OCCURRENCE OF THE DRY PERIODS IN EUROPEAN RUNOFF SERIES

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Abstract: Low flows of the Central European rivers in last years raised question if similar situation occurred also in the past or it indicates something extraordinary. The aim of the first part of the paper is to analyse the occurrence of the dry and wet periods in the Danube runoff series along the whole stream. The mean annual runoff from 7 stations along the Danube was taken for the analysis of the long-term variability of the annual flows. The most wet decade in Orsova was 1910–1919, and the driest one in 1857–1866. In the study some methods of the long-term trends identification in the hydrological time series are presented. Apart from the classical methods (like that of moving averages) the paper focuses in detail on the Hodrick-Prescott (HP) filter.
The dry periods of other 17 important European rivers are analysed in the second part of the paper. The annual discharge time series were recalculated to the standardised time series for three areas: territory of the West and Central Europe, territory of the East Europe and territory of North Europe. We used the Hodrick-Prescott (HP) filter for identification of the long-term trend of the standardized annual flows. The statistical analysis shows that in case of these series we can not observe long-term increase or decrease of the flows in last 150 years. We can identify only wet and dry periods of different duration. The extraordinary dry period occurred about the year 1863 as well as 86 years later about the year 1947 in Western and Central Europe. We identified the length of about 28–30 years of the dry cycles in Europe. In Eastern Europe are the peaks of the wet and dry cycles shifted by a few years compared to Northern and Western Europe. Generally we can state that the trend analysis did not show any important trends in selected European runoff series during the last 150 years.
Keywords: discharge, Europe, time series analysis, Hodrick-Prescott filter, long-term trends

VORKOMMEN VON TROCKENEN PERIODEN IN DEN EUROPÄISCHEN ABFLUSSREIHEN

Zusammenfassung: Die niedrige Abflüsse der Flüsse Zentraleuropas während der letzten Jahren haben die Frage hervorgerufen, ob es auch in der Vergangenheit zu ähnlichen Abflußverhältnissen kam, oder ob es etwas außergewöhnliches bedeutet. Zweck des ersten Teiles dieses Beitrages ist das Vorkommen von den Trocken – und Naßperioden in der Danauabflußserie zu analysieren, und zwar entlang der ganzen Flußstrecke. Für die langfristige Analyse der Variabilität, der mittlere Jahresabfluß von 7 Pegelstellen entlang der Donau wurde benutzt. Die nässeste Dekade im Pegel Orsova war die 1910 – 1919, und die trockenste war 1857 – 1866. In dem Beitrag sind auch einige Methoden für die Identifizierung der langjährigen Trenden in den hydrologischen Zeitreihen präsentiert. Im Unterschied von klassischen Methoden (wie z.B. die der gleitenden Mittelwerte), im Beitrag konzentrieren wir in Detail auf den Hodrick – Prescott (HP) Filter.
In dem zweiten Teil des Beitrages sind die Trockenperioden der 17 anderen wichtigen Flüsse Europas analysiert. Auf Grund der ursprünglichen Abflußreihen wurden standardisierten Abflußreihen entwickelt, für die Gebiete West-, Ost-, Zentral-, und Nordeuropa. Für die Feststellung der langjährigen Abflußtrende des standardisierten Jahresabflusses benutzten wir den Hodrick – Prescott (HP) Filter. Die statistische Analyse zeigt, dass in diesen Zeitreihen lässt sich kein Trend (weder steigend noch sinkend) während der letzten 150 Jahren feststellen. Es lassen sich nur Trockem- und Naßperioden von verschiedener Dauer zu identifizieren. Außerordentlich trockene

Perioden kamen herum den Jahren 1863 und 1947 vor, und zwar in West- wie auch in Zentraleuropa. Wie stellten auch die Länge der Zyklen der Trockenperioden als um 28 – 30 Jahren fest. In Osteuropa sind die Scheitel der trockenen und nassen Zyklen um einige Jahren verschoben im Vergleich mit jenem in Nord- und Westeuropa. Im allgemeinen kann man sagen daß die Trendanalyse hat keine bedeutende Trende während der letzten 150 Jahren in den ausgewählen Abflußreihen Europas bestätigt.
Schlüsselwörter : Abfluß, Europa, Datenreihenanalyse, Hodrick – Prescott Filter.

Introduction

Detection of the changes in river discharge trends is the most important and (at the same time) the most complicated step of water amount prognosis. Statistical analysis of the runoff oscillations depends on availability of long-term data series.

Systematic measurements of runoff in modern era started relatively late. The longest time series are available in Europe, but they do not exceed 200 years (Goeta (since 1807), Rhine (1808), Neman (1812), Dnieper (1818), Wesser (1821), Danube (1840), Vuoksa (1847), Elbe (1851), Neva (1859), Loire (1863), ...).

The longest available time series of mean annual runoff of the selected European largest rivers were used to analyse the long-term runoff trends.

In the first part of the paper, the occurrence of the dry periods in Danube River basin is analysed. The trend analysis of discharge time series of selected European main rivers is discussed in the second part of the study.

The annual runoff data series of European continent were obtained from following data sources:

i) Global Runoff Data Center in Koblenz, Germany;

ii) CD-ROM World Freshwater Resources prepared by I. A. Shiklomanov in the framework of the International Hydrological Programme (IHP) of UNESCO.

Runoff series fluctuations have their natural origin. Apart from it river discharge may have changed due to a range of human activities. Dams and artificial reservoirs dramatically change the natural flow regime. Currently the problems of the long-term runoff variability were discussed with respect to climate change. A number of studies was published all over the world. E.g., a special section of Hydrological Science Journal in February 2004 dealt with the issue of detecting changes in hydrological data. Authors Kundzewicz and Robson (2004), Sheng and Pilon (2004), Xiong and Guo (2004), Callčde et al. (2004) focused on detecting changes in hydrological long time series. In Radziejewski and Kundzewicz (2004) a new concept of visualisation of the comprehensive change detection is demonstrated. In Burn et al. (2004) the trends in the Liard River (northern Canada) were investigated using Mann-Kendall test. They showed that the observed trends are related to both, trends in meteorological data and a large-scale oceanic and atmospheric process. In Slovakia, Hlavcova et al. (1999) studied the possible impact of climate change upon runoff regime and analysed the unfavourable decreasing runoff trend in 1981–1995. Kostka and Holko (2000) studied the impact of climate changes to hydrological regime in small mountainous basin, and Halmova (2000) analysed the water storage in reservoirs. Pekarova and Miklanek (2004) analysed long-term course of 27 discharge series from the database of National Climate Programme SR (period 1930–2000). Regardless the fact that they showed the decrease of discharge in South Slovakia in decade 1982–1993, they emphasize from the long term point of view the necessity to identify hidden periods in the long-term series. As mentioned in Pekarova (2003) and Pekarova et al. (2003), it is necessary to come out from sufficiently long time discharge series, because of possible confusion between trend and cyclicity. Therefore, in the first step of discharge series analysis, we have to separate hidden cycles from long-term trend.

1. Methods

The basic methods for the long-term trend identification are:

- Exploratory data analysis

- Tests for step change (for example Wilcoxson-Mann-Whitney test, Distribution-free CUSUM test, Kruskal-Wallis test, ...)
- Tests for trend (Sperman's ρ test, Kendall's τ test, ...)

The general guidance to the methodology of the change detection in the hydrological time series can by found in Prochazka et al. (2001).

Generally, the most common assumptions in change point hypothesis testing are normality (population is distributed normally) and statistical independence (randomness) of observations.

1. Therefore, in the first step we test, whether the discharge time series x_t is distributed normally. In the case the series is not of normal distribution, we use appropriate transformation and work on with transformed time series y_t.
2. Then we test the covariance structure of the series y_t: we look for hidden periods, trend, and autoregressive and moving average component of the series.
   a) We search hidden periods by periodogram with Fisher's test or by combined periodogram method (Pekarova et al. 2003). In the case the hidden periods were found in the time series, we try to remove the harmonic (deterministic) component from the time series;
   b) We test long-term trend with Sperman's ρ test, or Kendall's τ test, ...;
   c) To remove the trend component (linear, quadratic), autoregressive component, and moving average component from the time series we search for the appropriate Box-Jenkins ARIMA model (autocorrelation function, partial autocorrelation function). We have to test the correctness of the ARIMA model specification (the autoregressive part of the B.-J. model must be stationary, the moving average part must be invertible, and residuals/innovations must be Gaussian white noise).

When significant periods λ_j, long-term trend, and autocorrelation component in the series are find, it is possible to describe the discharge time series y_t by the model of the following general form:

$$y_t = A_0 + \underbrace{\sum_{j=1}^{m}\left(A_j \cos(\lambda_j t) + B_j \sin(\lambda_j t)\right)}_{\textit{a harmonic component}} + \underbrace{ARIMA}_{\textit{an ARIMA component}} + z_t \qquad t = 1, ..., N. \qquad (1)$$

where:

y_t - the transformed average annual discharge;

λ_j - the significant frequencies given by the periodogram;

A_j, B_j, $j = 1,2, \dots m$ - parameters of the harmonic component (A_0 – the mean of the time series);

ARIMA - the autoregressive component, a.k.a. Box-Jenkins model;

z_t - the adjusted time series, residuals.

This model can be used for the long-term annual discharge prediction (Lohre et al.).

1.1. Hodrick-Prescott filter

To identify long term trends in this study we used the Hodrick-Prescott filter (HP filter) (Maravall, 2001). Hodrick-Prescott filter decomposes given time series to a trend as well as a cyclical component. Asset of HP-filter is, (compared to moving average technique) the values of trends are calculated as well as for the end values of the series, that is great advantage for the prognoses of discharge in the future.

Assume we are interested in decomposing a time series of yearly discharge $\{x_i\}_{i=1}^{n}$ into a long-term trend Tr_i and a residual, C_i. The HP filter provides the sequences $\{Tr_i\}_{i=1}^{n}$ and $\{C_i\}_{i=1}^{n}$ such that:

$$x_i = Tr_i + C_i \qquad i=1, ...,n, \qquad (2)$$

and the loss function

$$\sum_{i=1}^{n} C_i^2 + \alpha \sum_{i=3}^{n} (\nabla^2 Tr_i)^2 \qquad (3)$$

(where: $\nabla^2 Tr_i = Tr_i - 2.Tr_{i-1} + Tr_{i-2}$)
is minimized.

The first term in (3) penalizes large residuals (i.e. poor fit), while the second term penalizes lack of smoothness in trend. The parameter α regulates the trade-off between the two criteria.

1.2. Occurrence of the dry periods in Danube river basin

We assembled the mean annual runoff series of seven stations along the Danube River from the GRDC (Global Runoff Data Center, Koblenz) database with the aim to analyse the long-term variability of the mean annual runoff along the Danube River: 1. Hofkirchen; 2. Achleiten; 3. Kienstock (till 1970 Stein - Krems); 4. Bratislava; 5. Nagymaros; 6. Turnu Severin (till 1970 Orsova); 7. Ceatal Izmail.

The wet and dry periods as well as the long-term trends are easy to show on the plots of the filtered values. In Fig. 1 is the plot of double 5-year moving averages of the Danube discharge in seven stations and at the mouth. The wet and dry periods are easy to be identified at the graph. The course of the individual periods is identical along the whole river stretch.

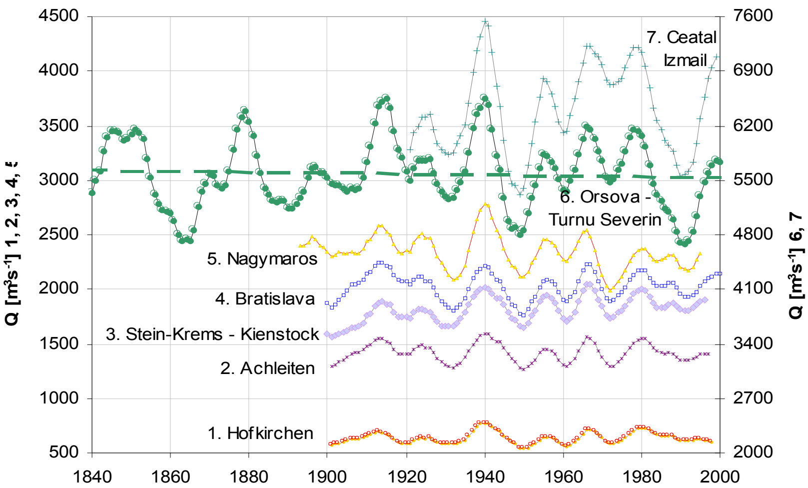


Figure 1. The double 5-year moving averages of discharge in seven Danube stations along the river.

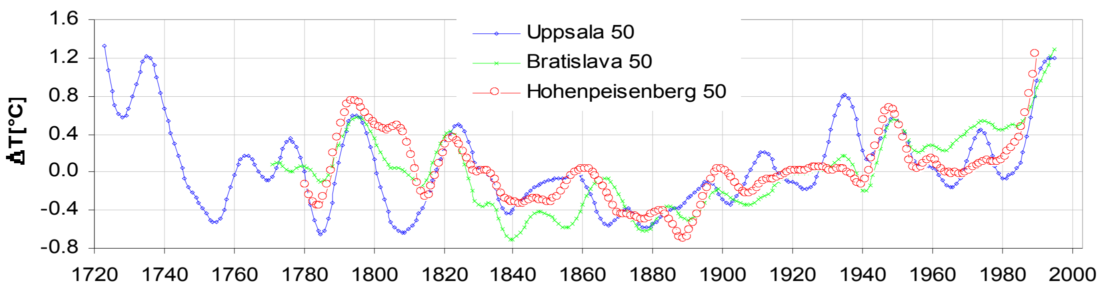


Figure 2. Courses of the filtered annual air temperature (HP filter for α = 50), deviation from the long-term mean. Hohenpeissenberg, Uppsala (Moberg, Bengström, 1997) and Bratislava stations (Koncek, 1972), 1720–1995 period.

The data from the station Turnu Severin are very important for the trend analysis, as they are collected in a rocky profile since 1840 and we can trust them. The minimum annual discharge in Orsova (today Turnu Severin) was in 1863, Qa_{min} = 3471 m^3s^{-1}, while the maximum one was in 1915, Qa_{max} = 8265 m^3s^{-1}. The analysis of the Orsova data shows that the wettest decade was in 1910–1919, while the driest one was in 1857–1866, when the global maximum and minimum annual discharge was observed, respectively.

These results indicate that the period around the year 1862 was the driest period in the Central Europe since 1840. It is interesting to notice that in the period around the year 1862 was the mean annual air temperature in Europe lower by about 0.8°C compared to the 1990s` (see Fig. 2).

Two of the driest periods of the instrumental era occurred in very different temperature conditions. It shows that the mean annual air temperature does not have direct influence on the runoff depth and the long-term runoff variability has its own dynamics. Therefore we cannot automatically suppose, that the expected increase of the air temperature will result in decrease of runoff in Danube River.

2. Occurrence of the dry periods in European runoff series

Our aim is to find if and when the dry periods occurred in other European runoff series. The longest runoff records are available in Europe and therefore they are suitable for the identification of the long-term trends. We analysed more than 30 runoff series of the main European rivers. We used Hodrick - Prescott filter for visual identification of the cyclic component with parameter α=10, 50, 400, and 1600 (Pekarova and Pekar, 2002). The results of the filter application on mean annual runoff series of Danube in Turnu Severin, Rhine in Cologne, Göta and Neva rivers for α = 10, 50, 400, and 1600 are in Figs. 3a-d.

On Fig. 3a we can identify significant dry periods 1861–1865; 1945–1948, and 1988–1993 on Danube. According to Lindström and Bergström (2004), the beginning of the seventies in last century (period 1972–1976) was extremely dry in Sweden (see Fig. 3c), and the end of the 20th century was above average wet (unlike the central Europe). Dry periods were recorded in Göta runoff series in 1855–1860 and 1940–1945, too.

The 29-year cycle of runoff variability can be clearly identified in the Neva river series. The Neva river drains the territory of the Finnish and Russian lakes which accumulate large volume of water, and thus multiannually regulate and smooth the runoff. The Neva runoff records are processed since 1859, therefore the dry period around 1858 is not recorded. It is possible to prolong the Neva runoff series by regression to the Finnish river Vuoksa having the records from 1847. The driest year on Neva was in 1940 with the mean discharge of 1340 m^3s^{-1}, the wettest one was 1924 with the mean discharge of 3670 m^3s^{-1}. The driest period on Neva occurred in 1939–1942, by about 7 years earlier than in the Danube basin. At the same time we should notice that the period 1939–1942 was quite wet in the Danube basin. Such analysis supports the hypothesis, that the dry periods do not occur in European rivers simultaneously, but they are a few years shifted depending on location of the basins.

The time lag of the dry periods between Danube and Neva runoff is shown on Fig. 4. The mean time lag is about 11-12 years. Typically, the dry periods in the Danube basin were accompanied by the wet periods in the Neva basin in the 20th century.

It follows from the analysis that we did not find long-term continuous decrease or increase of the runoff. We can identify the dry and wet periods in river runoff series. In case of the cyclic series (and hydrological series are such) we cannot express the trend simply by the linear function and to expect the continuation of the linear development in the future. If we want to apply the linear trend function, we must relate it to specific period. E.g. the linear trend of Rhine runoff was decreasing in 1870–1950, and increasing in 1945–1985.

In the next paragraphs we will try to compile one runoff series representing the runoff from Europe and to identify the long-term trend in such series.

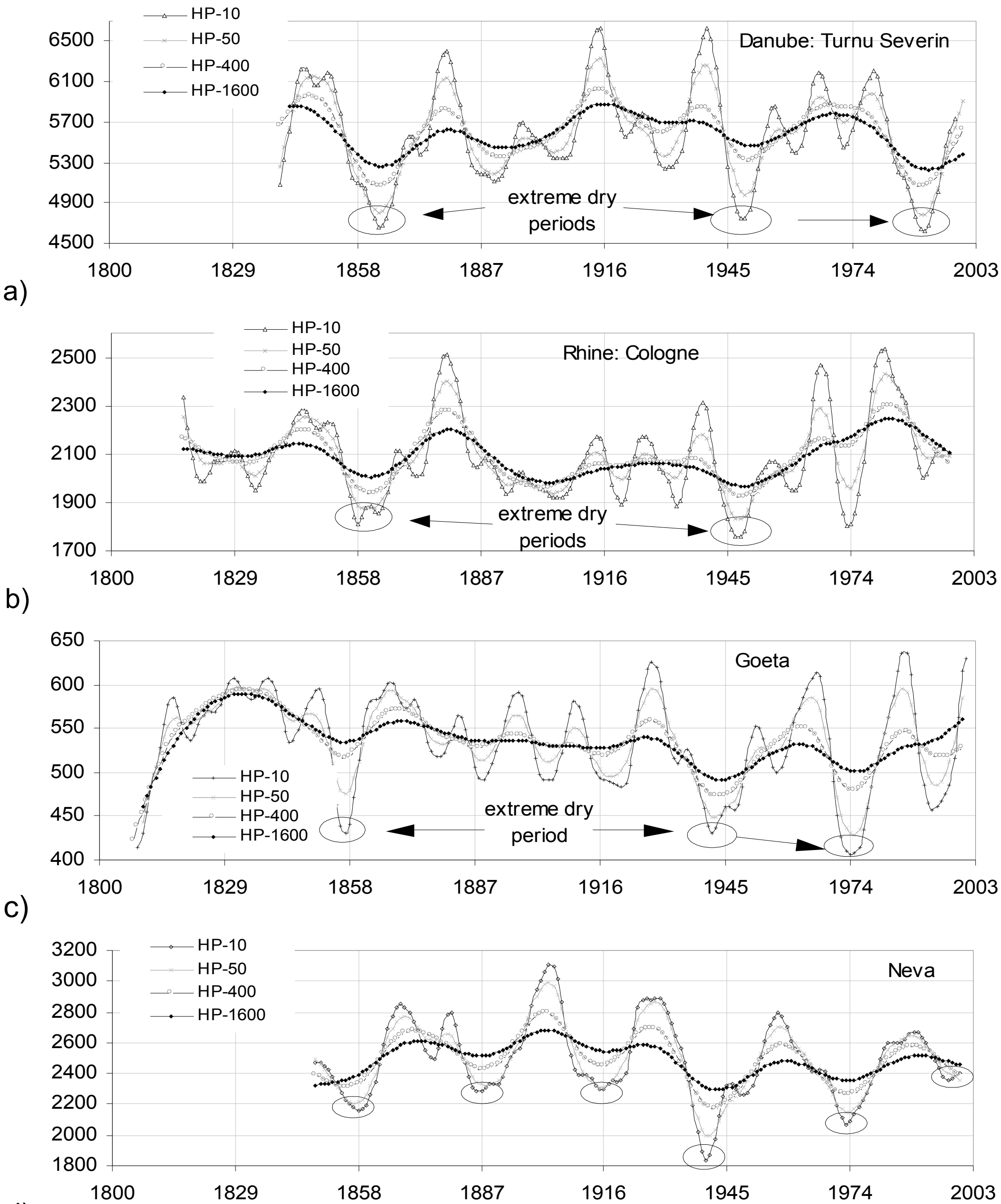


Fig.3 Course of the filtered annual mean discharge in [m^3s^{-1}], HP filter for α = 10, 50, 1600, 6400. Identification of dry and wet period, as well as of long - term trend.
a) Danube at Turnu Severin, period 1840–2000; b) Rhine at Cologne, period 1808–1998; c) Göta, period 1808–2002; d) Neva, period 1859–2000.

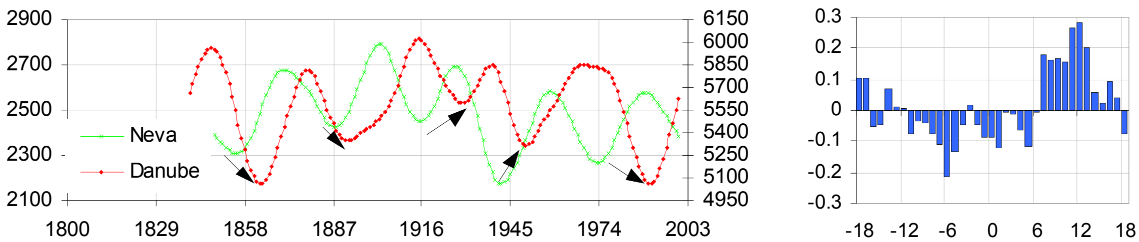


Figure 4. Course of filtered annual discharge [m^3s^{-1}] HP-filter for α = 400, Danube and Neva. Lag of dry periods – left. Cross-correlations between Danube and Neva discharge (raw data) - right.

2.1. Long term trend of European discharge series

In order to identify trends for some European rivers, discharge time series of eleven rivers for West/Central Europe were used (Rhine: Cologne, DE (1816–1997), Neman: Smalininkai, LT (1912–1993), Loire: Montjean, FR (1863–1986) Wesser: Hann-Muenden, DE (1831–1994), Danube, Turnu Severin, RO (1840–1988), Elbe: Decin, CZ, (1851–1998), Oder: Gozdowice, PL (1900–1993), Vistula: Tczew, PL (1900–1994), Thames: Kingston, GB (1881–2000), Rhone: mouth, FR (1921–1986), and Po: Pontelagoscuro, IT (1918–1979)). Three time series for East Europe were used (Dniepr: Locmanskaja Kamjanka, UA (1818–1984), Don: Razdorskaya, RU (1891–1984), and Volga: mouth, RU (1882–1998)). For North Europe four time series were used (Neva: Novosaratovka, RU (1859–1984), N. Dvina: Ust-Pinega, RU (1881–1990), Goeta: Vaenersborg, SE (1807–1992), Pechora: mouth, RU (1921–1987)). Location of selected rivers is sketched on Figure 5, basic hydrological characteristics are presented in Table 1. These data series were completed by the multiple regression methods (period 1850–1997) and the standardised average discharge time series was computed.

From the point of view of the annual discharge, the driest year during the period 1850–1997 was the year 1921. The extremely wet years were 1926 as well as 1941 (see Fig. 6 and 8a). Correlation matrix of the 17 selected discharge time series are presented in Table 2. From the values of the correlation coefficients (and from the previous analysis) follows negative correlation between discharge series of north-east European rivers and south-west European rivers – dry periods have a time lag.

The course of the filtered standardised discharge data by HP filter of the West European time series are given in Fig. 7a, of East Europe in Fig. 7b, and of Europe in Fig. 7c.

Finally, the representative standardised discharge time series of the whole Europe from the 18-discharge series was constructed (Fig. 8a) for the period 1850–1997 (annual discharge of 18 series were summed up and then standardised). Extreme values from the years 1921 and 1926 (minimum and maximum) influenced the course of 10-years moving averages of coefficients of variation as well as symmetry (Fig. 8b).

Figure 5. Locations of the selected European rivers.

Table 1. Basic hydrological characteristics:
A – area [10^3 km^2], period of observation (since - to), Qa – average annual discharge [m^3s^{-1}], qa – mean annual specific yield [$l.s^{-1}km^2$], cs – coefficient of asymmetry, cv – coefficient of variation, min/max – minimal/maximal mean multiannual discharge [m^3s^{-1}], R - annual runoff [mil. m^3a^{-1}]

River	station	A	since	to	Qa	qa	cs	cv	min	Max	R
1 Thames	Kingston	10	1883	2000	78	7.9	0.12	0.29	30	132	2
2 Loire	Montjean	120	1863	1986	844	7.1	0.62	0.32	282	1967	27
3 Rhone	mouth	99	1921	1986	2052	20.7	-0.19	0.21	851	2932	65
4 Rhine	Cologne	144	1816	2000	2087	14.5	-0.09	0.19	921	2996	66
5 Po	Pontelagoscuro	70	1918	1985	1517	21.6	0.83	0.26	905	2617	48
6 Wesser	Voltho	18	1821	1999	172	9.8	0.11	0.26	62	284	5
7 Oder	Gozdowice	109	1900	2000	531	4.8	0.54	0.25	285	890	17
8 Vistula	Tczew	194	1900	1994	1040	5.4	0.64	0.22	599	1780	33
9 Elbe	Decin	51	1851	2000	304	5.9	0.90	0.30	151	699	10
10 Danube	Orsova (1971:T. Severin)	576	1840	2000	5583	9.7	0.44	0.17	3471	8265	176
11 Neman	Smalininkai	81	1812	1993	537	10.5	0.37	0.17	349	798	17
	West and Central Europe	**1472**			**14744**	**10.0**					**465**
12 Dniepr	Locmanskaja Kamjanka	495	1818	1984	1627	3.3	0.77	0.33	673	3375	51
13 Don	Razdorskaya	378	1891	1990	778	2.1	0.87	0.40	286	1666	25
14 Volga	mouth	1380	1882	1998	8038	5.8	0.10	0.18	4541	12330	253
	East Europe	**2253**			**10443**	**4.6**					**329**
15 Goeta	Vaenersborg	47	1807	2000	535	11.4	-0.003	0.19	225	855	17
16 Neva	Novosaratovka	281	1859	2000	2499	8.9	0.24	0.16	1340	3670	79
17 N. Dvina	Ust-Pinega	348	1881	1998	3332	9.6	0.35	0.19	1796	5245	105
18 Pechora	mouth	320	1921	1987	4352	14	-0.11	0.12	3154	5549	137
	North Europe	**996**			**10688**	**10.7**					**338**

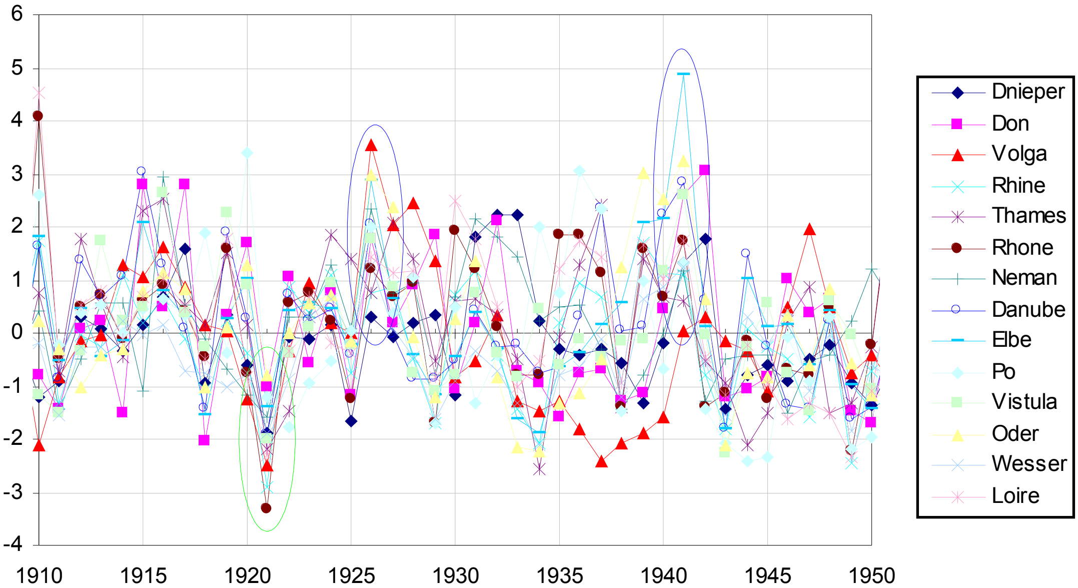


Figure 6. Course of standardised annual discharge time series during 1910–1950 period. West, Central and East Europe. The driest year - 1921, wet years - 1926, 1941.

Table 2. Correlation coefficients of annual discharge time series 1850–1997.

	Thames	*Loire*	*Rhone*	*Rhine*	*Po*	*Weser*	*Oder*	*Vistule*	*Elbe*	*Danube*	*Goeta*	*Neman*	*Dnieper*	*Don*	*Volga*	*Neva*	*Dvina*	*Pechora*
Thames	1.00																	
Loire	**0.58**	1.00																
Rhone	**0.56**	**0.91**	1.00															

Rhine	**0.50**	**0.72**	**0.73**	1.00														
Po	**0.44**	**0.52**	**0.58**	0.23	1.00													
Wesser	**0.37**	**0.40**	**0.40**	**0.77**	0.05	1.00												
Oder	**0.36**	**0.41**	**0.35**	**0.56**	0.18	**0.52**	1.00											
Vistula	**0.36**	**0.38**	**0.32**	**0.51**	0.13	**0.46**	**0.70**	1.00										
Elbe	**0.30**	**0.47**	**0.44**	**0.66**	0.15	**0.62**	**0.82**	**0.61**	1.00									
Danube	**0.34**	**0.47**	**0.46**	**0.61**	0.17	**0.46**	**0.52**	**0.67**	**0.69**	1.00								
Goeta	**0.35**	**0.30**	0.28	**0.33**	0.15	0.28	0.12	0.02	0.07	*-0.02*	1.00							
Neman	**0.30**	**0.31**	**0.34**	**0.36**	0.08	**0.36**	**0.31**	**0.52**	0.25	0.29	0.19	1.00						
Dnieper	0.17	0.19	0.15	0.27	*-0.01*	**0.34**	0.27	**0.45**	0.25	**0.34**	*-0.02*	**0.48**	1.00					
Don	0.19	0.10	0.13	0.18	0.10	0.22	0.32	0.29	**0.30**	**0.31**	*-0.03*	0.27	**0.64**	1.00				
Volga	0.14	0.02	0.02	0.14	*-0.08*	0.27	0.14	0.19	0.12	0.05	0.03	0.36	0.39	**0.49**	1.00			
Neva	0.07	*-0.05*	*-0.02*	0.02	*-0.07*	0.11	*-0.20*	*-0.10*	*-0.13*	*-0.09*	0.28	0.27	0.07	*-0.01*	0.21	1.00		
N. Dvina	0.00	*-0.03*	*-0.06*	0.03	*-0.21*	0.10	*-0.06*	*-0.05*	*-0.04*	*-0.09*	0.03	0.22	0.12	0.17	**0.58**	**0.38**	1.00	
Pechora	*-0.01*	*0.03*	*-0.01*	0.03	*-0.13*	0.07	*-0.11*	*-0.08*	*-0.08*	*-0.17*	0.01	0.11	*-0.04*	*-0.04*	0.16	**0.32**	**0.36**	1.00

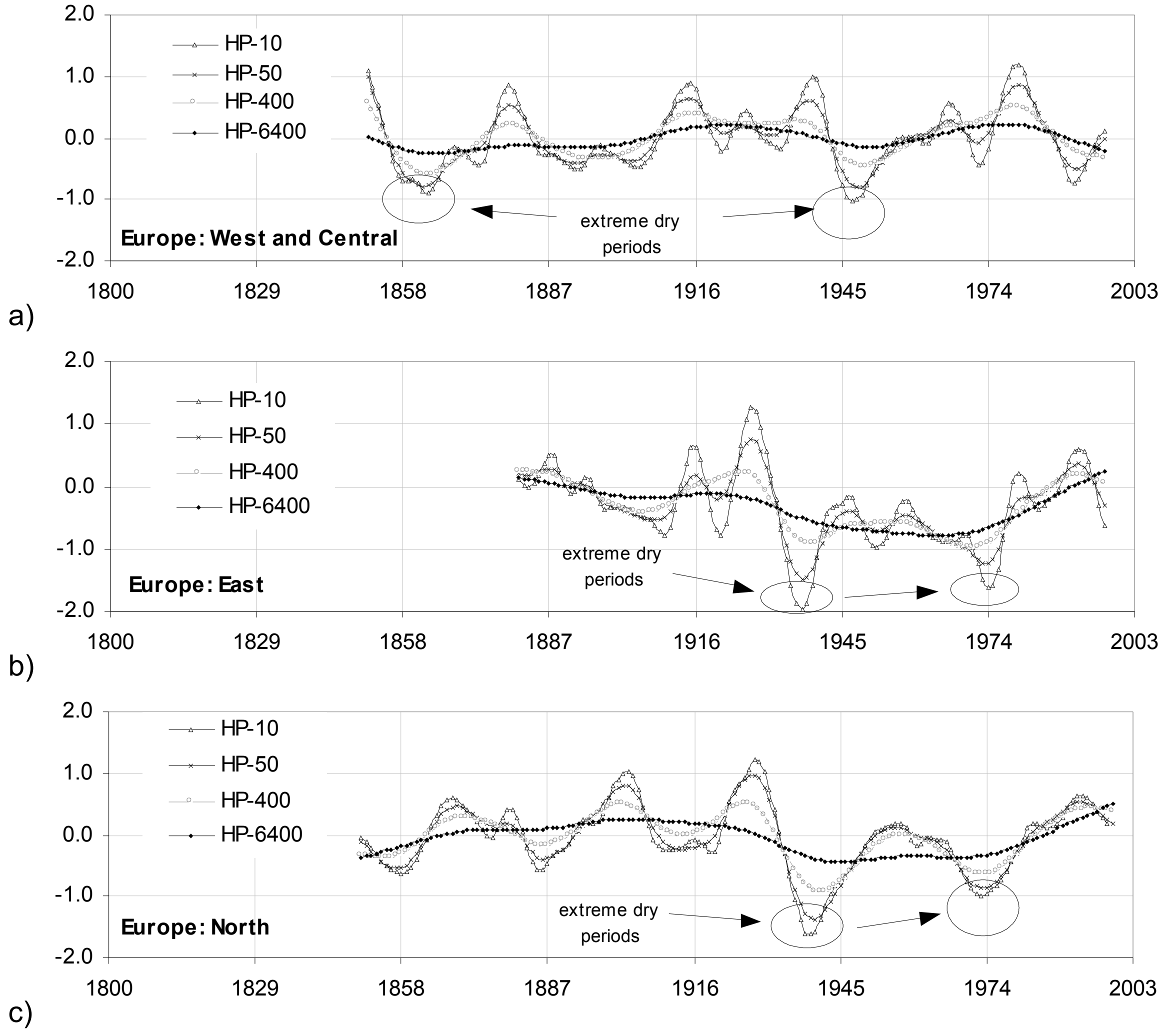


Figure 7. Course of filtered standardised discharge during 1851–1997.
a) West/Central Europe; b) East Europe; c) North Europe.

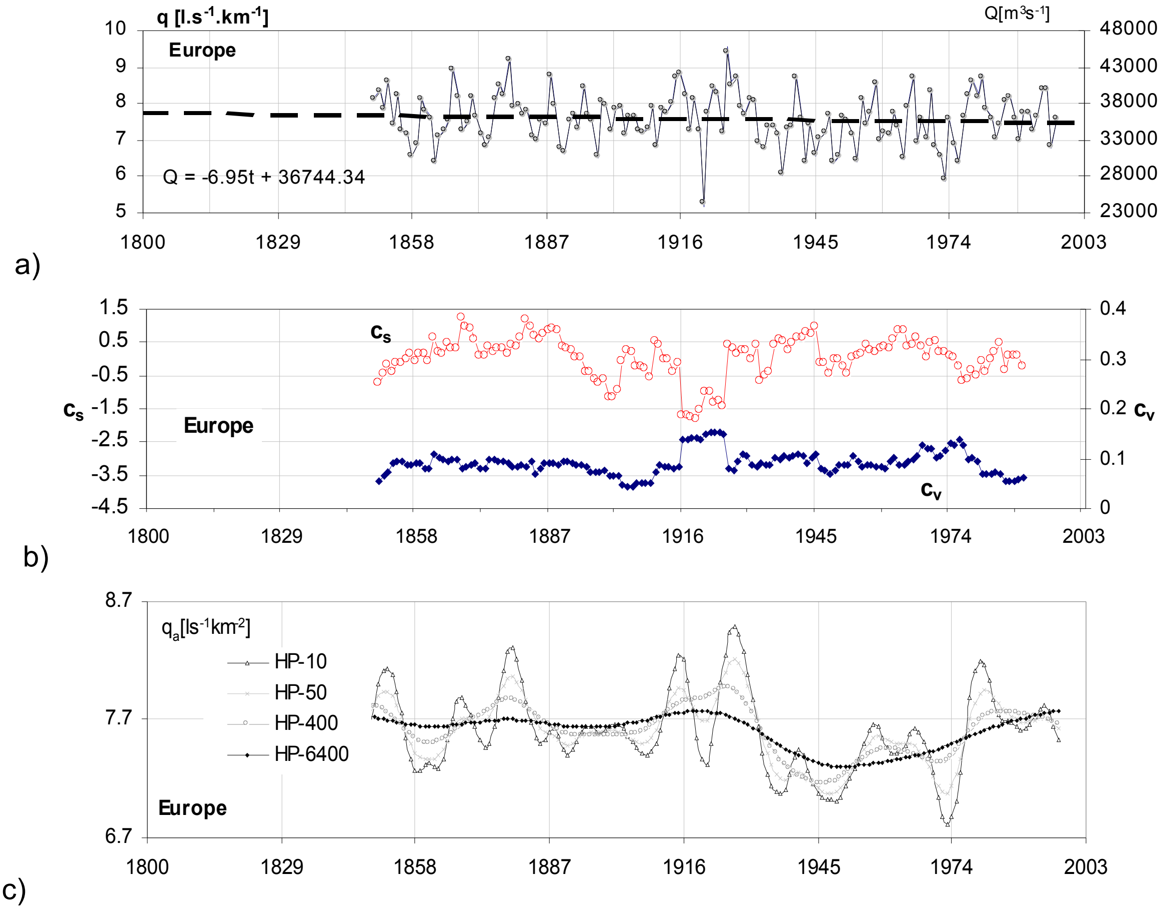


Figure 8. Course of the representative discharge series of Europe (1850–1997).
a) Annual specific yield [l.s^{-1}km^{2}] (or average annual discharge [m^{3}s^{-1}]).
b) Course of 10-years moving average of coefficients of variation and symmetry.
c) Filtered annual specific yield [l.s^{-1}km^{2}], HP - filter.

The dry period occurred in Europe around 1835 and the years 1857–1862 were very dry. In the 20th century the period 1946–1948 was the driest. Another dry period occurred in 1975.

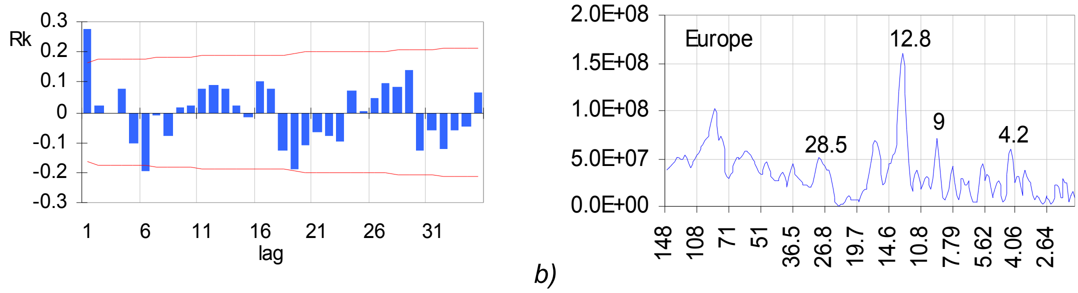
If we want to identify any trend uninfluenced by the periodicity of the discharge time series, we must determine the trend during a closed multiple loop, starting and terminating by either minima (e.g., 1861–1946 in Central Europe) or maxima (e.g., 1847–1930 or 1931–1984 in Central Europe). Trends determined for other periods are influenced by the periodicity of the series and depend on the position of the starting point on the increasing or recession curve.

The other way is to remove the cyclical component from the discharge series and test the adjusted series z_t (see eq (1)).

According the tests of normality it follows, that the discharge series of whole Europe is normally distributed. Using the test Number of runs we can reject on the significance level 0.05 the hypothesis H0, that the representative discharge series from the whole Europe is independent. The test detected a periodical change in this series.

On the Figure 9a, calculated values of autocorrelation function and confidence intervals of the representative discharge series (1850–1997) are presented. There exist statistically significant negative dependence of the discharge on the value six years ago. As you can see on Figure 9b from the combined periodogram, statistically significant period has 12.8-year duration.

The trend analysis does not show any significant linear trend change in long-term discharge series (1850–1997) in representative European discharge series. If we consider the 28-29-year cycle, we can expect the next wet period in Central Europe to occur in next years (around 2009).



a) b)

Figure 9 *a) Calculated values of autocorrelation function and confidence intervals*
b) periodogram, statistically significant period 12.8-year.
Representative discharge series of Europe, 1850–1997.

3. Conclusions

In the presented study, the long-term trends and cyclicity in hydrological time series are identified using the Hodrick-Presoctt (HP) filter. The HP filter seems to be a good tool for analysing annual time series. It clearly identifies the fluctuation in discharge time series.
The results indicate that the period around the year 1862 was very dry period in the Danube River. It is interesting to notice that in the period around the year 1862 was the mean annual air temperature in Europe lower by about 0.8°C compared to the 1990s`. Two of the driest periods of the instrumental era (around 1862 and 1990) occurred in very different temperature conditions. This shows that the mean annual air temperature does not have direct influence on the runoff depth and the long-term runoff variability has its own dynamics. Therefore we cannot automatically suppose, that the expected increase of the air temperature will result in decrease of runoff in Danube River.
In the Western Europe, the extremely dry periods were around the year 1863 and 86 years later around the year 1947. The runoff extremes (in both dry and wet periods) in the Eastern Europe precede by 3-5 years the peaks in the Western Europe. The time lag is increasing with the distance of the basins.
According the Figs. 5a-c we can estimate the length of the cycles of dry periods as 28–30 years in both Western-Central and Eastern Europe regions.
Generally we can comment that the trend analysis did not show any significant trends in cumulative runoff series of the major European rivers in last 150 years.

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4. References

Burn, D.H., Cunderlik, M., Pietroniro, A. (2004): *Hydrological trends and variability in the Liard River basin.* Hydrological Sciences Journal, Vol.49, 1, 53-67.

Callčde, J., Guyot, J.L., L'Hôte, Y., Niel H., De Oliveira, E. (2004): *Evolution du débit de l 'Amazone ŕ Óbidos. De 1903 ŕ 1999.* Hydrological Sciences Journal, Vol.49, 1, 85-97.

Halmova, D. (2000): *Comparison of the Effect of the Expected Climate Change upon Water Reservoirs in Eastern Slovakia.* Conf. Proc. CD XXth Conference of the Danubian Countries on Hydrological Forecasting and Hydrological Bases of Water Management, Slovak Hydrometeorological Institute, Bratislava, 924-931.

Hlavcova, K., Szolgay, J., Cunderlik, J., Parajka, J., Lapin, M. (1999): *Impact of Climate Change on the Hydrological Regime of Rivers in Slovakia.* (In Slovak.) Slovak Technical University and Slovak Committee for Hydrology, Bratislava, 98 pp.

Koncek, M., (1972): *Course of air temperature in Bratislava during 195 years 1776–1970.* (In Slovak.) Meteorologicke zpravy, 26, 6, 145–152.

Kostka, Z., Holko, L. (2000): *Impact of climate change on runoff in small mountainous basin.* (In Slovak.) Technical Report. National Climate Programme SR 8, Ministry of Enviroment and Slovak Hydrometeorological Institute, Bratislava, Slovakia, 91–109.

Kundzewicz, Z.W., Robson, A.J. (2004): *Change detection in hydrological records – a review of the methodology.* Hydrological Sciences Journal, Vol.49, 1, 7-19.

Lindström, G., Bergström, S. (2004): *Runoff trends in Sweden 1807 – 2002.* Hydrological Sciences Journal, Vol.49, 1, 69-83.

Lohre, M., Sibbertsen, P., Konnig, T. (2003): *Modeling water flow of the Rhine River using seasonal long memory.* Watre Resour. Res., 39(5), 1132.

Marvall, A., Ana Ded Rio. (2001): *Time aggregation and the Hodrick-Prescott filter.* Documento de Trabajo No. 0108, Banco de Espana, 43p.

Moberg, A., Bengstrom, H., (1997): *Homogenization of Swedish temperature data. Part III: The long temperature records from Uppsala and Stockholm.* Int. J. Climatol., 17, 7, 667–699.

Pekarova, P. (2002): *Dynamics of runoff fluctuation of the world and Slovak rivers.* (In Slovak.) VEDA, Bratislava, 222 pp.

Pekarova, P., Miklanek, P. (2004): *Abflusstrends slowakischer Flüsse und mögliche Zusammenhänge mit ENSO/NAO - Erscheinungen.* Österreichische Wasser- und Abfalllwirtschaft, Springer, 1-2, 17-25.

Pekarova, P., Miklanek, P., Pekar, J. (2003): *Spatial and temporal runoff oscillation analysis of the main rivers of the world during the 19th-20th centuries.* J. Hydrol., ELSEVIER Science, 274, 62-79.

Pekarova, P., Pekar, J. (2002): *The application oh the Hodrick-Prescott filter for identifying the long-term trends in hydrological time series.* (In Slovak.) Acta Hydrologica Slovaca, Vol.3, No. 2, 203–212.

Prochazka, M., Deyl, M., Novicky, O. (2001): *Technology for Detecting Trends and Changes in Time Series of Hydrological and Meteorological Variables (Change and Trend Problem Analysis - CTPA).* CD ROM, CHMU, WMO, Prague. 25 pp.

Radziejewski, M., Kundzewicz, Z.W. (2004): *Detectability of changes in hydrological records.* Hydrological Sciences Journal, Vol.49, 1, 39-51.

Sheng, Yue., Pilon, P. (2004): *A comparison of the power of the* t *test, Mann-Kendall and bootstrap tests for trend detection.* Hydrological Sciences Journal, Vol.49, 1, 21-37.

Shiklomanov, CD World Freshwater Resources.

Xiong, L., Guo, S. (2004): *Trend test and change-point detection for the annual discharge series of the Yangtze River at the Yichang hydrological station.* Hydrological Sciences Journal, Vol.49, 1, 99-112.