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Study of the Periodicity of Precipitation and Shallow Groundwater Data in Eastern Hungary with a perspective to the Carpathian Basin

Thesis Booklet

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1. Aims

Our groundwater aquifers are particularly important from the point of view of health, food supply, energy, and the ecosystem, a significant part of which is exposed to contemporary human and natural influences. In Hungary, 95% of drinking water is produced from deep groundwater layers, so the changing climate and extreme weather conditions, even a small change in the water cycle, can affect these aquifers and their recharge conditions. Therefore, the examination of these effects and consequences is a very important water management and water protection issue in the entire Carpathian basin. The effects of climate change were collected in detail in several studies, highlighting the affected areas in Hungary (Rothárné and Tóth, 2008 and Szlávik, 2003). As the number of extreme weather events is expected to increase, dry and wet periods will become more distinct. Longer periods without precipitation are forecasted in the dry season, while changes in the intensity of precipitation events are expected in the rainy season. An increase in the number of large amounts of precipitation falling in a short time is expected, which will increase the surface runoff due to the maximum infiltration capacity, so overall the amount of water reaching the groundwater table will decrease (Szöllősi-Nagy, 2020).

Recently, the impact of extreme weather conditions on groundwater has been investigated in a number of research projects, including at the University of Miskolc (Darabos et al., 2018; Madarász et al., 2015).

During my work, I tried to obtain new information about the recharge of groundwater by analyzing the available precipitation and groundwater time series, since in order to successfully solve water-related (global and local) problems, the cyclic behavior of the components of the water cycle must be understood. The aim of the thesis is to investigate the two elements of this hydrological cycle, the precipitation and the shallow groundwater layers in the Carpathian Basin, with the help of the available precipitation amounts and water level data series, using advanced mathematical methods.

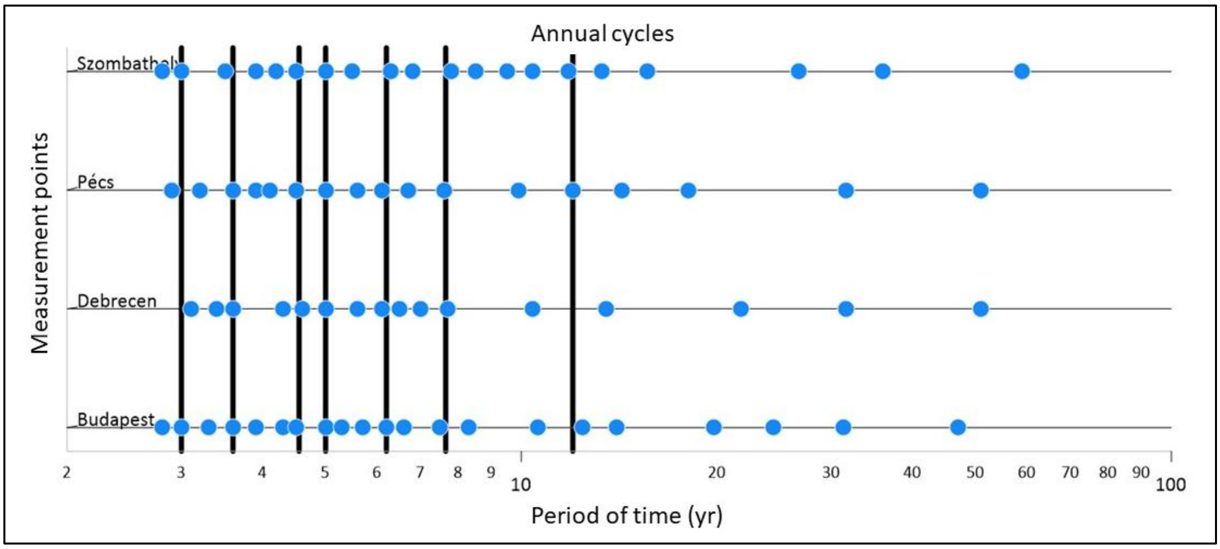
2. Applied methods, results – Examination of precipitation data

Based on the quantity and quality of the available data, I examined the precipitation totals in several resolutions for the entire Carpathian basin for the period 1901-2010. Due to the separation of local and regional effects, it is particularly important to compare the results obtained with other measurement sites in Hungary in addition to the main sample area of the research, the regions of Nyírség and Hajdúság. In the course of my work, I used spectral analysis based on discrete Fourier transformation to examine the annual, monthly and daily precipitation amounts from the measuring stations in Debrecen, Budapest, Pécs and Szombathely. With the help of the 110 datapoints included in the annual study, I was able to define 7 regional precipitation cycles (Figure 1), in addition to numerous local periodic components (Table 1). By using the monthly data, I managed to expand the number of nationally definable periods to 13 cycles, and I also showed a number of local cycles (Figure 2).

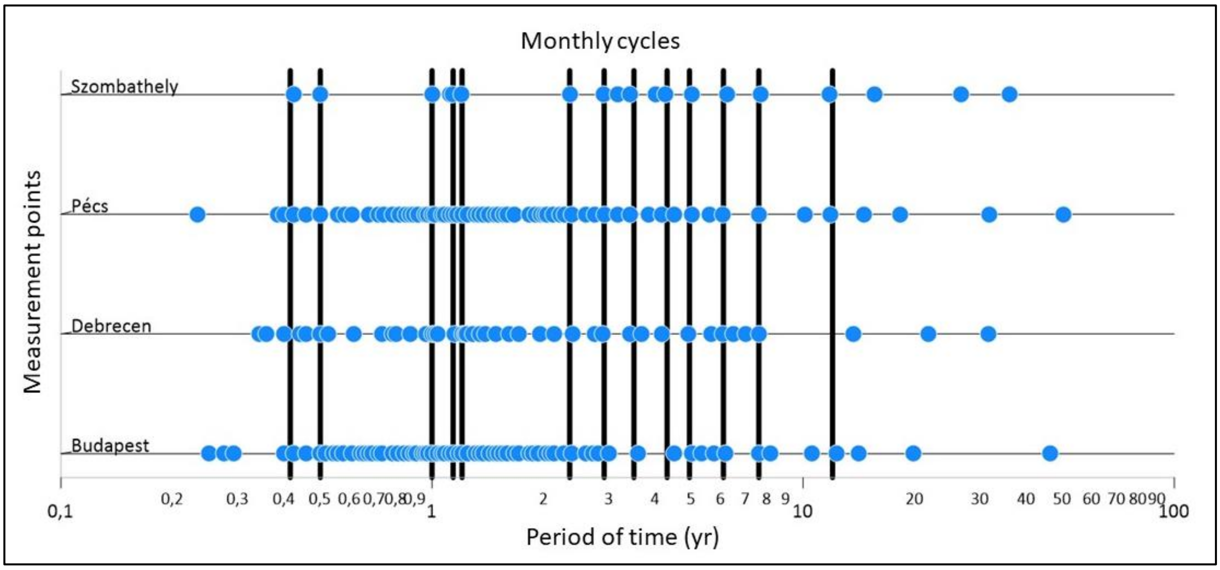
The large amount of daily data allowed me to perform calculations for several time intervals, so the beginning and the end of the 20th century became comparable, and possibly the changes could be mapped.

1. Table: Main and minor cycles calculated from the annual rainfall time series

Budapest		Debrecen		Pécs		Szombathely	
T [yr]	$\frac{A(T)_{max}^{lok}}{A(T)_{max}^{abs}}$ [%]	T [yr]	$\frac{A(T)_{max}^{lok}}{A(T)_{max}^{abs}}$ [%]	T [yr]	$\frac{A(T)_{max}^{lok}}{A(T)_{max}^{abs}}$ [%]	T [yr]	$\frac{A(T)_{max}^{lok}}{A(T)_{max}^{abs}}$ [%]
2.8	45.65	3.1	41.11	**2.9**	**88.95**	**2.8**	**50.20**
3	48.83	**3.4**	**56.89**	**3.2**	**61.44**	3	44.10
3.3	47.93	**3.6**	**100.00**	**3.6**	**95.02**	**3.5**	**71.06**
3.6	**90.15**	**4.3**	**71.45**	**3.9**	**64.36**	**3.9**	**54.00**
3.9	29.79	4.6	28.36	**4.1**	**82.77**	**4.2**	**55.97**
4.3	41.42	**5**	**77.45**	**4.5**	**100.00**	4.5	21.06
4.5	40.03	**5.6**	**55.18**	**5**	**99.50**	**5**	**52.84**
5	**90.88**	**6.1**	**61.87**	**5.6**	**55.28**	5.5	30.80
5.3	32.98	6.5	49.59	**6.1**	**66.19**	6.3	47.78
5.7	41.75	7	30.45	6.7	32.68	6.8	32.11
6.2	33.63	7.7	24.24	**7.6**	**60.27**	7.8	40.63
6.6	33.23	10.4	26.52	**9.9**	**67.53**	**8.5**	**51.41**
7.5	30.02	**13.5**	**69.34**	**12**	**54.49**	9.5	47.53
8.3	40.12	21.8	43.45	**14.3**	**65.71**	10.4	49.95
10.6	**53.15**	**31.6**	**77.77**	18.1	43.87	**11.8**	**80.05**
12.4	**60.56**	51	27.46	**31.6**	**73.43**	**13.3**	**61.30**
14	**57.74**			**51**	**55.10**	**15.6**	**72.15**
19.8	**59.76**					**26.7**	**100.00**
24.4	40.03					**36**	**80.94**
31.3	17.05					**59**	**65.26**
47	47.17						



1. Figure: Cycles calculated from annual data, common periods marked

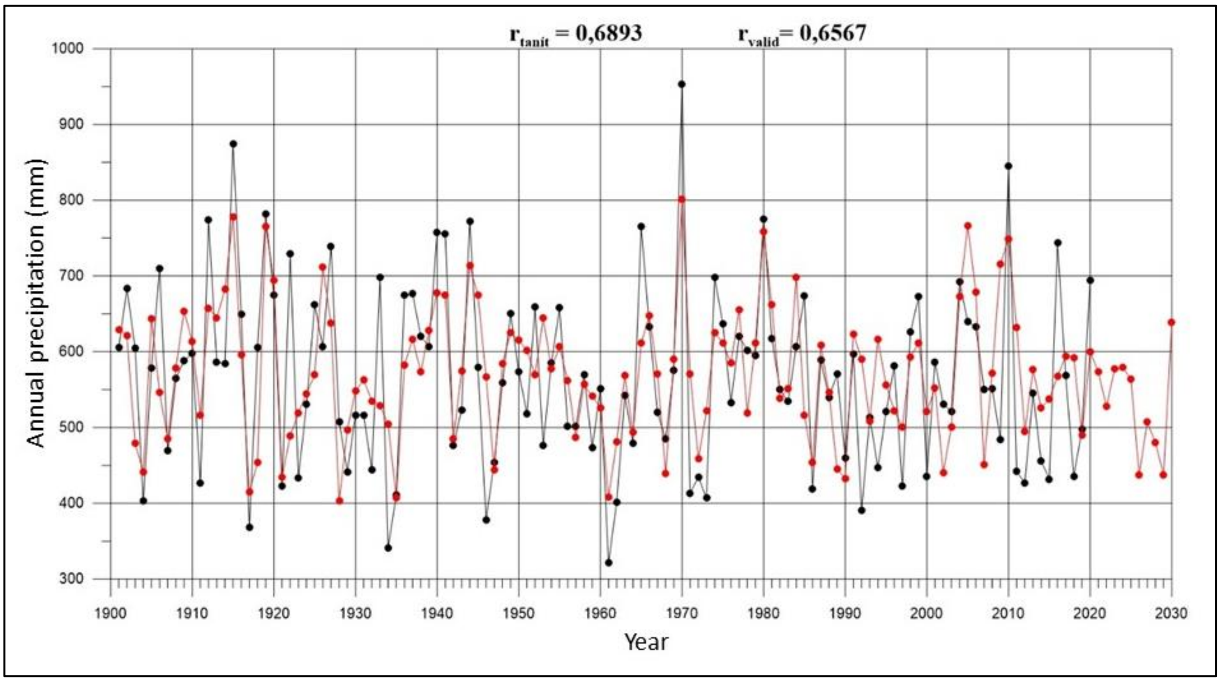


2. Figure: Cycles calculated from monthly data, marked with common periods

In the course of my work, I further examined the periods defined in Debrecen.

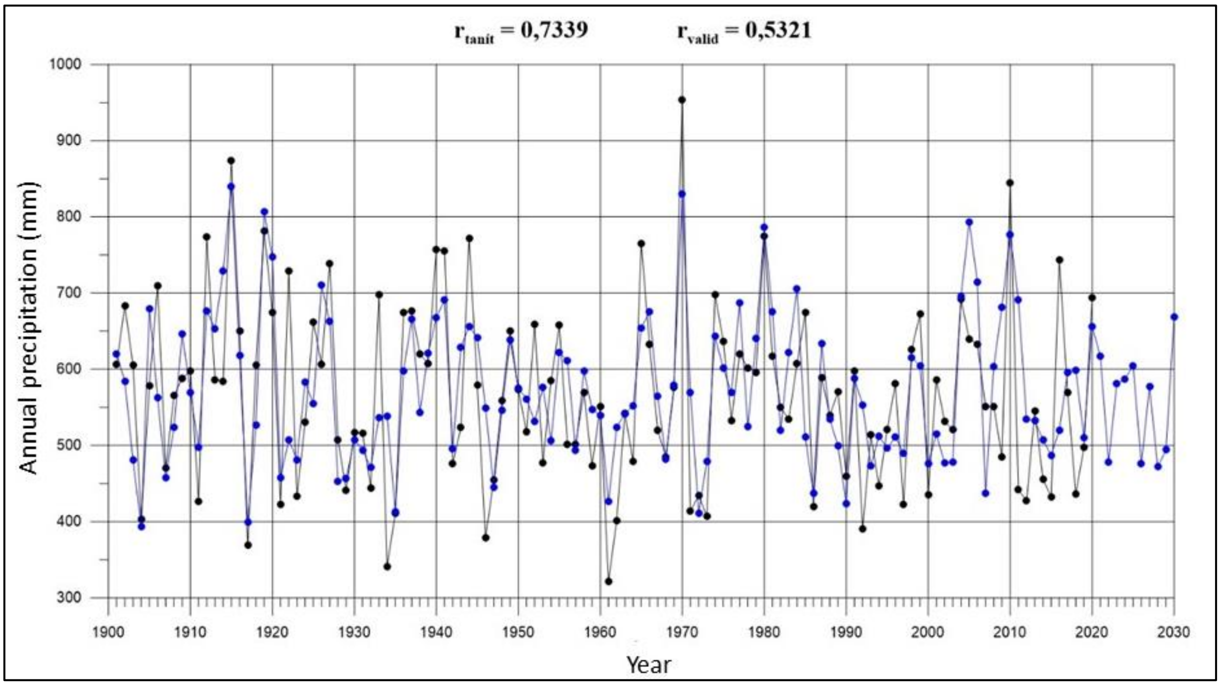
As a next step in order to get to know the area better, I used the property of the discrete Fourier transformation, that if the amplitude spectrum and the phase angle are known, the original time series can be restored. If I only use the main and secondary cycles I have shown, a deterministic time series can be generated, even beyond the time interval under investigation, making an estimate for the future.

To prepare the forecast, I selected the Debrecen measuring station. Using the monthly and annual precipitation amounts of the 110-year database, I made forecasts based on several scenarios. During the tests, the learning phase is the previously used period between 1901-2010, while the validation phase is the period that has passed since then until 2020.



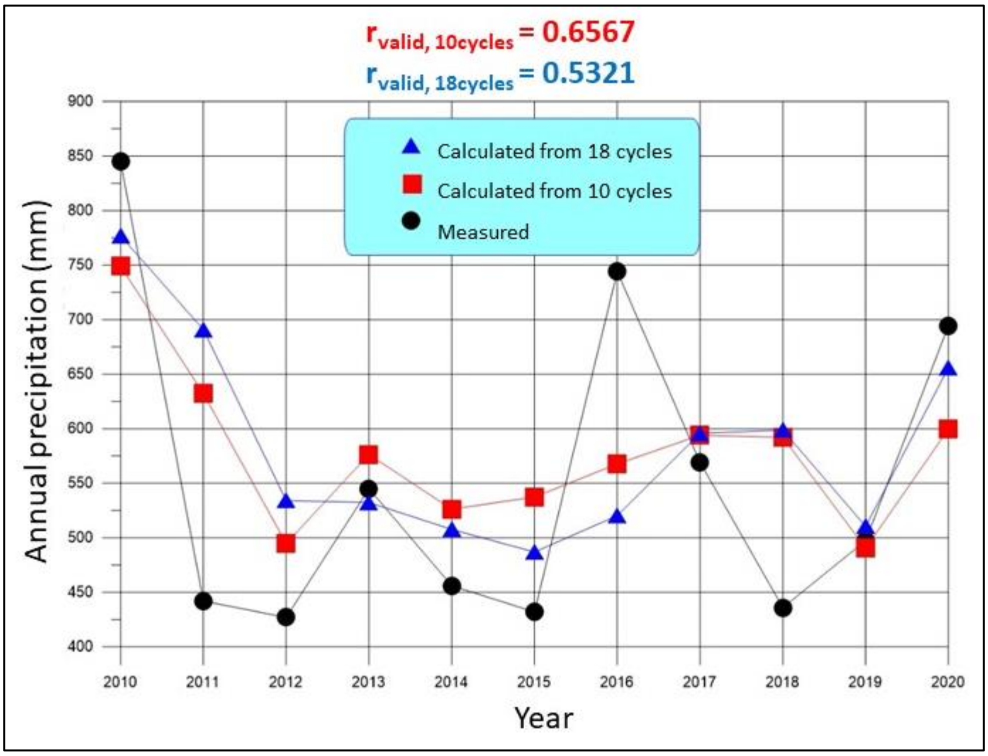
3. Figure: The forecast calculated from Debrecen's annual precipitation data using 10 cycles

In the first case, I used the 10 most dominant periods, the correlation coefficient of the calculated data series with the original measured precipitation amounts is 0.69, which is considered a moderately strong correlation. During the validation period, it is 0.66 (Figure 3).



4. Figure: The forecast calculated from Debrecen's annual precipitation data using 10 cycles

For the second calculation, all 18 major and minor cycles were used, so the correlation coefficient also increased, 0.73 in the teaching period, which is significantly higher (Figure 4). The validation phase is highlighted separately in Figure 5.



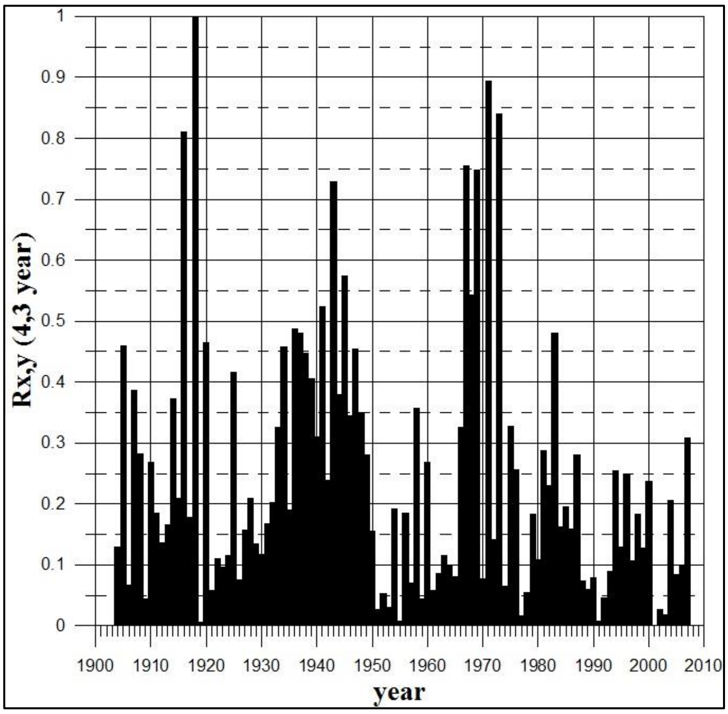
5. Figure: Correlation coefficients of the validation phase

The fact that a lower correlation coefficient can be calculated by using more periods during the validation phase can be an additional research direction in the future to determine which is the optimal number of periods to achieve the highest correlation.

During the calculations, deterministic calculated precipitation amount time series were also produced using the monthly data series, however, with the help of 15 periods, only a correlation coefficient of 0.47 was detected, which can be described as a weak relationship.

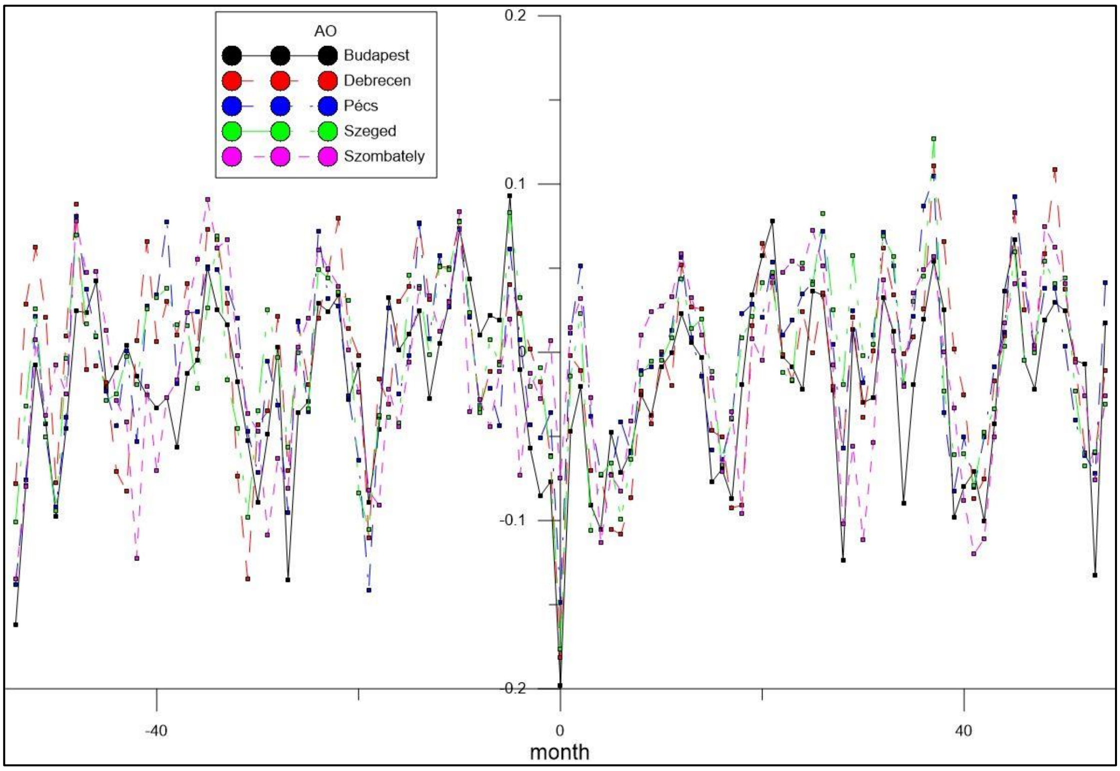
By increasing the number of periods and using the most dominant 164 cycles, I only got a correlation coefficient value of 0.62. The variability in monthly precipitation amounts is basically much greater than in the case of annual precipitation amounts, so the method did not prove to be effective for preparing this kind of forecast.

For further investigations, I used the Wavelet analysis methodology, which can be used to determine the time dependence and temporality of a dominant cycle. The sine wave with the appropriate period and unit amplitude was used. Each wavelet shows a maximum value near 4 places (correlation coefficient above 0.5), in the decades 1910, 1940, 1960, 1970. Within this is the wavelet of the 4.3-year cycle in Debrecen, with 4 maximum values, (in order) in 1918, 1971, 1973 and 1916. The years of the 1910s and 1960s almost always show the most dominant values of the cycles, while they are much less dominant after the 2000s. The wavelet result of the 4.3-year cycle is shown as an example in Figure 6.

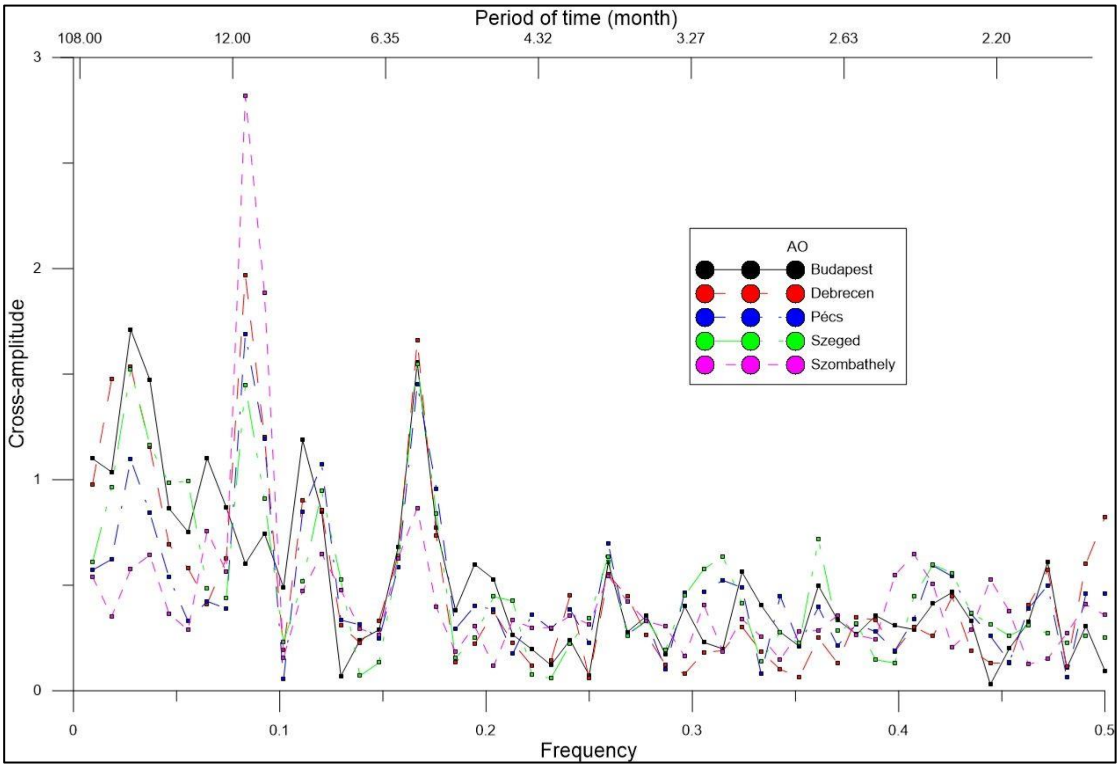


6. Figure: The result of the wavelet analysis of the 4.3-year cycle

As the last step in the analysis of the precipitation data, I examined how global climate phenomena affect the precipitation amounts measured in Debrecen. Using the methodology of cross-correlation and cross-spectral analysis, I examined the measured parameters of the Northern Oscillation, North Atlantic Oscillation, Atlantic Multidecadal Oscillation, Pacific-, and Southern Oscillation for the monthly precipitation totals. Based on the results of the linear analysis, the small but demonstrable relationship of remote connections present in the northern hemisphere can be quantified, however, the climate phenomena occurring in remote parts of the planet are not linearly related to the precipitation (Figures 7-8).



7. Figure: Cross-correlation between AO and Carpathian basin precipitation



8. Figure: Cross amplitude between AO and Carpathian basin precipitation

Since the examined area has significant needs for drinking, medicinal and irrigation water, a better understanding of its recharge is of strategic importance. My new research results from the immediate area of Debrecen can help to better understand local precipitation events and support a better determination of the recharge of groundwater layers in the future.

3. Applied methods, results – Grouping of groundwater data

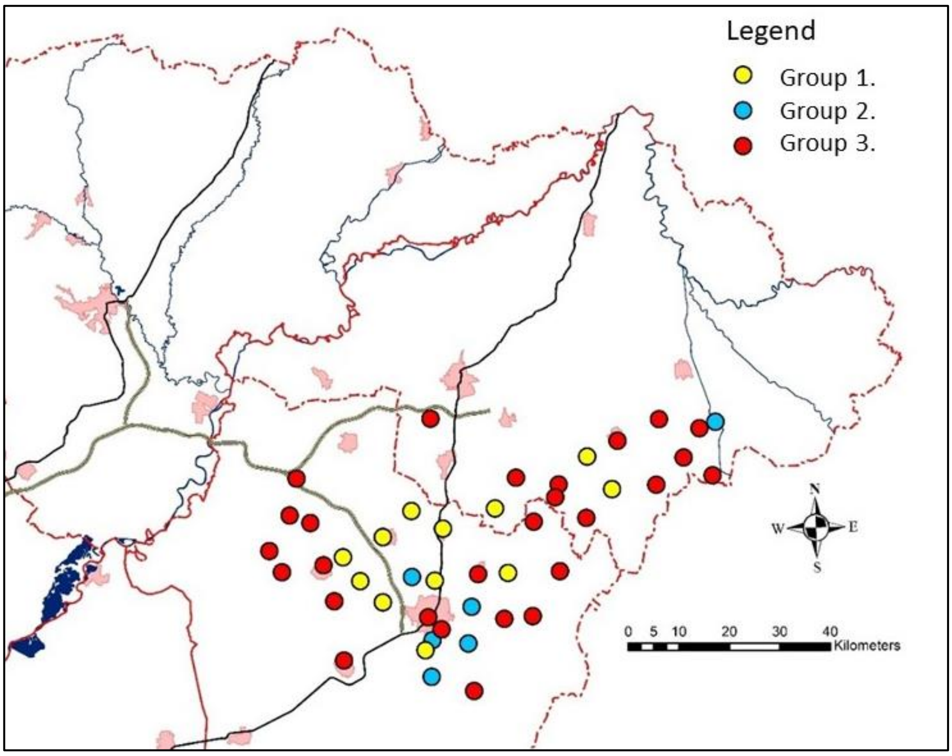
In the course of my work, I systematically selected 45 groundwater monitoring wells from the area of Hajdúság and Nyírség that are typical of the region. The characteristic of the wells is that they were measured over several time horizons, and in many cases, they are incomplete and sporadic. The goal was to develop a method based on which these time series can be grouped.

Based on the literature I have processed, analyzes based on time series analysis and neural networks are well suited for the analysis of groundwater data. However, these models have not yet been directly used to group data. The essence of my new approach is to combine these statistical methods with the grouping mathematical methodology in order to be able to perform the grouping even on my extremely incomplete and sporadic data set. In the first step, I broke down the time series based on their dynamic characteristics and grouped them. In the second step, I projected the time series into n-dimensional spaces with the help of neural networks, thus estimating the common components. Finally, I compared the results of the two methodologies.

Based on a thorough review of the existing literature, I believe that such a complex evaluation of the partial results so far has not been carried out, therefore I consider the research results presented in my thesis to be significant from the point of view of scientific and day-to-day water management, and partly of a methodological nature that can also be used in practice. With the basic equation, I was able to describe the annual flow of groundwater typical of the area, and I also managed to determine monthly coefficients.

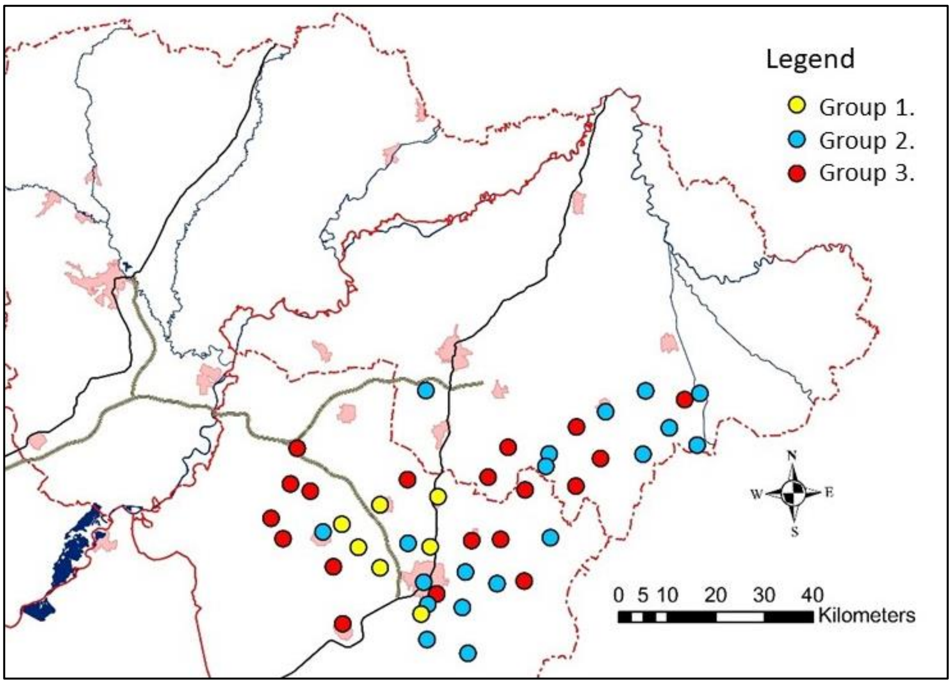
By increasing the complexity of the equations, I first performed trend-stationary and then difference-stationary modeling.

In the first round of grouping, I used the estimated coefficients of the trend-stationary autoregressive models - 12-month seasonal dummy variables and the coefficients of the 1- and 2-month lag variable. It can be concluded from the trained three groups (Figure 9) that they can be arranged in a row according to the average depth - with significant internal dispersion. The average depth of group 1 is 241 cm, group 2 346 cm and group 3 480 cm.



9. Figure: The results of the grouping based on the geographical location of the wells (with linear modeling)

In the second step, due to the nature of the data and frequent incomplete data, I chose a clustering procedure based on a neural network. When using neural networks, I did not make any prior assumptions about the form of the function, so it was possible to validate the clustering created in the first step. I estimated the neural network using the Adam optimization procedure, using the mean squared error (MSE) as the error function. I determined the cycle number, i.e. the stopping point of learning, using a validation sample. The results of the neural network are the coordinates of the embedding of the wells in 4-dimensional space, whose distances from each other represent the similarity of the dynamics of the wells. Based on these, I determined the clustering based on the methodology already performed on the results of the time series analysis.

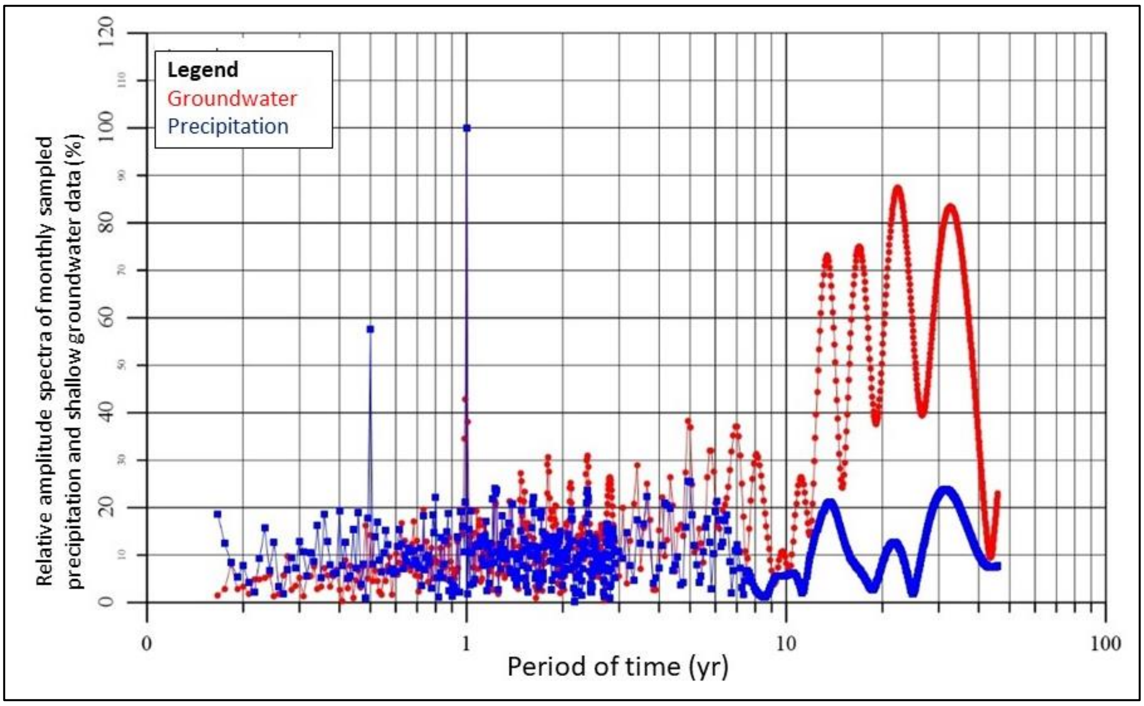


10. Figure: The results of the grouping based on the geographical location of the wells (with a neural network)

Comparing the two procedures, it can be concluded that despite the significantly flexible function form and increased degrees of freedom, the two completely different methodologies led to very similar results. Overall, it can be said that the developed methodology is suitable for the simultaneous analysis of this kind of data set. Sporadic time series of groundwater wells can be grouped based on dynamic characteristics using time series analysis and neural networks. The groups formed in this way are homogeneous in terms of their dynamic nature, so the information of incomplete data sets can be compressed. With the method, the depth limits of the groups in a given area can be specified using mathematical relationships.

4. Applied methods, results – Periodic components of shallow groundwater data

During my work, I used the methodology used in the analysis of precipitation time series, in order to better understand and quantify the relationship. In the first round, I examined the long-term data series of three selected shallow groundwater wells using discrete Fourier transformation-based spectral analysis. I also compared the data from the groundwater well in the Debrecen area with the results of the rainfall data, and I chose the results of the wells from Nyírség and Danube-Tisza Interfluve as an outlook for the calculations. With the help of cross-correlation and cross-spectral analysis, I managed to determine delay times for the case of several monitoring wells in the Hajdúság area, and I also calculated the periodic components inherent in the relationship.



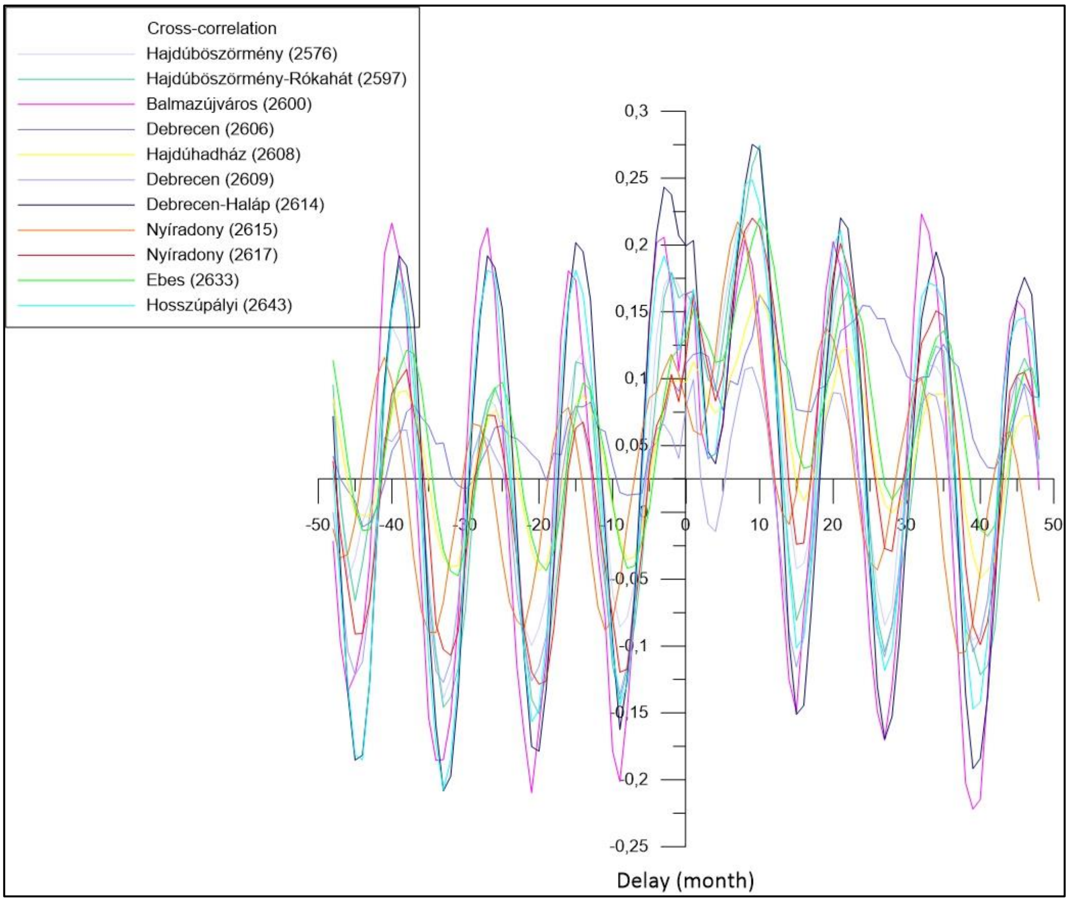
11. Figure: Spectrums of monthly sampling precipitation and groundwater level time series in Debrecen

2. Table: Lengths and relative weights of the most dominant cycles in the precipitation and groundwater level time series in Debrecen

Debrecen number	**prec. (rel. weight)**	**GW level (rel. weight)**
1.	**1 yr** (100%)	**1 yr** (100%)
2.	0.5 yr (57.6%)	12.3 yr (77.3%)
3.	**4.92 yr** (25.5%)	15 yr (45.4%)
4.	1.23 yr (24%)	18.9 yr (43.2%)
5.	31.5 yr (23.8%)	**5 yr** (41.7%)
6.	**2.39 yr** (23.6%)	10.5 yr (40.7%)
7.	**3.67 yr** (22.4%)	26.6 yr (38.1%)
8.	1.62 yr (22.2%)	9 yr (32.9%)
9.	0.8 yr (22.1%)	**2.38 yr** (32.9%)
10.	6.08 yr (21.4%)	**3.67 yr** (32.2%)
11.	13.7 yr (21.1%)	3.33 yr (31.4%)

Examining the spectra of the monthly sampling precipitation and groundwater level time series in Debrecen, it can be seen 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 effects which they trigger periodic changes in both rainfall and groundwater levels. Two longer-term cycles can be detected in the time series of both parameters, but they do not occur with exactly the same period time (Figure 11, Table 2).

For the cross-correlation and cross-spectral studies, I used the long-term groundwater level time series in 11 Hajdúság and Nyírség areas, as well as the monthly precipitation amounts measured in Debrecen.

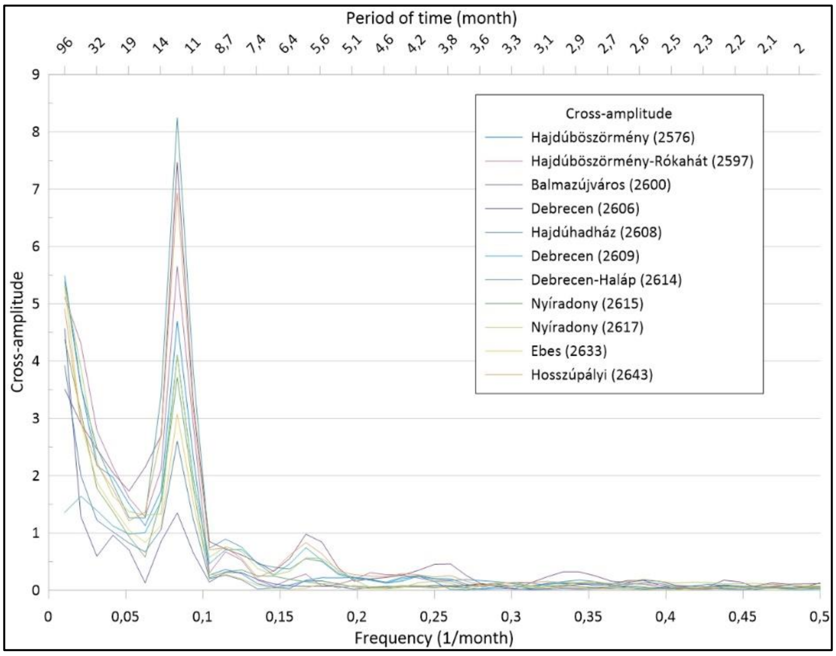


12. Figure: Results of cross-correlation calculations

Based on the results, it can be seen that a large amount of co-movement can be observed in the time series of the wells, the shift occurs between 8-10 months, which correlates best with the depth of the well.

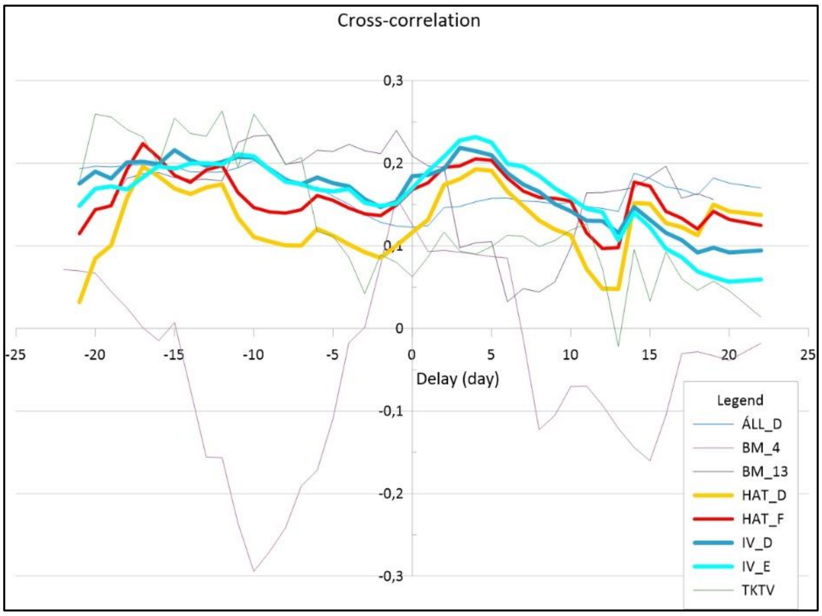
According to the results of the cross-spectral analysis, based on the period times, it can be seen that most of the wells have a periodicity of around 8 months, and some of them have a periodicity of around half a year. A 3-4 month cycle was also detected in two thirds of the wells. At the two measuring points located in Debrecen, I also showed the period times greater than the annual period.

For a more detailed examination, daily data with a better resolution than monthly data should be used (Figure 13).



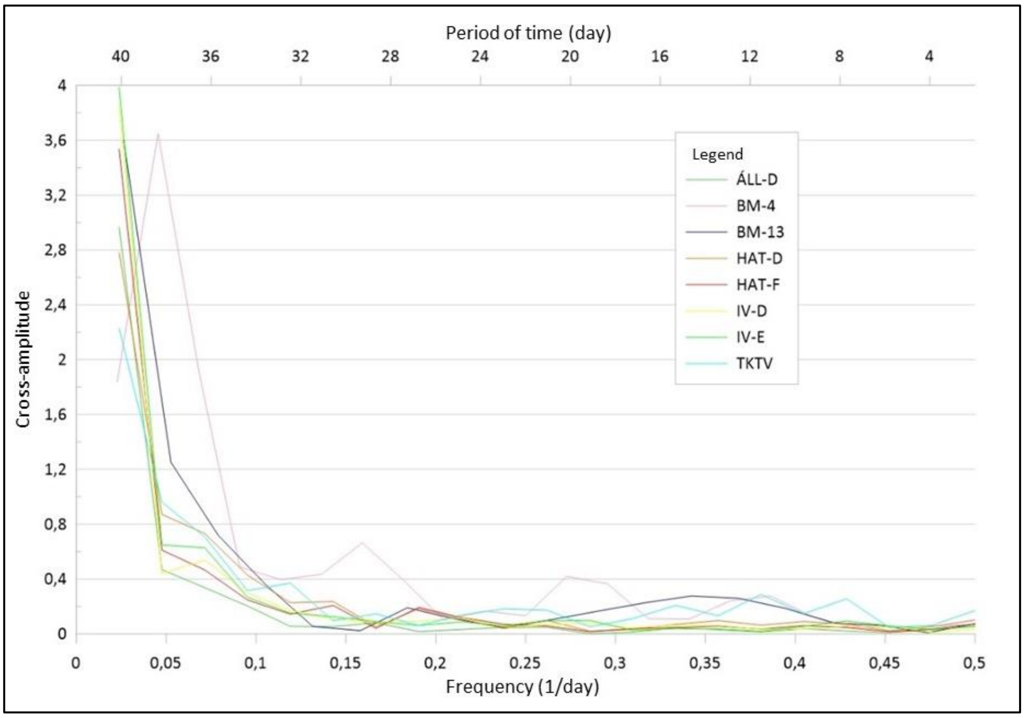
13. Figure: Groundwater level-precipitation cross-amplitude functions of the individual measurement sites

In order to carry out tests with daily data, I compared the data series of several groundwater monitoring wells from the Debrecen area.



14. Figure: The result of the cross-correlation calculation in Debrecen, based on daily data

Examining the relationship between time series of water level measured in wells and precipitation, no clear result can be shown in many cases. In the case of those wells where a clear maximum was detected during the examination of the relationship, a time lag of 3-4 days could be calculated.



15. Figure: Groundwater level-precipitation cross-amplitude functions of the individual measurement sites

Overall, during the spectral analysis, 25 and 27 cycles were detected from the two groundwater wells in Eastern Hungary, while only 18 from the one located between the Danube and Tisza.

The results of the cross-correlation studies show similarities with the findings of Ubell (1953) and with the several-month shift detected by Gy. Szabó (1960) in groundwater monitoring wells in Pest. Based on these, the displacement of several months successfully detected at the depth I investigated shows a real relationship in the investigated area.

In summary, it can be concluded that with the complex analysis of the rainfall totals and the groundwater level time series, it was possible to quantify many known relationships, several cycles with similar periods of time were detected from both data sets, thus demonstrating the direct relationship within the water cycle. I also successfully calculated the delay time of the connections near Hajdúság, Nyírség and Debrecen from monthly and daily data. Based on this, in the case of monthly values, a 7-8 month relationship can be demonstrated in the area, while in the case of daily values, a faster 3-4 day relationship can be found. I successfully made an estimate from the annual precipitation amounts, as well as demonstrated the effects of climate phenomena in the amount of precipitation. During the grouping of the data from the groundwater wells, I performed a cluster analysis using a new methodology, using the dynamic components inherent in the time series.

The results help to learn about the temporality of precipitation and groundwater, and help to understand the patterns and relationships inherent in the replenishment of subsurface layers. Based on the tests, I formulated the theses presented in Chapter 5.

5. Theses

Thesis 1: *I have developed a complex set of methods for the analysis of long-term hydrometeorological data, which is suitable for determining the deterministic and stochastic nature of the data series, as well as for making medium-term (5-10 years) forecasts. The set of methods includes the spectral analysis based on the discrete Fourier transformation, the prediction method made from the obtained cycles, and the wavelet analysis performed on the obtained cycles.*

Thesis 2: *From the 110-year-long annual and monthly precipitation total time series measured at four meteorological stations (Szombathely, Pécs, Budapest and Debrecen) in the country, which represent different domestic climatic conditions, I detected 13 common cycles in the temporal evolution of precipitation by means of spectral analysis. The cycles are the 0.4 years; 0.5 years old; 1 year old; 1.14 years old; 1.2 years old; 2.75 years 3 years; 3.5 years old; 4.5 years old; 5 years old; 6.2 years old; 7.6 and 12-13 years, behind which are global and regional climate phenomena. In addition, I defined additional local cycles in the data series of the measurement points.*

Thesis 3: *By examining the temporal dependence of the periods found in the Debrecen precipitation time series with the help of wavelet analysis, I determined when the deterministic and stochastic components were stronger in the period between 1900-2010. Based on the results, I determined that the deterministic effects were the most significant in the 1920-30 and 1960-70 decades. Thanks to the results, it can be stated that already earlier, in the 20th century, there were alternating periods when deterministic effects were more dominant and periods when stochastic effects prevailed more strongly, which is proven by the correlation values determined during the calculations.*

Thesis 4: *Based on the cycles obtained by the spectral analysis of the 110-year rainfall time series, I made a medium-term forecast for the sample area until 2030 based on several scenarios using the data measured in Debrecen. The estimate made using the 10 dominant periods gave a correlation coefficient of 0.68, while with the 18 cycles it gave a correlation coefficient of 0.73 compared to the original measured precipitation. The estimate was validated in the period between 2010-2020, with correlation coefficient values of 0.65 and 0.53. The analysis enables medium-term forecasting of annual precipitation values.*

Thesis 5: *Based on the cross-correlation and cross-spectral analysis of precipitation data and climate indices, I showed that in the case of certain global climate phenomena (AO, AMO and NAO), a clear linear relationship between climate oscillations and Carpathian basin precipitation can be demonstrated.*

Thesis 6: *I proved that the sporadic time series of shallow groundwater wells from the Hajdúság and Nyírség areas can be grouped based on dynamic characteristics, using time series analysis and neural networks. The depth limits of well groups can be defined in a given area. Thus, if we want to group the wells based on their dynamic characteristics, the average depth of the groundwater in the investigated area can be well predicted. The clusters formed in this way are suitable for further analyses.*

Thesis 7: *From the monthly average water level data of the selected groundwater monitoring wells of the Danube-Tisza junction, Hajdúság, and Nyírség, as well as the time series of the monthly precipitation amounts associated with them, I have demonstrated several similarities in the field of cyclical phenomena. The time series selected from all three areas includes the 1, 11-12, 5-5.5, and the 3.7-year cycle in two sample areas. In the periodicity analysis of both groundwater and precipitation data, I identified 1, 4,9-5; 2.38-2.39; 3.67, as well as a 12-13 year long cycle, behind which are the changes of the seasons, the effect of sunspot activity, and global climate phenomena. This confirms that the effects on groundwater strongly depend on the amount of precipitation.*

Thesis 8: *On the basis of cross-correlation and cross-spectral studies on the time series of rainfall and water level measured in the Hajdúság area, I established delay times and periods for each measuring site. Based on monthly data, a large-scale delay of 8-10 months on average can be detected in the relationship between precipitation and groundwater, which can be considered an integrating effect expressed in months. Using daily data, a delay time of 3-4 days was calculated for the immediate area of Debrecen, which is the concrete physical connection between the two parameters.*

6. References in the thesis booklet

1. **Darabos E., Miklós R., Tóth M. és Lénárt, L. (2018):** A BKÉR adatainak felhasználása a karsztkutatásban (*Use of BKWLMS data in karst research*). Műszaki Földtudományi Közlemények. 86(3), 66-78.
2. **Madarász T., Szűcs P., Kovács B., Lénárt L., Fejes Z., Kolencsikné Tóth A., Székely I., Kompár L. és Gombkötő I. (2015):** Recent ternds and activities in hydrogeologic reserach at the University of Miskolc, Hungary. Central European Geology. 58(1-2), 171-185.
3. **Rotárné S.Á. és Tóth G. (2008):** Klímaváltozás hatása a felszín alatti vizekre *(Impact of climate change on groundwater)*. Vízmű Panoráma. 16(2), 16-17, 19-20.
4. **Szabó Gy. (1960):** Talajvízszint változása Pest belterületén *(Changes in the groundwater level in the interior of Pest)*. Hidrológiai Közlöny. 40(2), 106-115.
5. **Szlávik L. (2003):** A klíma- és környezetváltozások földtudományi összefüggései - Klímaváltozás és a víz körforgása *(Geoscience correlations of climate and environmental changes - Climate change and the water cycle)*. Vízügyi Közlemények. 85(4), 533-535.

6. **Szöllösi-Nagy A. (2020):** A klímaváltozás hidrológiai hatásai: több víz, több aszály – mit tehetünk? *(Hydrological effects of climate change: more water, more drought - what can we do?).* in: Eörs S. (szerk.) (2020): Klímaváltozás és Magyarország. (Osiris Kiadó Kft., Budapest, 2020)
7. **Ubell K. (1953):** Talajvíztározódás csapadék hatására *(Groundwater accumulation due to precipitation)*. Vízügyi Közlemények. 35(2), 472-494.

7. Publications within the scope of the research

1. **Ilyés Cs., Tóth M., Szűcs P. 2023.** Calculating the Connection Between Precipitation and Shallow Groundwater, Multidiszciplináris Tudományok: A Miskolci Egyetem Közleménye, 13(3) pp. 292-299.
2. **Ilyés Cs., Szabó N. P., Dobróka M., Turai E., Szűcs P. 2023.** Klímajelenségek hatásainak vizsgálata 1500 éves vízszint adatsoron, in=A Kárpát-Medence Ásványvizei XVII: Nemzetközi Tudományos Konferencia, Csíkszereda, Románia, pp. 49-57.
3. **Kilik R., Ilyés Cs. 2023.** Klaszter és leíró statisztikai elemzés közel 1500 éves vízszint adatsoron. in=Új eredmények a műszaki föld- és környezettudományban 2023, pp. 318-328.
4. **Szabó N. P., Ilyés Cs., Turai E., Dobróka M., Kilik R., Miklós R., Hamdy E., Szűcs P. 2023.** Fourier Transformation and Unsupervised Learning for Extracting Hydrogeological Information from Time Series Data, in=14th IEEEE International Conference on Cognitive Infocommunications: Proceedings, pp. 19-24.
5. **Ilyés Cs., Szűcs P., Turai, E. 2022.** Appearance of climatic cycles and oscillations in Carpathian Basin precipitation data, Hungarian Geographical Bulletin, 71(1) pp. 21–37.
6. **Ilyés Cs., Wendo V. A. J. A., Carpio Y. F., Szűcs, P. 2021.** Differences and similarities between precipitation patterns of different climates, Acta Geodaetica et Geophysica, 56(4) pp. 781–800.
7. **Ilyés Cs., Tóth M., Lénárt L., Szűcs P. 2021.** Csapadék és talajvíz kapcsolatának spektrális vizsgálata, in=II. Országos Települési Csapadékvíz-gazdálkodási Konferencia Baja 2019, pp. 81–86.
8. **Ilyés Cs., Tóth M., Lénárt L., Szűcs P. 2021.** Csapadékösszegek és talajvízszintek kapcsolatának vizsgálata Debrecen környékén, in=XVI. Kárpát-medencei Környezettudományi Konferencia = 16th Carpathian Basin Conference for Environmental Sciences, pp. 134–139.

9. **Ilyés Cs., Turai E., Szűcs P. 2019.** Examination of the hydrologic cycle with long-term precipitation and groundwater level data, in=Groundwater management and governance. Coping with uncertainty, p. 179.
10. **Ilyés Cs., Szűcs P., Ilyés T. 2019.** Talajvizes idősorok vizsgálata szezonalitás alapján, in=XV. Kárpát-medencei Környezettudományi Konferencia, pp. 106–111.
11. **Ilyés Cs., Turai E., Szűcs P., Ilyés T. 2019.** Examination of Debrecen's 110-year rainfall data, Geosciences and Engineering: A publication of the University of Miskolc,
12. **Ilyés Cs., Turai E., Szűcs P. 2019.** Csapadékösszegek és talajvízszint idősorok spektrális elemzése, in=Országos Települési Csapadékvíz-gazdálkodási Konferencia, Baja tanulmányai, pp. 17–24.
13. **Wendo V., Ilyés Cs., Szűcs P. 2019.** Examining the differences and similarities of the precipitation patterns of Hungary and Kenya, Műszaki Földtudományi Közlemények, 88(1), pp. 141–146.
14. **Ilyés Cs., Turai E., Szűcs P. 2018.** Examination of the Hydrologic Cycles with Spectral Analysis, in=Lectures of 14th International Scientific Conference on Mineral Waters of the Carpathian Basin, pp. 7–15.
15. **Ilyés Cs., Turai E., Szűcs P. 2018.** Examination of rainfall data for 110 years using spectral and wavelet analysis, Central European Geology, 61(1) pp. 1–15.
16. **Szűcs P., Ilyés Cs., Turai E., Kompár L. 2018.** Szélsőséges időjárási viszonyok hatása a felszín alatti vizekre, in=Víz a gyógyászatban, pp. 22–33.
17. **Turai E., Ilyés Cs., Szűcs P. 2018.** Magyarországi csapadék és talajvízszint adatok spektrális elemzése, in=Műszaki Tudomány az Észak-Kelet Magyarországi Régióban 2018, pp. 382–389.
18. **Ilyés Cs., Turai E., Szűcs P. 2017.** Spektrális elemzésen alapuló előrejelzés Debrecen térségére, in=Tavaszi Szél 2017 Konferencia = Spring Wind 2017: Konferenciakötet I., pp. 427–435.
19. **Ilyés Cs., Turai E., Szűcs P. 2017.** 110 éves csapadékadatok vizsgálata spektrális analízissel és Wavelet-elemzéssel, in=Műszaki Tudomány az Észak-Kelet Magyarországi Régióban 2017 konferencia előadásai, pp. 146–153.
20. **Ilyés Cs., Turai E., Szűcs P. 2017.** Examination of 110 year long Rainfall Data using Spectral and Wavelet Analysis, in=Proceedings Book of the 20th Congress of Hungarian Geomathematicians and 9th Congress of Croatian and Hungarian Geomathematicians "Geomathematics in multidisciplinary science – The new frontier?", pp. 28–35.
21. **Ilyés Cs., Turai E., Szűcs P. 2017.** Csapadékösszegek periodicitás vizsgálatán alapuló előrejelzés Debrecen térségére, in=XII. Kárpát-Medencei

Környezettudományi Konferencia = 12th Environmental Science Conference of the Carpathian Basin, pp. 104–111.

22. **Ilyés Cs., Turai E., Szűcs P., Zsuga J. 2017.** Examination of the cyclic properties of 110 – year – long precipitation time series, Acta Montanistica Slovaca, 22(1) pp. 1–11.
23. **Turai E., Ilyés Cs., Szűcs P. 2017.** Talajvízszint-adatok spektrális feldolgozásának eredményei, Műszaki Földtudományi Közlemények, 86(1) pp. 60–68.
24. **Ilyés Cs. 2016.** Országosan kimutatható ciklusok hosszú idejű csapadék idősorokban, in=Doktoranduszok Fóruma 2016, Miskolci Egyetem, Műszaki Földtudományi Kar, pp. 33–39.
25. **Ilyés Cs., Turai E., Szűcs P. 2016.** Hosszú idejű csapadék idősorok spektrális elemzésén alapuló előrejelzés készítése Debrecen területére, in=Műszaki tudomány az Észak-Kelet Magyarországi régióban 2016, pp. 168–174.
26. **Ilyés Cs., Turai E., Szűcs P. 2016.** 110 éves hosszúságú hidrometeorológiai adatsorok ciklikus paramétereinek vizsgálata, Hidrológiai Közlöny, 96(1) pp. 61–70.
27. **Ilyés Cs., Turai E., Szűcs P. 2016.** Csapadékösszegek periodicitásvizsgálatán alapuló előrejelzés készítése Debrecen területére, in=XII. Kárpát-medencei Könyezettudományi Konferencia = XII. Environmental Scientific Conference of the Carpathian Basin, p. 1.
28. **Szűcs P., Ilyés Cs., Turai E. 2016.** Hidrológiai ciklusok változásának hatása a felszín alatti vízforgalomra, in=XII. Nemzetközi Tudományos Konferencia a Kárpát-medence Ásványvizeiről, pp. 1–7.
29. **Ilyés Cs., Turai E., Szűcs P., Kompár L., Osváth K. 2015.** A Nyírség havi csapadékviszonyainak komplex elemzése különös tekintettel a leíró statisztikai és ciklikus komponensek vizsgálatára, in=Proceedings of the 11th International Scientific Conference on Mineral Waters of the Carpathian Basin, pp. 2–10.
30. **Ilyés Cs., Turai E., Szűcs P. 2015.** A Nyírség csapadékidősorainak statisztikus és ciklikus jellemzőinek változása, in=Műszaki Tudomány az Észak-kelet Magyarországi Régióban 2015, pp. 392–397.