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Prediction of Monthly Streamflow at Ungauged Basin Using Flow Duration Curves

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Abstract

In order to make a reliable analysis, the requirements of the data in terms of their qualification and quantity are crucial. In this study, monthly streamflow values for target (ungauged) station were predicted by using a spatial interpolation approach based on flow duration curves. The monthly streamflow data of 5 gauge stations in Middle Euphrates basin were examined. The data contains a period of 31 years without any missing data in the dataset. In the first step of the procedure, flow duration curves (FDCs) of the 5 stations are constructed by gauged records. Each of the 5 gauge stations is assumed to be ungauged in turn. The weight values were determined by correlation coefficients. A streamflow prediction on any month at the target station was made by identifying the percentage point position on the flow duration curve of the streamflows for the same month at the source stations and reading off the streamflow value for the equivalent percentage point from the target station's duration curve. Then, each predicted streamflow value of target station was multiplied by the source station's weight. This study showed that promising results were obtained with this method, according to measured by the statistics of prediction performance, namely the Nash-Sutcliffe efficiency (NSE). The method used in this study can also be applied to other meteorological and hydrological variables such as pressure, temperature, evaporation, precipitation, etc.

Keywords: Monthly streamflow prediction, Flow duration curves (FDCs), Ungauged, Middle Euphrates basin, Turkey

INTRODUCTION

In river type hydroelectric power plant projects, the streamflow values measured at the stations are of considerable utility in determining the installed power and selecting the right turbine. However, where there are no stations or where the records are short, there is a need for data estimation. Streamflows at an ungauged site of a stream are estimated using the data at another site on the same stream or in a neighboring stream. The simplest way of doing this is assuming that the flows are proportional to the drainage areas of sites [1]. Benson and Matalas (1967) conducted the earliest study of the estimation of monthly streamflow time series in ungauged areas [2]. Hirsch (1979) compared alternative approaches in predicting monthly streamflow time series [3]. Then, Fennessey (1994), Hughes and Smakhtin (1996) and Archfield et al. (2009, 2012) made daily streamflow estimation at ungauged basin using flow duration curves [4,5,6,7]. Chang Shu and Ouarda (2012) have made improvements in estimating daily streamflows with area ratio (AR) and flow duration curve (FDC) methods [8]. One of the recent studies on this area was made by Farmer and Vogel (2013). It is conducted at 1300 American Geological Survey Authority (USGS) station to estimate monthly streamflow series using various parameters [9]. The method used for estimating streamflow at ungauged site is associated with the use of commonly used FDC, which gives good results. In this study, it was intended to evaluate the monthly streamflow estimation by using a spatial interpolation approach based on flow duration curves.

DATA and METHODOLOGY

In this study, 5 streamflow gauge stations in Euphrates basin in Turkey, which is the biggest water potential selected as a case study. Each streamflow station contains a 31-year period. General information about the stations are given in Table 1. Selected stations on the map of the Middle Euphrates basin and changes of annual mean flow of these stations are shown in Figure 1 and Figure 2, respectively.

Table 1. General information on the gauging stations

Station Number	Observation year	Mean streamflow (m3/s)	Drainage Area (km2)	Basin Elevation (m)
2102	1970-2000	239,34	25515,6	859
2122		46,56	5882,4	1552
2157		24,49	2098,4	1250
2158		18,88	1577,6	1310
2164		32,81	2232,0	998

Figure 1. Geographical locations of the gauging stations

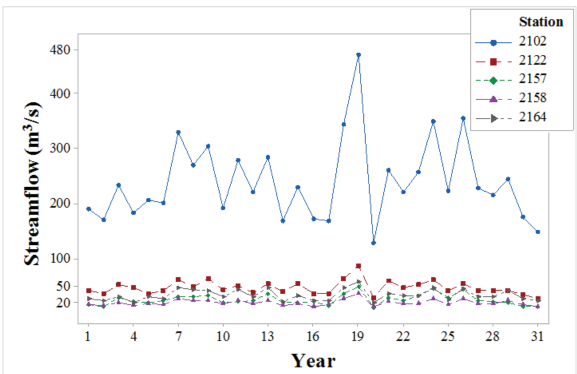

Figure 2. Changes of annual mean streamflows at the stations

In this study, similar to the approach proposed by Hughes and Smakhtin (1996), the spatial interpolation method based on flow duration curve (FDC) was used. FDC is a cumulative frequency curve that shows the percentage of time that flow in a stream is likely to equal or exceed some specified value of interest. Flow rate is usually referred to as "Q". The exceedence value as a subscript number. So, Q_{80} means the flow rate equalled or exceeded for 80% of the time.

In the first step of the procedure, flow duration curves (FDCs) of the 5 stations are constructed by gauged records. Each of the 5 gauge stations is assumed to be ungauged in turn. The selected 15 percentiles (high flow segment ($Q_{0.1}$, $Q_{0.5}$, Q_2, Q_5 and Q_{10}), medium flow segment (Q_{40}, Q_{45}, Q_{50}, Q_{55} and Q_{60}), and low flow segment (Q_{75}, Q_{80}, Q_{85}, Q_{90} and Q_{99}) of FDCs) were predicted as ungauged station. The weight values (between the target station and the source station) were determined by correlation coefficients. ri and rn are used to find weights. ri is the correlation coefficient, rn is the normalized correlation coefficient, and n is the number of stations. rn can be calculated from Equation (1).

$$r_n = \frac{r_i}{\sum_{i=1}^{n} r_i} \qquad i, n = 1, \ldots, 4 \qquad (1)$$

A streamflow prediction on any month at the target station was made by identifying the percentage point position on the flow duration curve of the streamflows for the same month at the source stations and reading off the streamflow value for the equivalent percentage point from the target station's duration curve. Then, each predicted streamflow value of target station was multiplied by the source station's weight.

Nash-Sutcliffe efficiency (NSE) is used for prediction performance evaluation. NSE which has been proposed by Nash and Sutcliffe and is used to measure the accuracy of many hydrological forecast, is a normalized statistic [10]. The Nash–Sutcliffe efficiency, NSE, is defined as

$$\text{NSE} = 1 - \frac{\sum_{i=1}^{N}\left(X_i^{obs} - X_i^{sim}\right)^2}{\sum_{i=1}^{N}\left(X_i^{obs} - X_i^{mean}\right)^2} \qquad (2)$$

where X_i^{obs} is the i-th observation for the monthly streamflows being evaluated, X_i^{sim} is the i-th simulated value for the monthly streamflows being evaluated, X_i^{mean} is the mean of observed data for the monthly streamflows being evaluated, and n is the total number of observations.

NSE ranges between $-\infty$ and 1 (1 inclusive), with NSE=1 being the optimal value. Values between 0 and 1 are generally viewed as acceptable levels of performance, whereas values <0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance.

APPLICATION and RESULTS

The selected stations are marked in Figure 3 on the Google Earth application. Table 2 shows the Pearson correlation coefficients of the stations in matrix format. The closest and most associated / correlated stations for each station in the application region are given in Table 3. The drainage area ratio method (DAR) was used to estimate the monthly streamflow values of each of the 5 stations to compare the estimated performances of the nearest and most relevant stations as the donor station. This method is based on the equilibrium of streamflows in the unit at any month in hydrologically similar basins. Each target station is estimated with the nearest and most associated donor stations. Table 4 gives the calculated NSE values. According this results, it may be possible to obtain better results by using the most correlated station as the source station for estimation of ungauged basins.

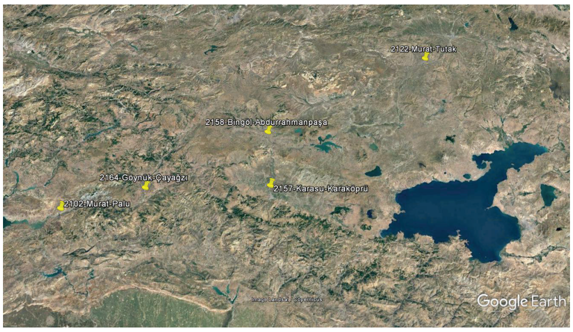

Figure 3. Streamflow gauging stations shown in Google Earth

Table 2. Correlation matrix (Pearson)

Station Number	2102	2122	2157	2158	2164
2102	1	0,948	0,929	0,962	0,972
2122	0,948	1	0,807	0,967	0,889
2157	0,929	0,807	1	0,823	0,935
2158	0,962	0,967	0,823	1	0,913
2164	0,972	0,889	0,935	0,913	1

Table 3. The nearest and the most correlated stations

Station Number	The nearest station	Euclidian distance	The most correlated station	Correlation coefficent
2102	2164	55	2164	0,972
2122	2158	120	2158	0,967
2157	2158	36	2164	0,935
2158	2157	36	2122	0,967
2164	2102	55	2102	0,972

Table 4. NSE values that are calculated from the nearest station and the most correlated station

Target station	The nearest station used as the source station	The most correlated station used as the source station
2102	0,126	0,126
2122	0,443	0,443
2157	0,652	0,728
2158	0,636	0,770
2164	0,719	0,719

Figure 4 gives the observed and estimated percentages for each station. It can be said that successful results are obtained according to the estimated and observed streamflow percentages.

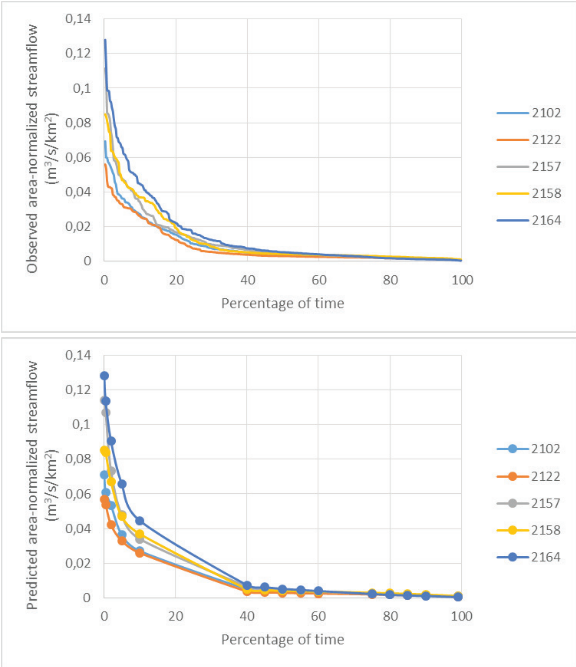

Figure 4. Comparison of observed and predicted FDCs

The method used in this study can also be applied to other meteorological and hydrological variables such as pressure, temperature, evaporation, precipitation, etc.

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REFERENCES

[1] Bayazit, M., 2001. Hydrology. Birsen Publishing House, Istanbul, 230 p.

[2] Benson, M.A., Matalas, N.C., 1967. Synthetic hydrology based on regional statistical parameters. Water Resour. Res. 3 (4), 931–935.

[3] Hirsch, R.M., 1979. An evaluation of some record reconstruction techniques. Water Resour. Res. 15 (6), 1781–1790.

[4] Fennessey, N.M., 1994. A hydro-climatological model of daily streamflow for the northeast United States. Ph.D. dissertation, Department of Civil and Environmental Engineering, Tufts University, Medford, MA.

[5] Hughes, D.A., Smakhtin, V., 1996. Daily flow time series patching or extension: a spatial interpolation approach based on flow duration curves. Hydrol. Sci. J. 41 (6), 851–871.

[6] Archfield, S.A., Vogel, R.M., Steeves, P., Brandt, S., Weiskel, P., Garabedian, S., 2009. The Massachusetts sustainable-yield estimator: a decision-support tool to assess water availability at ungauged sites in Massachusetts. US Geological Survey Scientific Investigative Report 2009–5227, 41 pp.

[7] Archfield, S.A., Steeves, P.A., Guthrie, J.D., Riess, K.G., 2012. A web-based software tool to estimate unregulated daily streamflow at ungauged rivers. Geosci. Model Dev. Discuss. 5, 2503–2526.

[8] Shu, C., Ouarda, T.B.M.J., 2012. Improved methods for daily streamflow estimates at ungauged sites. Water Resources Research.

[9] Farmer W.H., Vogel R.M., 2013. Performance-weighted methods for estimating monthly streamflow at unguaged sites. Journal of Hydrology, 477, 240-250.

[10] Nash, J. E. and J. V. Sutcliffe, 1970. River flow forecasting through conceptual models: Part I- A discussion of principles. Journal of Hydrology, Vol. 10, No 3, 282–290.