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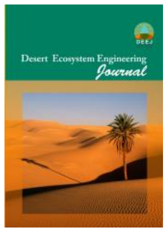

Hydrological Drought Forecasting Using Time Series

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Extended Abstract

Introduction: Hydrologic drought in the sense of deficient river flow is defined as the periods that river flow does not meet the needs of planned programs for system management. Drought is generally considered as periods with insignificant precipitation, soil moisture and water resources for sustaining and supplying the socioeconomic activities of a region. Thus, it is difficult to give a universal definition of drought. The most well-known classification of droughts is based on the nature of the water deficit: (a) the meteorological drought, (b) the hydrological drought, (c) the agricultural drought, (d) the socio-economic drought. Perhaps the most widely used model is the ARIMA model for predicting drought. The two general forms of ARIMA models are non-seasonal ARIMA (p, d, q) and multiplicative seasonal ARIMA (p, d, q)×(P, D, Q) in which p and q are non-seasonal autoregressive and moving average, P and Q are seasonal autoregressive and moving average parameters, respectively. The other two parameters, d and D, are required differencing used to make the series stationary. The differencing operator that is usually used in the case of non-stationary time series.
The aim of the study is to predict hydrological drought using time series analysis in the small forest watershed.

Materials and Methods: Monthly discharge of Nahrkhoran hydrometric station (53˚ 58΄ 02˝E, 36˚ 43΄ 02˝N) during 1980-1981 to 2010-2011 located in Gharasoo watershed, Iran were collected from Company of Water Resources Management of Iran.
The present study was carried out using Box and Jenkins (1976) modeling approach. This approach involves the following three steps:

Step 1-Model identification
In this step, the model that seems to represent the behavior of the series is searched, by the means of autocorrelation function (ACF) and partial autocorrelation function (PACF), for further investigation and parameter estimation. The behavior of ACF and PACF, is to see whether the series is stationary or not, seasonal or non-seasonal. Differencing is done to make non-stationary time series to stationary time series.
Step 2-Parameter estimation
After identifying models, we need to obtain efficient estimates of the parameters. These parameters should satisfy two conditions namely stationary and invertibility for autoregressive and moving average models,

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respectively. The parameters should also be tested whether they are statistically significant or not. Associated with parameters value are standard errors of estimate and related t-values.

Step 3-Goodness-of-fit test

Goodness-of-fit tests verify the validity of the model by some tools. The residuals of the model are usually considered to be time-independent and normally distributed over time. The most common tests applied to test time-independence and normality are the Mann-Kendall of test, the non-parametric Kolmogorov–Smirnov test.

Model calibration

In order to evaluate the accuracy of the streamflow forecasts obtained by applying the fitted model, Nash-Sutcliff (NS) coefficient of efficiency, root mean square error (RMSE), P-value of Wilcox and determination coefficient (R^2) were used.

Drought definitions and thresholds

A drought is defined as an uninterrupted sequence of streamflow below an arbitrary level. Thus, the mean and median value of streamflow time series is selected as the first truncation level. In the present study, as the monthly streamflow time series is applied for drought forecasting, the monthly mean and median values are also applied as the truncation level for each month. The two above truncation levels, we apply two other drought indices called standardized streamflow index (SSFI) and a probabilistic index which is based on hydrologic drought return periods. The SSFI for a given period is defined as the difference of streamflow from mean divided to standard deviation.

Results: A multiplicative seasonal autoregressive integrated moving average (SARIMA) model was applied to the monthly streamflow forecasting of the Naharkhoran River. In the first step of model identification, the ACF and PACF of the actual data and nonparametric Mann-Kendall test indicate the need of differencing. The Q–Q plot of the main series does not show normality. Thus, the logarithmic transformation was applied. The transformed Q–Q plot shows that the new series is normal. Based on Autocorrelation (ACF) and Partial Autocorrelation Functions (PACF) and results of Mann-Kendall test, SARIMA $(1,1,1)*(0,1,1)_{12}$ was selected. For testing the validity of SARIMA $(1,1,1)*(0,1,1)_{12}$ model for forecasting, the model is used for forecasting 10-, 9-, 5-, 3-, 2- and 1-year monthly streamflow. The present study result demonstrates the performance of time series models for 5-year period forecasting during October 2005 to September 2010.
The selected SARIMA model was then used to forecast streamflow from October, 1980 to September, 2011. The forecasted and observed flow rates are compared first with three truncation levels, which are SSFI, time series mean and median. The results showed that when SSFI is as truncation level, the selected model has not the ability to forecast drought. But when time series mean and median are as truncation level, the ability of the selected model is clear to forecast drought. Hydrologic drought frequency analysis was applied as an alternative truncation level for drought forecasting. Different frequency distributions were fitted to monthly streamflow and the flow rate for hydrologic drought in different 2-, 5-, 10- and 20-year return periods were estimated using maximum likelihood method of quantile estimation. The SARIMA model predict drought and humid periods as well.

Discussion and Conclusion: Due to the important role of drought forecasting in water resources management, a multiplicative seasonal autoregressive integrated moving average (SARIMA) model was applied to the monthly streamflow forecasting of the Naharkhoran River located in Gharasoo watershed, Iran. After normality examination of streamflow data, nonparametric Mann-Kendall test was used to detect trend analysis of data at confidence level of 95%. Based on ACF and PACF and results of Mann-Kendall test, SARIMA $(1,1,1)*(0,1,1)_{12}$ was selected. Mean and median streamflow as constant threshold and SSFI and drought frequency analysis in different return periods as variable threshold were used for determining drought periods. The present study result demonstrates the performance of time series models for 5-year period forecasting during October 2005 to September 2010. These models can be applied in water resources management.

Keywords: Hydrologic drought, SARIMA model, Stationary, Autocorrelation, Standardized streamflow index.