HU ISSN 2063-6997

GEOSCIENCES AND ENGINEERING

A Publication of the University of Miskolc

Volume 6, Number 9 (2018)

Miskolc, University Press
2019

GEOSCIENCES AND ENGINEERING
A Publication of the University of Miskolc
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UNIVERSITY OF MISKOLC
FACULTY OF EARTH SCIENCE & ENGINEERING
HU ISSN 2063-6997

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Geosciences and Engineering, Vol. 6, No. 9 (2018), pp. 118–126.

EXAMINATION OF DEBRECEN'S 110-YEAR RAINFALL DATA

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Abstract: In this examination the cyclic properties of rainfall data were prepared. To complement other climate change research, we defined the deterministic cycles of a 110-year-long precipitation dataset, both annual and monthly.

The sample area of Debrecen was chosen to for these calculations, and we defined 18 locally important cycles from annual rainfall and several other important cycles from monthly sampled datasets with spectral analysis based on the Discrete Fourier Transform. With the defined cycles and amplitudes, we calculated forecasts up to 2030 as well as analyzing the time-dependency of the cycles.

Keywords: *Debrecen, hydrology, precipitation, time series, wavelet*

INTRODUCTION

In climate research, the investigation of long-term datasets is becoming ever more important. At present it is possible to investigate 110-year-long equidistantly sampled datasets. It is also clear that climate change or extreme weather conditions can influence the water cycle on a global as well as on a local scale, and several scientists argue that the cycle's speed is increasing [1]. Water management practice should be able to handle these changes to fulfill increasing water demands. More and more water-related hazards are being observed all over the world. To solve water-related problems successfully, the cyclic behavior of water cycle components needs to be understood.

MATERIALS AND METHODS

Mathematical basis of spectral analysis

There are several ways to examine long-term time-series data, one of which is spectral analysis based on the Discrete Fourier Transform [2, 3].

With the Discrete Fourier Transform (DFT), the spectrum can be calculated with the following equation:

$$Y(T) = \int_{t=-\infty}^{\infty} y(t) e^{-j\frac{2\pi}{T}t} dt \tag{1}$$

where t is time, the independent variable of the registration, *y(t)* is the recording, registered signal, j is an imaginary unit, T indicates the period, the length of a cycle, and *Y(T)* is the spectrum of the registered signal.

$$Y(T) = \mathrm{Re}[Y(T)] + j\,\mathrm{Im}[Y(T)] \tag{2}$$

$$Y(T) = A(T) e^{j\Phi(T)}, \tag{3}$$

where *Re[Y(T)]* denotes real spectra, the first part of the complex spectra; *Im[Y(T)]* denotes imaginary spectra, the second part of the complex spectra, *A(T)* is the amplitude of the complex spectra, and *Φ(T)* is the phase angle of the complex spectra.

The amplitude and phase angle can be calculated from the real and imaginary spectra [4]:

$$A(T) = \sqrt{\mathrm{Re}[Y(T)]^2 + \mathrm{Im}[Y(T)]^2}\,, \tag{4}$$

$$\Phi(T) = arctg\,\frac{\mathrm{Im}[Y(T)]}{\mathrm{Re}[Y(T)]}\,. \tag{5}$$

With the previously discussed amplitude spectrum and phase spectrum, the original dataset can be recalculated, but when only using the major and additional cycles, a deterministic time series can be defined:

$$y(t)^{det} = \bar{Y} + \frac{2}{t_{reg}} \sum_{i=1}^{I} A_i \cos\left[\frac{2\pi}{T_i}(t-1901) + \Phi(T_i)\right] \tag{6}$$

where $y(t)^{det}$ indicates data calculated from the deterministic components, $\bar{Y}$ is expected value, declared static through the examined period, t_{reg} is length of the dataset, T_i is the period of cycle I, I is the number of the deterministic cycles, $\phi(T_i)$ is the phase angle of cycle i, and A_i is the amplitude of cycle i.

The linear relation between the original measured y(t) data and the deterministic $y(t)^{det}$ data, or the error term of the calculated data, which can be calculated with the Pearson-correlation coefficient, can be interpreted as the stochasticity in the time series.

If the t value exceeds the year 2010, predictions can be calculated for the future. In this paper the periodic components of the Debrecen dataset were used and a forecast was delivered up to the year 2030.

Wavelet-analysis

Wavelet time series analysis is a well-known method to investigate the time-dependence of a cycle within a time series. The shape of the cycles searched for in the registered signals can be described with harmonic functions; in the examination sine wave packet was used [5].

To carry out the wavelet analysis, a cross-correlation function is used [Rxy(τ)]:

$$R_{xy}(\tau) = \frac{1}{t_{reg}} \int_{\tau=t_{\min}}^{t_{\max}} x(\tau) y(t+\tau) dt . \tag{7}$$

A normalized cross-correlation function is:

$$R_{xy}^{(N)}(t) = \frac{R_{xy}(t)}{Max\{R_{xy}(t)\}} . \tag{8}$$

Materials

The data was acquired from the Hungarian Meteorological Service's Online Database [6], which contains several types of meteorological data from five different stations. Monthly and annual precipitation data from Debrecen covering a period of 110 years (1901–2010) were analyzed. The calculation was calculated with self-made software for spectral analysis.

For interpreting the results, the term "relative amplitude spectra" was defined, which means the values of the amplitude spectrum compared to the absolute maximum of the amplitude spectrum.

RESULTS AND DISCUSSION

Spectral analysis

First, we examined the annual rainfall data from Debrecen, where the registration period is 1901–2010. Thus the length of the registration period is t_{reg} = 110 years, meaning the number of samples are for each city is 110. With this method, the minimal length of the period – called the Nyquist period – can be calculated; it is 2 years in this case. The results of the spectral analysis, the cycles and their relative amplitude are shown in *Figure 1*.

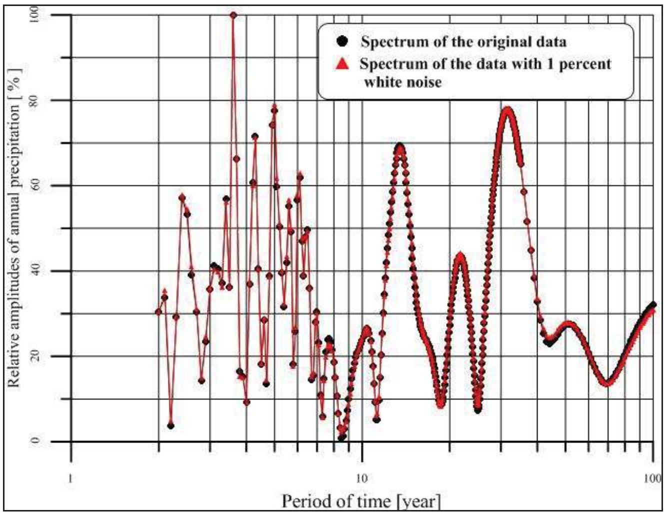

Figure 1. *Relative amplitude spectra from annual rainfall data of Debrecen, with 1% white noise*

From annual rainfall data 18 cycles were determined, 10 of which are major cycles. The most dominant cycle was 3.6 years long, with 100% amplitude, and most of the other main cycles were between 27 and 77%. The following dominant cycles are 5-year-long cycles and the 31-year-long cycles. The calculation with white noise showed a similar result; based on this the spectra from Debrecen were accepted to be correct.

The monthly precipitation datasets contain monthly rainfall data from January 1901 to December 2010, so the length of the registration period $t_{reg} = 1320$ months.

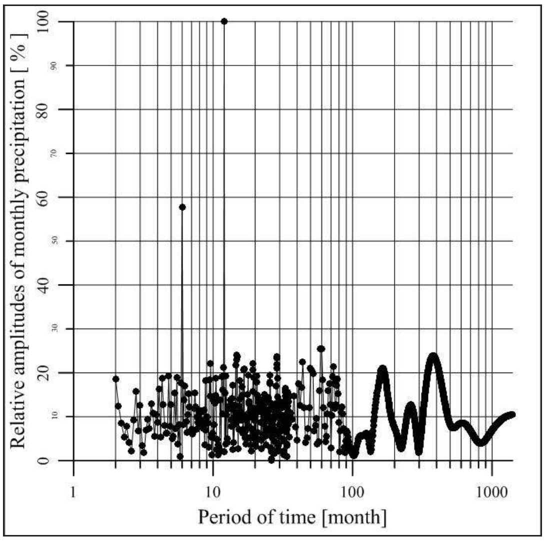

Figure 2. *Relative amplitude spectra from monthly rainfall data of Debrecen*

In the analysis of the Debrecen data, 43 cycles were detected *(Figure 2)*. In this case, the 1-year-long cycle had the 100% relative amplitude spectrum, and the six month long had the relative amplitude spectrum of 57.64%. The other cycles were additional cycles. The additional dominant cycles were the 59-month, 14.7-month, and 378-month cycles; most of the minor cycles have a relative amplitude range under the 20% value but were considered important in the precipitation dataset.

Forecasting

For this investigation the cyclic components of the annual and monthly precipitation data were used. We developed several scenarios to test the forecasting method.

First, 10 major cycles were used to calculate a deterministic rainfall dataset, and we made predictions up to the year of 2030. Teaching took place with the data between 1901 and 2010, and the validation phase was between 2010 and 2016 [7]

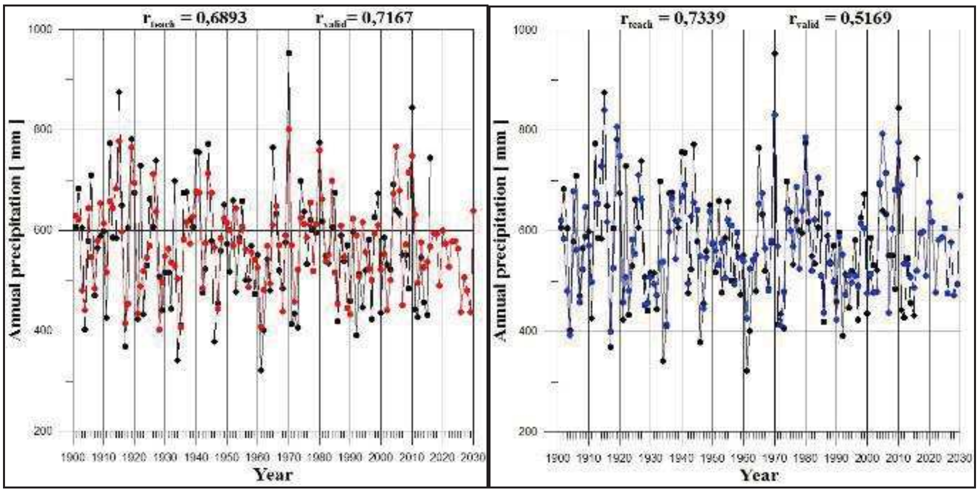

Figure 3. *Calculated rainfall data in the Debrecen area from 10 cycles (left) and from 18 cycles (right)*

Calculating with 10 dominant cycles, the correlation coefficient with the original measured data is 0.6893 in the teaching phase, and becomes higher in the validation phase. In the forecast the calculated annual rainfall data is between 400 and 600 mm, with a maximum value in 2030. The expected value between 1901 and 2010 is 574.8 mm/year, with a standard deviation of 89.7 mm/year, and for the predicted period, the average is 546.7 mm/year, with a standard deviation of 56.5 mm/year. The decrease from the teaching period is 5%.

When we used 18 cycles for the calculation, the correlation coefficient became higher, 0.7339. The values of the forecasting interval are 450 to 650 mm, without any extreme data. The expected value for the teaching phase is 574.4 mm/year, with 98.7 mm/year standard deviation, and for the forecasting phase 559.4 mm/year, with a standard deviation of 66.1 mm/year.

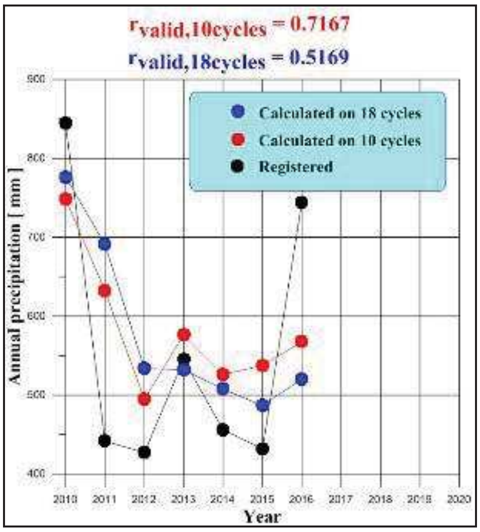

Figure 4. *Correlation in the validation phase*

As seen in *Figure 4*, the original measured and the calculated values show a strong connection for this short interval: the correlation coefficients are 0.7167, and 0.5169 with 10 and 18 cycles respectively. The only major difference between the measured and the calculated data is for the year of 2016.

The calculation was delivered also using the monthly dataset, but even with 164 cycles the correlation coefficient was only 0.62, which can be considered as moderate. The results also show that with fewer cycles a more adequate forecast can be calculated, so the number of necessary cycles for the calculations can be a direction of future studies [8].

Wavelet-analysis

For this analysis we used the cycles defined from the Debrecen dataset, with a sine wave packet with unit amplitude, and with the periods of time detected previously.

In *Figure 5* the correlation coefficient shows years when the cycle was more or less dominant.

For the examination all of the calculated periodic components were used, in this paper we present the more interesting ones, as the cycles with smaller periods of time showed many similarities.

The wavelet of the smaller cycles shows local maximum values in the 1910s, 1940s and 1970s, as seen in the graph of the 4.3 and the 5-year-long cycles. Much less dominance can be noticed after the year of 2000.

As for cycles with a longer period of time, a more consistent graph can be seen *(Figure 5)*. The time distribution of these cycles shows that the longer periods are not showing any changes in the examined time interval as opposed to the shorter cycles.

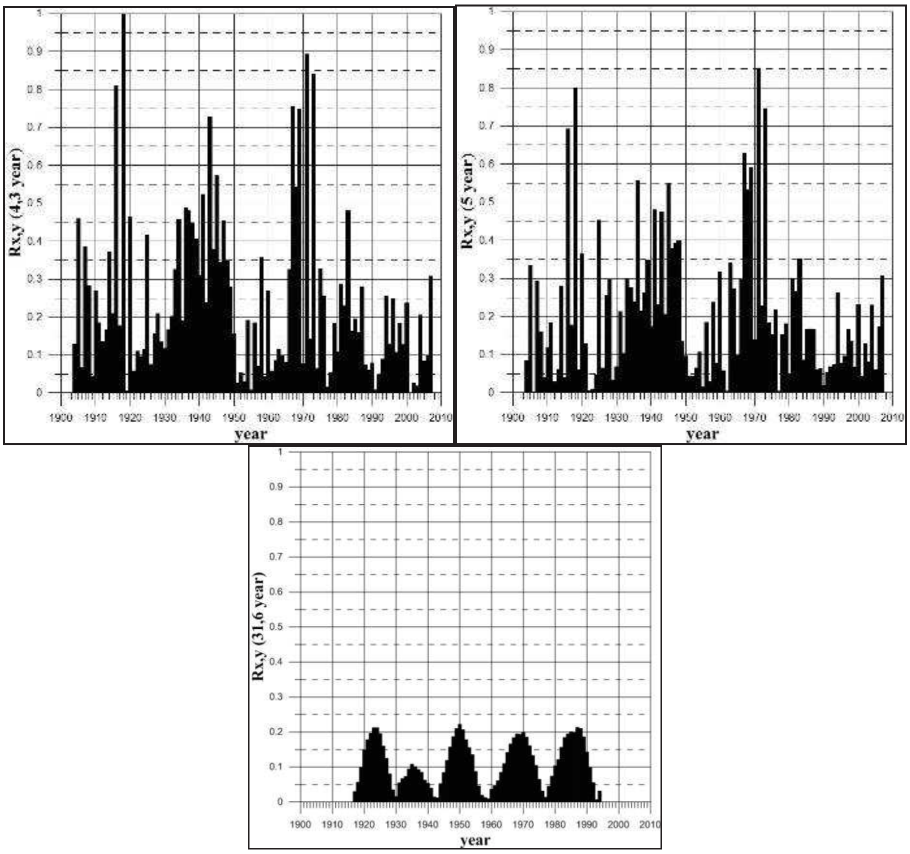

Figure 5. Wavelets of the dominant cycles

With this method a certain year can be examined as well, as seen in *Figure 6*.

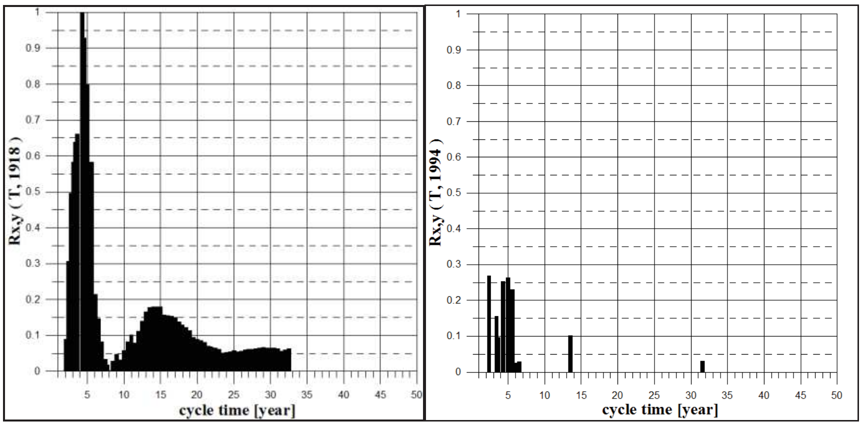

***Figure 6.** Dominance of the different cycles in the year of 1918 (left) and 1994 (right) in Debrecen*

As seen in the graph the correlation coefficient of the cycles is much smaller in 1994 than in 1914, which can mean that the dominance of the shorter cycles is less relevant at the end of the 20th century.

CONCLUSION

Based on our research, we analyzed 110-year-long rainfall records and defined several cycles that can describe the climate of the city of Debrecen. Also we developed a forecasting method that was tested in that area and we analyzed the time distribution of the cycles.

In this changing climate, finding deterministic values in a hydrological or meteorological parameter can be helpful to better understand the climate, and several uncertainties of rainfall events can be reduced by using this method.

Directions of future studies could be to understand the reasons for the cycles as well as finding a connection with the cycles of hydrogeological parameters, shallow and deeper groundwater levels.

ACKNOWLEDGEMENT

The research was carried out within the GINOP-2.3.2-15-2016- 00031 *Innovative solutions for sustainable groundwater resource management* project of the Faculty of Earth Science and Engineering of the University of Miskolc in the framework of the Széchenyi 2020 Plan, funded by the European Union, co-financed by the European Structural and Investment Funds.

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