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EXAMINATION OF THE HYDROLOGIC CYCLES WITH SPECTRAL ANALYSIS

Hidrológiai ciklusok vizsgálata spektrális elemzéssel

Csaba Ilyés¹ Endre Turai² Péter Szűcs¹

Abstract: *The paper examines the spectra of the daily sampled 110-year long rainfall time series in the four cities of Hungary (Debrecen, Budapest, Pécs and Szombathely). It analyzes spectral variability and detects dominant deterministic cycles. Based on the monthly sampled time series of the groundwater data (in Debrecen, in Nyírcsászári and in Kocsér), paper determines the deterministic cycles of groundwater change. By simultaneously examining the spectra of rainfall and groundwater time series, the mutually existing deterministic cycles in the time dependence of the two parameters are detected.*

Keywords: *spectral analysis, rainfall time series, groundwater time series, dominant deterministic cycles.*

Kivonat: *A dolgozat a napi mintavételezésű 110 éves csapadék idősorok spektrumait vizsgálja Magyarország négy városa (Debrecen, Budapest, Pécs és Szombathely) területén. Elemzi a spektrumok változékonyságát és kimutatja a domináns determinisztikus ciklusokat. A talajvíz adatok havi mintavételezésű idősorainak (Debrecen, Nyírcsászári és Kocsér) spektrumai alapján meghatározza a talajvíz változás determinisztikus ciklusait. A csapadék és a talajvíz idősorok spektrumainak együttes vizsgálatával kimutatja a két paraméter időfüggésében kölcsönösen meglévő determinisztikus ciklusokat.*

Kulcsszavak: *spektrális elemzés, csapadék idősorok, talajvíz idősorok, domináns determinisztikus ciklusok.*

Introduction

The satisfaction of drinking water and energy needs is one of the most important tasks to be solved globally today. In the future, the weight of this challenge will, according to some estimates, progressively increase in the context of the climate change. The amount of precipitation and its changes in time have an impact on the quantitative and qualitative characteristics of groundwater basins. The groundwater basins – alongside the rock matrix – play a significant role in forming a mineral water reservoirs. From the data of hydrometeorological parameters (precipitation, groundwater level, etc.), the degree (amplitude) and periodicity of cyclic changes can be detected by spectral analyzes based on the Fourier transformation (Bath, 1974), (Bracewell, 1978), (Meskó, 1984).

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The aim of our research, which has started nearly two decades ago, is to detect deterministic cycles in the time series of hydrometeorological parameters and to explore their causes. In addition to the calculations of the spectra with our own developed software (Turai, 1983), we determined the occurrence periods of certain cycles (Ilyés et al, 2017) along with cross-correlation functions and convolutional filters [wavelet transformations] (Turai, 2005) as well as the probability of each cycle in each year's environment. Assuming that the deterministic cycles will exert their effect in the near future, we have predicted (Ilyés et al, 2018), (Kovács-Turai, 2014) the expected evolution of precipitation time series. The prognosis was also validated (Ilyés et al, 2018) for the territory of Debrecen between 2010 and 2016. In this paper we present the results of the daily sampled precipitation and the results of the spectral analysis of the monthly sampled precipitation and groundwater level data.

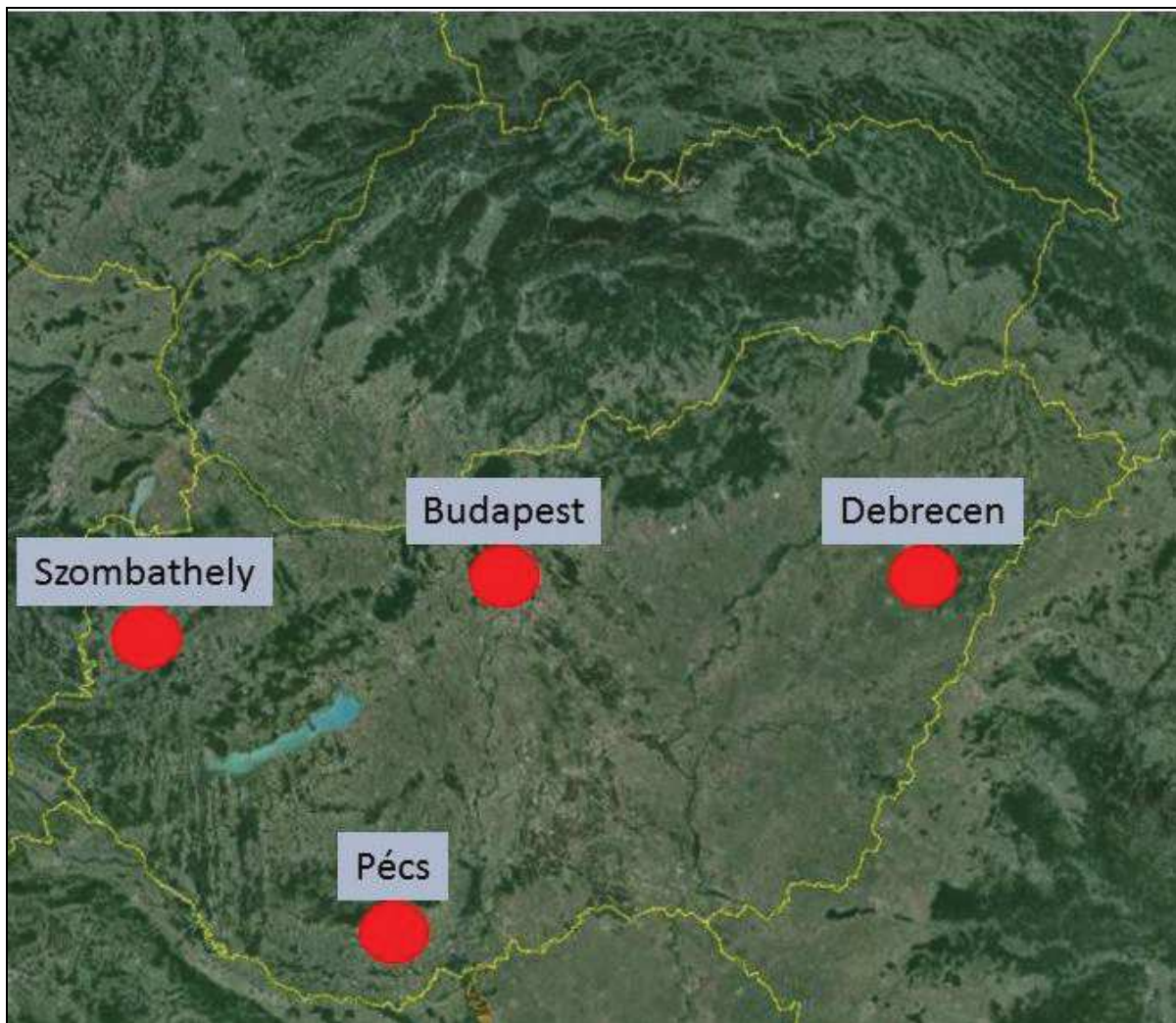


Fig. 1. The location of the four monitoring station in Hungary

The spectra of the daily sampled 110 year long dataset

The spectra of rainfall time series between January 1, and December 31, 2010 were calculated from four Hungarian cities (Debrecen, Budapest, Pécs and Szombathely). The registration interval for each city divided into four equal periods, were used to determine how spectral information changes in each period. We wanted to find the climate change relation as to whether the length of the precipitation cycles is actually shortened. From the four cities in Szombathely (Figure 2a) the stability of the cycles, while in Budapest (Figure 2b) time variability is the highest. The variability of the spectra calculated for Debrecen (Figure 3a) and Pécs (Figure 3b) is similar between Budapest and Pécs variability.

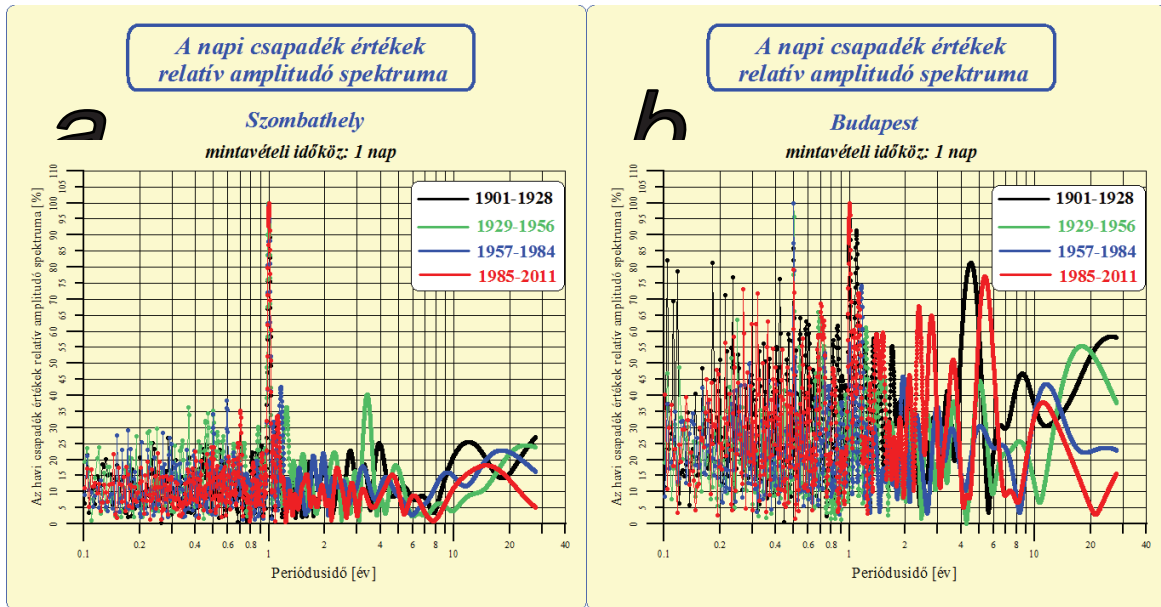


Fig 2. Spectra of daily sampled datasets of Szombathely (a) and Budapest (b)

The average spectrums for the entire 110-year period is shown in Figure 4 with a red line in Debrecen, blue in Budapest, green in Pécs and black in Szombathely. Table 1 summarizes the lengths of the most dominant 10 cycles and the amplitude of the maximal amplitude, the relative weights. The table shows that the 1 year, 0.5 years, 0.7 years, and 0.3-0.4 years – colored red – can be detected in the rainfall data series of all four cities, while the 1.23 year long cycle is in the series of three cities (Debrecen, Budapest and Pécs), however, it cannot be detected in Szombathely at the westernmost location.

Table 2 shows that the length of the one-year cycle with the highest weight and exactly how many day long it is in the four time intervals for each city, and the last line shows the extent of the change (the difference between the maximum and the minimum value). The largest is the case here in Budapest (18.7 days), while in Szombathely the smallest (1.5 days).

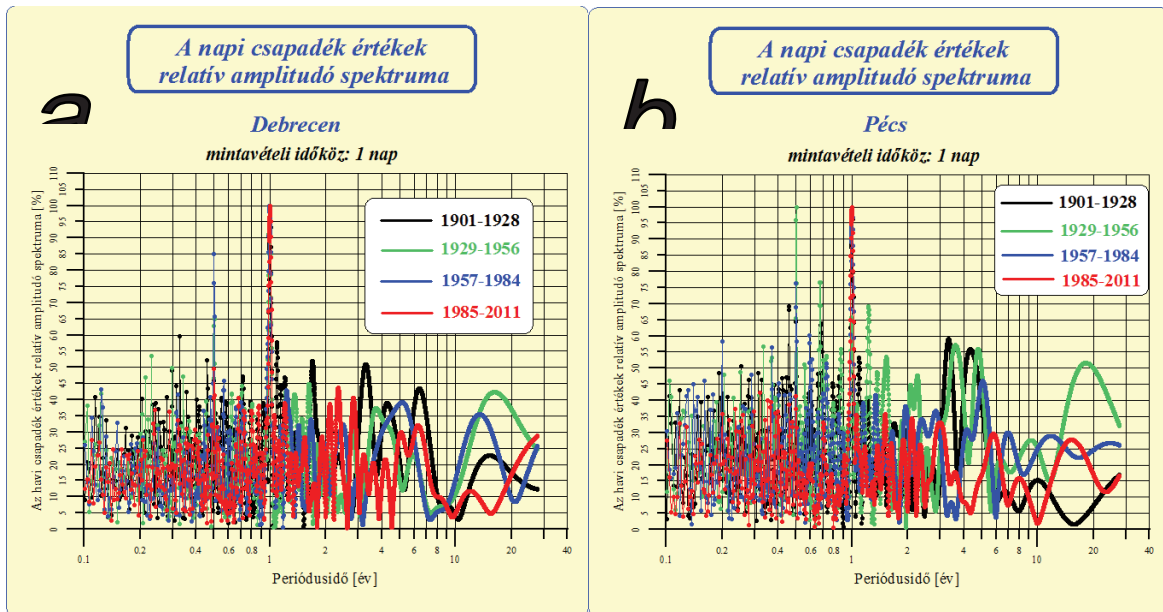


Fig. 3. Spectra of daily sampled datasets of Debrecen (a) and Pécs (b)

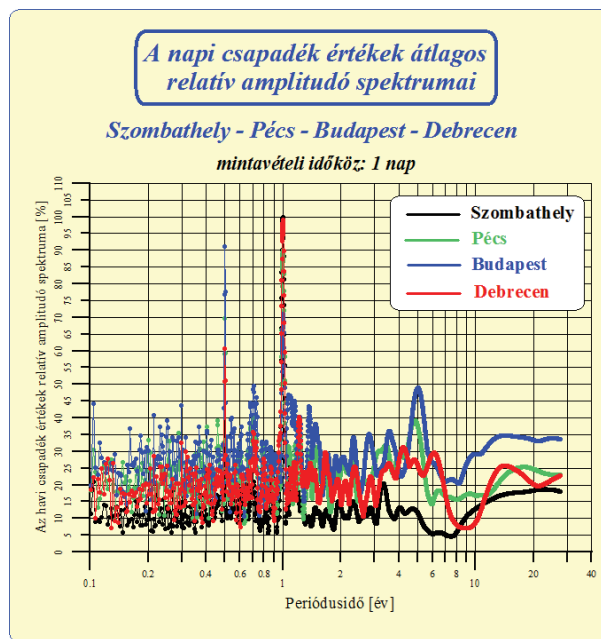


Fig. 4. Spectra of daily sampled rainfall data from Debrecen, Budapest, Pécs and Szombathely

If the rainfall cycles were actually shortened in countrywide terms, then the highest value must have been in the 1901-1928 period for all four cities and the lowest in the 1985-2011 period. As you can see, this is not true for any city, so the shortening of precipitation cycles is not verified by our analysis.

Table 1. The 10 most dominant cycle and its relative weight

| No. | Debrecen (relative weight) | Budapest (relative weight) | Pécs (relative weight) | Szombathely (relative weight) |
|-----|----------------------------------|----------------------------------|------------------------------|-------------------------------------|
| 1. | 1 year (99.1%) | 0.5 year (91.2%) | 1 year (90.1%) | 1 year (99.7%) |
| 2. | 0.5 year (60.8%) | 1.01 year (71%) | 0.5 year (69.7%) | 0.5 year (26.0%) |
| 3. | 1.22 year (40.3%) | 0.71 year (49.6%) | 0.7 year (39.9%) | 1.15 year (24.2%) |
| 4. | 0.73 year (33%) | 5.03 year (49%) | 4.84 year (39.3%) | 0.71 year (21.0%) |
| 5. | 0.3 year (32.7%) | 1.1 year (46.6%) | 0.46 year (39.3%) | 1.05 year (20.9%) |
| 6. | 4.22 year (31.2%) | 1.15 year (45%) | 0.4 year (37.3%) | 0.37 year (20.9%) |
| 7. | 1.67 year (29.8%) | 0.3 year (43.7%) | 1.23 year (35.7%) | 3.32 year (20.4%) |
| 8. | 6.09 year (29.6%) | 1.37 year (43.4%) | 0.29 year (35.5%) | 0.87 year (20.2%) |
| 9. | 3.56 year (26.6%) | 1.23 year (40.3%) | 3.43 year (31.9%) | 0.64 year (20.1%) |
| 10. | 14.2 year (25.8%) | 0.54 year (40%) | 1.51 year (31.2%) | 23 year (18.7%) |

Table 2. The real length of the one-year long cycle in four cities

| Time interval | Debrecen [day] | Budapest [day] | Pécs [day] | Szombathely [day] |
|------------------|---------------------|---------------------|-----------------|------------------------|
| 1901-1928 | 366.6 | 366.5 | 366.8 | 365.4 |
| 1929-1956 | 364.4 | 349 | 363.7 | 364.4 |
| 1957-1984 | 364.6 | 367.7 | 366.9 | 365.5 |
| 1985-2011 | 366.6 | 366.9 | 365.7 | 365.9 |
| extent | 2.2 | 18.7 | 3.2 | 1.5 |

Spectra of monthly sampled shallow groundwater time series

The spectra of the monthly sampled shallow groundwater level time series were calculated within the interval of 110 years between 1901 and 2011 in two neighboring (Debrecen, Nyírcsászári) and a far (Kocsér) location. The spectra are shown in Figure 5, and the lengths and relative weights of the deterministic cycles are shown in Table 3.

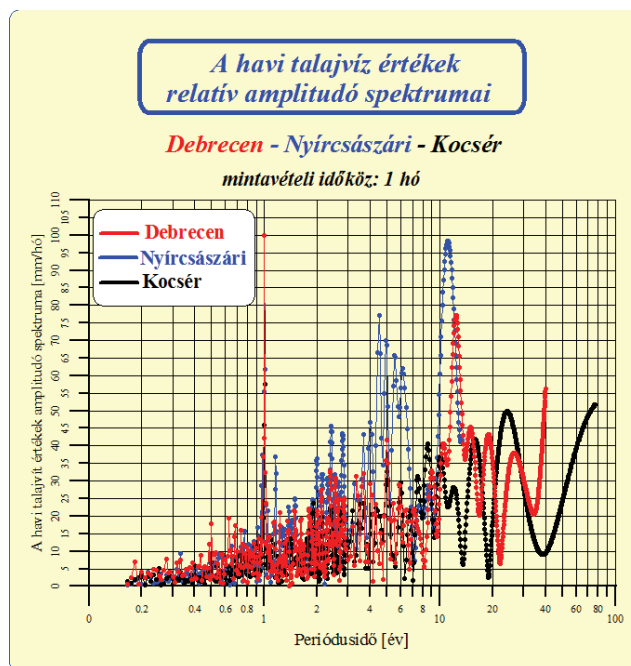


Fig. 5. The spectra of monthly sampled shallow groundwater level datasets form Debrecen (red), Nyírcsászári (blue) and Kocsér (black)

Table 3. The list of the most dominant cycles with it's period of tim and relative weight

| No. | Debrecen (relative weight) | Nyírcsászári (relative weight) | Kocsér (relative weight) |
|-----|-------------------------------|-----------------------------------|-----------------------------|
| 1. | 1 year (100%) | 1 year (100%) | 1 year (100%) |
| 2. | 12.3 year (77.3%) | 11.1 year (98.3%) | 24.2 year (49.9%) |
| 3. | 15 year (45.4%) | 4.5 year (77.2%) | 15.8 year (41.9%) |
| 4. | 18.9 year (43.2%) | 4.9 year (70.1%) | 8.5 year (40.6%) |
| 5. | 5 year (41.7%) | 5.5 year (65.8%) | 10.1 year (37.2%) |
| 6. | 10.5 year (40.7%) | 6.2 year (62.1%) | 5 year (32.6%) |
| 7. | 26.6 year (38.1%) | 4 year (46.8%) | 7.5 year (31.4%) |
| 8. | 9 year (32.9%) | 2.4 year (45.5%) | 6 year (29.5%) |
| 9. | 2.4 year (32.9%) | 2.8 year (43.5%) | 12 year (28.3%) |
| 10. | 3.7 year (32.2%) | 3.7 year (43.2%) | 1.9 year (23.7%) |
| 11. | 3.3 year (31.4%) | 0.98 year (37.4%) | 3.7 year (23.6%) |

Looking at Table 3, it can be stated that the red letters of 1 year, 3.7 years, 5 years and 11-12 years can be detected in the time series of the groundwater level in all three location. In the case of Debrecen and Nyírcsászár which are close to each other, a cycle of 2,4 years is also appeared as a common cycle, but this cycle is no longer visible in Kocsér area.

Spectra of the monthly sampled precipitation and groundwater level data in Debrecen

In case of Debrecen, we investigated whether there are common cycles in the monthly sampled rainfall and groundwater level time series. Fig 6 shows the precipitation spectra with blue color and the groundwater level spectra in red. The length and relative weight of dominant deterministic cycles are summarized in Table 4.

Table 4 shows that in Debrecen from the precipitation and the change of ground water level data a 1 year, 2.4 years, 3.67 and 5 year cycles can be detected (shown with red color). The 12.3 year cycle in the groundwater spectrum can be detected in the precipitation timeline of 13.7 years, while the 26.6 year groundwater cycle is also higher at 31.5 years.

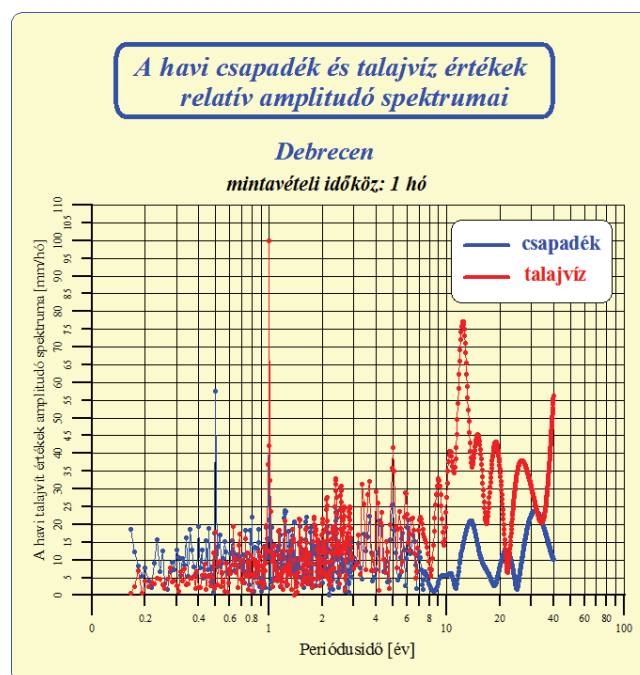


Fig. 6. The spectra of the monthly sampled precipitation and shallow groundwater levels in Debrecen

Conclusion

The analysis of the 110-year rainfall time series of daily sampling shows that there are probably regional deterministic reasons behind Hungary's 1 year, 0.5 year, 0.7 and 0.3-0.4 years cycles.

The changes in the 1-year cycle in the four-27-year subintervals is very small, only a few days long. The smallest is the scope of the change (1.5 days) in Szombathely, while the largest (18.7 days) in Budapest. The 1.23 year cycle can be detected in Debrecen, Budapest and Pécs, but it does not appear in Szombathely. The fluctuation of the spectrum is the smallest in Szombathely, while in Budapest it is the largest.

Table 4. *The length and the relative weight of the precipitation and shallow groundwater level cycles in Debrecen.*

| Debrecen No. | precipitation (relative weight) | shallow GW (relativeweight) |
|---------------------|--|------------------------------------|
| 1. | 1 year (100%) | 1 year (100%) |
| 2. | 0.5 year (57.6%) | 12.3 year (77.3%) |
| 3. | 4.92 year (25.5%) | 15 year (45.4%) |
| 4. | 1.23 year (24%) | 18.9 year (43.2%) |
| 5. | 31.5 year (23.8%) | 5 year (41.7%) |
| 6. | 2.39 year (23.6%) | 10.5 year (40.7%) |
| 7. | 3.67 year (22.4%) | 26.6 year (38.1%) |
| 8. | 1.62 year (22.2%) | 9 year (32.9%) |
| 9. | 0.8 year (22.1%) | 2.38 year (32.9%) |
| 10. | 6.08 year (21.4%) | 3.67 year (32.2%) |
| 11. | 13.7 year (21.1%) | 3.33 year (31.4%) |

By examining the spectra of the monthly sampled groundwater level time series spectra at three monitoring points (Debrecen, Nyíresászári and Kocsér), it can be stated that the 1 year, 3.7 years, 5 years and 11-12 years can be detected in all three locations, so presumably there are regional deterministic reasons behind it. The 2.4 year cycle only occurs in places close to each other (Debrecen and Nyíresászári) and cannot be detected in the more remote Kocsér area, so it is probable that this cycle has a local cause.

By examining the spectra of the monthly sampled rainfall and shallow groundwater level spectra in Debrecen, it is apparent that the 1-year, 2.5-year, 3.7-year and 5-year cycles appear in the time series of both parameters, therefore these cycles are caused by deterministic effecting both the periodic changes in the precipitation and ground water levels. Two long-term cycles can be detected in the time series of both parameters, but they do not occur exactly with the same period of time. The 12.3 year cycle in the groundwater spectrum can be detected in the precipitation timeline and a cycle of 13.7 years in the shallow GW, while the 26.6 year precipitation cycle in the groundwater levels is also higher at 31.5 years.

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