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Evaluation of Probabilistic Streamflow Forecasts Based on EPS for a Mountainous Basin in Turkey

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Abstract

When designing water structures or managing a watershed it is a challenging task to determine the response of a basin to storm and/or snowmelt. In this study, the Upper Euphrates Basin (10,275 km^2 area and elevation range of 1125-3500 m) located at the headwater of Euphrates River, one of Turkey's most important rivers, is selected as the application area. In this region, snowmelt runoff constitutes approximately 2/3 in volume of the total yearly runoff, therefore, runoff modeling and forecasting during spring and early summer is important in terms of energy and water resources management. The aim of the study is to make a forward-oriented, medium-range flow forecasting using Ensemble Prediction System (EPS) which is a pioneer study for Turkey. Conceptual hydrological model HBV, which has a common usage in the literature, is chosen to predict streamflows. According to the results, Nash-Sutcliffe model efficiencies are 0.85 for calibration (2001-2008) and 0.71 for validation (2009-2014) respectively. After calibrating/validating the hydrologic model, EPS data including 51 different combinations produced by ECMWF is used as probability based weather forecasts. Melting period during March-June of 2011 is chosen as the forecast period. The probabilistic skill of EPS based hydrological model results are analyzed to verify the ensemble forecasts.

Keywords:Ensemble Prediction System;HBV;Probabilistic Streamflow Forecasting, Karasu Basin

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1. Introduction

Problems related with water are becoming more important with time because of the fact that while water resources stay the same on the Earth, the population of the world and contamination of water are increasing continuously besides climate change. In this sense operational hydrological forecasting systems play a key role for water resources management and preparedness against extreme events like flood and drought. Improvement in the quality of different meteorological forecast techniques led to decreasing uncertainty of streamflow predictions. Particularly, during the last two decades ensemble based streamflow forecasts are widely used as a way to consider uncertainty in hydrological forecasting [1]. Several ensemble based streamflow hydrological forecasting systems have been created and a growing number of studies have been published, pointing towards the advantages of adopting ensemble forecasts in contrast to deterministic forecasts in hydrology [2-7].

In many countries of the world, hydrological models of various complexity are used in operational runoff forecasting. These models, which are valuable tools for water management problems, need to be calibrated in order to provide model outputs that closely resemble the observed data. [8-10].

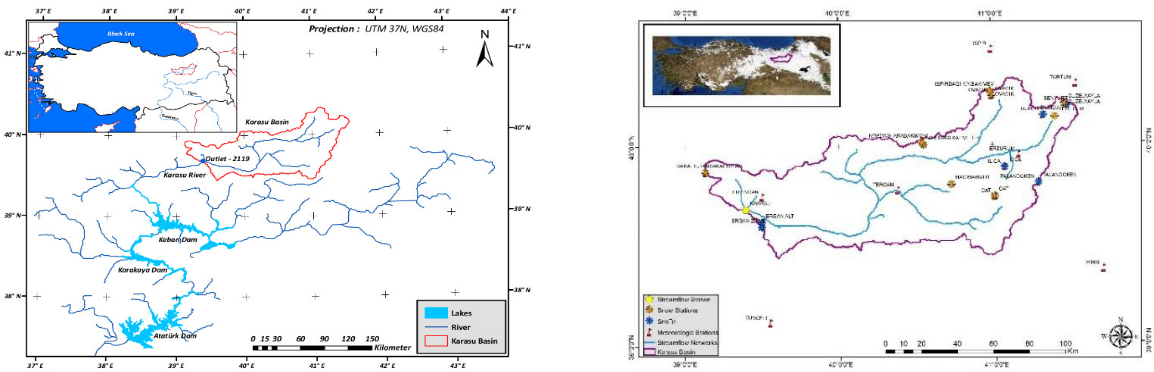
Snowmelt contributes significantly to runoff in the mountainous eastern part of Turkey during spring and early summer months. In order to monitor the changes, several Snow Telemetry (SnoTel) and Stream Gaging Stations are installed and hydrological modeling studies are applied in the region [11- 14]. Continuing the modeling phase, short term forecasting studies followed using deterministic numerical weather prediction data [15-18].

The main motivation of this study is to make a forward-oriented, medium-range flow forecasting using Ensemble Prediction System (EPS) for the first time in Turkey and evaluate the performance of the model and streamflow forecasts against runoff values.

2. Study Area and Data Sets

Karasu basin, located at the headwaters of Euphrates River in Turkey, is selected as the pilot area for this study. The basin has an area of 10,275 km^2 and elevation range of 1125-3500 m. The hypsometric mean is 1983 m and mean basin slope is 20%. Several meteorological and snow stations are located in and around Karasu basin (Figure 1). The area is mountainous and rugged with main land cover being pasture, grass and bare land. Discharge data for Karasu basin are collected by General Directorate of Turkish State Hydraulic Works (DSI) at the E21A019 stream gauging station.

Snowmelt has a considerable role on streamflow in mountainous regions. For Karasu basin, snowmelt runoff constitutes approximately 2/3 in volume of the total yearly runoff, during spring and early summer months. The general climatological conditions indicate a cold, dry and windy region.



a) b)

Figure 1. (a) Location of Karasu basin; (b) meteorological observation network

3. Methodology

3.1. Hydrological Modeling

To estimate the amount and timing of discharge is a very crucial part of water resources management in order to be used for generation hydropower, irrigation, flood mitigation and designing water structures. The selected model in this study is the well-known HBV model [9], developed during the early 1970s and since then different model versions of HBV have been applied in some 45 countries with different climate conditions ranging in size from small research basins to the continental scale.

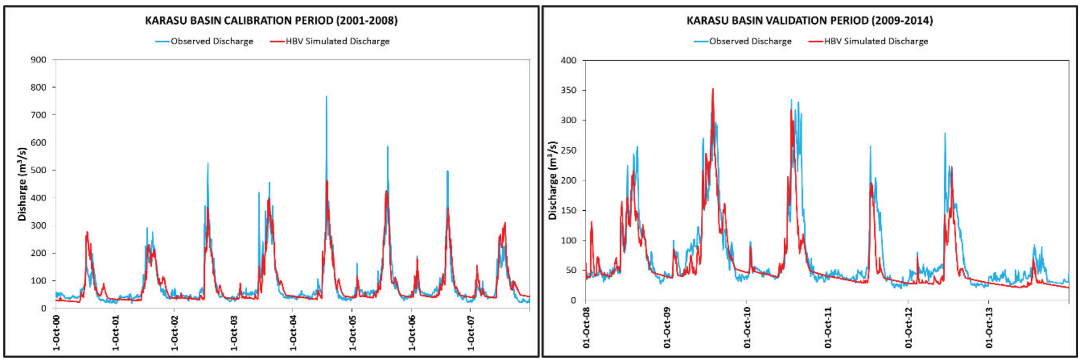
The HBV model, which simulates daily discharge using daily precipitation, temperature and monthly potential evaporation, is a semi-distributed conceptual precipitation-runoff model. The model has three components as Snow Routine, Soil Moisture Routine and Routing Routine. Several platforms and programs can be used for HBV model. The HBV model used in this study is run under Flood Early Warning System (FEWS) platform [19].

Being a conceptual model, free parameters of the HBV model need to be calibrated in order to provide model outputs that closely resemble the observed data. The goal of calibration is to reduce the uncertainty associated with the model parameters and depending on the techniques used to infer parameter estimates, calibration can be done either manually or in an automatic manner. In this sense, HBV model is automatically calibrated under FEWS platform in conjunction to Matlab [20].

2001-2008 and 2009-2014 periods are used for calibration and validation respectively. The results are evaluated with two different goodness-of-fit criterion, namely Pearson Correlation Coefficient (R^2) and Nash-Sutcliffe Model Efficiency (NSE) as shown in the equations below. Figure 2 depicts the model simulations for calibration and validation periods and Table 1 indicates the goodness-of-fit criterion results.

$$NSE = 1 - \frac{\sum[(Q_{obs} - Q_{sim})^2]}{\sum[\left(Q_{obs} - \overline{Q_{obs}}\right)^2]} \tag{1}$$

$$R^2 = \frac{\left[\sum\left(Q_{obs} - \overline{Q_{obs}}\right)\left(Q_{sim} - \overline{Q_{sim}}\right)\right]^2}{\sum(Q_{obs} - \overline{Q_{obs}})^2 \; \sum(Q_{sim} - \overline{Q_{sim}})^2} \tag{2}$$



a) b)

Figure 2. (a) 2001-2008 calibration period; (b) 2009-2014 validation period

Table 1. Calibration / Validation simulation goodness-of-fit criterion results

	R^2	NSE
Calibration (2001 – 2008)	0.86	0.85
Validation (2009 – 2014)	0.78	0.71

3.2. Numerical Weather Prediction Data

Meteorological forecasts play a key role in many aspects of the hydrometeorological forecasting process, especially for hydrological forecasting systems. In meteorology, forecasts are often described as short-range, medium-range or long-range with lead times of 0–3 days, 3–15 days and more than 15 days, respectively. Due to improvements in numerical weather modeling techniques and ground observation methods, the lead times at which forecasts show skill are constantly improving [21].

Ensemble forecast techniques have comprehensive solutions, which include uncertainty, instead of a single solution. In this study, the meteorological ensemble input data used is provided by European Centre for Medium-Range Weather Forecasts (ECMWF) [22]. These ensembles consist of one control forecast and 50 additional perturbed forecasts starting from slightly different initial conditions which are designed to represent uncertainties in the operational analysis. The spread of the control and 50 forecasts give an estimate of the uncertainty of the predictions on that particular day. Due to the non-linear and chaotic (complex) nature of atmospheric processes, small differences in initial conditions can lead to weather forecasts with biases. To enhance these biases, several bias correction methods have been developed recently, ranging from simple scaling to rather sophisticated approaches.

In this study, 2011 EPS data produced by ECMWF having 28 km/grid (T639/N320) resolution are utilized in forecasting. Total precipitation and temperature EPS data having a 6x10 pixel window is downloaded for Karasu Basin (Figure 3).

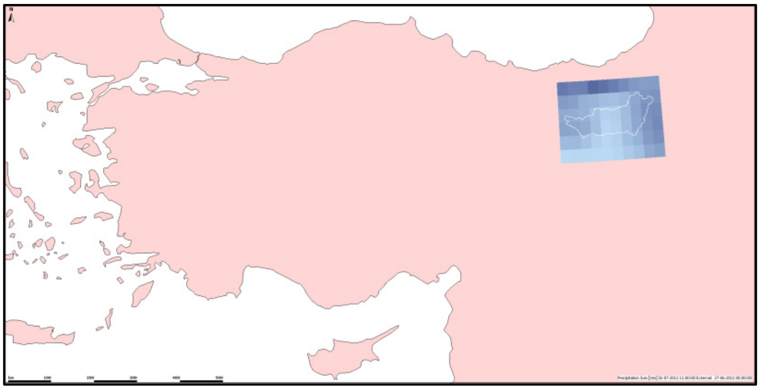


Figure 3. EPS data example for Karasu Basin

The EPS forecast data are compared with gridded ground observations in total basin terms using EVS program [23] with different statistical criteria, namely Mean Absolute Error and Root Mean Square Error. Linear scaling [24] bias correction method is applied both for temperature and precipitation data. Evaluation of performance analysis for EPS and ground data are shown in Figure 4.

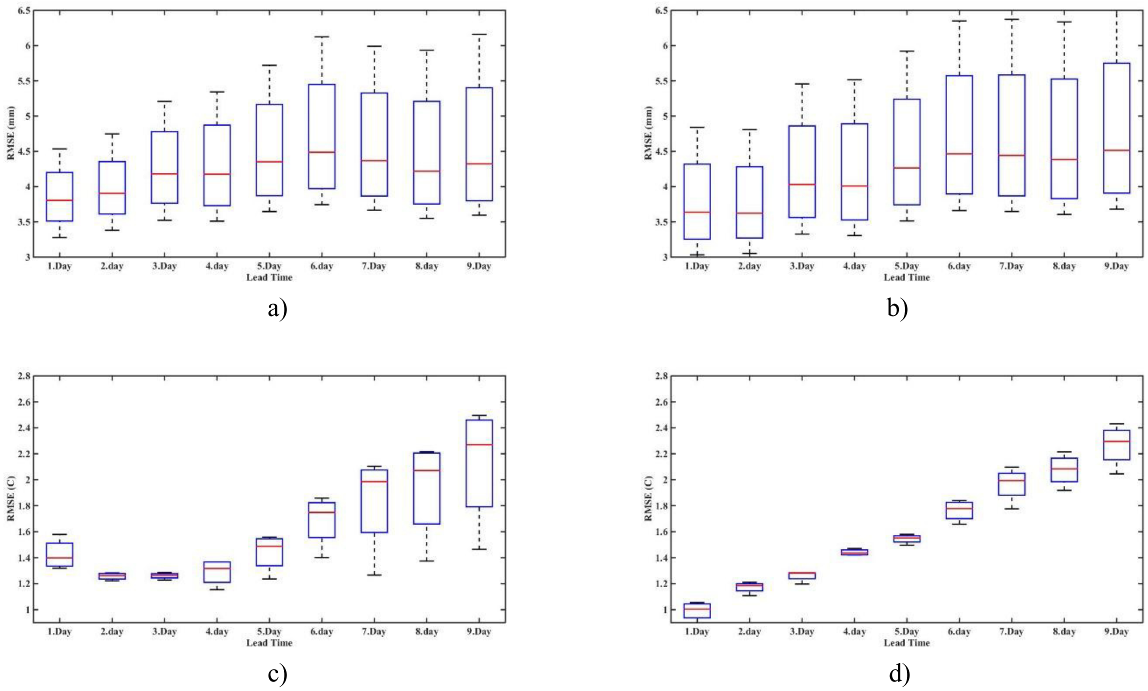


Figure 4. (a) Raw precipitation; (b) Corrected precipitation; (c) Raw temperature; (d) Corrected temperature

Due to the complex nature of atmospheric processes, weather forecasting is a difficult task in meteorology, especially for precipitation. A sufficient observation network is essential for a proper initial state of the atmospheric model. The performance evaluation of EPS data shows that precipitation has 3.8 mm and 4.4 mm, temperature has 1.4 ºC and 2.3 ºC errors as RMSE for first and last lead time, respectively.

4. Results

For the melting period (March-June) of 2011, bias corrected EPS forecasts up to 9 days are input to the HBV model to determine predicted discharge spread. Due to the demonstration difficulty of all forecasts 9 day time step spaghetti plots are shown in Figure 5. Performance evaluation of the hydrologic model daily forecasts is given in Figure 6. The streamflow forecasts based on EPS indicate that for the first and ninth days have approximately 12 m^3/s and 43 m^3/s errors as RMSE, respectively. Because of the increasing uncertainty in weather predictions, the spread is widening and streamflow performance is decreasing through the lead time.

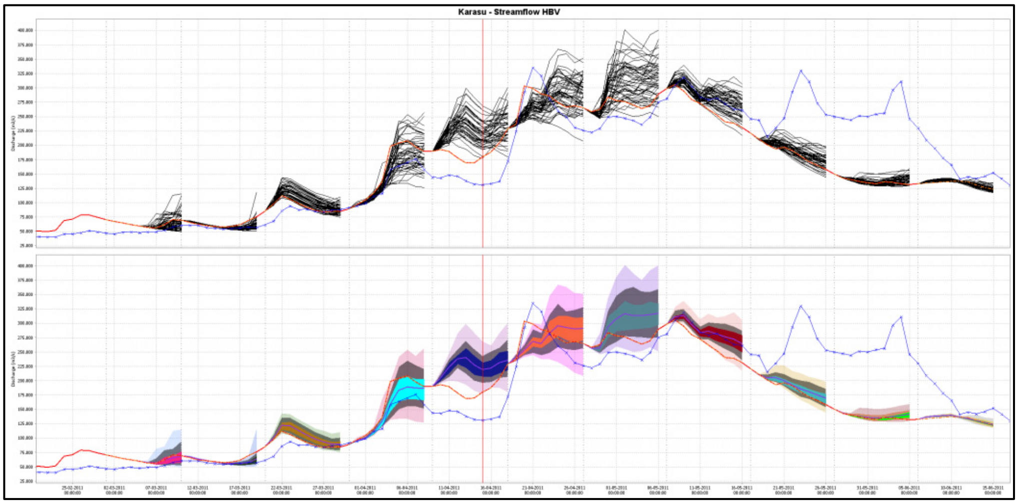


Figure 5. Spagetthi plot of 2011

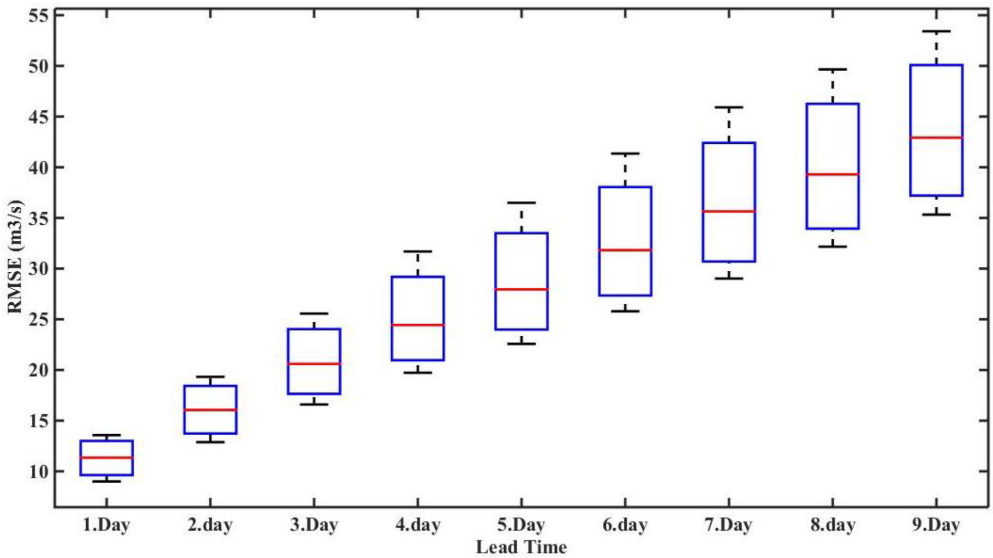


Figure 6. Forecast performance evaluation

5. Conclusion

In this study, EPS based medium-range probabilistic streamflow forecasts are implemented for the first time in Turkey at the headwaters of Euphrates River where large dams storing important resources for water and energy are located. The selected pilot basin (Karasu basin) is firstly calibrated and validated with a widely applied hydrologic model, HBV, using observed ground data. The results of the cal/val study show that model parameters are setup to a certain degree showing Nash-Sutcliffe model efficiencies as 0.85 for calibration (2001-2008) and 0.71 for validation (2009-2014) respectively. Since Karasu basin is largely fed by snowmelt; EPS forecasts are applied only for the melting period (March-June) of the selected 2011 year at a daily time step. In the first phase, EPS temperature and precipitation forecast data consistency is evaluated with ground observations up to 9 days lead time and bias correction is performed to resolve systematic errors. Then using corrected EPS data, calibrated HBV model is used to determine daily runoff forecasts up to 9 days ahead. The preliminary results of the probabilistic streamflow forecasts show a spreading and increasing error margin from 12 m^3/s for the first lead time to 43 m^3/s for the ninth day in terms of RMSE.

This first time application of an EPS based study for hydrologic forecasting in Turkey shows promising results. It is clear that hydrological forecast analyses are highly dependent on the meteorological prediction data as well as on model performance to some degree. On the other hand, the accuracy of the forecast results may be increased by valuable updating of the model initial states at the beginning of the forecast period in order to start the forecast values as close as possible to the measured values. Data assimilation could be one of the solutions to this problem which is planned as a future study for this work done.

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