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Analyzing and forecasting the ten-days natural flow of the Blue Nile using the periodogram technique

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Abstract

The periodogram or the spectrum analysis is a tool to investigate both the pattern and the hidden periodicities of the time series data. In this study, the continuous spectrum is applied to the series of the Blue Nile ten-days natural flow during the flood season at three main stations (Khartoum, Sennar, and Roseires). Also, the analysis includes the ten-days annual flow series. It was found that the periodicities of the Blue Nile natural flow are of complex nature. The pattern of the times series shows two main components viz. (periodicity and stochasticity). The tendency components appeared only in the month of July. The contribution of the stochasticity component to the total explained variance is dominant. Based on the obtained periodicities, attempts are made to make a long-term forecast for ten-days natural flow of the Blue Nile, but it was found that the obtained forecast has some gaps at some periods. It is concluded that a better forecast may be obtained if each component is forecasted separately by the proper forecasting technique and then superimposed to obtain more accurate and logical forecast. Accordingly, an algorithm for forecasting the ten-days natural flow of the Blue Nile is presented.

1 Introduction

The information regarding the hydrology of the Blue Nile Basin is available in details in Shahin [13] and El-Sayed [4]. The Blue Nile which originate at Lake Tana near Bahir Dar has a drainage area of 324,530 km^2 approximately. It supplies nearly 84% of the water to the Nile River during the high flow

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season with the remainder being supplied by the White Nile and other tributaries. Therefore, the Blue Nile is the main source of water not only for Ethiopia but also for Sudan and Egypt. The Blue Nile travels from Lake tana southward, then turns from west to northwest to the Eithiopia-Sudan border, where it begins a more northern path [15]. Several investigations regarding the hydrology of the Nile River and the forecasting of its natural flow are available in the literature, see e.g. Negm et al [7,8], El-Sayed [5], El-Sayed et al [6]. But only few analysis are available on the hydrology of the Blue Nile due to lack of stream flow data, see. e.g. Nur et al [10] and Negm et al [9]. The theory of the spectrum analysis and the investigation of the periodicities of the hydrologic time series data can be found in many sources, Andel [1], Shuster [12] and Yevjevich [15]. The time series analysis and hydrologic data modelling are discussed in many standard text books as Box and Jenkins [3], wei [14], Sales et al [11]. Some important aspects of the hydrologic time series concerning the determinism, stochasticity, structure and periodicities and their causal effect are discussed by Yevjevich [16,17,18]. In this paper the ten-days natural flow time series of the Blue Nile are analyzed using the spectrum analysis in order to provide more information on the structure of the series to help in making a long-term forecasting of the Blue Nile.

2 Power spectrum model

The discrete spectrum has some difficulties and thus some deficiency exists. As a result, the obtained results from applying the discrete spectrum may be confusing the analyzer. By applying the continuous spectrum to the hydrological time series data, the deficiencies of the discrete spectrum can be avoided [15]. The continuous spectrum is sometimes called power spectrum or periodogram or variance density spectrum. The latter term will be used in this paper as it appreciate the application of the spectrum analysis to the hydrological data.

The Variance Density Spectrum VDS(f) of a continuous series X_t (t=1 to N, N> >) is related to its corresponding continuous autocorrelation function by the following equation which is based on Wiener-Khinlchine equation [15]:

$$VDS(f) = 2\left(\rho_o + 2\sum_{k=1}^{N/2} \rho_k \cos(2\pi fk)\right) \qquad (1)$$

in which ρ_0 is the first population autocorrelation which is taken as unity and ρ_k is the autocorrelation at lag k and f is the ordinary frequency. The population autocorrelation can be estimated by the sample autocorrelation, r_k, as given below:

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$$r_k = \frac{\frac{1}{N-k}\sum (X_t-\bar{X})(X_{t+k}-\bar{X})}{\frac{1}{N}\sum (X_t-\bar{X})^2} \qquad (2)$$

where N is the total number of the time series observation, $\bar{X}$ is the mean of the series.

To estimate a continuous spectrum in the range $0<f<0.5$, the range is divided into intervals each of Δf, then the total number of frequency density spectrum to be estimated is given by $(1+0.5/\Delta f)$. However, the estimates obtained by equation (1) is biased because they are somewhat greater than the expected or population variance density spectrum. For the estimate to be unbiased and efficient, the following two conditions should be satisfied:

$$E\ [\ V\hat{D}S(f)\ -\ VDS(f)\ ]=0$$
$$VAR\ VDS(f)=E\ [\ E\ [\ V\hat{D}S(f)\ -\ VDS(f)\ ]\ ]^2=Minimum \qquad (3)$$

The unbiased estimate can be obtained by modifying the obtained spectrum from equation (1) for the selected range of f either by smoothing the r_k or by smoothing the computed adjacent spectrum ordinates. Many smoothing function are available in the literature [15]. One of these functions, are Hanning smoothing one which can be written in the lag domain, D_k, as follows:

$$D_k=(1+\cos(2\pi fk))/2 \qquad k \leq N/2 \qquad (4)$$

Combining equations (1) and (4), the unbiased estimate of the VDS(f) can be expressed as follows:

$$VDS(f)=2\left(1+2\sum_{k=1}^{N/2} r_k\ D_k\ \cos(2\pi fk)\right) \qquad (5)$$

The estimates of the VDS(f) with the range of $0<f<0.5$ of a normal and independent series are independently distributed as a chi-square variable, χ^2, which is a good approximation for finite N [15]. Consequently, to test the significance of a particular ordinate (peak), the value of the power spectrum ordinate, VDS(f), is compared to the value of the (χ^2) divided by an equivalent degree of freedom ν, or the square of the earlier is compared to square of $(\chi^2)/\nu$, where ν is the degree of freedom which can be given by 8N/3h to 2N/h for Hanning smoothing function. The value $(\chi^2)/\nu$ is called the upper tolerance limit, while the lower tolerance limit is given by $(1-\chi^2)/\nu$. The upper confidence interval is obtained by multiplying the upper tolerance limit by the power spectrum ordinate at each particular frequency.

2 Collection of Data

Generally, the modelling and analysis of hydrologic time series are based on the natural flow. The natural flow at a particular location is defined as the amount of water which would be observed if there is no man-made works existed along the stream or no other withdrawl of water in the upper basin. Recently, a complete set of naturalized flow for the Nile River and its tributaries including the Blue Nile at the different key stations have provided by El-Sayed et al [6]. Regarding the Blue Nile, the naturalized flows are available for the period from 1912 to 1982 at three main stations, namely, Roseires, Sennar and Khartoum. The data for Roseires station during the high flow season are taken at about 443 km from the Blue Nile junction with the white Nile. The data for Sennar station are taken at Sennar at about 358 km south of Khartoum, while the data for Khartoum are taken just above its junction with the white Nile.

3 Results

The analyzed series in this study are those of July, August, September, October and the annual series as ten-days natural flow for the period from 1912 to 1981. The results show that all the series consisted of two components, namely, the stochasticity and the periodicity ones, except few series from July month, in which the tendency component (trend) appears. This is mainly due to the fact that the commencement of floods begins nearly at the middle of July and ends at the middle of October. This facts corporate with the past studies Negm et al [9] which have shown that the low flow season series consisted of stochasticity, periodicity and tendency components. Figure 1 shows the percent contribution of the explained variance to the total explained variation due to the stochasticity, the periodicity and tendency components. It is seen that the major contribution is due to the stochasticity component. The lowest contribution of the stochasticity component appeared in Khartoum station 21.4% in the first ten-days series of July and a maximum of 100% in the third ten-days series of October from Sennar station.

On the other hand, the investigation of the series using the power spectrum yields three basic significant periodicities denoted as P_1, P_2 and P_3 and arranged according to their relative importance in table 1. The most important periodicity is the one which has higher contribution to the total explained variation (i.e. P_1). This table shows that ten-days natural flow series have

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periodicities of 6.4 (i.e. 7), 10, 14, 17.5, 23 and 35.

Table 1. The periodicities of the ten-days natural flow series of the three station of the Blue Nile.

Ten	1 st			2 nd			3 rd			
Period.	P1	P2	P3	P1	P2	P3	P1	P2	P3	Remarks
Month										
July	6.4	10.0	-	6.4	8.8	17.5	6.4	8.8	-	
Aug.	10.0	-	-	5.8	-	-	5.8	10.0	-	Khartoum
Sep.	23.3	-	-	14.0	-	-	6.4	14.0	10.1	station
Oct.	6.4	-	-	6.4	-	-	6.4	-	-	
Annual	6.4	10.0	-	6.4	-	-	10.0	-	6.4	
July	35.0	-	-	6.4	8.8	-	8.8	5.8	-	
Aug.	5.8	-	-	10.0	5.8	-	5.8	-	10.0	
Sep.	14.0	6.4	5.4	10.0	-	-	6.4	14.0	-	Sennar
Oct.	6.4	-	-	6.4	-	-	-	-	-	station
Annual	6.4	-	-	10.0	-	6.4	10.0	6.4	23.3	
July	10.0	6.4	-	6.4	8.8	-	6.4	-	-	
Aug.	5.8	-	-	5.8	-	-	5.8	8.8	-	
Sep.	14.0	6.4	-	14.0	6.4	10.0	14.0	6.4	-	Roseires
Oct.	6.4	-	-	6.4	-	-	23.3	-	-	station
Annual	6.4	-	-	10.0	6.4	-	10.0	6.4	14.0	

4 Forecasting

Several attempts are made to use the periodicities appeared in the series to make a long-term forecast for the ten-days natural flow series of the Blue Nile but the obtained forecasting contains some gaps (discontinuous at some periods) due to the complexity of the structure of the flow which contains more than one component. However, the results of the study enable us to suggest the following algorithm for making a proper long-term forecasting for the ten-days natural flow series of Blue Nile .

4.1 Forecasting Algorithm

The use of periodicities to make long-term forecasting is no longer valid as the series consisted of more than one component. Neither the deterministic models nor the stochastic model will provide long-term accurate forecast for the ten-days natural flow of the Blue Nile. Thus, one has to use a combination of deterministic and stochastic methods of forecast to minimize the forecast errors. The following simple algorithm is proposed to achieve the desired forecast using more than one type of forecasting models.

1. Select the location where the forecasting is desired.
2. Collect the available data and perform naturalization [6] for the regulated flow.
3. Calculate the statistical properties and check the distribution of the series.

If it is normally distributed, goto step 5, otherwise goto step 4.
4. Make the proper transformation to normalize the series.
5. Use the spectrum analysis to investigate the structure of the series, if the series is consisted of stochasticity component, goto step 9, otherwise goto step 6.
6. If the series contains tendency and/or periodicity components goto step 7.
7. Remove the periodicity component from the series, goto step 8.
8. Select a proper forecasting model for the tendency component and perform forecasting.
9. Forecast the stochasticity component using a suitable forecasting model which may be ARMA [2] or ARIMA [5] or any other suitable models.
10. Superimpose the three components obtained in steps 7, 8 and 9 to get the desired forecasting.

It should be noted that all validation checks to the selected forecasting model for this algorithm should be made before making final forecasting.

5 Conclusions

The power spectrum is used to investigate the structure of the ten-days natural flow series of the Blue Nile at three main stations during the flood season. The analysis proved that the series are consisted of two main components, they are the stochasticity and the periodicity components. The tendency components appeared only in July series where the flood is going to commence. It is concluded that it is not possible to make a long-term forecast depends only on the periodicity component due to the complex structure of the series. However, an algorithm for making more proper and accurate long-term forecasting for the ten-days natural flow series of the Blue Nile is presented. Also, the proposed algorithm can be used for the flood series of the Nile River as its flow series have similar structure [8].

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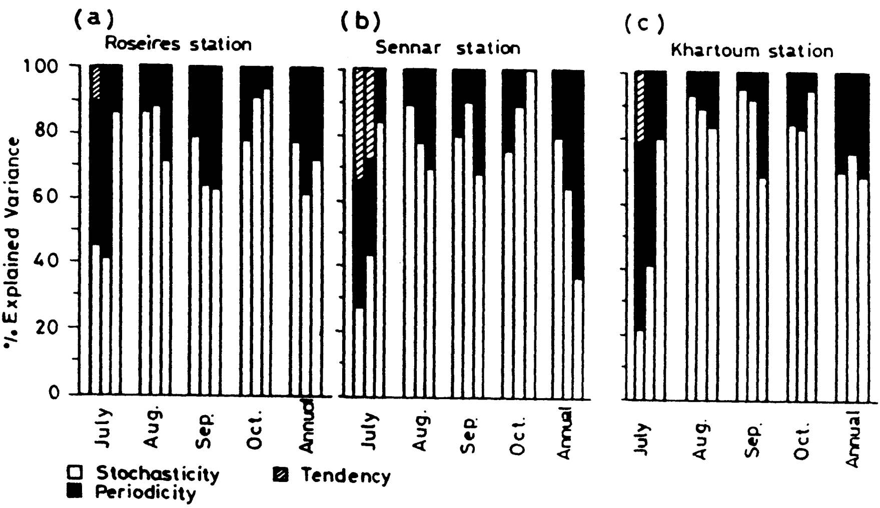

Figure 1: Contribution of the periodicity and stochasticity components to the total explained variance for flood series of (a) Roseires station (b) Sennar station and (c) Khartoum station