DOI: 10.2478/mgrsd-2004-0019

MISCELLANEA GEOGRAPHICA
WARSZAWA 2004 Vol. 11

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INERTIA OF THE CATCHMENT SYSTEMS WITHIN THE POLISH LOWLANDS*

Abstract: The paper presents a method for assessing the hydrological inertia of the river catchment areas using the autocorrelation function. The method presented can be used as the criterion for the determination of the degree of hazard to the river basins from the potential hydrological droughts. The basins with high inertia are less susceptible to the shortages of supply and are less threatened by the occurrence of hydrological droughts.

Keywords: Hydrological inertia of the catchments, hydrological droughts, autocorrelation function.

The purpose of the work reported was to determine the degree of inertia of the dynamic resources of underground waters within the Polish lowlands, exposed to frequent occurrence of hydrologic droughts. The autocorrelation method was used for determining the measure of inertia. Autocorrelation is the correlation occurring between the elements of a given series of observations, ordered in time or space (Bartnik, Jokiel, 1998). The coefficients of autocorrelation were calculated on the basis of the measurement data and the normalised data. Various magnitudes of lag or shift were adopted in the calculations, which allowed for the determination of the memory of the system of a given river catchment.

The degree of autocorrelation in the time series of mean flows is treated as the measure of strength of inertia of the outflow from a catchment (Bartnik, Jokiel, 1998). Simultaneously, inertia of flows is closely associated with the retention capacity of the watershed area (Bartnik, Jokiel, 1998). This statement is based on the assumption that high inertia of the monthly or annual averages of outflows may result from the correspondingly high retention capacities of the given are. Thus, one can expect high inertia of flows in the catchments characterised by a large share of lakes and by the conditions, which are advantageous for the longer-term supply of the river waters by the underground sources. Pasławski (1962) provides the example of Drawa river catchment as an instance of a basin characterised by high hydrological inertia. Its inertia is reflected, in the opinion of the author quoted, through

* The research presented constitutes a part of the Ph.D. dissertation.

the smooth course of outflow, which is the consequence of the large number of intermediary lakes along the course of the Drawa river and its tributaries, as well as the bogginess of the basin. The existence of the lakes, making a part of the river courses, is, in the opinion of the author quoted, the primary regulating factor, meaning that during the swells the lakes store excess water, and then during the periods of the potential low discharges – supply the river courses with the stored water reserve.

In the case of a strong correlation it becomes purposeful to determine the autoregression function, which can serve as the basis for generating the series of the further values, on the basis of the assumption that every element of the series depends to an extent upon the element(s) having occurred at an earlier period. The time interval, at which this dependence becomes apparent, is the so-called lag, defining the autocorrelation function order.

The problems of the river inertia was considered, in particular, by Pasławski (1962) – in a descriptive approach having treated the instance of Drawa river. Bartnik and Jokiel (1998) conducted a study with the use of the statistical methods and for a broader area.

The issue of inertia of rivers, though, has not been cognised sufficiently and there is an obvious need for continued research in the domain. The work here reported tried to analyse the inertia of the river basins considered in reference to monthly minimum discharges, i.e. the characteristic that is most associated with the underground supply of the rivers.

The study here reported was conducted for six basins, of which four (the ones of Flinta, Kopel, Mogilnica and Noteć) are located within the Greater Polish Lake District, while the fifth is situated on the Northern Masovian Lowland (the basin of Łydynia), and the sixth – on the Central Masovian Lowland (the basin of Mroga). They were selected from the point of view of the differentiation of their locations within the Polish Lowlands and of their physical-geographical features, having an influence on the course of discharge. The analysis was based on the specially produced time series of the monthly minimum discharges from the 30-year period of 1966-1995.

The measure of inertia of the particular time series of the minimum discharges and the underground water heads was constituted by the autocorrelation coefficient R_a:

$$R_a = \left[\sum_{i=1}^{N-1} (x_i - \overline{x_i}) \times (x_{i+1} - \overline{x_{i+1}}) \right] \times \left[(N-1) \times S_i \times S_{i+1} \right]^{-1}$$

where:

$\overline{x_i}$, S_i – mean and standard deviation of the series for i = 1 to N-1,

$\overline{x_{i+1}}$, S_{i+1} – mean and standard deviation of the series for i = 2 to N.

The coefficients of autocorrelation were calculated for the lags ranging between i = 1 and i = N-1, where N is the number of elements of the series.

Based on the analysis of the courses of curves on the correlation charts, Salas (1992) mentions White Nile down to the profile of Mongalli as a river characterised by a high hydrological inertia, while Blue Nile down to the profile on Khartoum is considered to be an example of a river with very limited memory.

The shape of the curves, determined on the basis of the values of the autocorrelation coefficient, calculated from the measurement time series, indicates clearly the appearance of the monthly seasonality of the monthly minimum flows, this seasonality forming the cycles of 12 month periodicity. This would imply a persistent cycle of renewal of the underground water resources and the underground water retention states, with which the minimum discharges in the rivers are associated. This seasonality characterises the minimum flows in all the basins considered and, except for the basin of Mroga, the river's memory weakens with each cycle. The long term memory of the Mroga basin ought to be attributed to the strong influence exerted by the human intervention, which is lacking in the other basins. The autocorrelation coefficients take the highest, gradually decreasing, values for the lags between 1 and 4 months (R_a = 0.4 to 0.8).

The analysis was carried out – side by side with the measurement series – also for the normalised series of these measurements (i.e. the ones, in which the mean equals 0 and the standard deviation equals 1), in order to get rid of the seasonality contained in the measurement series. This operation allowed for the determination of the inertia of the groundwater supply, characterised in this case by the minimum monthly discharges. The normalisation was carried out according to the formula

$$x_z = \frac{x - \bar{x}}{\delta}$$

where x_z is the normalised variable, $\bar{x}$ is the measured value of the variable, x is the mean value of the measured series, and δ is the standard deviation of the measured series.

The use of the normalised series of the minimum discharges allowed for the identification of the differences in the hydrological inertia of the rivers considered, resulting from the influence of the physical-geographical factors of the basins. The curves, in view of the eliminated seasonality of the flows, have not taken on the sinusoidal shapes, but the shape of an exponential function (Fig. 1). The values of the autocorrelation coefficient, along with the increasing lag, decrease from 0.8 down to -0.2. The zero value of the autocorrelation coefficient is attained the first by the basin of Łydynia (after 14 months), and the last by the basin of Flinta (after 34 months), while for the basin of Mroga it does not take the values lower than 0.15. The maximum values of the autocorrelation coefficient occur for the lag of T = 1 month and are equal between 0.84 for Flinta and 0.55 for Łydynia. It can be concluded from the analysis of the course of the curves that in the initial period (first

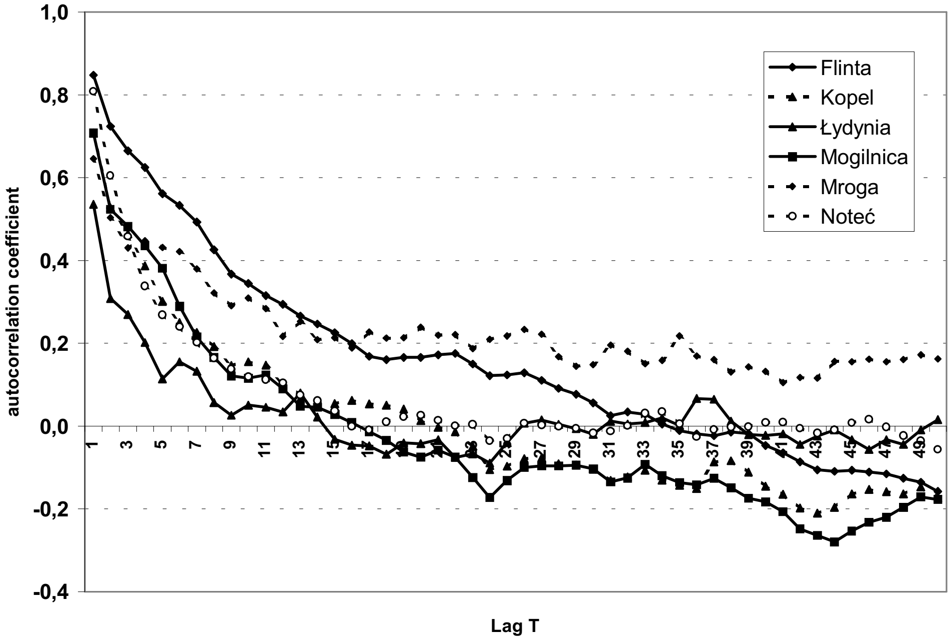

Fig. 1. The variability of the autocorrelation coefficient in the time series of the normalised monthly minimum discharges in the 30-year period of 1966–1995

16 months) the highest hydrological inertia is displayed by Flinta, while the lowest – by Łydynia. Generally, over a longer time horizon, the highest inertia characterises the catchment of Noteć (the flattest curve), while the smallest one characterises the catchment of Mogilnica (the steepest curve). The basins of Kopel, Noteć and Mogilnica feature over the period considered very similar shapes of curves. Mroga, which is characterised in the first three months of lag application by the similar values of the autocorrelation coefficient to the three basins mentioned before, starts to feature, beginning with the fourth month, a smaller decreases of the value of the autocorrelation coefficient, meaning an increased hydrological inertia of the catchment. At the lag of 17 months the values of the autocorrelation coefficient become higher than for the basin of Flinta and remain at almost the same level, although the autocorrelation coefficient is already very low.

The reasons for the high inertia of the basin of Flinta, in terms of minimum flows, should be sought in the high forest share in the basin's land use structure (47%). The presence of he forest complexes in the basin, along with the pastures and meadows, advantageous for the retention capacity in the first phase of the atmospheric and hydrological drought, causes, due to the root zone uptake and evapotranspiration, the exhaustion of the retention reserves in case of the long-term low discharges.

High permeability of the surface formations (60% of the basins' area is covered by the sands and gravels) causes a quick filling of the underground water reservoirs, situated in the sand aquifers on clayey bedding. The significant thickness of the sandy-gravel formations on the area of the outwash has essential importance for the process of accumulation of underground water. Flinta features one of the highest base flows among the catchments considered (QB = 1.05 dm^3/s km^2). On the other hand, in the catchment of Mroga the decisive factor for the high inertia of the watershed appears to be the presence of the artificial reservoirs, numerous over the course of Mroga, reflected through the regular increases of the minimum discharges during the low discharge periods.

The low hydrological inertia of Łydynia ought to be associated with the high share of clayey sands in its catchment (52% of the area). Besides, large area of arable lends and low surface retention cause that the basin quickly sheds the retention reserves, and the autocorrelation of the minimum flows quickly decreases. High base flow (QB = 1.36 dm^3/s km^2) of Łydynia is the effect of the good conditions for accumulation of water in the river valley and in the sandy formations close to the closing profile. Most probably this reservoir more clearly affects the discharge only during the dry periods.

The influence of the surface retention on the inertia of the basin is visible in the comparison between Łydynia and Noteć – these two basins being characterised by a similar permeability of the bedding and the higher share of surface waters in the basin of Noteć being decisive for the stronger memory of this system.

In the catchment areas of Kopel and Mogilnica the curves have a very similar course. The higher inertia of these two river systems in the period of the first 24 months of lag than in the case of Łydynia is due to weak permeability of the bedding (in both basins clays dominate in a clear manner). The inertia of the basins of Kopel and Mogilnica is also the reason for the delay in the change of underground retention with regard to infiltration supply of these basins (Pokojski, 2002).

It appears, therefore, that different factors are decisive for the inertia of the system in each of the river systems. Of particular importance with this respect are: permeability of the bedding, the nature of the aquifer formations and their distribution over the area of the basin, the forest share, and the capacity of surface retention. On the other hand, the basin of Mroga is an instance of a basin with a significant anthropogenic impact.

REFERENCES

Bartnik A., Jokiel P., 1998, Kilka uwag o autokorelacji w szeregach czasowych średnich miesięcznych przepływów rzek Polski [Some remarks on the autocorrelation in the time series of the mean monthly discharges of Polish rivers; in Polish], *Wiad. IMGW*, vol. 21 (42), issue 4.

Pasławski Z., 1962, Zarys hydrologii Drawy jako przykład opracowania rzeki o znacznej bezwładności hydrologicznej [An outline for the hydrology of Drawa river as an example of analysis of a river with a significant hydrological inertia; in Polish], *Wiad. Służby Hydrolog. i Meteo.*, issue 49 (3/1962).
Pokojski W., 2002, *Wpływ warunków fizycznogeograficznych na kształtowanie się przepływów niżówkowych rzek nizinnych w Polsce* [The influence of the physical-geographical conditions on the course of low discharges of the Polish lowland rivers; in Polish] Ph.D. dissertation, Faculty of Geography and Regional Studies, Warsaw University.
Salas D.J., 1992, Analysis and modeling of hydrologic time series, [in:] *Handbook of hydrology*, D.R. Maidment (ed.), McGraw-Hill, New York.

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