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METHODS ESTIMATING ANTHROPOGENIC CHANGES OF RIVER RUN-OFF BASED ON EXAMPLES FROM THE UPPER SILESIA COAL BASIN

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Introduction

Significant transformation of particular elements of the environment, especially water is characteristic feature of urbanized and industrialized areas with intensively developed mining industry — underground exploitation of natural resourses. In this case, changes of river run-off and its regime seem to be the most important.

Long-term series of the discharge measurements are necessary to estimate changes of the run-off. Such series should be devided into two periods: a — the period of natural or quasi-natural conditions of run-off, called a calibration period and b — the period of transformed conditions of the run-off caused by enthropopression, called a period of evaluation (Dynowska, Jankowski, Soja, 1985). In case of the lack of data from the period prior to intensive human interference (calibration period) such estimation is very difficult, sometimes almost impossible. In such situation thorough analysis of climatic conditions which influence development of the run-off and its changes is essential.

Statistical analysis of the measurement series is limited to the answer if the process of urbanization and industrialization of the catchment has caused any changes of the run-off and in what degree, thus in what extent the changes have been caused by natural factors (fluctuations of climatic conditions) and in what extend by anthropogenic ones (land development, industrialization).

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Estimation of changes of the run-off

To estimate the amount of the run-off changes the method comparing mean long-term annual discharge can be used. Perennial sequence of measurement data is divided into the equal subperiods (e.g. 5-years), $x_1, x_1, x_1, \ldots x_n$, and then mean annual discharge (or run-offs) in the periods are summed up ($\sum x_1, \sum x_2, \sum x_3, \ldots \sum x_n$), then mean values ($\bar{x}_1, \bar{x}_2, \bar{x}_3, \ldots \bar{x}_n$) are calculated and compared. Quantity of fluctuations of the mean values of run-off in particular 5-years periods prove changes of the run-off. Mean annual sums of precipation in the given catchment area in the same sub-periods should also be compared to find estimated quantity of changes caused by natural fluctuations and anthropogenic factors.

This method was used to estimate changes of run-off of the Rawa and the other rivers in Katowice province (Jankowski, 1983; 1986 b: 1988). In case of the Rawa (tribuatary of the Brynica), which is intensively anthropogenically transformed, the run-off in the period 1954 — 1985 was analyzed. The means of long term periods are presented in tab. 1.

It can be easily observed in the table that within the period 1981 — 1985 the mean annual increase of discharge and obviously of the run-off was almost two times higher (181 %). Such extremely high and systematic increase of the discharge compared with slight increase of precipitation undoubtfully proves influence of anthropogenic factors (continuous urbanization process) on changes of Rawa run-off.

Estimation of the quantity of changes of the river run-off and distinguishing the quantity of the run-off caused by natural factors (percipitation) and the one caused by anthropogenic factors can be done by a cumulated curve method of differences of the values of the discharge coefficient (K-1), proposed by I.S. Zajcewa (1984) and partially developed by A.T. Jankowski (1986 a, b, 1988). This method leads to satisfactory results when it is possible to distinguish two periods in a given hydrometric measuring sequence: calibration (the period before urbanization or its little influence) and evaluation (significant influence of anthropogenic processes).

This method is very easy and includes only determination of a mean annual run-off in the calibration period and calculation of annual coefficients of discharge for the whole investigated period. The mean annual discharge in the calibration period is taken as 1. Then differences (K-1) in particular years of the analyzed periods should be determined and placed on a diagram. Cumulated value of the differences of discharge coefficients in the evaluation period multiplied by the value of the mean annual discharge in the calibration period is the general quantity of changes (total) in the evaluation. When the value is divided by the number of years of the evaluation period we obtain the mean quantity of changes in this period. If the influence of anthropogenic factors causes decrease of the river run-off the total difference (K-1) will be negative, but when the run-off increases it will be positive. The method can be modified by considering annual sums of precipitation in the catchment area and their similar statistical analysis (P-1) to find long-term trend of precipitation and its simultaneous comparison with the trend of run-off.

Table 1: *Percentage of increase of man long-term annual discarge and related run-off of the Rawa at the profile Scopenice and mean long-term annual sums of particioation in Katowice.*

Period	*Mean annual*			*Mean annual in %*	
	precipitate	*discharge*	*run-off*	*precipitate*	*discharge*
	(mm)	*(m^3/s)*	*(mm)*		
1954-1960	701	1.90	678	100	100
1961-1965	679	2.24	800	97	118
1966-1970	729	2.36	843	104	124
1971-1975	821	3.01	1075	117	158
1976-1980	765	3.24	1157	109	171
1981-1985	689	3.45	1236	98	181

Estimation of changes of the run-off and determination of the beginning of its significant anthropogenic disturbances may be done by means of the double mass curve. Total values of discharge and run-off are introduced into a system of coordinates. When the run-off directly depends on natural conditions (precipitation) the total values of consecutive years will lie along a straight line equalizing total long-term values. When the influence of anthropogenic factors is significant the run of the mass curve is broken. The relation of the gradient of the straight line of the evaluation period and the gradient of that of the calibration period determine the degree of the anthrpogenic influence. Precision of such estimation depends on the relation between run-off and precipitation.

Both these methods were applied to estimate the run-off of the Rawa river in the period 1954 — 1980 (Jankowski, 1988), which catchment area is intensively urbanized — 76.5 % of the area is covered by buildings. (Fig. 1)

Mean annual run-off was taken as a unit, assuming that in that period urbanization process did not influence the run-off in such a degree as in subsequent years. Differences (K-1) between particular years were calculated and the curve of

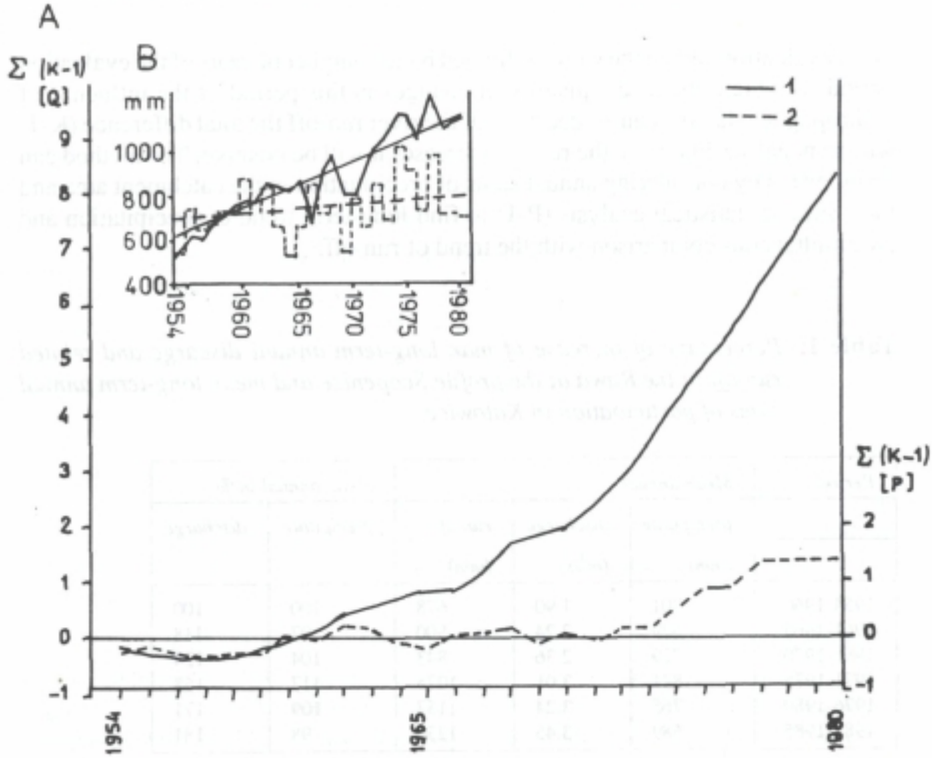

Fig. 1. A Mass curves of differences values of the discharged coefficients of the Rawa at Szopienice profile (1) and total annual difference of precipitation in Katowice (2) in the period 1954 — 1980.

B Course of mean annual run-off of the Rawa at Szopienice profile (1) and annual total precipitation in Katowice (2) in the period 1954 — 1980 and straight lines of the run-off (a) and precipitation (b) regresion (after A. T. Jankowski, 1988)

Slika 1. A Kumulativni krivulji razlik vrednosti odtočnega količnika v profilu Rave pri Szopienici (1) in celoletne razlike v padavinah v Katovicah (2) v obdobju 1954 — 1980,

B Krivulja povprečnega letnega odtoka na profilu Rave pri Szopienici (1) in celoletne količine padavin v Katovicah (2) v obdobju 1954 — 1980 in ravne linije odtočne (a) ter padavinske regresije (po Jankowskem, 1988).

cumulated values of discharge coefficient was drawn. Annual sums of precipitation were treated in the similar way (fig. 1 A). It occurred that cumulated values of differences (P-1) of annual sums of precipitation in the period 1954 — 1980 was 1.32, when cumulated value of differences of the discharge coefficient was 8.33. It provided very large influence of anthropogenic factors on the increase of the Rawa discharge and rather small, but distinguished influence of natural, methodological factors (1.32). Precipitation in this period showed small increasing tendency (a straight regression line b, in fig. 1 b). When recalculated into a mean annual run-off these values were equal; 44 mm — the increase caused by methodological conditions and 237 mm — connected with the increasing anthropogenic component of the run-off (mainly water transfer and disposal of underground-mining water into rivers). Their cumulated values were marked on a double mass curve of discharge and run-off (Fig. 2). Its run shows distinct break down in the years 1962 — 1964, which proves increasing advantage on the anthropogenic component over the natural one.

Method estimating a trend of changes

The simplest method to estimate a tendency of run-off changes is to draw a mass curve of mean annual discharge in long-term periods. But the basic method is application of the least squares method according to the following formula:

$$y_t = a_0 + a_1 t$$

where:

y_t — theoretical value discharge trend function

a_0 — value of trend function in the month prior to the investigated period [m^3/s]

a_1 — value of the monthly increase of the trend

t — number of observations

parameters a_0 and a_1 are calculated according to the following statistical dependence:

$$a_0 = \overline{y} - a_1\overline{t},$$

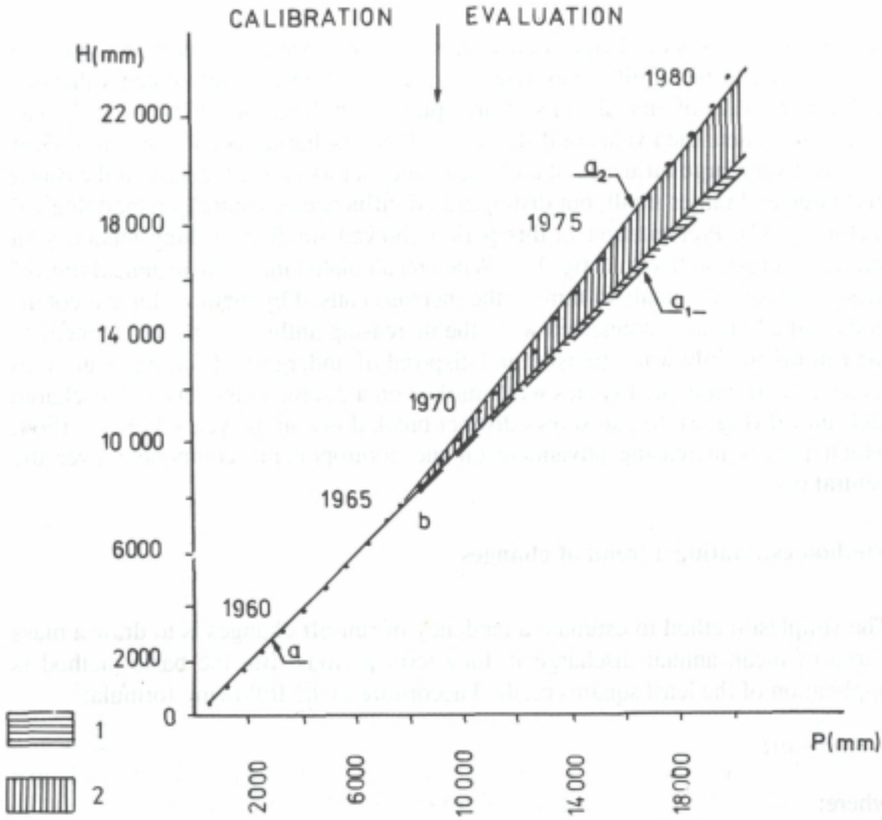

Fig. 2. Double mass curve of anual run-off (H)of the Rawa at Scopienice profile and precipitation in Katowice (P) in the period 1954 — 1980:

- a cumulated annual run-off in the calibration period
- a_1 asssumed discarge in the evaluation period based on the trend of the run-off in the calibration period
- a_2 commulated real run-off
- b approximate beginning of the run-off changes

Slika 2. Dvojna kumulativna krivulja letnega odtoka (H) na profilu Rave pri Szopienici ter padavin v Ktovicah (P) v obdobju 1954 — 1980:

- a letni odtok v kalibriranem obdobju kumulativno
- a_1 predviden odtok v obravnavanem obdobju zasnovan na trendu odtoka v kalibriranem obdobju
- a_2 dejanski odtok kumulativno
- b približen začetek sprememb v odtoku

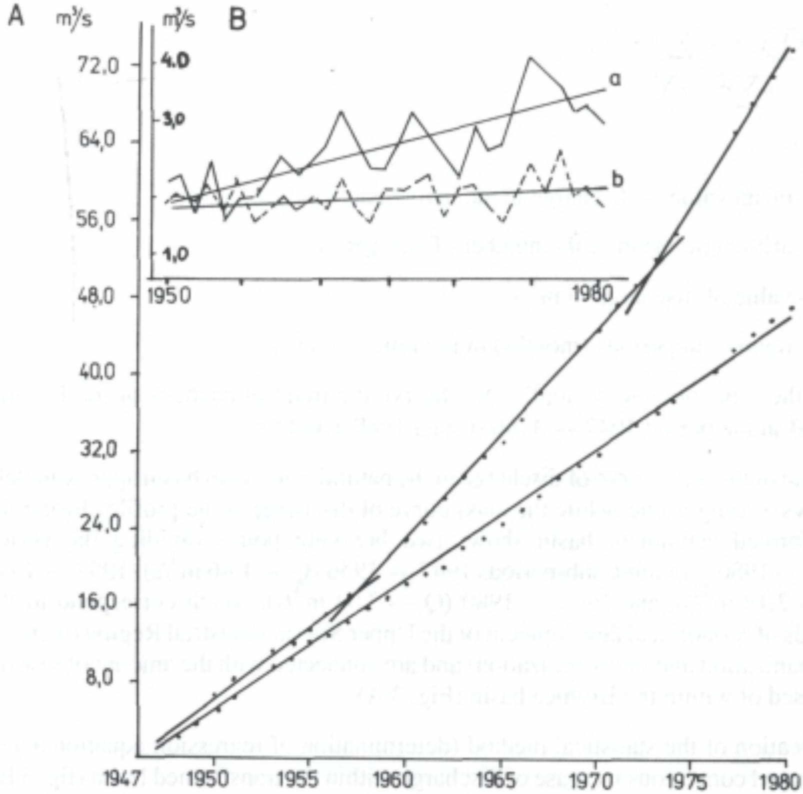

Fig. 3. A Curves of sums of mean annual discharge of the Brynica at Kozłowa Góra profile:

a (quasi-natural basin) and
b Sosnowiec (transformed basin) in the period 1947 — 1980,

B Mean annual discharge and values of the trend function at Kozłowa Góra profile:

a (quasi-natural basin) and
b Sosnowiec (transformed basin) in the period 1951 — 1980 (after S. Czaya, 1988 a).

Slika 3. A Krivulje vsot povprečnega letnega odtoka na profilu Brynice pri Kozłowi Góri:

a (skoraj naravno območje) in Sosnowiec
b (preoblikovano območje) v obdobju 1947 — 1980,

B Povprečni letni odtok in vrednosti funkcije trenda na profilu Kozłowa Góra:

a (skoraj naravno območje) in Sosnowiec
b (preoblikovano območje) v obdobju 1951 — 1980 (S. Czaya, 1988 a).

$$a_1 = \frac{n\sum y_t * t - \sum y_t * \sum t}{n\sum t^2 - (\sum t)^2}$$

where:

$\bar{y}$ — mean value of discharge in the investigated period [m^3/s]

$\bar{t}$ — arithmetic mean of the number of sub-periods

y_t — value of discharge in m^3/s

n — number in periods (months) in the time sequence

Both these methods were applied to observe the trend of changes of the Brynica run-off in the period 1947 — 1980 (Czaja 1988 a and b).

The run of the mass curve of discharge in the natural catchment basin approximately follows a straight line, while the mass curve of discharge at the profile closing the transformed catchment basin shows two breaking points dividing the period 1947 — 1980 into three sub-periods 1947 — 1956 (Q — 1.46 m^3/s), 1957 — 1972 (Q — 2.18 m^3/s), and 1973 — 1980 (Q — 3.04 m^3/s), which correspond to the periods of economical development of the Upper Silesia Industrial Region (increase of urbanization and industrialization) and are connected with the amount of sewage disposed of within the Brynica basin (Fig. 3 A).

Application of the statistical method (determination of regression equations) also confirmed continuous increase of discharge within the transformed basin (fig. 3 B). During the analyses period precipitation in both basins reached the approximate value of annual sum, showing simultaneously slight increase trend. Hence, such great difference between the values of run-off from the natural basin and the transformed one is caused by anthropogenic factors. Slight positive trend of run-off, which corresponds to the increase of the precipitation trend can be observed in the natural basin.

Estimation of changes of the run-off regime

A model of fluctuations in a given may be used to estimate changes of the run-off regime (Czaja, 1988 a and b; Czaja, Jankowski, 1986, 1989; Jankowski, 1986). It enables estimation of the run-off trend, annual rythm of fluctuations (seasonal fluctuations) and a role of hydrometeorological conditions in a give tear (accidental fluctuations) constituting a rivers discharge. The model consists of a few stages and monthly discharge during the whole analyzed period are necessary for circulations. The following steps should be followed:

— distinguishing a discharge trend y_t, the method of calculation has been presented above,

— determination of a cycle and an amplitude of seasonal fluctuations in particular months. These fluctuations enable to determine the role of cyclical factors (climatic regularities) in the run-off formation. The quantity of seasonal fluctuations will constitute a seasonal coefficient in the particular months of a year in absolute values or in percentage i.e.:

$$S_i = \frac{\bar{y} * d}{\sum \bar{y}_i} * 100,$$

where:

s_i — indicator of a seasonal character of a given "i" month

$\bar{y}_i$ — mean value of discharge in a given "i" month [m^3/s]

d — number of months in a year in absolute values [m^3/s]

$$g_i = \left(\frac{s_i}{100} - 1\right) * \bar{y}$$

gi — an absolute value of a seasonal fluctuations in the "i" month in [m^3/s]

S_i — indication of seasonal character of the "i" month

$\bar{y}$ — mean value of discharge in the investigated period in [m^3/s]

Total aberration of absolute values of seasonal fluctuations is equal to zero.

$$\sum_{i=1}^{d} g_i = 0$$

— determination of random fluctuations, informing about time displacement of periodical phenomena. being a result of their random character, i.e. proving irregular appearance of seasonal fluctuations and the influence of anthropogenic factors on the run-off regime. Calculation of random fluctuations is derived from a remainder component. It can be calculated for each month in the following way:

$$z_t = y_t - y_t - g_{it},$$

where:

z_t — accidental fluctuations in absolute values

t_t — values of discharge in a given month [m^3/s]

y_i — theoretical value of the trend function of the discharge in t period [m^3/s]

g_{it} — absolute value of seasonal fluctuations [m^3/s]

It is also possible to calculate average accidental fluctuations for the whole analyzed period. They are determined as standard aberration of a remainder component:

$$s\,(z_t) = \frac{\sqrt{z_t^2}}{\sqrt{n-2}},$$

where:

$s(z_t)$ — absolute value of accidental fluctuations in the investigated period,

n — number of periods (months) within a time sequence

z_t — accidental fluctuations in absolute values for particular months [m^3/s]

This method was applied to estimate change of the run-off regime of the Brynica (Czaja, 1988 a i b), rivers in the Rybnik Coal Region (Jankowski, 1986) and rivers in Katowice province (Czaja, Jankowski 1989). The catchment basin of the Brynica the Przemsza tributary) was devided into three parts depending on the degree of urbanization of the basin (czaja, 1988 b): the upper part (A) was characterized by quasi-natural conditions of the run-off and tight urban-industrial land development at the level 8.2 % the middle part of the basin (B_1) — partly transformed where 48.5 % of the area was covered by buildings and the lower part (B_2) — intensively transformed where 82 % of the area was covered by buildings (fig. 5). The range of accidental and seasonal fluctuations, as well as the amount of elementary run-off in partial basins are presented in tab. 2 and changes o of the run-off regime in these basins are shown in tab. 4.

As a results from the table and the figure, the rhythms of seasonal fluctuations in quasi-natural and partly transformed basins are similar but the amplitude of the run-off is almost three times smaller in the partly transformed basin than in the quasi-natural one. In the intensively transformed basin both the minimum and the maximum cannot be related to any of the observed seasonal changes and the amplitude does not exceed 20 % of the average run-off. Random fluctuations play important role in the natural basin and decreases in partly intensively transformed ones, which proves increasing influence of anthropogenic.

Table 2: *The range of seasonal and accidental fluctuations and the elementary run-off in partial basins of the Brynica in the period 1961-1980 (after Czaja 1988b).*

Basin			*Range of fluctuations in %*		*Elementary run-off q*
			seasonal	accidental	*(l/s * km²)*
A	—	quasi-natural	64 - 172	44 - 84	7.85
B1	—	partly transformed	86 - 120	21 - 42	8.75
B2	—	intensive transformed	42 - 112	20 - 33	36.60

Estimation of the degree of changes of the river regime

Describing quantitative changes of the river run-off in Katowice province, basing on determination of trend and quality of the run-off and determining changes of the run-off regime by estimating an annual rhythm of the run-off (seasonal fluctuations), as well as the influence of hydrometeorological conditions (accidental fluctuations, 4 indicators of the run-off changes can be obtained. Five points value was ascribed to the indicators most intensively destroyed by human interference, one point value was ascribed to the indicators formed by natural factors only or very slightly transformed by human activity. Total sum of points collected by each of the basin allows to form a sequence of basins depending on the degree of the influence of anthropogenic factors on water relations in the investigated area (Fig. 5). The highest number of points, which means the highest degree of destruction of the natural run-off, has been collected by the Rawa basin which was situated in the central part of the Upper Silesia Industrial Region (fig. 5, part 7). The run-off from this basin shows significantly antheopogenic character. The basins situated near the borders of the Upper Silesia Industrial Region and the Rybnik Coal Region are characterized by smaller numbers of points (fig. 5, part 6 and 5). The run-off from these basins is anthropogenically distributed but geographical influence is also important. The other basins are characterized by natural (fig. 5, part 3) or quasi-natural character (fig. 5, part 4).

Final remarks

The methods presented in the paper are only a part of methods which can be applied to investigate anthropogenic changes of run-off. However, these are the methods

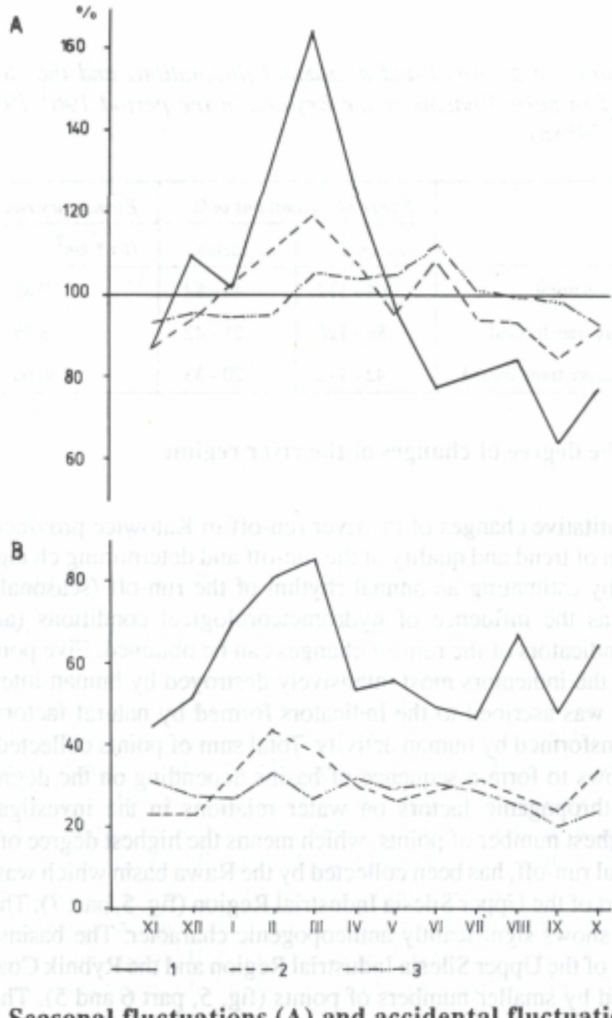

Fig. 4. Seasonal fluctuations (A) and accidental fluctuations (B) in differential basins of the Brynica:

1 quasi-natural basin,
2 partly transformed basin,
3 intensively transformed basin (after S. Czaja, 1988 b).

Slika 4. Sezonska (A) in slučajna (B) nihanja v različnih območjih Brynice:

1 skoraj naravno območje,
2 delno preoblikovano območje
3 močno preoblikovano območje (S. Czaja, 1988 b).

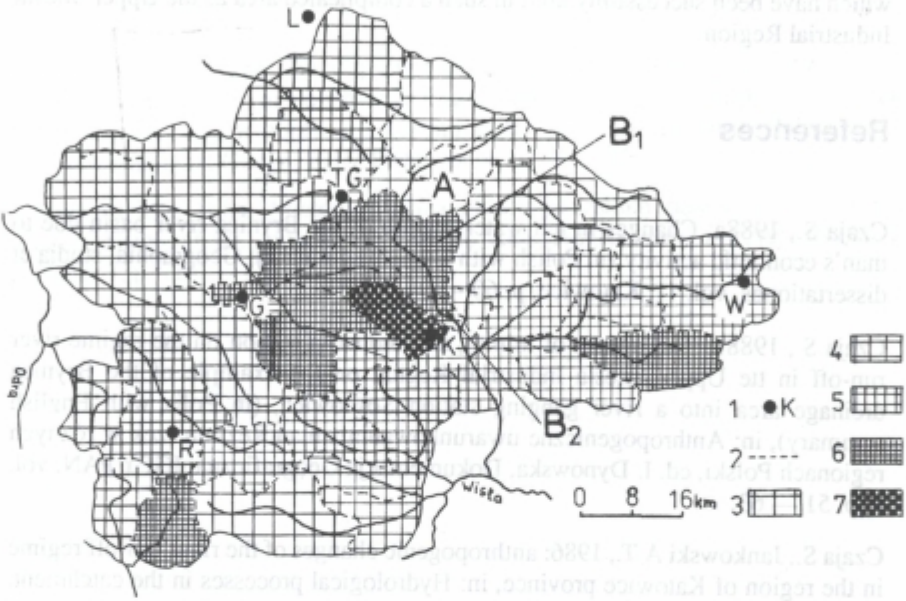

Fig. 5. Degree of influence of human economic activity on the run-off of rivers in Katowice province (after S. Czaja, A. T. Jankovski, 1989):

1 towns: TG - Tarnovskie Góry, L - Lubliniec, W - Wolbrom, G - Gliwice, R - Ratibórz
2 watersheds of particular basins,

degree of influence of anthropogenic factors on the run-off:

3 slight,
4 low,
5 medium,
6 high,
7 very high (Rawa basin).

Slika 5. Stopnja vplivov gospodarskih dejavnosti na rečni odtok na območju Katowic (S. Czaja, A. T. Jankovski, 1989):

1 mesta: TG - Tarnovskie Góry, L - Lubliniec, W - Wolbrom, G - Gliwice, R - Ratibórz
2 razvodnice med posameznimi porečji:

stopnja vplivov antropogenih dejavnikov na odtok:

3 neznatna,
4 nizka,
5 srednja,
6 visoka,
7 zelo visoka (območje Rave).

which have been successfully used in such a complicated area as the Upper Silesia Industrial Region.

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The anthropogenical water reservoir in subsidence basin.
Antropogeni vodni zbiralnik v depresiji.
***Foto* A. Jankovski**

Metode za ocenjevanje človekovega vpliva na spremembe rečnega odtoka, preizkušene na primerih iz Gornješlezijskega premogovnega bazena

Andrzej T. Jankowski:

Povzetek

Občutna transformacija posameznih elementov okolja, zlasti voda, je značilna poteza urbaniziranih in industrializiranih področij z intenzivno razvito rudarsko industrijo. Za oceno sprememb odtoka so potrebne dolgoročne serije meritev pretoka. Te serije se lahko razdelijo na dve obdobji: a — obdobje naravnanih oz. skoraj naravnih razmer za odtok, imenovano "obdobje umirjanja", in b — obdobje spremenjenih razmer za odtok, povzročenih s človekovimi posegi, imenovano "obdobje vrednotenja". Zaradi pomanjkanja podatkov iz obdobja pred intenzivnim vmešavanjem človeka (obdobje umirjanja), je takšno ocenjevanje zelo težko, včasih celo nemogoče. V taki situaciji je bistvenega pomena podrobna analiza klimatskih razmer, ki vplivajo na razvoj in spremembe odtoka.

Statistična obdelava serije meritev je omejena na iskanje odgovora, ali je proces urbanizacije in industrializacije povodja povzročil kakšne spremembe v odtoku in do kakšne stopnje, torej, do kakšnega obsega so spremembe povzročili naravni faktorji (spreminjanje klimatskih razmer) in v kakšnem obsegu človeški (razvoj izrabe zemlje, industroalizacija).

Za oceno obsega sprememb odtoka se lahko uporabi metoda primerjanja povprečnega dolgoletnega pretoka. Večletna zaporedja podatkov meritev se razdelijo na enaka podobdobja (npr. 5 let), nato se povprečni letni odtoki po obdobjih seštejejo, nakar se izračunajo in primerjajo povprečne vrednosti.

Obseg spreminjanja povprečnih vrednosti odtoka v posameznih 5-letnih obdobjih pokaže spremembe odtoka. Za ugotavljanje ocenjenega obsega sprememb, povzročenih s spreminjanjem naravnih in človeških faktorjev, je treba v istih podobdobjih primerjati povprečne letne padavine v danem povodju.

Ocenitev obsega sprememb odtoka in ločevanje velikosti odtoka, povzročenega z naravnimi faktorji (padavine), od tistega, ki ga povzročijo antropogeni faktorji, se lahko izvede z metodo kumulativne krivulje razlik vrednosti pretočnega količnika (K-1). Ta metoda da zadovoljive rezultate, kadar je možno v danem zaporedju hidrometričnih meritev razlikovati dve obdobji: obdobje umirjanja (obdobje pred urbanizacijo oz. njen minimalen vpliv) in obdobje vrednotenja (občuten vpliv antropogenih procesov).

Ta metoda je zelo preprosta in obsega samo opredelitev povprečnega letnega odtoka v obdobju umirjanja in izračun letnih pretočnih koeficientov za celotno raziskovalno obdobje. Povprečni letni pretok v obdobju umirjanja je označen z 1. Nato je treba določiti razlike (K-1) za posamezna leta raziskovalnih obdobij in jih vnesti v diagram. Kumulativna vrednost razlik pretočnih količnikov v obdobju vrednotenja, pomnožena z vrednostjo povprečnega letnega pretoka v obdobju umirjanja, predstavlja skupen obseg sprememb v obdobju vrednotenja. Ko se ta vrednost deli s številom let obdobja vrednotenja, se dobi povprečen obseg sprememb za to obdobje. Če vpliv človeških faktorjev povzroči zmanjšanje rečnega odtoka, bo celotna razlika (K-1) negativna, kadar je odtok povečan, pa pozitivna. Metoda se lahko modificira z upoštevanjem letnih padavin v povodju podobnih statističnih analiz (P-1) za ugotavljanje trenda padavin in njegovo istočasno primerjavo s trendom odtoka.

Ocenitev sprememb odtoka in opredelitev začetka njegovih občutljivih antropogenih motenj se lahko naredi s pomočjo krivulje dvojnih količin. Skupne vrednosti pretoka in odtoka se vnesejo v koordinatni sistem. Kadar je odtok neposredno odvisen od naravnih razmer (padavin), bodo skupne vrednosti zaporednih let ležale ob ravni liniji, ki izenačuje skupne dolgoročne vrednosti. Kadar je vpliv antropogenih faktorjev močan, je potek krivulje količin lomljen. Razmerje med gradientom ravne linije na obdobje vrednotenja in gradientom linije za obdobje umirjanja opredeljuje stopnjo antropogenega vpliva. Natančnost take ocene je odvisna od razmerja med odtokom in padavinami.

Najpreprostejša metoda za ocenitev tendence sprememb odtoka je izris količinske krivulje povprečnega letnega pretoka za dolgoletna obdobja. Osnovna metoda pa je uporaba metode najmanjših kvadratov po naslednji formuli:

$$y_t = a_0 + a_1 t$$

kjer je:

y_t —funkcija teoretične vrednosti trenda pretoka,

a_0 — vednost funkcije trenda v mesecu pred obdobjem raziskovanja (m3/s),

a_1 — vrednost mesečnega porasta trenda,

t — število opazovanj;

parametra a_0 in a_1 sta izračunana po naslednji statistični odvisnosti:

$$a_0 = \bar{y} - a_1\bar{t},$$

$$a_1 = \frac{n\sum y_t * t - \sum y_t * \sum t}{n\sum t^2 - (\sum t)^2}$$

kjer je:

$\bar{y}$ — povprečna vrednost pretoka v obdobju raziskovanja (m^3/s),

$\bar{t}$ — aritmetično povprečje števila podobdobij,

y_t — vrednost pretoka v m^3/s,

n — število obdobij (mesecev) v časovnem zaporedju.

Model nihanj v določenem času se lahko uporabi za oceno sprememb odtočnega režima. Ta omogoča ocenitev trenda odtoka, letnega ritma nihanj (sezonska upadanja) in vlogo hidrometeoroloških razmer v danem letu (slučajna nihanja), ki sestavljajo rečni pretok. Model je sestavljen iz nekaj stopenj in za izračune so potrebni mesečni pretoki skozi celo analizirano obdobje. Opraviti je treba naslednje postopke:

— A. ločevanje trenda pretoka y_t, način izračunavanja je bil opisan zgoraj;

— B. opredelitev ciklusa in amplitude sezonskih nihanj v posameznih mesecih. Ta nihanja omogočajo opredelitev vloge cikličnih faktorjev (klimatske regularitete) v formaciji odtoka. Obseg sezonskih nihanj sestavlja sezonski koeficient v posameznih mesecih leta v absolutnih vrednostih ali odstotkih, t.j.:

$$S_i = \frac{\bar{y} * d}{\sum \bar{y}_i} * 100,$$

kjer je:

S_i — indikator sezonskega značaja danega meseca "i",

$\overline{y}_i$ — povprečna vrednost pretoka v danem mesecu "i" (m^3/s),

d — število mesecev v letu;

v absolutnih vrednostih (m^3/s)

$$g_i = \left(\frac{s_i}{100} - 1\right) * \overline{y}$$

kjer je:

g_i — absolutna vrednost sezonskih nihanj v mesecu "i" v (m^3/s)

S_i — indikator sezonskega značaja meseca "i",

$\overline{y}$ — povprečna vrednost pretoka v raziskovanem obdobju v (m^3/s);

Skupen odklon absolutnih vrednosti sezonskih nihanj je enak ničli.

$$\sum_{i=1}^{d} g_i = 0$$

— G. opredeljevanje slučajnih nihanj, ki dajejo podatke o časovnem premiku periodičnih pojavov, ki so rezultat svojega slučajnostnega karakterja, t.j. — dokazujejo nepravilnost pojavljanja sezonskih nihanj in vpliv antropogenih faktorjev na odtočni režim. Izračun slučajnih nihanj je izpeljan iz komponente preostanka. Izračuna se lahko za vsak mesec na takle način:

$$z_t = y_t - y_t - g_{it},$$

kjer so:

z_t — slučajna nihanja v absolutnih vrednostih,

y_y — vrednosti pretoka v določenem mesecu (m^3/s),

y_t — teoretična vrednost funkcije trenda pretoka v obdobju t (m^3/s),

g_{it} — absolutna vrednost sezonskih nihanj (m3/s).

Izračunati je možno tudi povprečna slučajna nihanja za celotno analizirano obdobje. Opredeljena so kot standardni odklon komponente preostanka:

$$s(z_t) = \frac{\sqrt{z_t^2}}{\sqrt{n-2}},$$

kjer je:

$s(z_t)$ — absolutna vrednost slučajnih nihanj v raziskovanem obdobju,

n — število obdobij (mesecev) v časovnem zaporedju,

z_t — slučajna nihanja v absolutnih vrednostih za posamezne mesece (m^3/s).

V članku predstavljene metode so le nekatere od metod, ki se lahko uporabijo za raziskovanje človekovega vpliva na spremembo rečnega odtoka. Vsekakor pa so to metode, ki so bile uspešno uporabljene za tako zapleteno območje, kot je industrializirana Gornja Šlezija.