USE OF GIS AND UA TECHNIQUES IN HYDROLOGICAL MODELLING

Jabiyeva T.
Azerbaijan Architecture and Construction University, Department of Geomatics
Baku, Azerbaijan
ORCID: 0009-0006-5423-1092
Gudratzade Sh.
Azerbaijan Architecture and Construction University, Department of Geomatics
Baku, Azerbaijan
ORCID: 0000-0002-7631-4650
https://doi.org/10.5281/zenodo.15220803

Abstract

Providing water management; can be achieved sustainably on a basin basis by evaluating hydrological, ecological and economic aspects together and in harmony. Hydrological modeling studies, which are the basis of all components within the framework of water management practices, are an indispensable part of decision support systems. Hydrological models, which provide scientific support to decision makers in decision-making processes, play an important role in taking measures to protect and improve current situations of investments, solutions to problems through scenario-based estimations.

The aim of this study is to compare the soil moisture and snow-covered area data, which are the outputs of the hydrological modeling study conducted with the HBV model in the Upper Basin of Lake Manyas, one of the important wetlands in terms of ecosystem in Turkey, with remote sensing methods. Satellite images produced by the European Center for Medium-Range Weather Forecasts (ECMWF) for soil moisture and the National Oceanic and Atmospheric Administration (NOAA) for snow-covered areas were used to perform verification analyses covering the water years 2012-2015 in the study basin. According to the results, there is a successful agreement between the hydrological model outputs and satellite data, which indicates that reliable model parameters were selected.

Keywords: hydrological modeling, snow cover area, soil moisture, remote sensing

INTRODUCTION

Nowadays, as the importance of water increases, revealing the distribution of hydrological components, solving a specific problem regarding the amount of water within a study area or determining the situation can be done through hydrological modeling studies, which are increasing day by day.

In the last quarter of the twentieth century, water management at the basin scale has come to the forefront, and the current situation is being presented with a holistic approach and solutions to problems are being sought. The methods that have been developed since the 1900s are currently used as both packaged product software and open source coded hydrological models. The complexity of hydrological systems, the lack of understanding in detail and system behavior and reactions can be resolved through models.

There are two main purposes of basin-based hydrological modeling. The first is to better understand the functioning of the system and the effects of changes in the system. The second is to produce time series for prediction and design. However, the purposes of hydrological modeling in practice can be detailed as follows in the studies carried out on water management [2].

- Forecasting the data needed for the planning, operation and development of dams and facilities built to increase the usability of water resources
- Producing hydrological data in basins where measurement data is not available
- Determining the effects of changes such as land use change and climate change on the basin
- Calculating water budgets and managing and estimating the amount in order to ensure water allocation on a sectoral basis
- Determining and estimating the flows to be used in mass balance studies for the evaluation of water quality in surface waters
- Hydrological modeling studies are carried out for purposes such as estimating hydrological events such as drought and flood, which are considered natural disasters.

In this context, the basin extraction and spatial analyses that form the basis of the study were carried out on the GIS platform and the soil moisture and snow-covered area data obtained from the hydrological modeling study carried out in the Upper Basin of Manyas Lake between 2012 and 2015 were compared with remote sensing methods. This study reveals the importance of remote sensing data regarding the verification and reliability of hydrological models.

MODEL STUDIES

Hydrological Modeling studies have been carried out in many areas from the beginning of the twentieth century to the present and have taken their place in the literature.

The basin of the Sava River, one of the largest rivers in Slovenia, was modeled by Primožič et al. [4] with the HBV model of Swedish origin. The Sava River Basin, which has a basin area of 10,700 km2, is also an important tributary of the Danube River. The model was structured according to daily calibration by creating 26 sub-basins. The model, which was run between 1990-2006, was calibrated between 1990-1999. The years 2000-2006 were used for validation purposes. An average model efficiency of 0.86-0.90 was obtained.

Normand and his colleagues ran the HBV model in the Tamor basin in Eastern Nepal between 1987 and 1996 and calibrated it with the GAP (genetic algorithm package) optimization method. The study showed that low flows were well simulated, with a model efficiency of 69%. In capturing peak flows, the model efficiency dropped to 62%, and there was less agreement than in low flows [3].

Study Area

In this study, the Manyas Dam Lake Upper Basin was selected as a basin where there is no or very little anthropogenic impact in order to carry out the hydrological modeling application in a healthy and accurate approach.

The Upper Basin of Manyas Lake, determined as the study area, covers the area formed by the streams draining into Manyas Lake, which is administratively located within the borders of Bandırma and Manyas in Balıkesir province, and the geographical coordinates are between 40°10´ North and 28°00´ East.

HBV Model

The HBV model used in this study was first used in the 1970s in the "Hydrologiska Byrans Vattenavdelning" unit of the Swedish Meteorological and Hydrological Institute (SMHI) for the purpose of modeling the flow in the basin. Over the years, the HBV model has been developed by the Swedish Meteorological and Hydrological Institute (SMHI) and is widely used for flow simulation purposes. However, HBV and its modified versions are implemented in approximately 45 countries [1].

The working flow diagram in the HBV model is shown in the flow diagram in Figure 1 as snow module, soil module, groundwater module and current module, respectively.

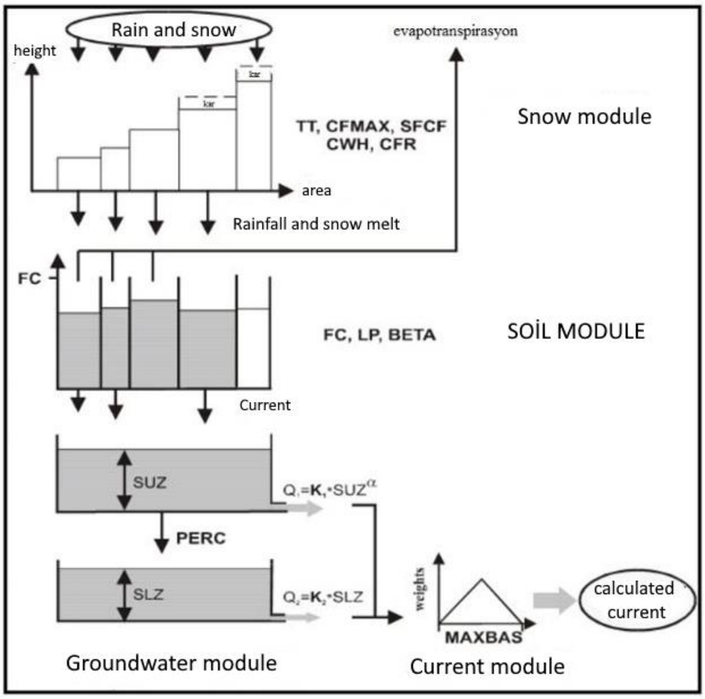


Figure 1. HBV flow diagram.

Model Inputs

The HBV model requires historical data including precipitation [mm/Δt], temperature [ºC] and flow values [mmΔt], and long-term monthly average values for evaporation data [mm/Δt]. Daily data was used in this study, which was carried out with the model that accepts data at time steps such as different time series (hourly, daily, seasonal).

The institutions responsible for hydrometeorological data in Turkey are the General Directorate of State Hydraulic Works (DSI) and the General Directorate of Meteorology (MGM). The necessary data for this study were obtained from the institutions in question. Considering the location of the Upper Basin of Lake Manyas, which is the study area, 9 observation stations from which data could be obtained were identified in the MGM databases. Daily flow data collected at the Flow Observation Stations (FOB) operated by DSI were obtained from 3 stations by investigating the FOBs located within the basin that were currently open and had data (Figure 2).

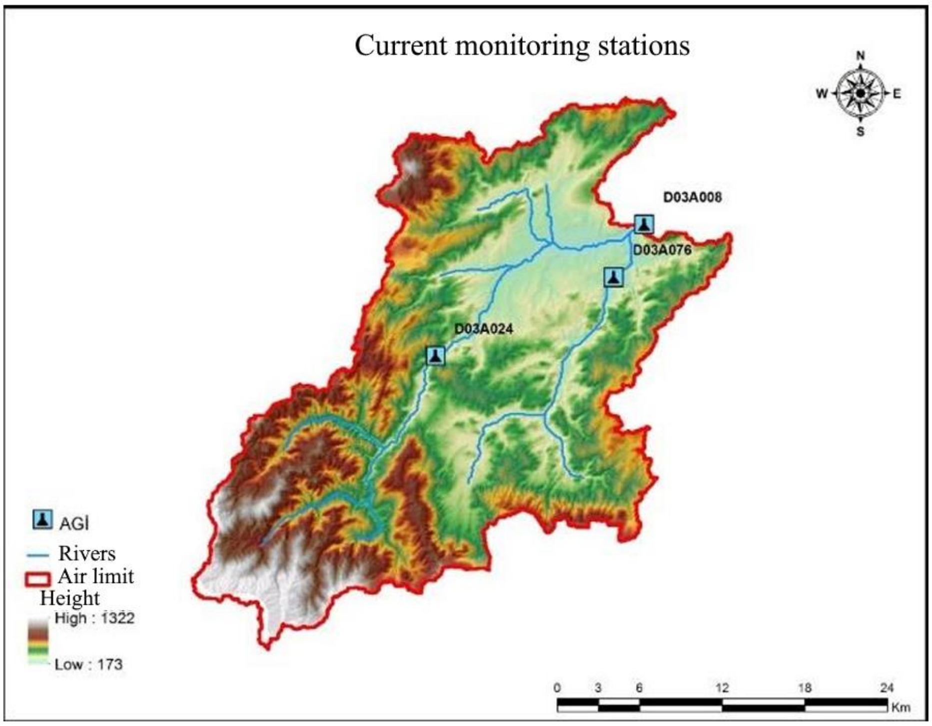


Figure 2. Hydrometeorological station in the study area

Within the scope of this study, the Manyas Lake Upper Basin Contour Map was created and the data belonging to the area was calculated in the GIS environment and the model was used as a semi-distributed model. As a result of the examination of the obtained data on the scale of the impact on the basin, the meteorological stations determined in figure 2 were used, which were accepted to best represent the basin: Bergama in the south, Burhaniye in the west and Balıkesir Airport stations in the east.

Calibration and Validation

Calibration refers to the optimization of the fit by converting inputs into outputs using mathematical equations and making changes to the parameters called model parameters that constitute the mathematical equations of the input-output fit. Calibration of a hydrological model is usually carried out by trial and error method [1].

Validation is the process of applying parameters whose suitability has been accepted to the outputs obtained by using inputs in the time interval outside the calibration. Validation is, in a sense, the verification of the parameters, and therefore the model.

Different criteria are used to evaluate the compatibility of observed and modeled values in order to evaluate calibration studies. For Hydrological Models, this criterion is usually the Nash-Sutcliffe (NSE) model efficiency criterion. Model efficiencies also mean the objective function for hydrological models. The objective function defined as Reff can be calculated over logarithmic, maximum, minimum and weighted values.

$$Reff = 1 - \frac{\sum(Qsim(t) - Qobs(t))^2}{\sum(Qobs(t) - Qobs(t))^2} \quad (1)$$

Within the scope of this study, the model was calibrated using 5 different objective functions (Reff, LogReff, PeakReff, 0.5Reff + 0.5 PeakReff and 0.5Reff + 0.5 LogReff) in the Manyas Lake Upper Basin.

In the application, the hydrological years 2003-2015 were taken as basis and the calibration period was chosen between 2007-2011 in order to include different hydrological periods (dry, rainy, normal) and to be the period that gives the most efficient results together with the preliminary study. Validation of the model was carried out between 2003-2006 and 2012-2015.

The optimum objective function obtained as a result of this study and the efficiency values according to these other objective functions are given in Table 1, and the hydrograph comparison showing the validation results between 2012-2015 is given in Figure 3.

Table 1.

Results of the Optimum Objective Function.

Objective function	Year	Weighted R_{eff}	R^2	R_{eff}	R_{eff} Peak	Log R_{eff}
$0.5R_{eff}$ + $0.5\ LogR_{eff}$	2003-2006 (val)	0.68	0.63	0.62	0.31	0.73
	2007-2011 (kal)	0.66	0.70	0.60	0.55	0.72
	2012-2015 (val)	0.57	0.67	0.51	0.32	0.76

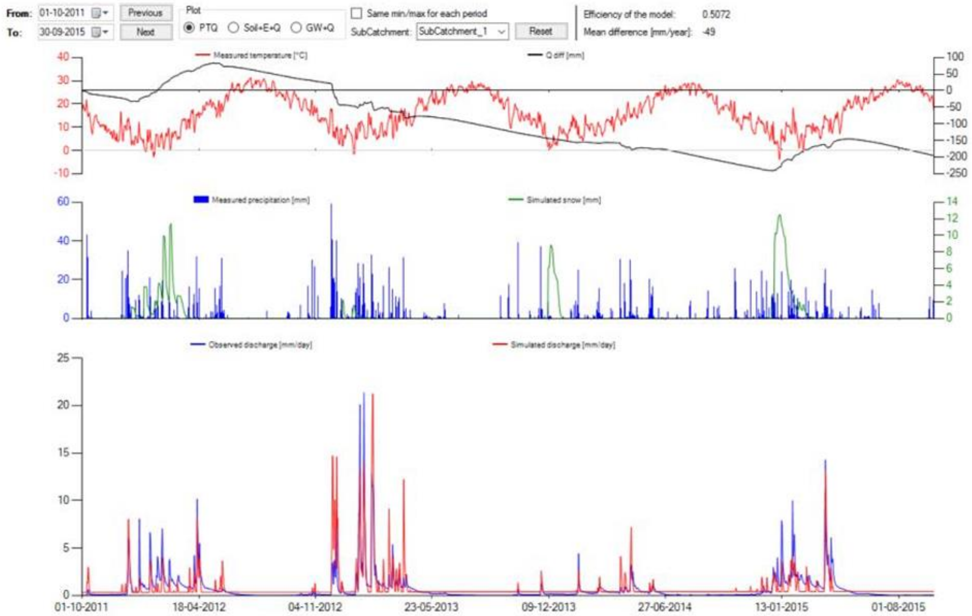


Figure 3. Validation results for the years 2012-2015.

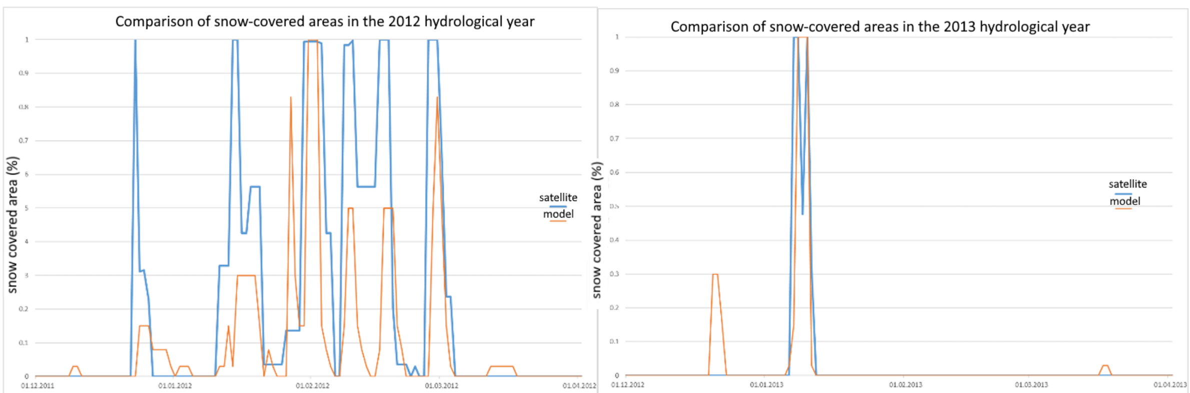
In addition to verifying the parameters obtained as a result of calibration, the model results produced between the periods of 2012-2015 within the scope of this study were verified with soil moisture and snow-covered area data obtained using remote sensing methods.

Remote Sensing Data

The processing of satellite images and their use in many studies around the world has become quite widespread today. In addition, important weather centers and organizations provide satellite imagery data within the scope of collecting data on water resources and components. In this context, the snow-covered area data in this study was obtained from the National Oceanic and Atmospheric Administration (NOAA), an institution of the United States of America, for the purpose of researching weather and sea events on Earth. The soil moisture data for the 2013-2015 hydrological years was obtained from the European Center for Medium-Range Weather Forecasts (ECMWF) satellite images and used as layers of 4 different heights.

Results. In this study, soil moisture and snow-covered area data obtained from the hydrological modeling application carried out in the Manyas Lake Upper Basin were compared with the data obtained from satellite images using remote sensing methods.

Within the scope of the evaluation made by taking into account the number of snow-covered days between the model and observation results, the comparisons of snow-covered areas in the winter months of 2012-2015 hydrological years are shown in Figure 4.



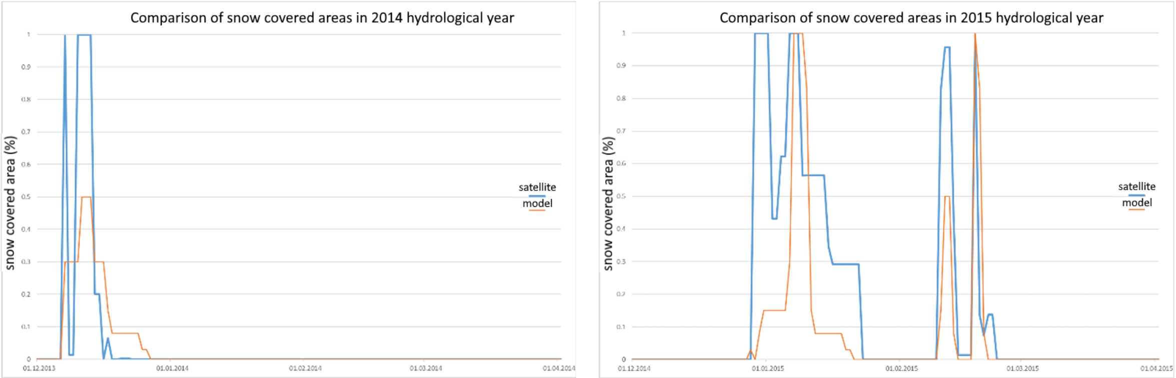


Figure 4. Comparison of snow-covered area between 2012 and 2015 water years.

The model results and observation values agree in terms of order and general tendency. However, the percentage relationship between the number of days covered with snow in the observation and model results was found to be 93%, 98%, 98%, 97% for the years 2012, 2013, 2014, and 2015, respectively, considering the months of 01 December-01 June (184 days) when snow is likely to be found. These values show that the snow module of the model works with high accuracy.

Model and satellite image comparison results for soil moisture data for the 2013-2015 hydrological years are given in Figure 5.

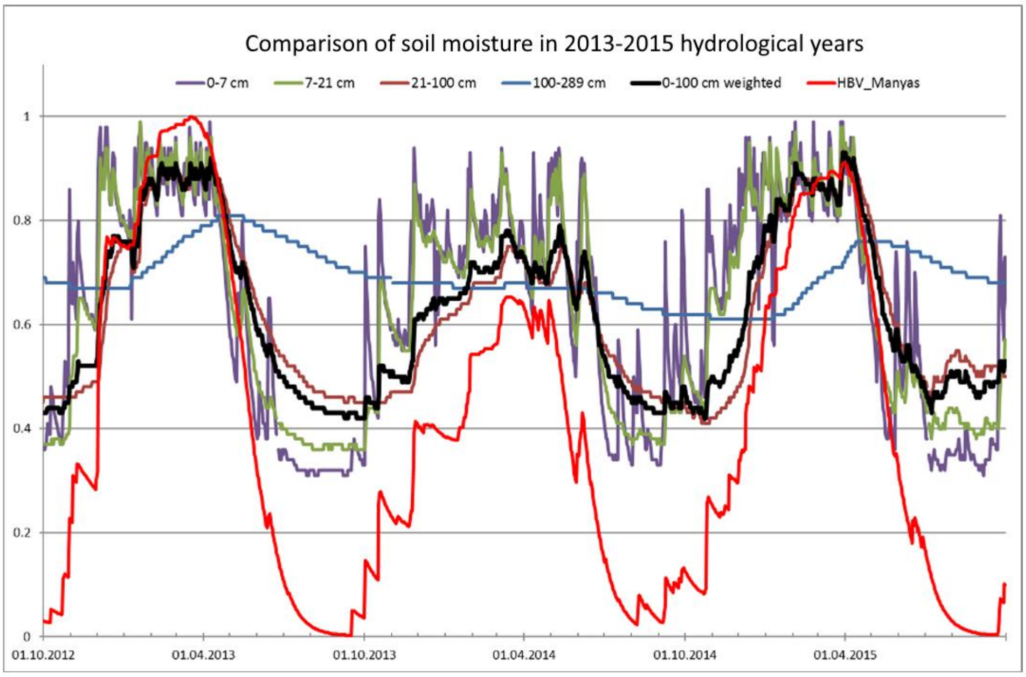


Figure 5. 2013-2015 water year soil moisture comparison.

As can be seen from the graph given in Figure 5, the average soil moisture observed up to one meter and the model results are compatible with each other in terms of order and trend, especially in winter and spring. It shows that in summer, the soil module brings the soil moisture values closer to 0. It is thought that this situation is caused by the parameters of the model affecting the soil moisture, and a separate study should be conducted to observe its effects. However, the fact that the soil moisture pulses have a common trend shows that the soil module works correctly. The observation values for the study area show that the soil moisture does not fall below 40%. This situation reveals the idea that the model should limit the soil moisture with a threshold parameter.

References:

1. Bergström, S. ve Lindström, G. (2015). Interpretation of runoff processes in hydrological modelling-experience from the HBV approach. Hydrological Processes, 29 (16), 3535-3545.

2. Chong-yu, X. (2006). Chapter 1 Modellıng In Hydrology, Hydrologıc Models (s. 1-1, 1-11). UPPSALA: Uppsala University Department of Earth Sciences Air and Water Sciences.

3. Normand, S., Konz, M., ve Merz, J. (2010). An application of the HBV model to the Tamor Basin in Eastern Nepal. Journal of Hydrology and Meteorology, 49-58.

4. Primožič, M., Kobold, M., ve Brilly, M. (2008). The Implementatıon Of The Hbv Model On The Sava Rıver Basın. IOP Conference Series: Earth and environmental science.