently, a limited number of hydrological model applications considering both HEC-HMS SMA and HBV are documented in literature [43]-[45] with this being the first in Turkey.

The main objective of this paper is to show the applicability of different conceptual hydrologic models in a mountainous area of Turkey which is complex in terms of climate, topography and data. In addition to this, a pioneer modeling study is performed as a source of motivation for future studies in the Aras River Basin where large dams for energy production and irrigation are planned.

2 Material and methods

2.1 Study area

Kayabasi Basin with a stream gauging station D24A096 (39:50:16N-41:50:19E) located at the headwaters of Aras River in eastern Turkey (Figure 1) is selected as the study area. The basin has an area of 2758 km² with a mean slope of 19.6%. Elevation ranges from 1659 to 3187 m with a hypsometric mean of 2218 m. The main land cover types are grassland/pasture (50.4%), bare land (30.8%) and agricultural area (15%). The basin is quite mountainous therefore, snow plays a significant role in the hydrologic cycle.

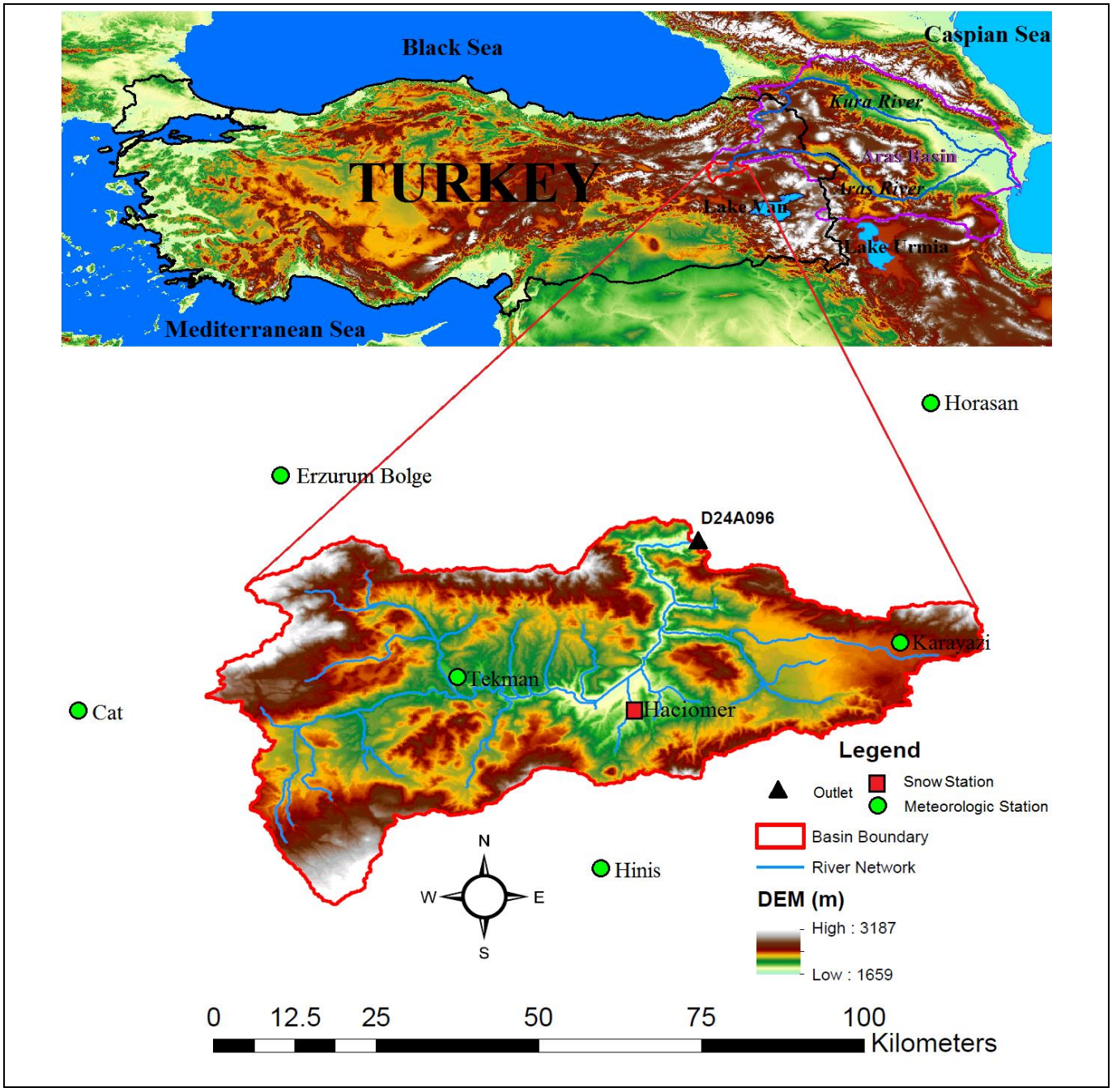


Figure 1. Geographical position and DEM of Kayabasi Basin.

Meteorological data is obtained from 6 meteorological observation stations located in the vicinity of Kayabasi Basin (Figure 1). Hydro-meteorological conditions of the basin are presented in Figure 2, where the annual mean precipitation (P) is around 450 mm and the annual mean temperature (T) is 7 °C. The average discharge (Q) of Kayabasi stream gauging station is 20.6 m^3/s (235 mm) which has observations since 2008 and a maximum observed streamflow of 383 m^3/s [46]. In accordance to the monthly mean discharge values at the station, snowmelt contributes roughly 76.5% of total annual runoff volume during the melt season (spring and early summer months). Being located on a transboundary region and having a high snow potential at the headwaters of Aras River, Kayabasi Basin is a crucial area to operate hydrologic models in the future for a more effective water resources management.

2.2 Hydrological models

2.2.1 HEC-HMS model

HEC-HMS, formerly known as HEC-1 and developed in 1998 by United States Army Corps of Engineers-Hydrologic Engineering Center (USACE-HEC) is a conceptual model that simulates hydrological process as continuous or event based. In this paper, SMA module considering continuous situation based soil moisture variation is carried out that calculates the amount of water stored in and moving through vegetation, soil surface, profile and groundwater layers [4].

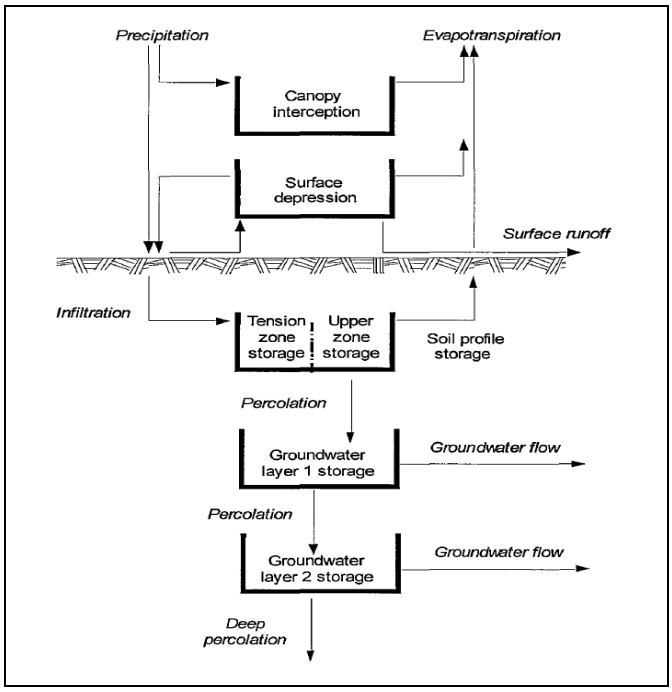
Inputting precipitation, temperature and potential evapotranspiration data into the model, SMA computes surface runoff, groundwater flow, losses due to evapotranspiration/infiltration, soil moisture, snow water equivalent and deep percolation over the entire basin using elevation zones. The SMA model represents the watershed with a series of storage layers, as illustrated by Figure 3(a). Rates of inflows to, outflows from, and capacities of these layers control the volume of water lost or accumulated in these storage components. Current storage contents are calculated during the simulation and vary continuously both during and between storms [47].

2.2.2 HBV model

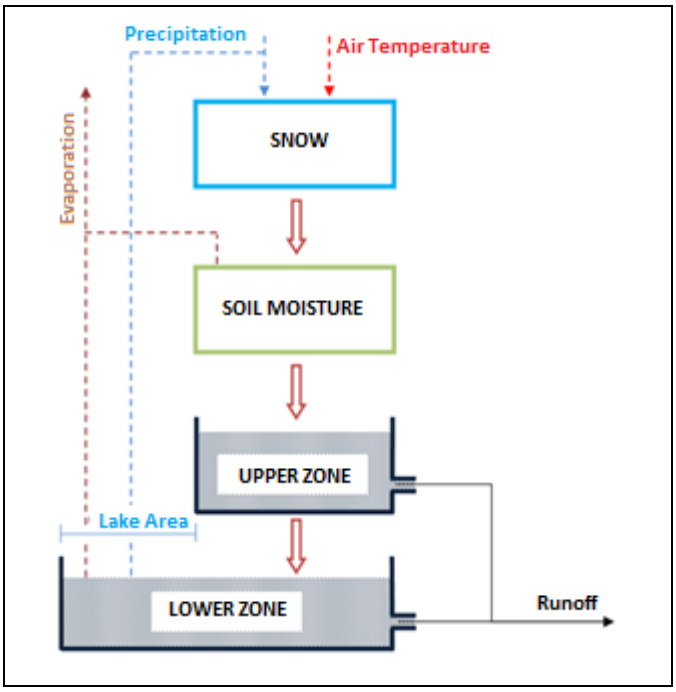
HBV is a conceptual and continuous hydrological model Figure 3(b) created in 1972 by Swedish Meteorological and Hydrological Institute (SMHI) for forecasting the inflow to reservoirs and flood warning. Many different versions of the HBV model are used worldwide. The model used in this study is the HBV-Light version developed by [48] that has user-friendly graphical interface and automatic calibration option.

HBV model distributes precipitation, temperature and potential evapotranspiration inputs based on elevation and vegetation zones. The model simulates daily flow by calculating the snow and soil moisture layers based on zones, the runoff and routing processes based on the whole basin.

Figure 2. Hydro-meteorological conditions of Kayabasi Basin.



(a): HEC-HMS SMA model [4].



(b): HBV model [49].

Figure 3. Hydrological models used in the study.

3 Results

In this study, 8-year period flow data of Kayabasi stream gauging station (D24A096) from 1 October 2007 to 30 September 2015 (2008-2015 water years) are used for hydrological modeling. In addition, 2007 water year meteorological data are used to warm up the models. Application period is divided into two separate parts of 4 years for model calibration and validation. Firstly, parameters for both models are manually adjusted by taking into consideration the discharge values only. Afterwards, by setting allowable ranges for the model parameters, automatic calibration is carried out using Genetic Algorithm method in HBV model and Nelder-Mead method in HEC-HMS model. Final parameters are given in Table 1. To measure the success of the model results, Nash-Sutcliffe Efficiency (NSE) criterion [50], commonly used in the literature and given in Equation 1 is utilized. The NSE criterion ranges from– ∞ to 1, with 0 representing average flow success.

$$NSE = 1 - \frac{\sum(Q_O - Q_M)^2}{\sum(Q_O - \overline{Q_O})^2}$$
$$Q_O = Observed\ discharge \quad (1)$$
$$Q_M = Modeled\ discharge$$
$$\overline{Q_O} = Observed\ mean\ discharge$$

In each modeling case, initially 2008-2011 water years are treated as calibration and 2012-2015 years as validation periods. Then by applying a split sample test, these cal/val periods are shifted (2012-2015 calibration, 2008-2011 validation) to check the data variability for different years. Model runoff and snow water equivalent results are depicted in Figure 4 and Figure 5 respectively. Overall model performance results are summarized in Table 2.

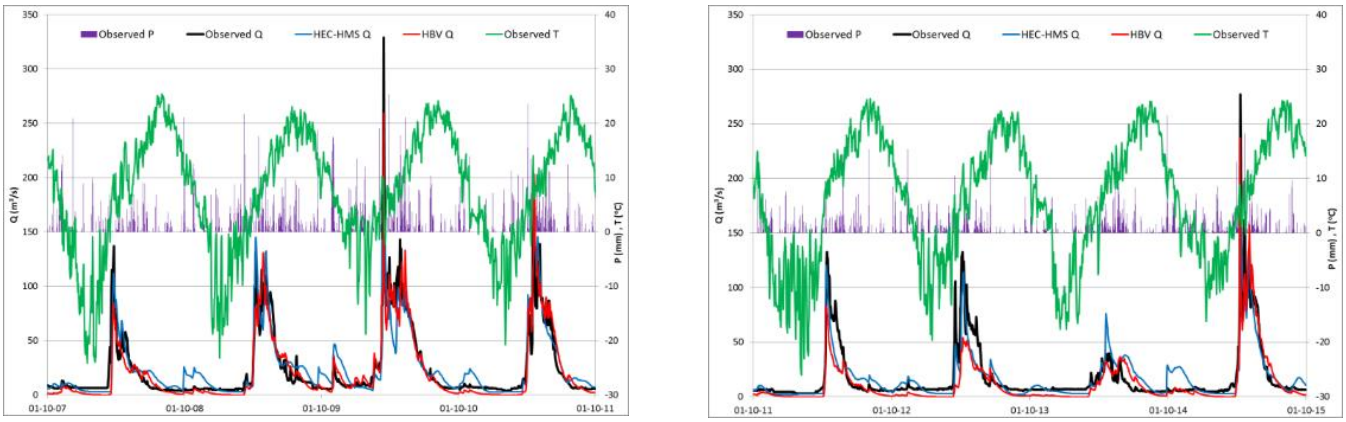
When the modeling results are considered, performance of both models can be accepted as successful with calibration scores above 0.81 and validation above 0.70 according to the NSE benchmark [51]. After the split sample test, there is no significant change in the model performance meaning that the model can produce successful results even with different inputs. While HEC-HMS model gives similar values for the calibration and validation criteria, HBV model yields more successful calibration but slightly lower validation results. A reason for this could be attributed to automatic optimization algorithm of HBV where model parameters are forced to match the high flows more than the low values considering NSE. When runoff values are compared graphically (Figure 4), HEC-HMS model responds quicker to runoff peaks while HBV model underestimates the observed low flow values most probably due to quick drying up of the soil layer. Evaluating the snow water equivalent (SWE) output of both models (Figure 5), HBV tends to accumulate more snow within the basin. Fortunately, there is an in-situ manual snow site conducted at Hacıömer station (1865 m) (Figure 1) within Kayabasi Basin which is located at a lower altitude than the basin hypsometric mean. When ground point SWE measurements are compared with basin average model results, the increasing trend during the snow accumulation, timing of near to maximum SWE and decreasing trend in the depletion phase can easily be detected. Due to the varying number of in-situ SWE observations, more measurements on the accumulation period than the depletion part, as well as 12 measurements between 2008-2011 seasons compared to 22 in 2012-2015 years, calculating a SWE performance would be biased. Hence for SWE, visual trend and timing comparison is found to be reasonable enough. Therefore, it can be stated that while HEC-HMS model accumulates slightly lower snow within the basin, it produces similar runoff values with HBV model.

Table 1. Model parameters.

HBV Parameters			HEC HMS Parameters		
TCALT (gradient parameter for temperature)	°C/100 m	0.485	Lapse Rate (temperature adjustment with respect to elevation)	°C/1000 m	-6.9
PCALT (gradient parameter for precipitation)	%/100 m	3.521	Index (precipitation adjustment with respect to elevation)	mm/1000 m	10.0
TT (threshold temperature for snowfall)	°C	0.123	PX Temperature (rain/snow temperature)	°C	2.686
CFMAX (degree day factor)	mm/day °C	4.727	Base Temperature (snow melt temperature)	°C	0.797
CWH (water holding capacity of snow)	-	0.1	ATI-Meltrate Function (meltrate of snowpack)	mm/day °C	0.0-7.5
FC (max soil storage)	mm	338.1	Water Capacity (water holding capacity in snowpack)	%	13.3
LP (limit for potential evapotranspiration)	-	0.886	Max Infiltration	mm/hr	2.05
BETA (shape coefficient)	-	1.911	Tension Storage (soil zone prone to evapotranspiration)	mm	50.0
PERC (max percolation)	mm/day	3.365	Soil Storage	mm	75.0
UZL (threshold parameter for extra outflow from upper zone)	mm	19.0	Time of Concentration	hr	6
K0 (upper store recession coefficient)	1/day	0.500	Storage Coefficient (time lag for transforming water in storage to become lateral outflow)	hr	250
K1 (middle store recession coefficient)	1/day	0.101	Ground Water 1 Storage	mm	0.3
K2 (lower store recession coefficient)	1/day	0.047	Ground Water 2 Storage	mm	40.0

Table 2. NSE model runoff performance results for calibration and validation periods.

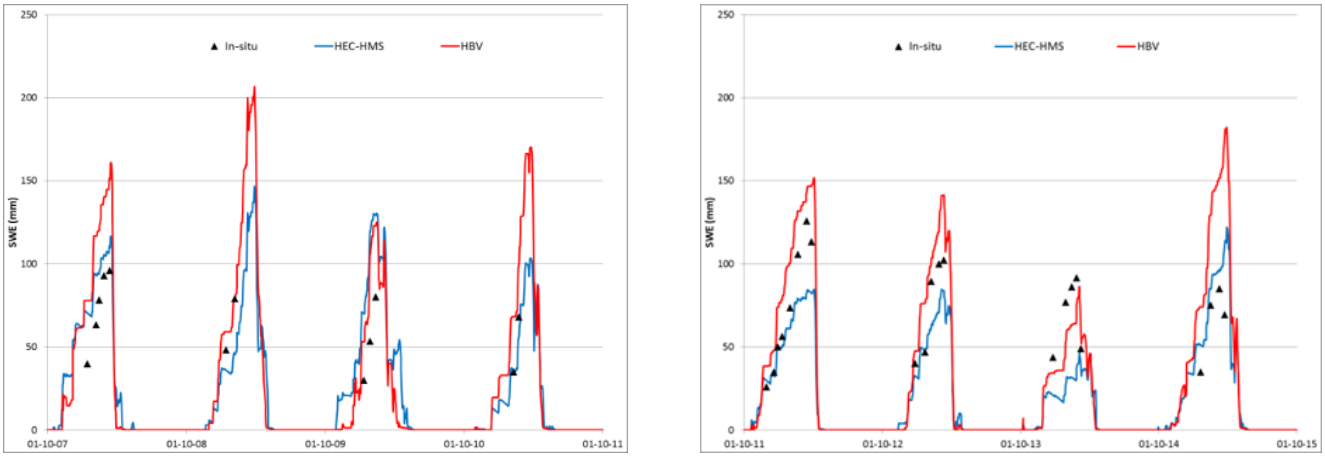
Model	2008-2011 Calibration	2012-2015 Validation	2008-2011 Validation	2012-2015 Calibration
HEC-HMS	0.82	0.78	0.83	0.81
HBV	0.86	0.72	0.70	0.88



(a): 2008-2011 calibration period.

(b): 2012-2015 validation period.

Figure 4. Model runoff results.



(a): 2008-2011 calibration period.

(b): 2012-2015 validation period.

Figure 5. Model snow water equivalent (SWE) results.

4 Conclusion

In this study, a hydrological multi-modeling application is presented in the upstream part of Aras River which is a transboundary water resource rising from the high elevations of eastern Turkey. Within the considered area of interest, no conceptual hydrological modeling study has been carried out before whereas on the other hand, crucial hydraulic structures are being planned for the near future. This situation increases the value of the research.

In the framework of multi-model approach, two different conceptual hydrological models (HEC-HMS and HBV) are set through calibration/validation processes using 8-year hydro-meteorological data in the pilot basin. Both models presented similar successful results in terms of runoff performance while behaving a little differently in the snow output. In hydrological modeling, it is crucial to match the end product runoff values as well as the internal states of the model. Therefore, comparing model results with different in-situ measurements is very valuable for model reliability.

In mountainous eastern regions of Turkey, snowmelt induced runoff generates approximately 2/3 of the total annual flow volume in spring and early summer months [52]-[53]. For this reason, it is important in such areas to have a dense hydro-meteorological gauge network as well as accessibility to real-time data. In the recent years, governmental institutes are working very hard to increase the automatic gauge network density especially in the elevated areas. Therefore, future research on the region will concentrate more on multi-model (comparing different model results) as well as multi-criteria (multiple performance measures) modeling using up-to-date ground measurements and areal remote sensing data.

5 Acknowledgement

This study is supported by Eskişehir Technical University Scientific Research Project BAP1705F122. Hydro-meteorological data used in the modeling analysis is provided by Turkish State Meteorological Service and State Hydraulic Works.

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