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# The Dynamics of Low Flows Characteristics and Exposure to Hydrological Drought along the River Vistula and in its Basin

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Abstract

The process of propagation of low flows is studied in the River Vistula in Poland. A history of low flow events in the basin is derived on the basis of statistical analysis of flow measured at 15 gauging stations located along the river and in 12 stations on its main tributaries in the 1951–2018 period. The main characteristics of low flows: minimum flow, duration and deficit of flow are calculated and analysed (at-side trend analysis, variability with the course of the river). On this base the most severe low flows are listed at each gauging stations and on the Little, Upper, Middle, and Lower Vistula reaches. The method of QdF (flow-duration-probability) was used to estimate the flow non-exceeded in *d*-days with the probability 50% and the index of low flow dynamics *D*. The results are compared in time and along the river. The exposure to drought are examined in terms of temporal and spatial aspects.

**Keywords:** low flows, the Vistula basin, statistical analysis, temporal and space exposure to drought.

## 1. INTRODUCTION

In Poland, there are two types of low flows of different origin. The summer low flows, preceded by atmospheric and soil drought, begin with a depletion of the catchment retention resources. Summer low flows are generally long-lasting, large-scale, and dominant in the lowland part of the country. They often extend into the autumn period and are then called summer–autumn low flows posing a long-term important threat to the water supply for the population, industry, and agriculture. The end of the summer low flow is most often associated with the occurrence of precipitation and a reduction in evapotranspiration.

Winter low flows are characteristic mainly in mountain rivers, although they can also occur in lowland rivers. Their occurrence is associated with longer periods of negative air temperature. In those conditions the surface runoff is stopped and inflows of groundwater to the riverbeds are strongly reduced (Dębski 1967; Fal 2007; Hydrologia 2017).

This research was carried out to resolve several important issues regarding the low flows on the Vistula:

- Is the combined impact of climatic change and human activities revealed in the long-term series of low flow characteristics in the Vistula and its basin and what form does that impact take?
- Which characteristics of the low flow regime are most affected and where?
- What are the time frames of low flows on the Vistula and the areas prone to drought?

## 2. DATA AND METHODS

### 2.1 Study area

This study covers the River Vistula from its sources to the hydrological station in Tczew (closing station) presented in Fig. 1.

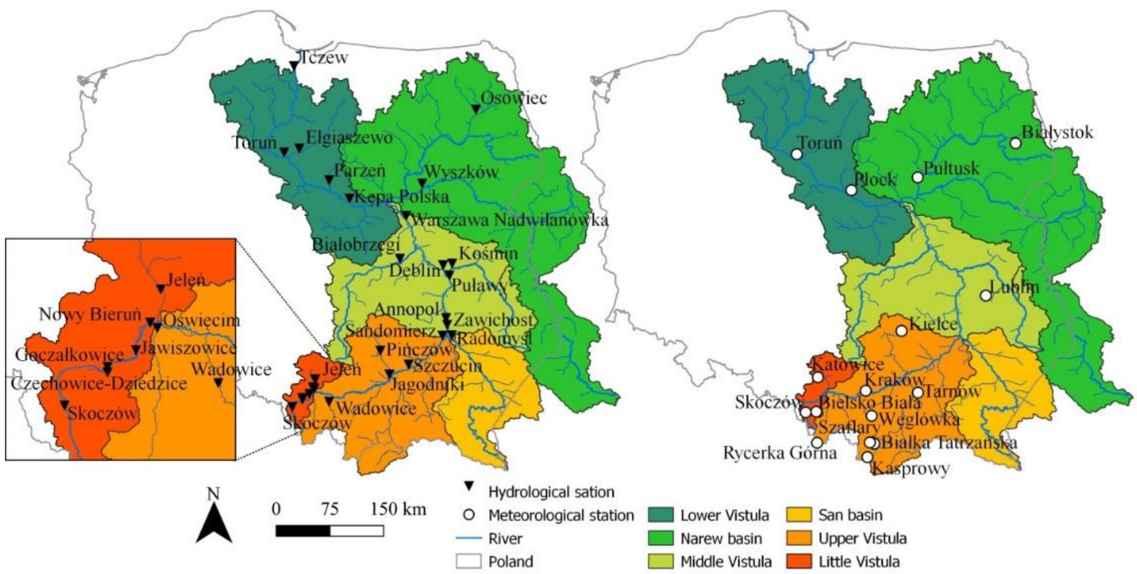


Fig. 1. The River Vistula basin with location of hydrological stations used in the study (Bogdanowicz et al. 2021).

### 2.2 Methodology

The lowest annual flow, still often used in Polish hydrological practice, was adopted as the threshold of the low flow event. Several days of higher flow periods (2–5 days) have been included (Fal 2007). The flow minima, deficits and durations were calculated and their trends are estimated. The flow-duration-probability (QdF) model were used to estimate design characteristics. The method for time and space exposure to droughts to point the most potentially affected areas.

## 3. PRELIMINARY RESULTS AND CONCLUSIONS

The results concern three problems formulated in the introductory section. The combined impact of climatic change and human activities in seasonal minima is depicted in Fig. 2. in the form of linear trends in the mean value and standard deviation estimated by means of the method proposed by Strupczewski and Kaczmarek (2001).

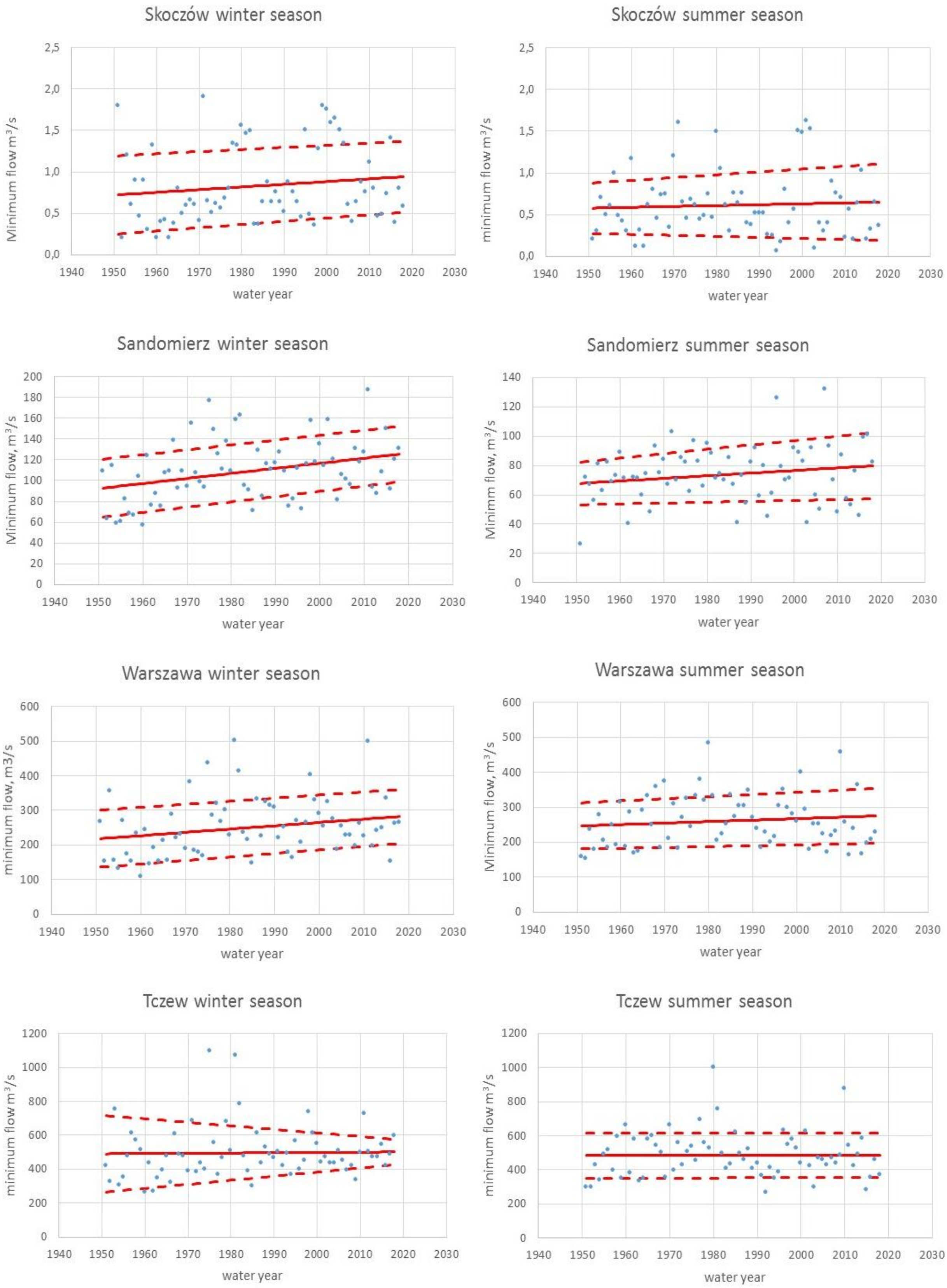


Fig. 2. Trends in mean seasonal minimum flow (red line) and standard deviation (dashed line).

Analyzes of trends in many outflow characteristics have shown, inter alia, that the minimum winter flows increased in the period 1951–2018. In general, the summer minima do not show a downward trends (Bogdanowicz et al. 2021).

The exemplary result of QdF (i.e., low flow dynamics parameter *D*, the flow non-exceeded in 10 days with probability 50% – $Q_{10,50\%}$ and the mean annual lowest flow (mean LQ), modelling are presented in Fig. 3.

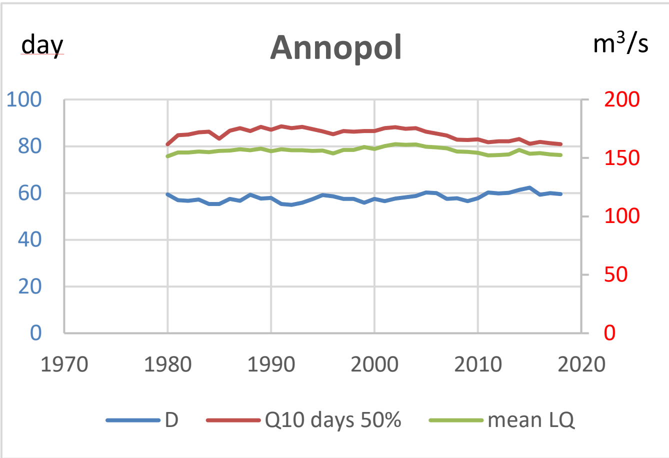


Fig. 3. Design characteristics of low flows $Q_{10,50\%}$, mean LQ and *D*.

The calculations were performed for moving window of 30-year data. On the Middle Vistula the course of the *x* and *y* values in the 30-year moving window does not reveal any significant changes in $Q_{10,50\%}$ and *D*.

The chart of mean daily flows for stations on the Vistula shows the period of low flows (Fig. 4).

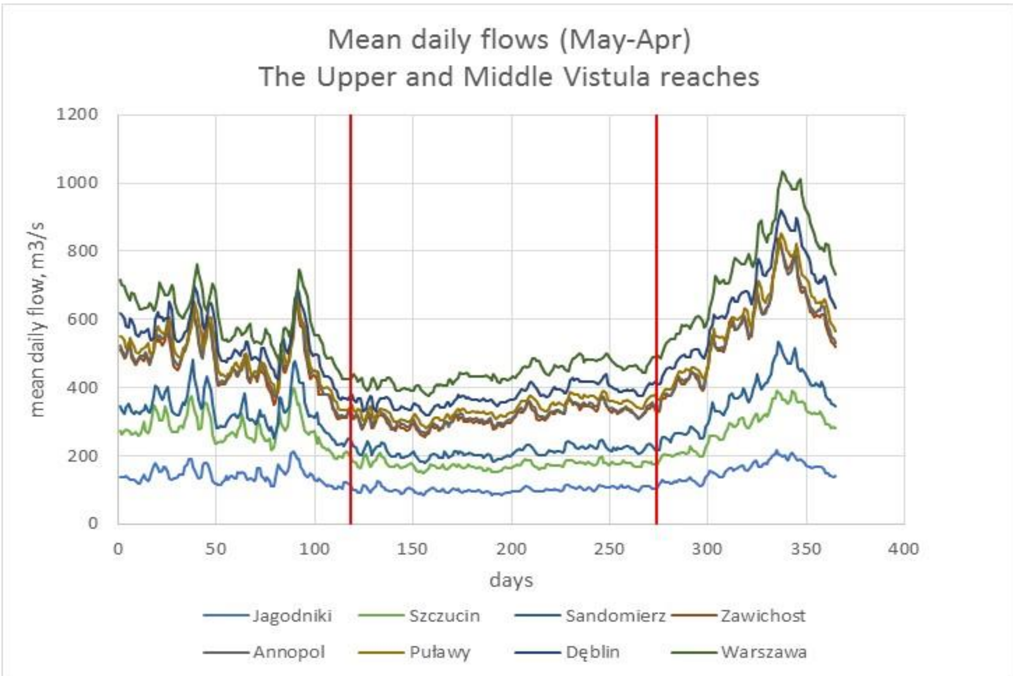


Fig. 4. The potential time period of summer-autumn low flows occurrence for the Upper and Middle Vistula reaches.

The vertical red lines mark the approximate limits: the end of August till the end of January which can be treated as main time of exposure to low flows.

Drought prone areas are difficult to exact designation because in fact the drought can happen everywhere. In this presentation we define the regions of the most probable drought occurrence supporting this decision by hydrologic and human pressures data.

The reliable human activity data are difficult to get and the main problems arise from the fact that national databases identifying all types of pressures are often not spatially referenced. Most of the necessary data are collected, but access to them is difficult or they do not cover all the period required (Karamuz et al. 2021). However it is possible to use and compare maps of different aspects of pressures on water resources and space distribution of hydrological characteristics important from the point of view of low flows development. Here several maps were analysed and five of them are attached below (Figs. 5–9). They are maps of population density, Gross Domestic Product, water withdraw from groundwater bodies, the map of river network density, and mean annual runoff module.

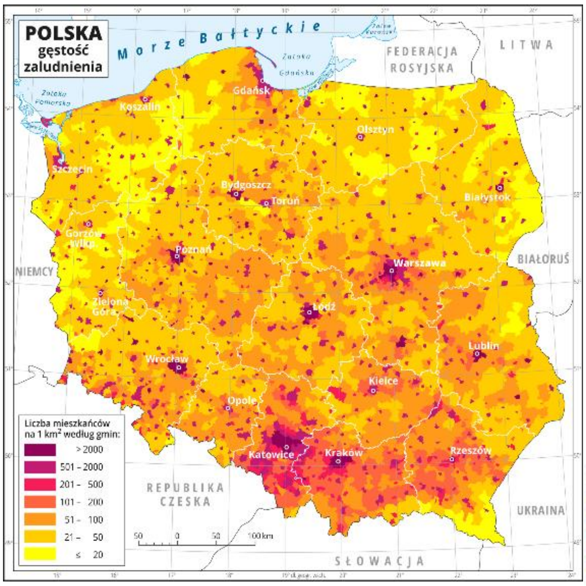


Fig. 5. Population density (persons per 1 km$^2$ in Poland (by communes).

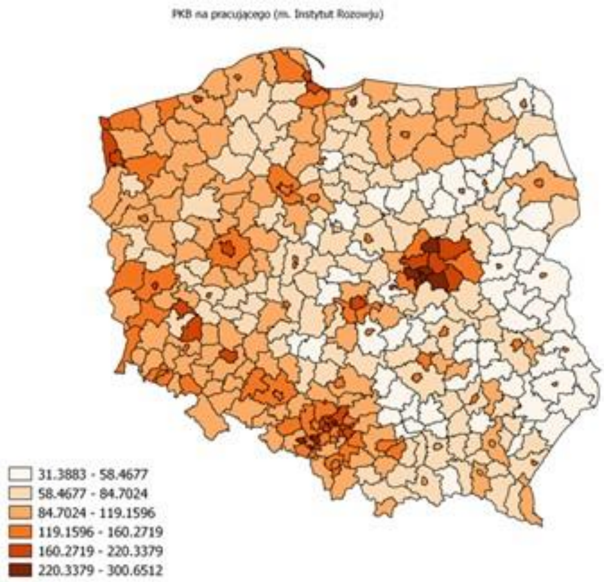


Fig. 6. Gross Domestic Product (GDP) per capita in poviats as a percentage of Total Polish GDP.

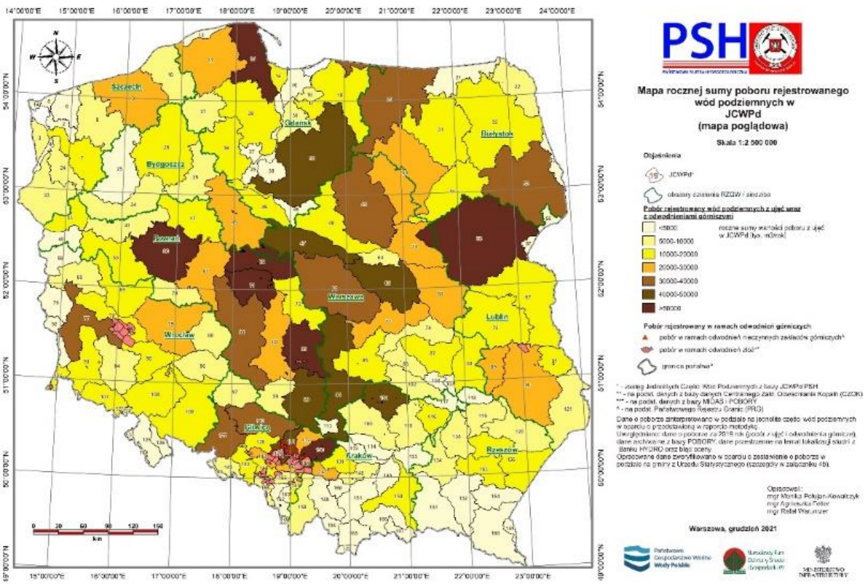


Fig. 7. Annual water withdraw (thousand cubic m/year) from groundwater bodies (colours from light yellow < 500 to darkest brown > 5000).

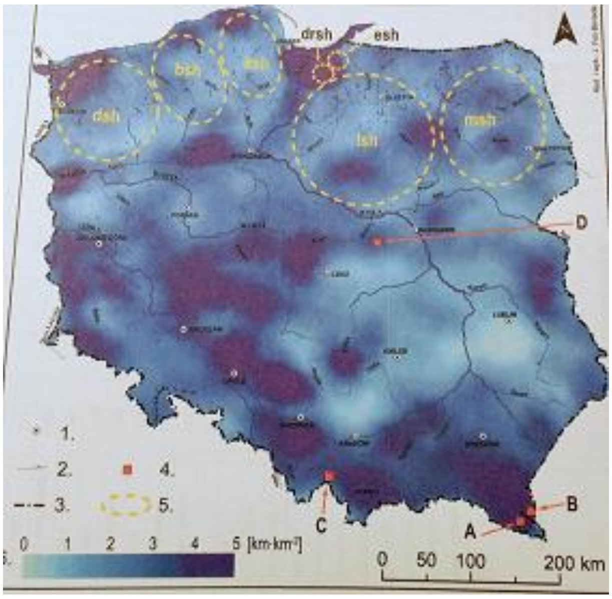


Fig. 8. River network density (km/km$^2$).

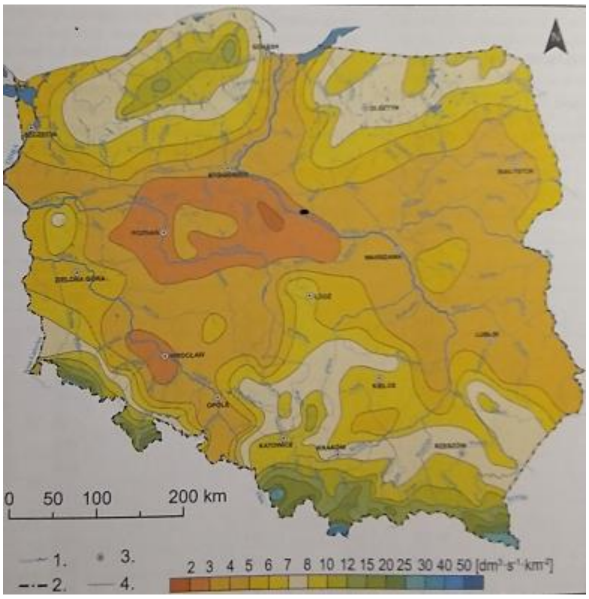


Fig. 9. The runoff module (dm$^3$ s$^{-1}$ km$^{-2}$) in Poland.

The visual inspection of this material leads to the conclusion that the most vulnerable to soil and hydrological drought are the areas located in the middle reach of the Vistula especially in Kujawy and Lublin Upland regions. This statement will be made more specific in the future.

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