A method of spectral analysis of hidrological time series on the example of river Veternica discharge

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Abstract: The time series provides crucial information for the analysis and identification of dynamical properties of a wide range of geophysical systems. Here we present the method of spectral analysis known as Fast Fourier Transformation (FFT) in case of river Veternica discharge series. Importance of proper decomposition of time series and preparation of data for analysis is emphasized. As a result we get the main periodicity in Veternica discharge.

Key words: discharge, Veternica, time series, decomposition, spectral analysis, periodicity

1. Introduction

The analysis of hydrological system variability realized in time series of observational data needs adequate statistical methods. The purpose of time series analysis is to determine some of the system's key properties by quantifying certain features of the time series. These properties can then help understand and predict the system's future behavior.

There are two general aspects of time series analysis, analysis in time domain and analysis in frequency domain. As the analysis in time domain, such as auto-correlation or cross-correlation analysis, are fairly familiar to physical geographers, principals of frequency domain analysis are mostly unknown. The aim of this paper is to discuss some practical aspects of time series analysis in frequency domain, using a study of river Veternica discharge series to illustrate some practical problems which can arise.

Spectral analysis includes many useful methods based on the Fourier analysis of the time series. The most fundamental is the estimation of the spectral density function, whose graphical representation is called periodogram (Bloomfield, 1976). Spectral analysis provides a frequency based description of the time series and indicates interesting features such as long memory, presence of high frequency variation and cyclical behavior (Percival et al., 1993).

2. Methodology

There is a collection of measured river discharge data, and the data are measured every day at the same time. Such collection of data is called daily discharge time series, and we shall denoted as q_n:

$$q_n = \{Q_1, Q_2, \dots, Q_N\}$$

where Q_k is measured discharge in day $k, k = 1.2, \dots, N$.

Averaging daily time series in time, we can easily derivate monthly or yearly time series.

Now we can ask the questions: is there any cyclicality in this time series and, if there is, what is the periodicity? Answering these questions is very important for predicting models of river discharge.

We define Discrete Fourier Transformation – DFT of time series q_n (McLeod et al., 1995):

$$DFT(q_n) = \{\hat{Q}_1, \hat{Q}_2, \dots, \hat{Q}_N\}$$

where

$$\hat{Q}_k = \sum_{n=1}^{N} Q_n e^{-i2\pi(k-1)\frac{(n-1)}{N}}, k = 1.2, \dots, N$$

Now we construct periodogram as a natural estimator of the spectral density function of q_n is presented as the modulus squared of the $DFT(q_n)$.

Examination of periodogram provides information of cyclicality and periodicity of time series. There are numerous algorithms of DFT calculation, but most important and widely used is FFT. FFT is implemented in various commercial software, such as MS Excel, MatLab, R, etc.

3. About river

In our analysis we used daily discharge series of Veternica River in Leskovac, in the period 1948-2012. Data are provided by Republic Hydrometeorological Service of Serbia (RHMZ).

Veternica is a small river which basin lies in south part of Serbia. River is formed by joining Manastirski and Jezerski creak on mountain Kitka. Veternica is a left tributary of Južna Morava (South Morava), with length of 75 km and catchment area of 515 km². Gauging station Leskovac is located 11 km from the mouth, covering 500 km² of Veternica catchment area. (Gavrilović, 2011). Veternica has a simple regime with maximum discharge occurring in March-April and minimum in August-September (Figure 2).

Figure 1: Gauging station Leskovac (Source: RHMZ)

Table 1: Main discharge parameters (1948-2012)

Observational period		N	F [km^2]	Q_{max} [m^3/s]	Q_{min} [m^3/s]	Q_{avg} [m^3/s]	σ	c_v	q [l/s /km^2]
1948.	2012.	65	500	216	0	3.98	6.49	1.63	7.96

Source: (Martić Bursać, 2015)

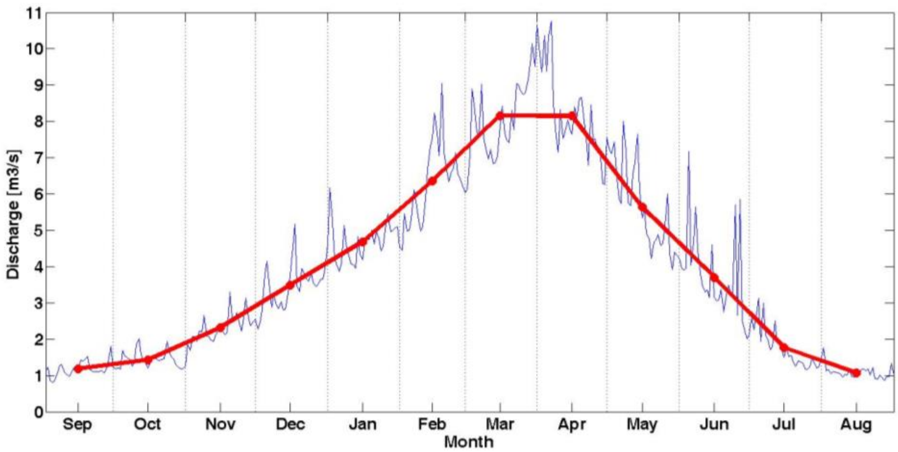

Figure 2: Hydrograph of Veternica (blue line – daily average, red line – monthly average)

4. Results and discussion

Applying FFT on river Veternica discharge series, we construct periodogram shown in Figure 3. It is obvious that spectral component with period of one year is highly dominant, so that the rest of the specter could be considered as a noise. This way of reasoning brings us to wrong conclusion (Ghil et al, 2002).

An important component of Earth climatological and hydrological data is the seasonal variation in the time series (Kawale et al., 2011). Seasons occur due to the revolution of the Earth around the Sun. The Sun is main energy source of climatic system, and dominant one-year spectral component in periodogram is consequence of repeating of the same energetic conditions during Earth's revolution. The seasonal component is the most dominant component in all climatological and hydrological data series with sampling period less than a year. As a result of such a dominant effect of seasonal patterns, other signals in the data are almost completely suppressed.

In order to solve the emerged problem, hydrological time series is decomposed into several components (Yevjevich, 1972, 1984). There are various ways to decompose time series. Here we adopt four element additive model of decomposition:

$$q_n = t_n + s_n + c_n + e_n$$

where t_n is a trend, s_n seasonal component, c_n cyclic component, and e_n is stochastic component or error.

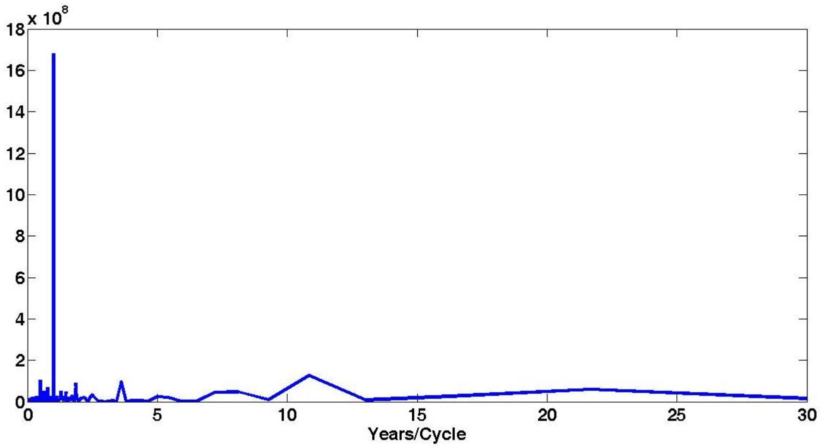

Figure 3: Veternica discharge periodogram (row daily data)

The trend represents long term changes, and its existence in the time series is checked with various statistical tests. Applying Man-Kendall test on data shows Veternica discharge has no significant trend in the observational period. In general, when we are interested in spectral analysis, if there is a trend it should be removed from time series. Numerous methods are proposed for detrending, one comparative analysis is given by Zhang and associates (Zhang et al., 2011).

The existence of a seasonal component depends on the type of data in a time series. As we have seen daily hydrological series has strong seasonal component. Removing seasonal component from time series is very important for proper analysis. What method of deseasonalization will be used depends on the type of seasonality we need to remove from time series (Ghil et al, 2002; Zhang et al., 2011; Douglass, 2011).

Most common method of removing seasonality that we are facing here is an average removing method (McLeod, 1995). The method consists of the following: first, we construct a matrix so that each column contains data from the time series that corresponds to a calendar year. The number of columns corresponds to the number of years of observation. After that we construct column vector as an average of each row. Constructed column vector contains daily averages in observational period. At the end we subtract daily average vector from every matrix column, and decompose the matrix in a time series in the same way that we formed. Resulting time series is deseasonalised.

Deseasonalization time series contains cyclic and stochastic component of discharge signal we often call anomaly.It is usual to normalize the anomaly to be comparable with the other proxies.

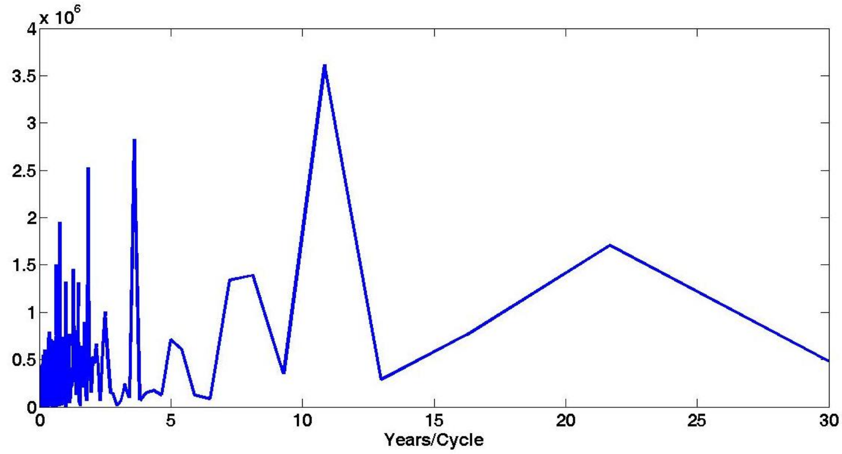

Figure 4: Veternica discharge periodogram (deseasonalised daily data)

Now we construct new periodogram by applying FFT on deseasonalised time series, which is shown in Figure 4. As we can see, after removing dominant spectral component rich specter of background processes is sappears. Every peak of periodogram represents period of cyclicity in discharge of Veternica.

5. Conclusion

In the study, we proposed FFT based periodogram analysis as a simple method for finding periodicity in discharge data.

Interannual cycles were found in Veternica discharge. Periodogram analysis of deseasonalised discharge time series reveals periodicity of 2.4; 3.6; 7-8; 20-24 years.

We have shown that even small streamflows as Veternica show periodic behavior. Such periods have been found in most of European rivers (Pekarova et al, 2003). Equality found in periods suggests that there is a common agent in the phenomenon. The source of this interannual cyclicity is unclear, but it has been shown that it may be linked to global climate indices, as NAO, ENSO, PDO, etc (Robertson, 1998; Labat, 2006, Martić Bursać, 2015).

North Atlantic Oscillation (NAO) and Artic Oscillation (AO) are the most prominent climate modifiers of northern hemisphere. It is shown that all the periods found in Veternica discharge are linked to a greater or lesser extent with NAO and AO (Hurrell, 1995). Unfortunately, these oscillations exhibit stochastic behavior with very low predictability (Gamiz-Fortis, 2002) so their usability in discharge models are low.

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