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VARIABILITY OF THE WARTA RIVER DISCHARGE IN POZNAŃ

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ABSTRACT. Values of daily discharges of the Warta river in Poznań in the years 1822-1997, annual precipitation totals and mean annual temperatures for Poznań in the years 1848-1997 were used as output data in the paper. A characteristics of meteorological conditions in the last 150 years is presented here, along with periodicity, time trends and discharge variability within the period of recorded observations, i.e. since 1822. Periodicity of discharge changes was determined using the method of harmonic analysis, whereas time trends were established with the use of the least square method.

Key words: hydrology, river outflow, time trends, periodicity

Introduction

The set of values of the Warta discharges in Poznań is one of the largest in the world as the daily observations of river stage have been conducted without interruptions since January, 1st, 1822 (**Olejnik** 1989). Also the set of meteorological observations and measurements in Poznań is of significant value (e.g. precipitation and air temperature have been measured here since 1848).

The Poznań measurement profile is situated in the 243.6 km (or in the 565 km of the Warta course, as calculated from the river-head) and closes the catchment area of approximately 25 thousand square kilometres. A characteristic topographic feature of the catchment is its flatness. Until the river reaches Poznań, lakes are seldom found as they are located mainly in the northern part of the catchment. The area of standing water includes two retention reservoirs situated in the upper and

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central part of the catchment basin, i.e. "Poraj" (total storage volume of approx. 25 000 000 m^3, built in 1979) and "Jeziorsko" (total storage volume 203 000 000 m^3, officially put to use on September, 9th, 1987). The latter one plays a highly significant role in the flow transformation.

Materials and methods

Data used as output in the paper were daily values of the Warta discharges in Poznań in the years 1822-1997. The data for 1822-1990 were taken from the paper by **Olejnik** (1989), and for the years 1991-1997 they were purchased in the Poznań office of the Weather Bureau (IMGW). The course of meteorological conditions was determined on the basis of totals of annual precipitation and average annual air temperatures for Poznań in the years 1848-1997, taken from the author's earlier paper (**Miler** 1998) as well as data obtained in the Poznań office of the Weather Bureau. The last 10-year long period covers also the time the "Jeziorsko" reservoir has been in use. The characteristics of weather conditions in the last 150 years, time trends and variability of discharges were established in a standard way, using appropriate methods, i.e. least square (for time trends) and parameter tests (test t by Student – mean values, test F by Snedecor – variances). Periodicity of discharge changes was estimated using the method of harmonic analysis.

Results and discussion

Course of meteorological conditions

The climate in Poznań, a city situated in the centre of the Wielkopolska region, exhibits considerable stationarity. The difference between mean annual precipitation, i.e. 512 mm in the 1848-1997 period (150 years), and the respective average of 513 mm in the 1948-1997 period (50 years) is only 1 mm. Moreover, there is no difference between mean annual air temperatures for the above mentioned periods, which for both of them was 8.3°C. This phenomenon results in a lack of statistically significant time trends in precipitation and air temperature changes during the last 150 years (Figs 1-4).

Characteristics of river runoff

Climatic changes, and consequently also changes in river runoff are caused by natural factors (such as e.g. changes in solar activity in 11-, 22-, 35-, 90- and 180-

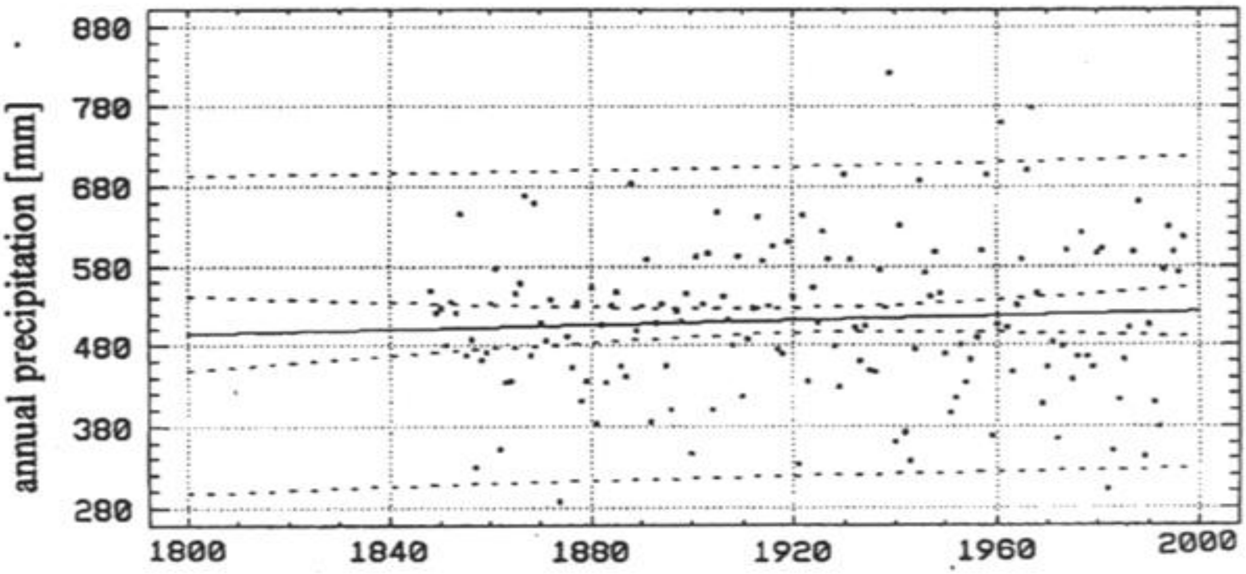

Fig. 1. Time trend of annual precipitation in Poznań in the years 1848-1997
Ryc. 1. Trend czasowy sum rocznych opadów atmosferycznych w Poznaniu w latach 1848-1997

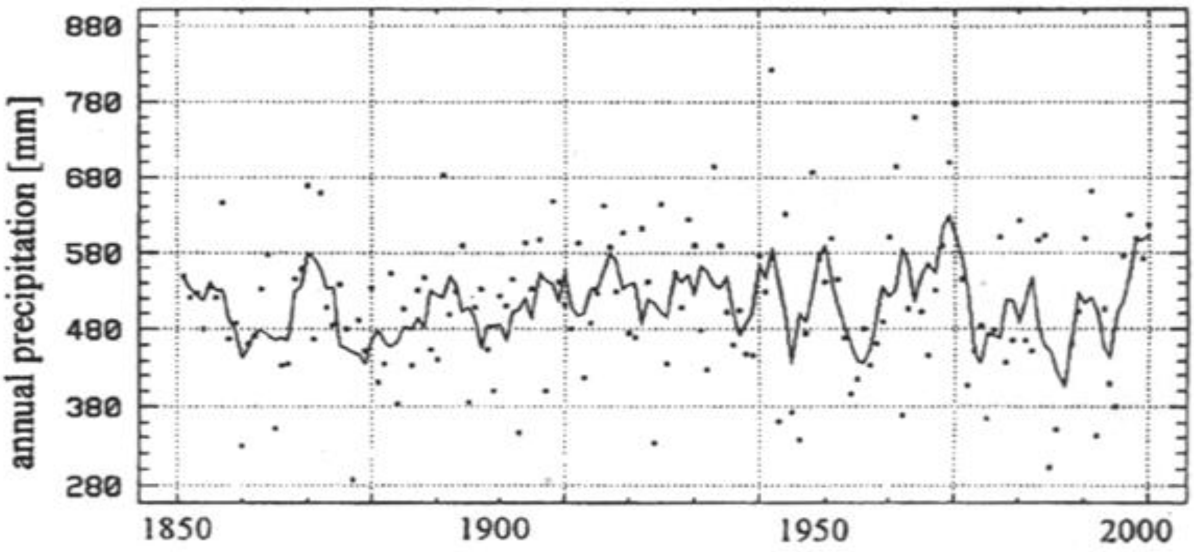

Fig. 2. Time series of annual precipitation in Poznań in the years 1848-1997, smoothed with simple five yearly moving averages
Ryc. 2. Przebieg czasowy sum rocznych opadów atmosferycznych w Poznaniu w latach 1848-1997 wyrównany przez 5-letnie średnie konsekutywne

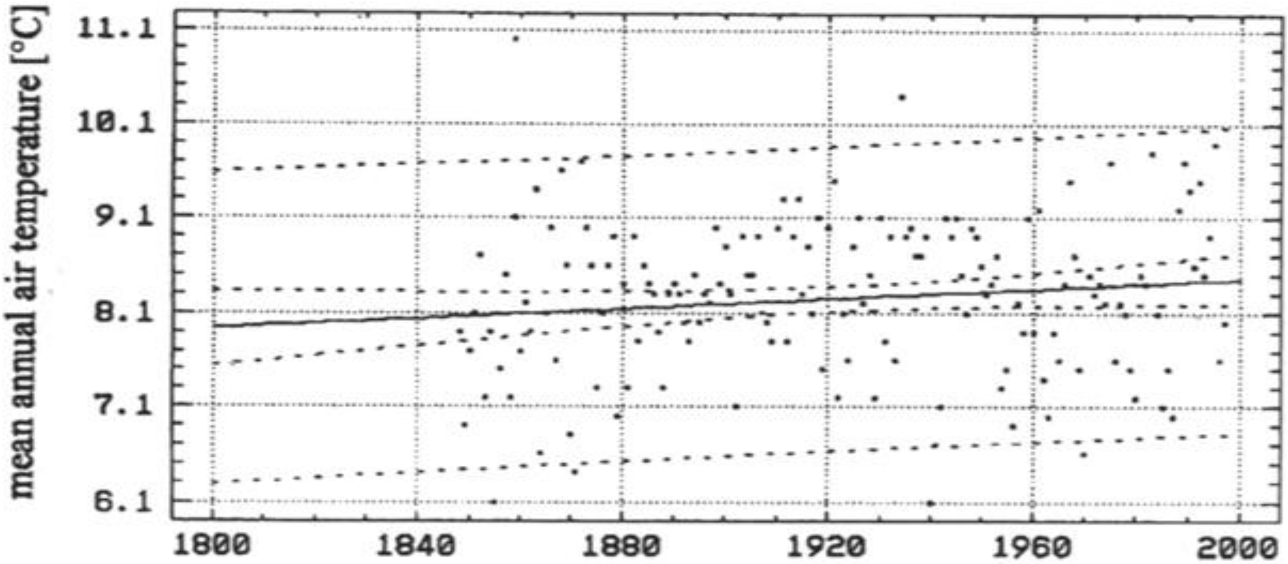

Fig. 3. Time trend of mean annual air temperature in Poznań in the years 1848-1997
Ryc. 3. Trend czasowy średnich rocznych temperatur powietrza w Poznaniu w latach 1848-1997

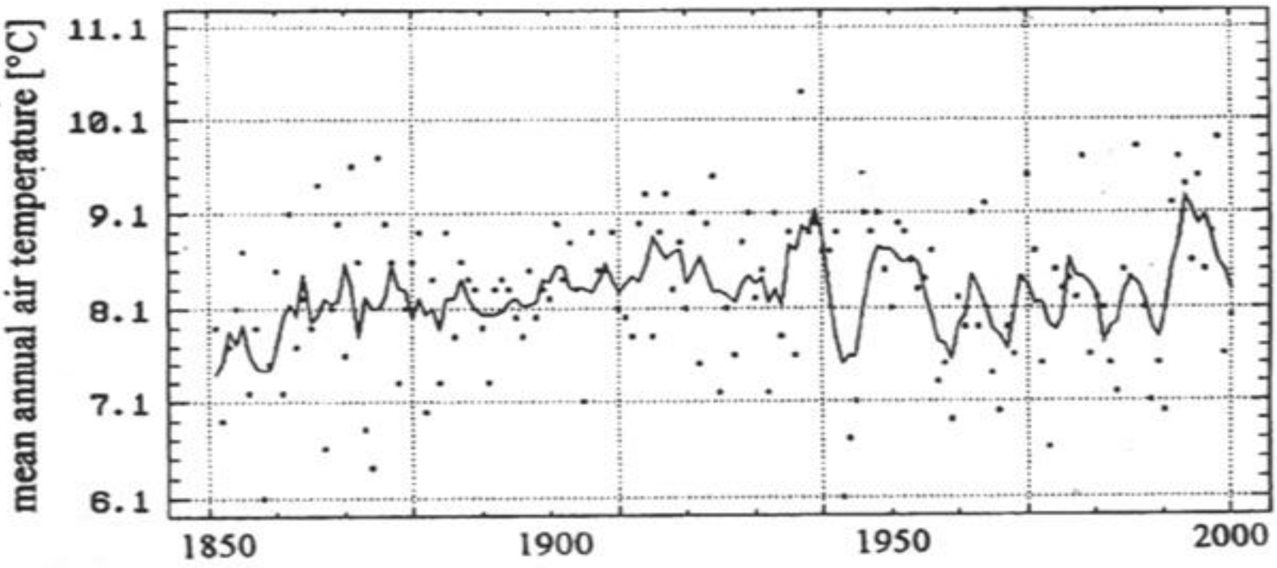

Fig. 4. Time series of mean annual air temperature in Poznań in the years 1848-1997, smoothed with simple five yearly moving averages
Ryc. 4. Przebieg czasowy średnich rocznych temperatur powietrza w Poznaniu w latach 1848-1997 wyrównany przez 5-letnie średnie konsekutywne

year periods) and anthropogenic ones (e.g. an increase in air pollution) (see e.g. **Boryczka** 1993, **Woś** 1994). Chronological sequence – i.e. time series $F(t)$ for a given parameter may be described as follows:

$$F(t) = A_o + A \cdot t + \sum_{i=1}^{\infty} A_i \cdot \sin\left(\frac{2 \cdot \Pi}{T_i} \cdot t + \varphi_i\right) + \varepsilon(t) \tag{1}$$

where: A_o – constant value,
A – variability trend,
t – time,
A_i – amplitude,
T_i – period,
φ_i – phase displacement,
i – harmonic number,
$\varepsilon(t)$ – random component.

The Warta river runoff shows considerable stationarity (Figs 5 and 6), especially in terms of mean annual values. Time trend for the mean annual discharges ($Q_{\acute{s}r} = 89.2 + 0.084 \cdot T$ (m^3/s), T – years) is not statistically significant (for $\alpha = 0.05$) in the whole observation period, i.e. in the years 1822-1997. Short-term trends are random in character. While analysing mean daily discharges of the Warta river in Poznań smoothed, e.g. with respective moving averages, or the course of mean monthly discharges, it is easy to notice the annual periodicity, which obviously is connected with the annual periodicity of weather conditions. The Warta tributaries also exhibit such an annual periodicity (**Miler** 1997). Within the last 10 years due to the impact of the "Jeziorsko" reservoir, the variability of daily discharges and, in consequence, also maximum values of discharges have become markedly lower. It should at the same time be noted that meteorological conditions in the years 1988-1997 in the Warta basin were comparable to the average conditions for the area. Mean standard deviation for one year in case of daily discharge in the period of 1822-1987 (166 years) was 75.3 m^3/s, but the corresponding standard deviation in the 10-year period of the "Jeziorsko" reservoir operation was only 38.8 m^3/s. This decrease in the daily variability is obviously statistically significant (for $\alpha = 0.05$). Within the last 10 years there has been an increase in the mean lowest discharge (SNQ) and a decrease in the mean highest discharge (SWQ). In both cases the changes are statistically significant (for $\alpha = 0.05$). Moreover, during that period a slight decrease in the mean discharge was also observed, but it was not statistically significant (for $\alpha = 0.05$). No statistically significant trend was found in the changes of mean annual discharge in the years 1988-1997. The above values, presented in Table 1, indicate clearly that the effect of the "Jeziorsko" reservoir on the Warta discharges is considerable.

Basically two methods were used to examine the periodicity of time series: harmonic analysis (based on the Fourier series) and spectroanalysis (autocorrelation method). Harmonic analysis was used in this paper as it gives more information than the autocorrelation method (**Miler** 1998).

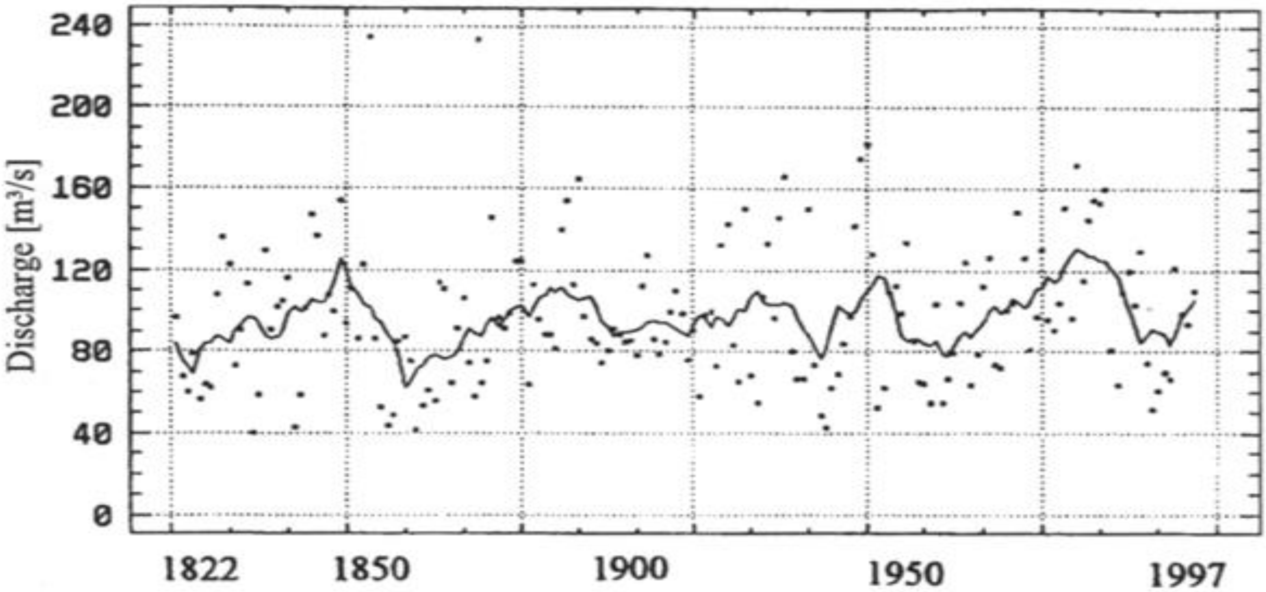

Fig. 5. Time series of mean annual discharges of the Warta river in Poznań in the years 1822-1997, smoothed by simple 11 yearly moving averages

Ryc. 5. Przebieg czasowy średnich rocznych przepływów Warty w Poznaniu w latach 1822-1997 wyrównany przez 11-letnie średnie konsekutywne

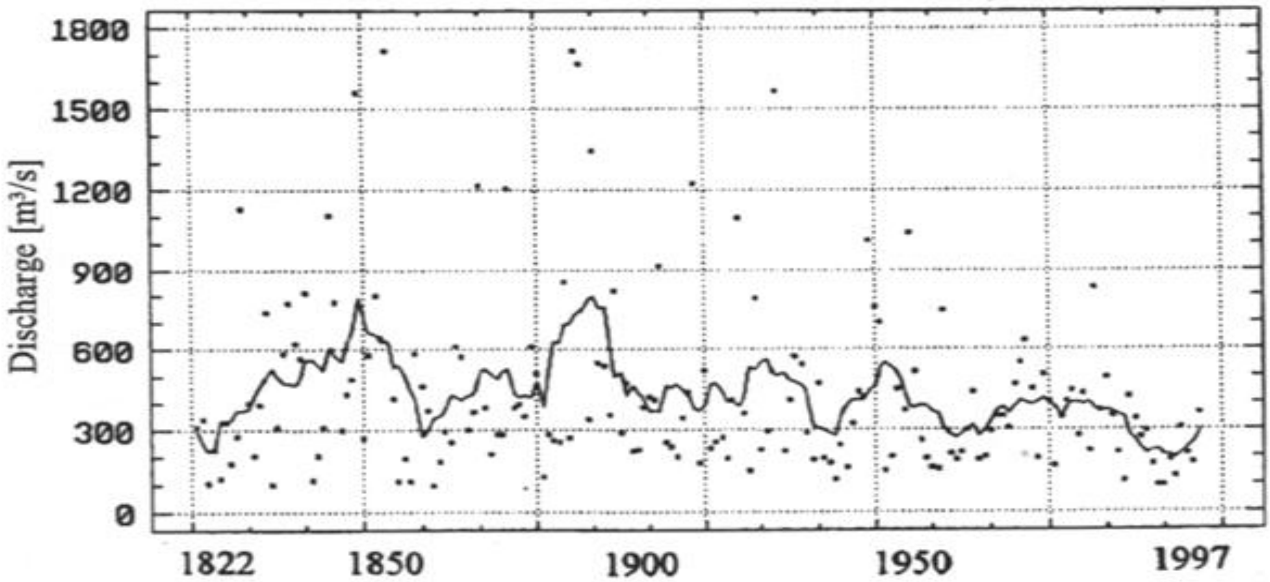

Fig. 6. Time series maximum annual discharges of the Warta river in Poznań in the years 1822-1997, smoothed by simple 11 yearly moving averages

Ryc. 6. Przebieg czasowy maksymalnych rocznych przepływów Warty w Poznaniu w latach 1822-1997 wyrównany przez 11-letnie średnie konsekutywne

Table 1

List of specific discharges (m^3/s) of the Warta river in Poznań · Wykaz przepływów charakterystycznych (m^3/s) Warty w Poznaniu

Characteristic Charakterystyka	Period – Okres		
	1822-1997	1822-1987	1988-1997
The lowest recorded value in period (NNQ)	11.5	11.5	32.5
Mean of the annual lowest recorded values (SNQ)	32.5	**32.1**	**39.5**
Mean recorded value (SSQ)	96.6	97.2	87.4
Mean of the annual highest recorded values (SWQ)	435	**449**	**201**
The highest recorded value in period (WWQ)	1 720	1 720	359

The term Fourier series of the integrable function $f(x)$ is used to describe the expression:

$$\frac{1}{2} \cdot a_o + \sum_{n=1}^{\infty} (a_n \cdot \cos nx + b_n \cdot \sin nx) \tag{2}$$

where:

$$a_n = \frac{1}{\Pi} \cdot \int_{-\Pi}^{+\Pi} f(x) \cdot \cos nx \cdot dx \tag{3}$$

$$b_n = \frac{1}{\Pi} \cdot \int_{-\Pi}^{+\Pi} f(x) \cdot \sin nx \cdot dx, \quad (n = 0, 1, 2, ...) \tag{4}$$

It may be shown (**Leja** 1973) that when function $f(x)$ is monotonic at intervals in the interval $[-\Pi, +\Pi]$ and periodic with the $2 \cdot \Pi$, then the above series (2) is always convergent and has a sum $f(x_o)$ in each point x_o of the function continuity, and in each point of discontinuity it has a sum $[f(x_o+) + f(x_o-)]/2$. Thus, with the use of the Fourier trigonometric series in the interval from $-\Pi$ to $+\Pi$ also functions to some extent arbitrary may be presented. Formulas (3) and (4) to obtain series coefficients may be arrived at with the use of interpolation (**Miler** 1998).

Obviously, interval $[-\Pi, +\Pi]$ may be replaced by another interval, especially interval $[0, T]$. In that case, function $f(t)$ monotonic in the interval $[0, T]$ and periodic with period T is considered here. Formulas for coefficients α_v, β_v (corresponding to a_n and b_n) will have the following form:

$$\alpha_v = \frac{2}{2 \cdot n + 1} \sum_{j=0}^{2n} f(t_j) \cdot \cos v \frac{2 \cdot \Pi}{T} t_j, \quad (v = 0, 1, 2, ..., n) \tag{5}$$

$$\beta_v = \frac{2}{2 \cdot n + 1} \sum_{j=0}^{2n} f(t_j) \cdot \sin v \frac{2 \cdot \Pi}{T} t_j, \quad (v = 0, 1, 2, ..., n) \tag{6}$$

where:

$$t_j = \frac{T}{2 \cdot n + 1} \cdot \left(\frac{1}{2} + j\right), \quad (j = 0, 1, ..., 2n) \tag{7}$$

Trigonometric multinominal will have the following form:

$$\frac{1}{2} \cdot \alpha_o + \sum_{k=1}^{n} \gamma_k \cdot \sin\left(k \cdot \frac{2 \cdot \Pi}{T} \cdot t_j + \varphi_k\right) \tag{8}$$

where:

$$\gamma_k = \sqrt{\alpha_k^2 + \beta_k^2} \quad \text{– amplitude of } k_{th} \text{ harmonic} \tag{9}$$

$$\varphi_k = \text{arctg}\, \frac{\alpha_k}{\beta_k} \quad \text{– initial phase of } k_{th} \text{ harmonic} \tag{10}$$

Values γ_k (9) is the basis for the evaluation which of the harmonics "plays a significant role". Calculated amplitudes (γ_k) for 87 harmonics for mean annual discharges of the Warta river in Poznań are presented in Figure 7. The following harmonics have significant values: 4 (dominant), 10, 14, 22, 25, and 33. It indicates that periodicity exists, respectively, for: 44-, 17.5- 12.5-, 8-, 7-, and 5.3-year periods. The 44-year periodicity may be connected with the periodicity of solar activity, and the 8-year one with the periodicity of air temperature in Poland (7.7-year

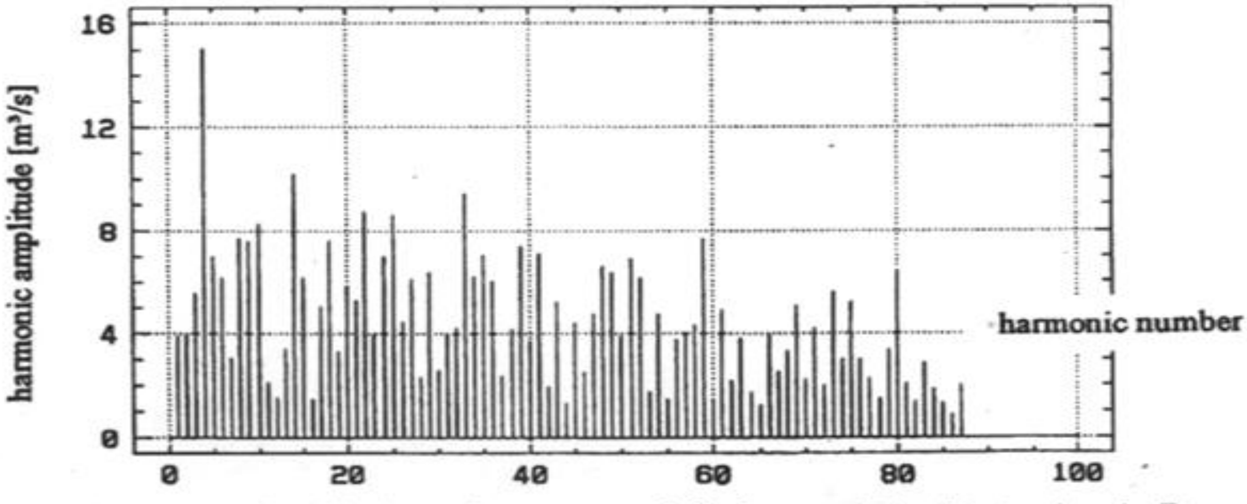

Fig. 7. Spectrum of oscillations of mean annual discharges of the Warta river in Poznań in the years 1822-1997

Ryc. 7. Widmo oscylacji średnich rocznych przepływów Warty w Poznaniu w latach 1822-1997 periodicity of air temperature in Poland in the years 1951-1990 was presented by **Żmudzka** (1995), the same periodicity may be observed for air temperatures in Poznań in the years 1848-1995 (**Miler** 1997).

Conclusions

Time trend for mean annual discharges of the Warta river in Poznań is statistically insignificant (for $\alpha = 0.05$) in the whole observation period, i.e. 1822-1997, as well as in the last 10 years. There were short-term change trends, but they were completely random in character. Calculations indicate that the effect of the "Jeziorsko" reservoir on the regime of the Warta discharges is considerable. It is marked in statistically significant lowering of the daily discharge variability, as well as in the increase in the mean lowest discharge (SNQ), and the decrease in the mean highest discharge (SWQ).

Calculated harmonic amplitudes for mean annual discharges of the Warta river in Poznań show that there are main periodicities of 44 and 8 year lengths. The 44-year periodicity may be connected with the periodicity of solar activity, whereas the 8-year one with the periodicity of air temperature in Poland.

Literature

Boryczka J. (1993): Naturalne i antropogeniczne zmiany klimatu Ziemi w XVII-XXI wieku. Wyd. UW, Wydział Geografii i Studiów Regionalnych, Warszawa.

Leja F. (1973): Rachunek różniczkowy i całkowy. Bibl. Mat. 2.

Miler A. (1997): Okresowość odpływu ze zlewni Strugi Dormowskiej. Rocz. AR Pozn. 294, Melior. Inż. Środ. 19 cz. 1: 333-342.

Miler A. (1998): Modelowanie obszarowych zmienności różnych miar retencji. Wyd. AR, Poznań.

Olejnik K. (1989): Przepływy Warty w Poznaniu 1822-1988. Fundacja „Warta", Poznań.

Woś A. (1994): Klimat Niziny Wielkopolskiej. Wyd. UAM, Poznań.

Żmudzka E. (1995): Tendencje i cykle zmian temperatury powietrza w Polsce w latach 1951-1990. Przegl. Geofiz. 40, 2: 129-139.

ZMIENNOŚĆ PRZEPŁYWÓW WARTY W POZNANIU

Streszczenie

W pracy są wykorzystane jako dane wyjściowe dobowe wartości przepływów Warty w Poznaniu w latach 1822-1997 oraz sumy roczne opadów atmosferycznych i średnie roczne temperatury powietrza dla Poznania z lat 1848-1997. Ostatni 10-letni przedział czasowy obejmuje okres eksploatacji zbiornika Jeziorsko. W zlewni Warty do profilu Poznań rzadko występują jeziora. Powierzchnię wód stojących zwiększają dwa zbiorniki retencyjne, zbudowane w górnej i środkowej części zlewni „Poraj" i „Jeziorsko". Szczególną rolę w transformacji przepływu ma ten ostatni zbiornik. W pracy przedstawiono charakterystykę porównawczą warunków meteorologicznych w ostatnim 150- i 50-leciu, okresowości, trendy czasowe i zmienności przepływów oraz przepływy charakterystyczne w ostatnim 10-leciu na tle przepływów w ponad 150-letnim okresie poprzedzającym. Charakterystykę porównawczą warunków meteorologicznych, trendy czasowe i zmienności przepływów oraz przepływy charakterystyczne opracowano w sposób standardowy, wykorzystując stosownie metody: najmniejszych kwadratów (trendy czasowe), największej wiarygodności (prawdopodobieństwo temperatur, opadów i przepływów) i testy parametryczne (t – wartości średnie i F – wariancje). Okresowości zmian przepływów oszacowano metodą analizy harmonicznej (szereg Fouriera). Klimat centralnie położonego w Wielkopolsce Poznania wykazuje stosunkowo dużą stacjonarność. Obliczone amplitudy harmonicznych dla średnich rocznych przepływów Warty w Poznaniu wskazują na istnienie dominujących okresowości: 44- i 8-letnich. Pierwszą cykliczność można wiązać z okresowością aktywności Słońca, natomiast drugą – z okresowością temperatur powietrza w Polsce. Odpływy Warty wykazują, podobnie jak klimat, dość dużą stacjonarność. Trend czasowy średnich rocznych przepływów jest statystycznie nieistotny w całym okresie prowadzonych obserwacji, tj. w latach 1822-1997, jak i w ostatnim 10-leciu. Występowały wyraźne krótkookresowe tendencje zmian, lecz miały charakter efemeryczny. Wykonane obliczenia wskazują na istotnie duży wpływ zbiornika „Jeziorsko" na reżim przepływów Warty w Poznaniu. Zaznacza się to w istotnym statystycznie obniżeniu zmienności dobowej przepływów, wzroście średniego niskiego przepływu oraz obniżeniu średniego wysokiego przepływu.