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Monthly Streamflow Prediction of Yesilirmak Basin by Using Chaotic Approach

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Abstract

Streamflow prediction relies highly on reliable hydrological data. However, hydrological data are often inadequate because of ungauged or poorly gauged basins. Obtaining reliable streamflow time series in developing countries such as Turkey is required when planning and managing water resources. Although the streamflow time series usually show seasonality, the high instability of affecting factors leads to the chaotic and relatively random behavior. This behavior makes it difficult to predict and modelling streamflow time series. In this study, it was intended to predict short-term monthly streamflow by using chaotic approach. Thus, the phase space was reconstructed by using monthly streamflow data for different stations located in Yesilirmak Basin in Turkey which is used as a case study. The observation period was taken to be 1969-2011 for all stations. Phase space has two parameters that are time delay (τ) and embedding dimension (m). Firstly, Mutual Information Function (MIF) was obtained in order to find an optimum time delay. Then, False Nearest Neighbor (FNN) algorithm was applied to define embedding dimension. After obtaining phase space parameters, monthly streamflow data were predicted successfully by using local prediction method. Reliable streamflow time series obtained with the use of the chaotic approach will provide an important contribution to water resources planning and management.

Keywords: Streamflow prediction, Chaos theory, Local Prediction Method, Nonlinear time series analysis, Yesilirmak basin

INTRODUCTION

Hydrological researchers face the challenge of streamflow prediction at ungauged locations. In most countries, streamflow gauging stations are often scarce and measurements are inadequate and there is no measurement in many river basins. There are many approaches in literature for streamflow prediction at ungauged site. The most common approaches are linear [1,2]. But the nonlinear behavior of hydrologic systems had been known for a long time. The rainfall-runoff process is nonlinear. The studies of chaotic analysis in hydrology are still limited because nonlinear studies are more complicated. The nonlinear approaches that are popular in hydrology include: nonlinear stochastic methods, artificial neural networks, data-based mechanistic models and deterministic chaos theory. Among the nonlinear approaches, chaos theory seems to be the suitable methods for hydrological processes.

Dynamical system theory was applied a great number of areas in hydrology and meteorology last few decades. Chaotic systems are sensitive to initial conditions. Even a very slight change in the initial conditions can lead to significant different in the outcomes. There are successful studies which can prove the evidence of chaotic behavior in streamflow data [3,4,5].

In a phase space, trajectories of a dynamical system produce a distinct pattern which is called “attractor”. If it is not possible to make long term prediction, it can be said that there is a dependency on initial conditions. Thus, it can be expected there is a fractional number of attractor size in system. This type of attractors have fractional dimension and they are called “strange attractor” in literature. Long term prediction is quite hard for this kind of chaotic systems.

One of the main target in atmospheric sciences is to make prediction like most scientific areas. If we know the behaviour of the weather, can we predict the future situation? This is one of the most significant questions in meteorology. One of the applications for weather prediction is to construct a model. Numerous differential equations belong to fluids are solved numerically in this models [6].

In nonlinear dynamical systems, it is possible that the time evolution of a system can be represented by its trajectories in phase space. Coordinates of phase space are consist of necessary state variables which can present the time evolution of a system. There are too many state variables in atmosphere to detect the development of a system.

As mentioned before, chaotic attractors that are named as “strange attractors” have important properties. The most important property of this attractors is the divergence of two nearby orbits with time in phase space. The most important result of this property is the limitation in prediction. In this kind of situation, it is not possible to make long term prediction [7].

In this study, it was tried to predict monthly flow values of Yesilirmak basins by using chaotic approach. Firstly, the phase space was reconstructed by using observed data. Then, monthly values were predicted by using Fortran program.

METHODOLOGY

Study Area

In this study, The Yesilirmak River basin was selected for monthly streamflow estimations. It is one of the twenty-six major basins in Turkey. It is located in Northern Turkey. The data were gathered from two streamflow stations 1412 and 1424. Each streamflow station contains a 43-year period spanning from 1969 to 2011. General information about the stations are given in Table 1. Selected stations on the map of the Yesilirmak basin are shown in Figure 1.

Table 1. General information of the gauging stations.

Station Number	Drainage Area (km^2)	Basin Elevation (m)	Observation years	Mean Flow (m^3/s)
1412	3668,8	530	1969-2011	6,309
1424	1032,8	1040	1969-2011	3,933

Figure 1. Geographical locations of the gauging stations.

Lyapunov Exponents

One of the most important properties of a complex signal is not to predict its future situation. Any two nearby orbits of chaotic system diverge exponentially. They move to different phase space region with time. This excessive sensitivity to differences in initial conditions is a sign of chaos. This situation is named as "sensitive dependence on initial conditions".

Figure 2 represents two attractors with different initial conditions. The difference between initial conditions of each is 10^{-5} in x-axis. However, there is a clear difference between final forms of two attractors. This situation can be explained by sensitive dependence on initial conditions.

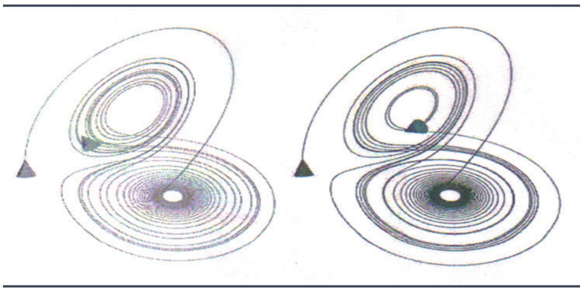


Figure 2. Divergence of two orbits that have different initial points.

Figure 3 represents time evolutions of phase space for any weather predictions that have difference initial conditions. Any small difference in initial condition leads to a bigger change in long-term prediction. This situation can also be explained by sensitive dependence on initial conditions.

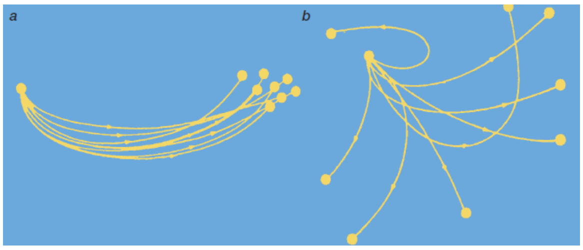


Figure 3. Time evolution of phase space for different weather prediction.

Reconstruction of Phase Space

First step of chaotic approach to reconstruct the phase space. In order to accomplish this, attractor information must be estimated from a given time series [9]. This information is time delay (τ) and embedding dimension (m).

Time delay is the period that must pass in order to for a system to change its character. Time delay can be defined by using two methods. First method is autocorrelation method which considers linear inner-dependency of a time series. However, nearly all variables in meteorology do not have normal distribution. Thus, there is an alternative approach to detect time delay which is called mutual information function (MIF). MIF considers nonlinear correlations in any time series [10]. Therefore, this approach is more useful in atmospheric science. The time which correspond to first minimum of MIF can be accepted as optimum time delay (τ).

After finding optimum time delay, the next step is to find the embedding dimension. Embedding dimension is the number of necessary state variables which describe the dynamics of a system. The method to find embedding dimension is False Nearest Neighbors (FNN) approach. If an attractor is embedded in a space that has lower dimension, some no-neighboring points of any single point appear like neighbor. However, the percentage of false neighbors decrease while increasing dimension step by step. If we plot percentages of false neighbors versus embedding dimension, the minimum percentage value is considered as the optimum embedding dimension (m) [11].

Local Prediction Method

Figure 4 shows mechanism of local prediction model [12]. In this prediction method, the change of X_t with time on the attractor is assumed to be the same as those of nearby points, (X_{Th} , h=1, 2,...,n). Herein, x_{t+p} is determined by the d-th order polynomial $F(X_t)$ as shown in Figure 4.

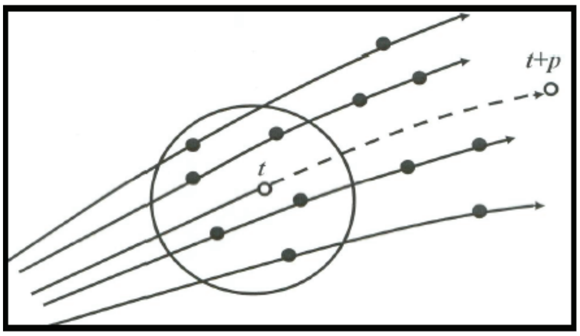


Figure 4. Mechanism behind the local prediction model.

Application and Results

Monthly Streamflow data of 2 gauged stations of Turkish General Directorate of State Hydraulic Works (abbreviated as DSI) on Yesilirmak River basins were examined by way of chaotic approach. The observation period was taken to be 1969-2011 for all stations.

The dataset is divided into two parts: the first 38 years (1969-2006) of the data is used for the phase-space reconstruction and identification of system behavior. Subsequent 5 year dataset (2007-2011) is used for prediction.

The first minimum of the mutual information of the time series is considered to be the preferred delay time (Figure 5). Optimum time delays can be considered as 6 and 4, respectively.

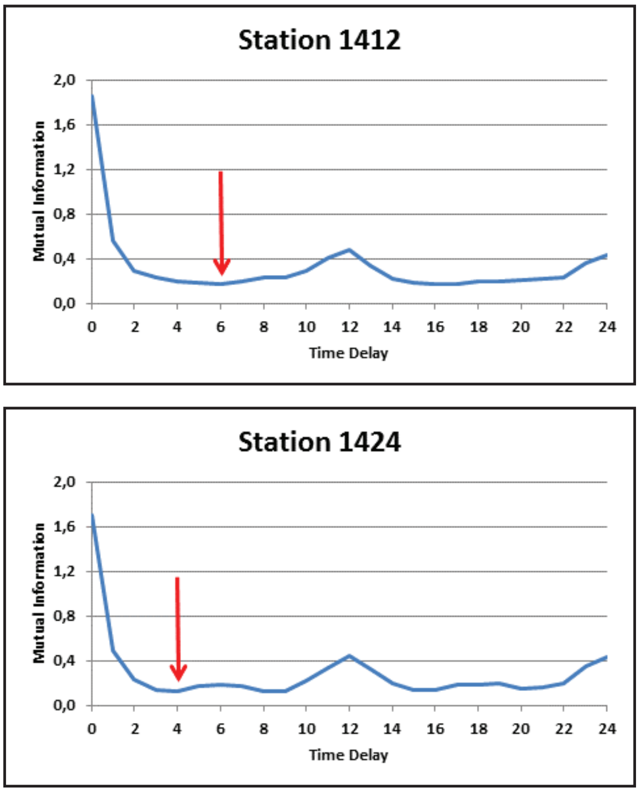


Figure 5. Mutual information function vs. delay for stations.

The first minimum of the percentage FNN gives an estimate of the embedding dimension (Figure 6). Embedding times can be accepted as 3 and 4 for stations.

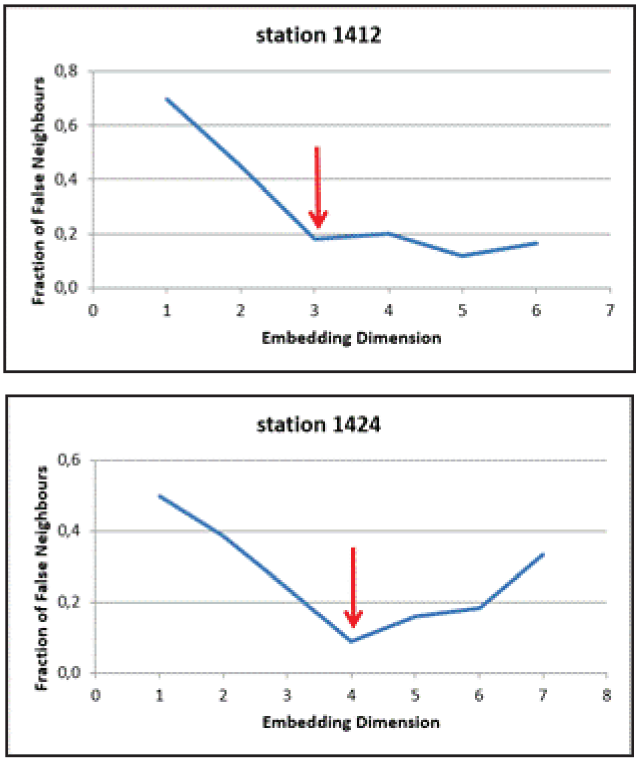


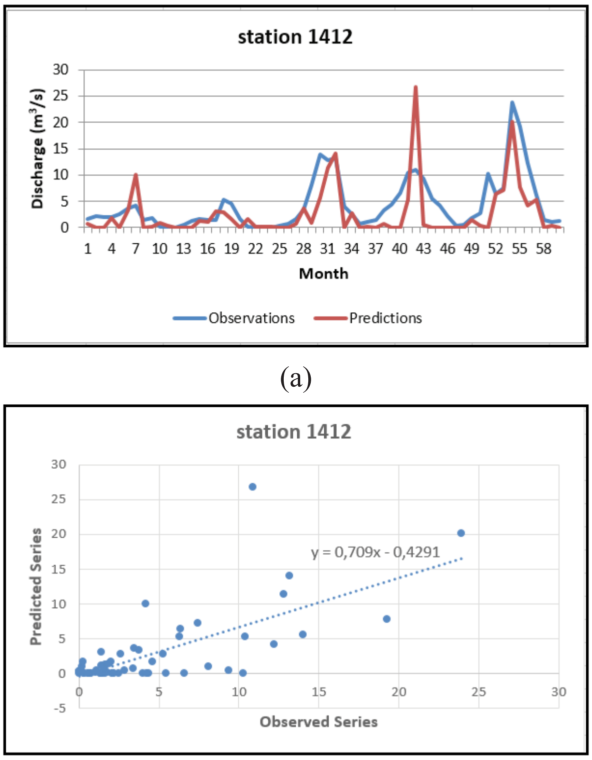
Figure 6. The fraction of false nearest neighbours as a function of the embedding dimension.

Phase space reconstruction parameters were given in Table 2.

Table 2. Reconstruction parameters of the phase space.

Station Number	time delay (τ)	embedding dimension (m)
1412	6 month	3
1424	4 month	4

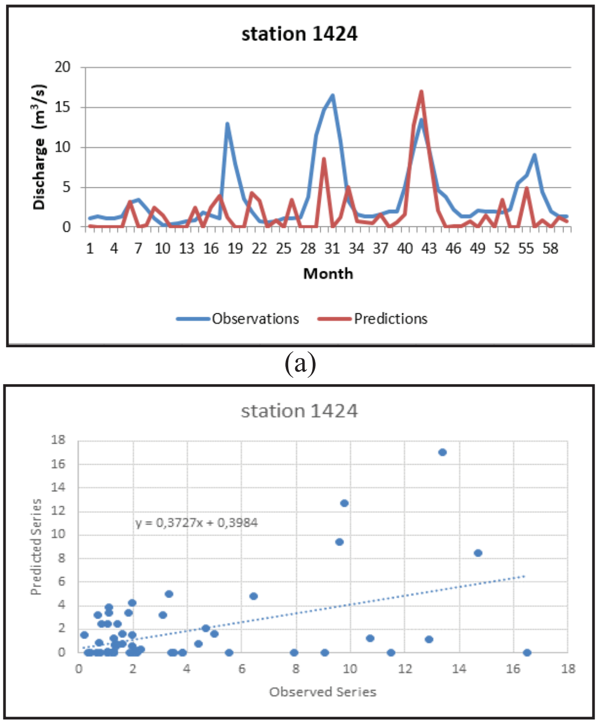
Results of this study were given in Figure 7 and 8. It can be seen in Figure 7(a) and 8(a) that the performance of peak discharge value prediction was acceptable. Figure 7(b) and 8(b) show the scatterplots of observed and predicted values for each station.



(a)

(b)

Figure 7. Prediction performance of station 1412.



(a)

(b)

Figure 8. Prediction performance of station 1424.

Such results certainly indicate the appropriateness of the phase-space-based nonlinear prediction technique, employed herein on monthly streamflow data of the gauge stations of Yesilirmak Basin.

CONCLUSIONS

This study investigates possible chaotic behaviors in the monthly discharge data from the gauge stations on Yesilirmak Basin, Turkey. The analysis was performed on 2-gauged stations with a record 43 years (1969-2011). Monthly streamflow data were predicted successfully by using local prediction method. The results obtained from the chaotic approach will provide an important contribution to water resources planning and management. In the future, it is planned to apply the method for different hydrological variables such as water level, precipitation and evaporation.

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