Hydrological drought and low-flow hazard in Poland

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Abstract. Despite frequent drought events in Poland, the problem is still underestimated and has not been addressed by definite and satisfactory regulations. Hence the idea of the comprehensive analysis of hydrological drought hazard in Poland. The basis for the analysis was data of daily flows from 72 gauging stations located throughout the entire area of Poland, covering the period of 1951-2000. The definitions of low-flows and hydrological drought were adopted. An indicator of low-flow hazard was also developed on the basis of the number of events in a given area, the total duration and probability of non-exceedance of the lowest flows.

Key words

low-flow, hydrological drought, indicator of low-flow hazard.

Introduction

Small water resources place Poland among the countries with the least available water in Europe. The amount of water available per capita (gross) is little more than 1500 m^3 and during exceptionally dry years it drops to nearly 1000 m^3 annually. According to the Falkenmark Water Stress Indicator, Poland belongs to the group of those European countries which experience water stress [IPCC 2001]. However, water management is impeded not only by modest water flows in Polish rivers but also their high instability throughout a year resulting from climate conditions (while values of multi-year runoff remain relatively constant). During a year, runoff can fluctuate from very high in time of floods caused by spring melting snow or surplus of rainfall in summer to extremely low during low-flows resulting from acute and prolonged shortage of precipitation. Such variability causes frequent periods with low river runoffs – either due to rainfall shortage in summer or frozen ground in winter and the lack of groundwater recharge.

The negative effects of low-flows and hydrological droughts depend not only on the intensity of the phenomenon but also on the population density in the affected areas, economy, technology, land use, use of water resources, level of economic development, economic diversity etc. In the past centuries, water shortage or its absence in rives caused disturbances in navigation, timber floating and transport of goods by barges. Wells, which were the basic source of water supply for people and domestic animals, dried out, water mills and sawmills could not work, etc. Presently, due to the progress of technology, many adverse effects of water level drop in rivers have been eliminated, especially those that pose a direct threat to health and lives of humans and animals. However, from the point of view of economy, hydrological droughts still pose a serious problem for water consumers and users. The adverse effects of droughts can be divided into three basic groups: environmental, economic and social.

The impact of droughts on the environment can manifest in the decreasing level of surface water and groundwater, dropping of flow values, drying of wetlands, increasing number and extent of fires, increasing intensity of entrainment and loss of biodiversity. Hydrological drought is also accompanied by a higher increased pollution concentration.

Economical effects of droughts include losses in agricultural and livestock production as well as in fishery, higher costs of food production, lower energy production by hydropower plants, losses in aquatic tourism and transport, etc. The vulnerability of particular economic branches is different. The most vulnerable branch of economy is agriculture and the losses in production caused by atmospheric drought depend on its duration and intensity. The crop losses in Poland can vary from a few to several dozen percent.

The social effects of droughts refer mainly to the negative impact on health of people directly exposed to this phenomenon – heat waves, possible limitations on water use, increased water pollution, high food prices, stress caused by crop losses, etc.

One of the direct problems resulting from low-flows are possible problems with water supply. The volume of water resources stored in retention reservoirs, indispensable for water supply, becomes then of the outmost importance. However, at the same time, because of a lowered flow, the stored water depletes and an excessive loss of water can occur. A prolonging drought affecting surface waters decreases groundwater level which has a direct impact on farm wells diminishing their capacity and limiting amount of water available for population in rural areas.

Long drought can, therefore, disturb the entire water management in a region. However, only the knowledge of losses that can be caused by drought allows to estimate the potential risk and to manage it, i.e. to monitor it and to mitigate its effects.

The alarming climatologists' reports on progressing climate change and increasing frequency of extreme phenomena occurrences resulted in a growing interest in atmospheric and hydrological droughts. Nonetheless, despite frequent drought events in Poland, the problem is still underestimated and has not been addressed by definite and satisfactory regulations. Hence the idea of the comprehensive analysis of hydrological drought hazard in Poland.

Material and methods

The analysis was based on data of daily flows from 72 gauging stations closing catchments with the area of minimum 300 km^2 and located throughout the entire territory of Poland for the period of record 1951-2000. Runs test was applied to check the data homogeneity. Such abundance of data allowed to carry out analyses of both spatial and temporal distribution of low-flows in Poland. The basic criterion of low-flow identification was the hydrological criterion based on the mean value of minimum annual flow values (SNQ). The following definitions were adopted: (i) low-flows are daily flows lower than the threshold flow (SNQ) for the minimum of 21 days and (ii) hydrological drought occurs when low flows are noted in at least 20% of the total country area. Hence, the concept of low-flows indicates a point phenomenon (in a given river profile) while the concept of drought – a non-point phenomenon.

Low-flows were characterized by parameters such as: low-flow minimum and mean values, onset and offset dates, duration and deficit volume. In case of each profile, the values of minimum flows of a given probability of non-exceedance were calculated using the Gumbel distribution (1963).

Results and disscussion

Periods with noted low-flows in Poland occur in summer-autumn months and winter. The dominant type, in regards of both frequency of occurrences and duration, are summer-autumn low-flows (Fig. 1). On the average, they occur every five years, however, their frequency varies considerably in given regions – from two to twenty five years. Winter low-flows are much less frequent (the average for the entire country is twenty years) and in case of many profiles, there were no occurrences recorded in 1951-2000.

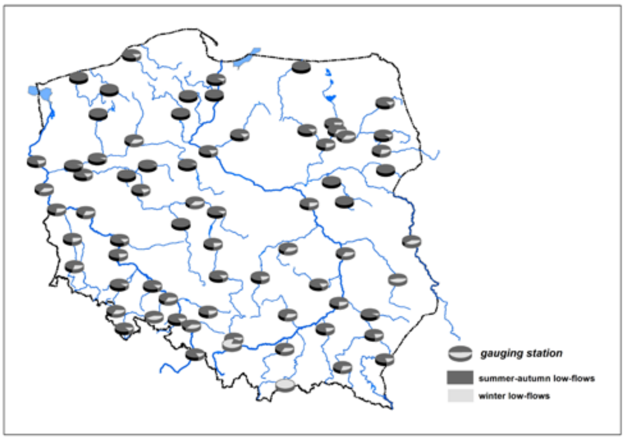

Figure 1. *Ratio of summer-autumn low-flows and winter low-flows to the total number of low-flows in 1951-2000 (for selected gauging stations in Poland).*

There is a high dependency between summer-autumn low-flow occurrences and precipitation shortage. The first low-flows appear 1-2.5 months after the onset of precipitation shortage combined with high air temperature (and, consequently, higher field evaporation). Low-flows, however, disappear rather quickly after high precipitation totals – within a month at the latest.

Winter low-flows occur after longer periods of air temperatures below zero causing the lack of rainfall (snow does not aliment the runoff) and groundwater alimentation (frozen ground).

Mean duration of summer-autumn low-flows in particular profiles shows high diversity, i.e. from 29 to 107 days (most often from 40 to 70 days). In the period of 1951-2000, in the Odra River basin, the mean duration of low-flows was nearly 65 days which was almost 12 days longer than the mean duration in the Vistula River basin and 24 days longer than the value for rivers flowing directly to the Baltic Sea (Fig. 2). The longest low-flows (130-220 days) occur mostly in areas spreading from the western state border on the Odra River through the central Poland to the far north-eastern part of the country.

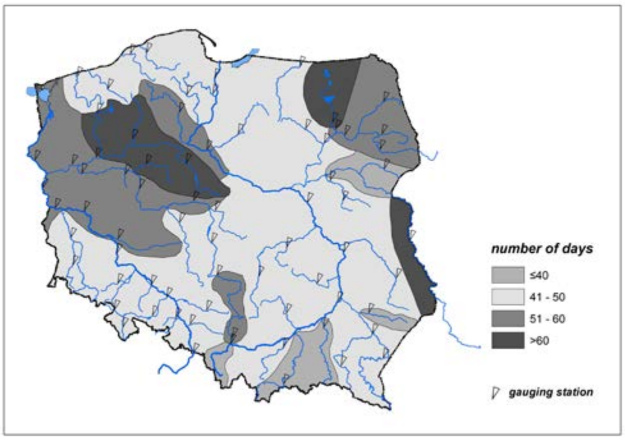

Figure 2. *Spatial distribution of mean duration of summer-autumn low-flows in 1951-2000 (Poland).*

Mean duration of winter low-flows is much shorter counting 41-42 days in both the Odra and Vistula rivers basins.

Typical months of summer-autumn low-flow occurrences are July to November and (less frequently) June. In June, the phenomenon is noted in north-eastern Poland, in July – in northern and central Poland and in August – in southern parts of the country. The earliest dates of low-flow offset are in August (north and north-south of Poland) and the most frequent offset dates are noted in September and October (all other parts of the country).

First winter low-flows appear in November while the majority of their occurrences are registered in December and January. Because of the relatively short duration of winter low-flows, they disappear in the month of their appearance or the following month (mostly in February or March, and partially already in January).

The maximum water shortage during low-flows in the majority of cases is connected with extremely low flow values and less frequently with their duration.

The number of occurrences of extreme values of particular parameters in 1951-2000 indicates that the decisive majority of deep low-flows were registered in the first decade of the period, especially in 1951-1954 and the beginning of the 1960's. Deep low-flows also occurred in the first years of the 1990's and – to a lesser degree – in the first half of the 1980's.

In respect to the quantity of hydrological droughts, the majority of them took place in the period of 1951-70. The decade of 1971-1980 was the only period with no hydrological drought occurrences (Tab. 1).

Table 1. *Comparison of hydrological droughts in the period of 1951-2000 in chronological order*

No.	Hydrological year	No. of profiles affected by low-flows	
		Total	Ratio of the total number of analyzed profiles [%]
1	1951 [1]	41	57
2	1952 [1]	43	60
3	1953 [1]	40	56
4	1954 [2]	42	58
5	1954 [1]	40	56
6	1959 [1]	54	75
7	1961 [1]	22	31
8	1963 [1]	31	43
9	1964 [2]	18	25
10	1964 [1]	33	46
11	1969 [1]	25	35
12	1983 [1]	29	40
13	1985 [2]	15	21
14	1989 [1]	15	21
15	1990 [1]	19	26
16	1992 [1]	56	78
17	1994 [1]	26	36

1 – summer-autumn drought
2 – winter drought

For the purpose of hazard estimation for particular catchments and regions of the country, an indicator of low-flow hazard has been created (W_z). It was assumed that the most threatened areas are those where the phenomenon is most frequent, its total duration is the longest and the probability of non-exceedance of low-flow values (NQ) is high. The developed equation includes all three parameters: total duration of low-flow, number of low-flow occurrences and probability of non-exceedance of the lowest registered flow in a given profile, and their weight. It has been found that the frequency of phenomenon and its duration are more damaging than probability of non-exceedance of the lowest registered flow. Consequently, particular parameters are given the following weights: total duration – 40%, number of occurrences also 40% and probability of non-exceedance of NQ – 20%.

The equation can be used for calculation of indicator of low-flow hazard in summer-autumn and winter seasons.

$$\mathbf{W_z = \alpha_1 (T_w/T_{max}) + \alpha_2 (L_w/L_{max}) + \alpha_3 (P_w/P_{max})}$$
$$\mathbf{\alpha_1 + \alpha_2 + \alpha_3 = 100\%}$$

where:
W_z - indicator of low-flow hazard in a given gauging profile; α_n – parameter weight; T_w – total duration of low-flows in a given gauging profile; T_{max} – maximum value of low-flow duration of all gauging profiles; L_w - number of low-flow occurrences in a given gauging profile; L_{max} – maximum number of low-flow occurrences of all gauging profiles; P_w – probability of non-exceedance of the lowest flow registered in a given gauging profile during low-flow occurrences; P_{max} – maximum value of probability of non-exceedance of the lowest flow of all gauging profiles.

Presented below is the estimate of hazard level of particular areas for summer-autumn low-flows only since this type of phenomenon dominates in Poland in regards to both frequency and duration and has much larger impact on water resources than winter low-flows.

The calculated indicator of summer-autumn low-flow hazard (W_z) has taken values from 13 to 85 in given profiles. Based on these values, five hazard levels were distinguished: very high, high, medium, low, none (Fig. 3).

The indicator of low-flow hazard level described above characterizes a hazard generated by natural phenomena, i.e. lack or shortage of rainfall causing the reduction of flow in rivers below threshold values. It has to be kept in mind, however, that low-flows in a river can be accompanied by anthropogenic factors worsening the situation thus decreasing further water resources available in a given area. The basic anthropogenic factor is water abstraction. For this reason, in order to estimate levels of hazards in water management, the actual and planned water abstractions for the industry and domestic consumption, including the actual trends in economy, population and climate, should be identified. The volume of the abstracted water implies the necessary adaptive actions.

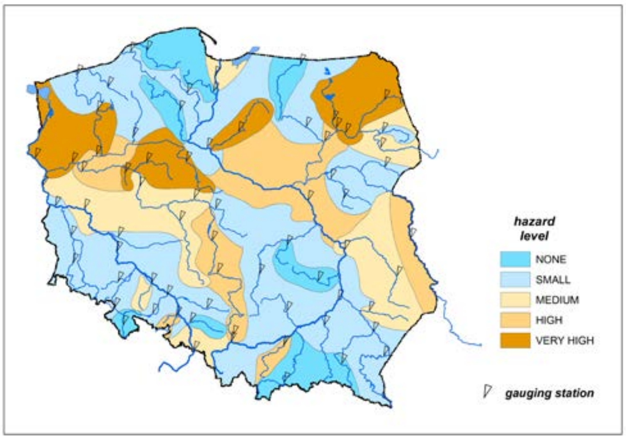

Figure 3. *Spatial distribution of summer-autumn low-flow hazard indicator (Poland).*

Assuming that the visible effects of climate change are visible in Poland from the 1980's, the analysis of trends of flows was conducted. It was found out that trends of NQ values in the period of 1981-2000 show gradual decrease (over 60% of the studied profiles). If this trend continues in the following years, the problems in water management will intensify in the nearest future.

Conclusions

The developed indicator of low-flow hazard (W_z) is based on duration, frequency and probability of non-exceedance of low-flow values (NQ). It allowed to establish that almost 30% of the territory of Poland is at a high risk of summer-autumn low-flows and another 20% is at a very high risk. The affected areas are crucial for the agricultural production. The economic and social losses in this sector are especially acute since the shortage of water caused by droughts occurs mostly in the growing seasons.

Changes in water management taking into account drought hazard are necessary. Water management needs to be reoriented towards drought preparedness and risk management. It will bring measurable effects, especially in the context of climate change trends which show that the amount of available water may continue to decrease in the near future.

References

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