O 27. ASSESSMENT OF THE WATER BUDGET BY USING A CONCEPTUAL MODEL: THE CASE OF ÇARŞAMBA BASIN

Muhammet Cafer Ulker[1*], Cihangir Koycegiz[2], Meral Buyukyildiz[3]

[1]*Department of Civil Engineering, Konya Technical University, Turkey*
[2]*Department of Civil Engineering, Konya Technical University, Turkey*
[3]*Department of Civil Engineering, Konya Technical University, Turkey*

E-mail: ulker.mcafer@gmail.com, ckoycegiz@ktun.edu.tr, mbuyukyildiz@ktun.edu.tr

ABSTRACT: Hydrologic models are crucial to detect, understand and improve water resources and their behaviour. The Hydrologiska Byråns Vattenbalansavdelning (HBV) model which is deterministic, lumped, daily rainfall-runoff model, was implemented to the headwater of Çarşamba Basin, located on Konya Closed Basin in Turkey. The basin is in a region data-scarcity hence we used the data of Seydisehir and Hadim meteorological stations nearby. We aimed to understand the hydrological processes and obtain information that will facilitate the identification of water management strategies. Initially, the model was calibrated using the Generalized Reduced Gradient (GRG) nonlinear solving method for optimization, and at this stage, the HBV model showed an adequate performance. For daily runoff, the HBV model has performed at Kling-Gupta efficiency coefficient (KGE)=0.676 and Nash-Sutcliffe efficiency coefficient (NSE)=0.501. In this study, we also calculated the water budget as annual and seasonal to appraisal temporal performance of the model. Consequently, the best results have been achieved for spring months while achieving worst for summer months.

Keywords: Generalized Reduced Gradient, The HBV Model, Hydrological Modelling, Water Budget

1. INTRODUCTION

Water has always been indispensable for the regions that have hosted civilizations. Therefore, the cautious use of water resources is important for the welfare of societies and for the continuity of civilizations. Hydrologic models allow us to develop strategies for problems and improve water resources.

Assessment of the water budget is part of the developing strategies. In order to calculate the water budget, meteorological data and model outputs such as precipitation, evapotranspiration, soil moisture, runoff, process of capillarity can be used.

In the literature, studies have been achieved to calculate the water budgets of basins by using hydrological modelsHydrologiska Byråns Vattenbalansavdelning (HBV), Soil and Water Assessment Tool (SWAT), Water Evaluation and Planning System (WEAP), Système Hydrologique Européen (SHE), Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS).

Hydrological models can be variously classified. One of the classification methods, used by Singh (1988), basically divided hydrological models as two sections. These are material (also called a physical model) and formal (can be empirical, conceptual and theoretical). Physical-based models create an equality in the computer environment for each natural process. A formal model is idealized and simplified version of the structural conditions of the original system. Conceptual models contain parameters that have no equivalent in the original system. These conceptual parameters are expected to help the model to simulate the original process. The HBV model, used many times in literature, is one of the conceptual models established especially for the snow routine. The HBV model uses precipitation, evapotranspiration and temperature data to make daily soil moisture and flow estimates.

The HBV model is widely used all around the world. Tecklenburg et al. (2012), applied HBV-D REG (enhanced version of HBV) to the Ötztal catchment, Austria. They investigated the impact of climate change on the water balance. Their study showed that mean areal snow coverage decreased with time, whereas runoff in winter and spring increased. Jia and Sun (2012), first time applied HBV model for Liao river Basin, China. In their study, the HBV model significantly simulated the typical year's flood runoff and that of typical arid year. Bruland and Killingtveit (2002), in general, the HBV model has been tested in arctic regions since 1991. In their study, some aspects of the model developed for arctic regions have been tested. These aspects are the soil moisture routine with variable field capacity, the glacial melting routine, the snow routine, and the snow cover discharge curves for the simulation of the dispersed snow deposits. Their R^2 values are between 0.7 and 0.9. Normand et al. (2010), established the HBV model to Tamor Basin, in Eastern Nepal. They calibrated and validated the model for bigger and gauged basins, because of unavailable discharge data at the study area. The model applied to the Tamor basin showed good results at low flows. However, in the pre-monsoon and monsoon seasons, they noticed that there was a flaw in the model performance. Brink (2009), used simplified version of the HBV. Nine years of daily data are used as input for the model. As a result, the model predicted the discharge well. During extreme peak flows, relatively more errors were obtained.

Although it is difficult to find examples of the HBV model applications in Turkey, of course there is carried out successful studies. Sürer (2015), applied the HBV model to upper Euphrates basin, in Turkey. The model was calibrated by using the Multi-Objective Shuffled Complex Evolution (MOSCEM) algorithm. Thus, individual sensitivity of the parameters is analysed.

As far as we know, a conceptual model has not been applied to this region before. The purpose of this study is simulate the hydrological processes of the region well enough by using conceptual daily rainfall-runoff model. So, the model results, including water budget, can be evaluated and water management strategies can be developed in the headwater of the Çarşamba Basin, located on Konya Closed Basin, Turkey.

2. MATERIAL AND METHOD

2.1. Study Area and Data

To calculate the water budget by model-dependent values, the HBV model was implemented to the Çarşamba Basin, Turkey. The location map of the region is presented in Figure 1.

The headwater of the Çarşamba Basin, located on Konya Closed Basin, has 153.87 km^2 drainage areas. The elevation of the highest point of the study area is 2400 m while the lowest point is 1100 m. The region is located between 37°14′ to 37°01′ north latitude and 31°58′ to 32°11′ east longitude. Mean annual precipitation is 785 mm, mean maximum and mean minimum temperatures are 17.5 °C and 6.1 °C, respectively. According to long-term annual measurements, the highest observed flow was 6.329 m^3/s and the lowest observed flow was 0.385 m^3/s (Koycegiz and Buyukyildiz, 2019).

The standard HBV model requires precipitation potential evapotranspiration and temperature data. In this study, since the snow routine was ignored, no temperature data was needed. Potential evapotranspiration estimated by using Penman-Monteith equation. Study area is in a data-scarcity region, the meteorological station in the region does not have sufficient period observations hence we used the data of Seydisehir and Hadim meteorological stations nearby. The data of these stations were transformed into meteorological data of the region using Thiessen method. In this study, the HBV model, established to the region, was simulated from 2006 to 2015.

Figure 1. Study area map

2.2. The Hydrologiska Byråns Vattenbalansavdelning (HBV) Model

The HBV, daily rainfall-runoff conceptual model, was first time applied successful in the spring of 1972 (Bergström, 1972).The general water balance can be conceptualized as in Equation (1).

$$P - E - Q = \frac{d}{dt}[SP + SM + UZ + LZ + Lakes] \qquad (1)$$

Where
P= Precipitation
E= Evapotranspiration
Q= Runoff
SP= Snow
SM= Soil moisture
UZ= Upper groundwater
LZ= Lower groundwater
Lakes= Lake volume

Model can generate the runoff based on daily precipitation, evapotranspiration and temperature data. Different countries have developed and used the model according to their climatic conditions. Therefore, there are many versions of the model. The model is used for calculating water budget, flood forecasting, analysing level of drought and evaluate water resources.

The model consists of phases that snow routine, interception routine, soil routine and response routine. Every routine uses mathematical equations that contain conceptual parameters. (Bergström, 1992)

The snow routine of The HBV model, based on temperature, has a snow cover capable of holding water. This snow cover delays runoff. Interception routine is a process ofwater retention temporarily. Gradually, this water held in the recesses releases. Soil routinesymbolizes water processes in the soil. Soil has a limited water held capacity.Runoff response routine represents groundwater flows. The HBV model structure is exhibited schematically in Figure 2.

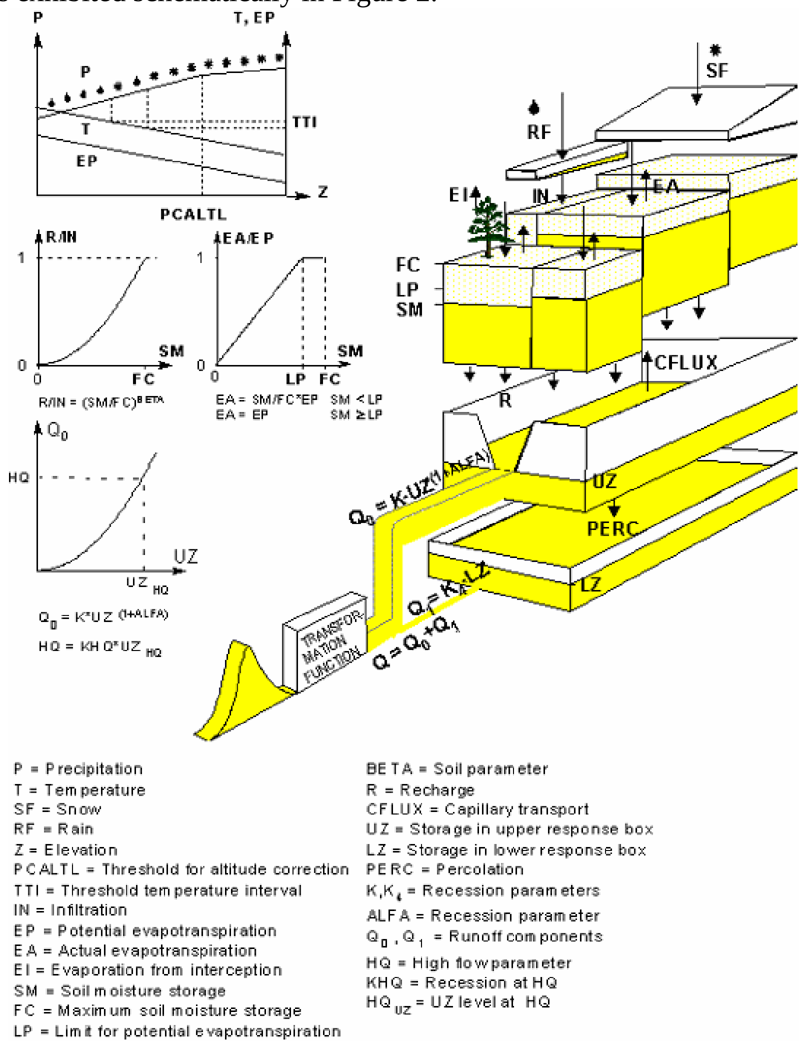

Figure 2. Schematic structure of the HBV-96 model (Lindström et al., 1997)

2.3. Calibration and Performance Metrics

The HBV model has conceptual parameters and there are boundary conditions which are recommended to keep these parameters between that values. In this study, model was calibrated using the Generalized Reduced Gradient (GRG). GRG, an algorithm for solving problems and calibrating models, allows nonlinear limitations and optional boundaries on the variables.

Nash-Sutcliffe Efficiency Coefficient (NSE), determination coefficient (R^2), percent bias (PBIAS) and Kling-Gupta efficiency (KGE) were used to evaluate model performance during the calibration stage (Nash and Sutcliffe, 1970; Gupta et al., 1999; Legates and McCabe, 1999; Halefom et al., 2018). These are as follows:

$$NSE = 1 - \frac{\sum(OBSi - SIMi)^2}{\sum(OBSi - mOBS)^2} \quad (2)$$

$$R^2 = \left(\frac{\sum(OBSi - mOBS)x\,(SIMi - mSIM)}{\sqrt{\sum(OBSi - mOBS)^2}\sqrt{\sum(SIMi - mSIM)^2}}\right)^2 \quad (3)$$

$$PBIAS(\%) = 100 \text{ x } \frac{\sum(SIMi - OBSi)}{\sum OBSi} \quad (4)$$

$$KGE = 1 - \sqrt{(CC - 1)^2 + (\frac{OBSd}{SIMd})^2 + (\frac{mOBS}{mSIM})^2} \quad (5)$$

Where
OBS: Observed data
SIM: Simulated data
mOBS: Mean observed data
mSIM: Mean simulated data
OBSd: Standard deviation of observed data
SIMd: Standard deviation of simulated data
CC:Pearson coefficient value

2.4. Water Budget

Water budget is an analysis of relationship between inflow and outflow in a region. The water budget gives us the amount of water held in the area. This knowledge provides us to develop water management strategies and brings the predictions of future evapotranspiration and drought closer to accuracy. Water budget equation is as follows:

$$\Delta S = P - AEP - Qdr - R - C \quad (6)$$

Where
P: Precipitation
AEP: Actual evapotranspiration
Qdr: Direct flow
R: Recharge flow
C: Capillarity

3. RESEARCH FINDINGS

In this study, GRG algorithm was used to calibrate 8 parameters and additionally we examined the seasonal behaviour of the model. The results obtained from the calibration are given in Table 1.The NSE closest to 1 was obtained for the parameter values in the table.

Table 1. The parameters and values used in the calibration.

Parameters	Parameter Definations	Unit	Values
FC	Maximum soil moisture storage	mm	141.53
$\boldsymbol{\beta}$	Soil parameter	-	0.207225
LP	Limit for potential evapotranspiration	-	0.1
$\boldsymbol{\alpha}$	Recession parameter	-	0.1
Kf	Recession parameter	1/d	0.0076966
Ks	Recession parameter	1/d	0.0005
PERC	Percolation	mm/d	0.586523
CFLUX	Capillary flux rate	mm/d	8.65E-07

Performance values based on the results obtained from the calibration performed with the GRG algorithm are given in Table 2. The HBV model showed an adequate performance. According to Table 2, the results obtained for R^2 and NSE are satisfactory while PBIAS is good. For the KGE, it can be interpreted as sufficient level (Moriasi et al., 2007).

Table 2. The results of the calibration

Performance Metrics	Calibration Stage
NSE	0.501
R^2	0.518
PBIAS	11.454
KGE	0.676

The precipitation data and time series of comparison of simulated and observed data are represented in Figure 3. The scatter plot of the model is given in Figure 4.

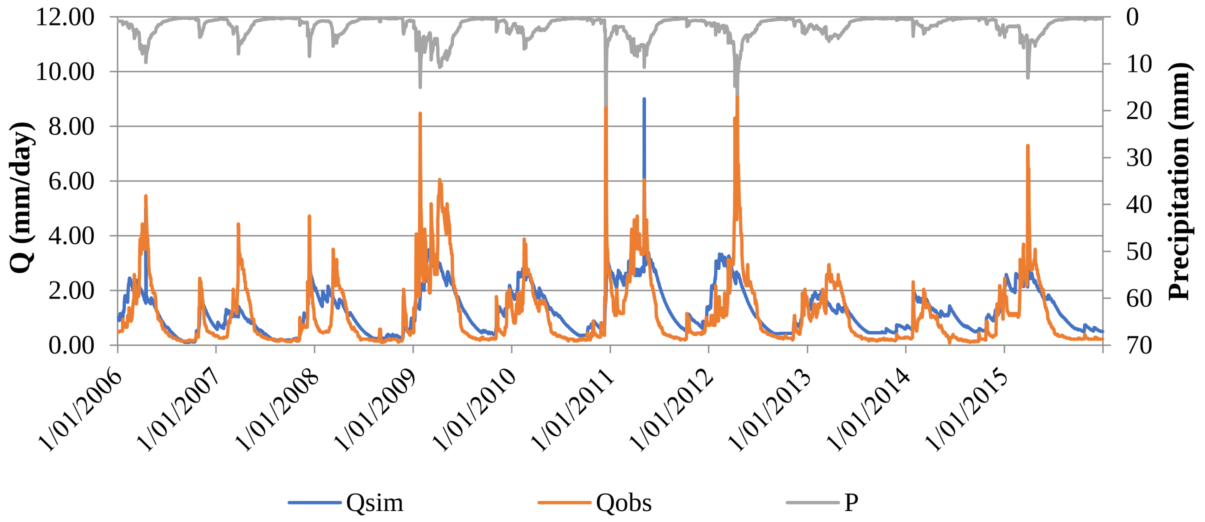

Figure 3. Time series graph for calibration stage

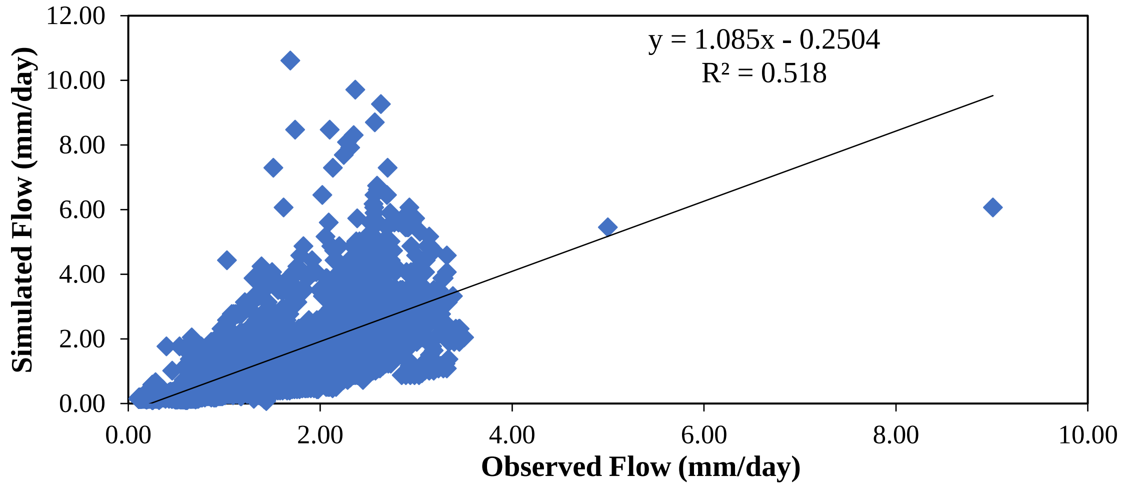

Figure 4. Scatter plot for calibration stage

The model was more successful at the low flow values than peaks. Sudden convective rainfall due to the geographic location of the region may mislead the model.

This situation may also be related to meteorological and climatic conditions of the region. In winter, frost occurs and receives snowfall. As the summer comes, snow and frozen water which in the soil turns into water suddenly and this water passes into flow. Assessment of seasonal behaviour of the model shows us the same implication. In the summer, the model could not exhibit results as good as the other seasons. That because the snow is melting and the flow reaches its peak abruptly.
In this study, the water budget was calculated by the model-dependent values annually. Water budget results by years are given in Figure5. According to Figure5, similar amounts of water accumulate in the watershed every year. But especially, in 2008 and 2013, amount of water held is lower than the other years. The reason of this would be temperature changes in the region. Temperature affects evapotranspiration i.e. the amount of water retained.

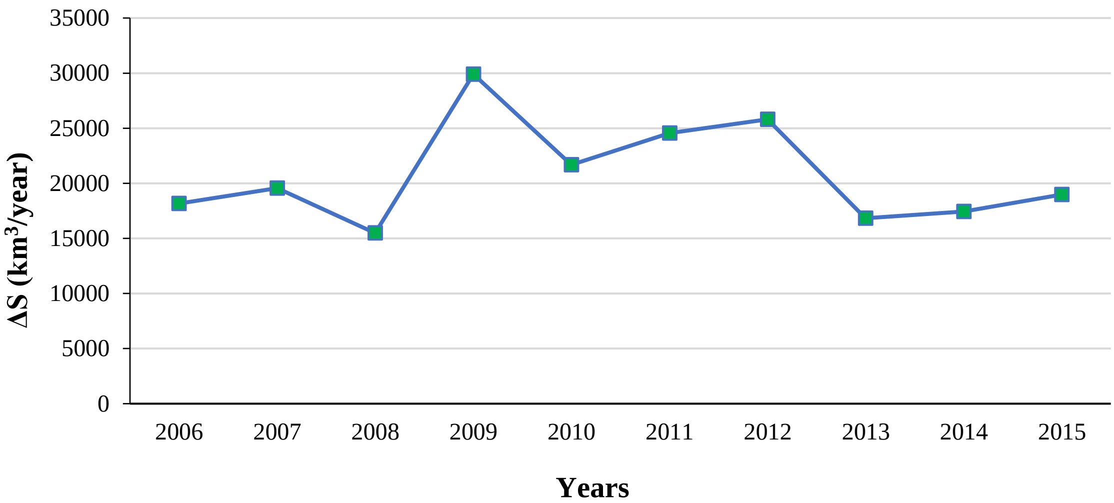

Figure 5. The water budget results

Also, it should be noted that the region has snowfall. Rainfall in the region may remain as snow cover. On the other hand, the precipitation waters may be removed from the area by undetected ground waters. The presence of these conditions should be investigated.

4. CONCLUSION

In this study, we established the HBV, daily rainfall-runoff conceptual model, to data-scarcity region, headwater of Çarşamba Basin. We evaluated the model results during calibrating stage. Additionally, seasonal behaviour of the model was examined.
The HBV model performed more successfully at low flows than high flows. Taken data from a meteorological station within the region will be played an important role in the development of the results. Unfortunately, there is no station in the catchment. In addition, the model's performance can be improved by adding snow routines to the model and examining groundwater resources in the region.
The water budget assessed shows that a similar amount of water is kept in the basin each year. However, it should be kept in mind that the water budget is calculated based on the model data. It is useful to examine how much of the water accumulated in the region remains as snow cover. Also, there is benefit in determining the water consumption of the people of the region.

REFERENCES

Bergström, S., 1992, The HBV Model -its structure and applications, *SMHI Reports Hydrology*, No: 4.
Brink, F.van den, 2009, Modelling the discharge of the Cidanau River in West Java with the HBV model.
Bruland, O. and Killingtveit, Å., 2002, Application of the HBV-Model in arctic catchments – some results from Svalbard, *Conference: XXII Nordic Hydrological Conference*, Norway.
Gupta, H.V., Sorooshian, S. and Yapo, P.O., 1999, Status of automatic calibration for hydrologic models: Comparison with multilevel expert calibration, *Journal of Hydrologic Engineering, 4, 135-143.*

Halefom, A., Sisay, E., Worku, T., Khare, D., Dananto, M. and Narayanan, K.,2018, Precipitation and Runoff Modelling in Megech Watershed,Tana Basin, Amhara Region of Ethiopia, *American Journal of Environmental Engineering,* 8(3), 45-53.

Jia, Q.Y., and Sun, F.H., 2012, Modeling and forecasting process using the HBV model inLiao river delta, *Procedia Environmental Sciences,* 13, 122-128.

Koycegiz, C. and Buyukyildiz, M., 2019, Calibration of SWAT and Two Data-Driven Models for a Data-Scarce Mountainous Headwater in Semi-Arid Konya Closed Basin, *Water*, 11(1), 147.

Legates D.R., McCabe, G.J. 1999, Evaluating the use of "goodness-of-fit" measures in hydrologic and hydroclimatic model validation, *Water Resources Research*, 35 (1), 233-241.

Lindström, G., Johansson, B., Persson, M., Gardelin, M. and Bergström, S., 1997, Development and test of the distributed HBV-96 hydrological model, *Journal of Hydrology*, 201, 272-288.

Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Bingner, R.L., Harmel, R.D. and Veith, T.L., 2007, Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations, *Transactions of American Society of Agricultural and Biological Engineers, 50(3), 885-900.*

Nash, J.E. and Sutcliffe, J.V., 1970, River Flow Forecasting through Conceptual Models, *Journal of Hydrology, 10, 282-290.*

Normand, S., Konz, M. and Merz, J. 2010, An application of the HBV model to the Tamor Basinin Eastern Nepal, *Journal of Hydrology and Meteorology,* 7(1), 49-58.

Singh, V.P., 1988, Hydrologic Systems, Volume 1: Rainfall-runoff modelling, *Prentice Hall*, New Jersey.

Sürer, S., 2015, The use of multimetric framework in calibrating the HBV model, PhD Thesis, *The Middle East Technical University*, Ankara, Turkey.

Tecklenburg, C. et al., 2012, Modeling of water balance response to an extreme future scenario inthe Otztal catchment, Austria, *Advances in Geosciences,* 32, 63-68.