Multi-annual fluctuations in precipitation and their hydrological and ecological consequences at regional scale

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Abstract The paper considers ecological effects of precipitation in agriculture. The background of the research is an analysis of multi-annual and temporal fluctuations in precipitation totals. Special attention is paid to long-lasting droughts and their influence on ecological systems of meadows. The studies were carried out in the region of Kujawy (central Poland).

Key words drought; ecology of meadows; Kujawy, Poland; precipitation

INTRODUCTION

Among the possible aspects of climate change in temperate climatic zones are temporal fluctuations of meteorological elements. Because of the great importance of water balance to different kinds of human activity, fluctuations in precipitation are in the research interest of various branches of fundamental and applied studies e.g. agriculture, water supply systems, etc.

The aim of this paper is to discuss the influence of fluctuations in precipitation totals (*RR*) on the hydrological regime of the Kujawy region in Poland (Fig. 1). Special attention is paid to the functioning of the ecological system of meadows in the upper Notec River valley.

The general feature of the precipitation regime of Poland (temperate warm, transitory climatic zone) is a predomination of summer precipitation totals over the winter ones (Blazejczyk, 1985). The Kujawy region has the least precipitation in Poland: average *RR* of about 500 mm (Fig. 1). Another feature of Kujawy is very frequent and long-lasting periods without rainfall (22 days on average, 38 days maximum). As a result of these features, the most important ecological problem in this area is insufficient soil water (Kaczorowska, 1962; Kasperska-Wolowicz *et al.*, 2003; Konopko, 1988).

Peatlands in the upper Notec valley are under a variety of anthropogenic pressure. Non-degraded ecosystems occur mainly along the river channels. The transformed natural grassland ecosystems in the peatlands are located in cultivated areas. To intensify agriculture in the region, systems of drainage and irrigation–drainage ditches

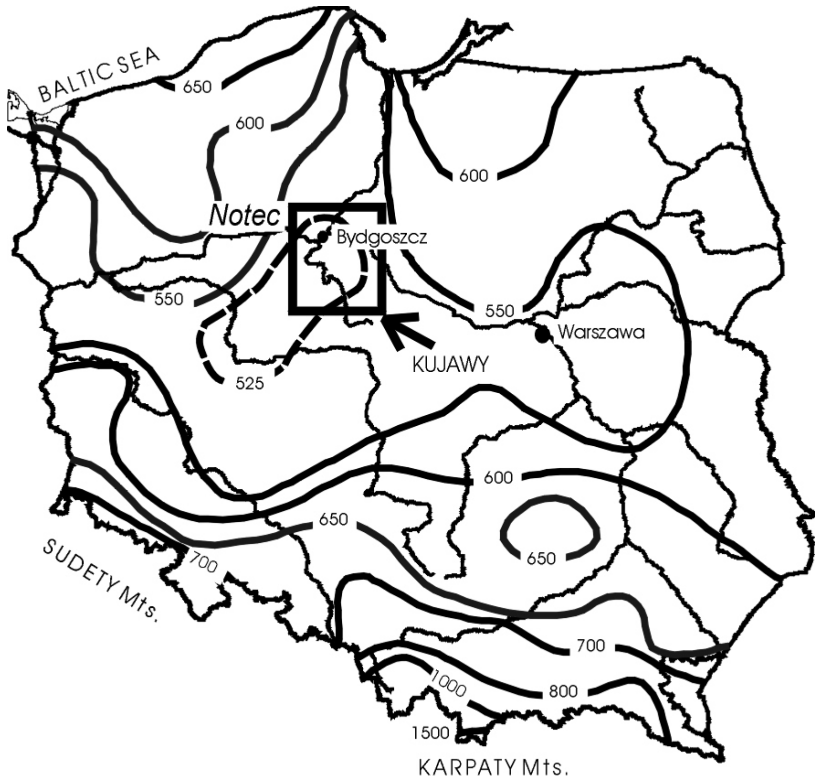

Fig. 1 Annual precipitation totals (mm) in Poland, 1961–1990.

were set up. These projects led to the lowering of the groundwater table and they improve the conditions for agriculture. On the other hand, they result in unfavourable changes in the peatland ecosystems, such as overdrying of peat soils. In addition, frequent atmospheric, hydrological and soil droughts in the region contribute to the degradation of the peatlands (Labedzki, 2003). The soils in the upper Notec valley belong to the soil-moisture complexes: wet (A), periodically wet (AB), moist (B), periodically dry (BC) and dry (C) (Okruszko & Ilnicki, 2003).

MATERIALS AND METHODS

The background of the studies is precipitation series from the period 1931–2000 from several regions in Poland: seashore, Kujawy and mountains. Multi-annual trends in annual precipitation totals (*RR*) and year-to-year differences in precipitation (d*RR*) are discussed. Two indices are used to validate the hydrological regime: an index of precipitation stability (*RRS*) and an index of instability of hydrological regime (*IHR*). The *RRS* index was calculated as follows:

$$RRS = RR\text{avg}/(RR\text{max} - RR\text{min}) \quad (1)$$

where *RR*max is the maximum annual total precipitation, *RR*min is the minimum annual total precipitation, and *RR*avg is the average annual total precipitation.

The *IHR* index was calculated as follows:

$$IHR = (\text{d}RR\text{max} - \text{d}RR\text{min})/RR\text{avg} \quad (2)$$

where d*RR*max is the greatest positive year-to-year difference in precipitation, and d*RR*min is the greatest negative year-to-year difference in precipitation.

The extreme dry weather events were compared with soil droughts. As a case study of ecological implications of long-lasting droughts, two meadow sites on the peat–moorsh soil have been chosen. The sites represent periodically dry (BC) and dry (C) soil-moisture complexes. The course of groundwater table depth, meadow evapotranspiration and hay yield were examined in the very dry year 1992. The observations were made at the IMUZ Research Station Frydrychowo (upper Notec River valley). The statistical characteristics of data series were calculated with the use of the STATGRAPHICS Plus software package.

RESULTS

Mean *RR* varied from about 510 mm at Kujawy, to 660 mm at the Baltic seashore and 720 mm in the mountains. In all regions a wide range of precipitation totals was observed. The extreme *RR* varied at Kujawy from 245 mm in 1989 to 760 mm in 1970. A similar amplitude of precipitation was also observed at the seashore and in the mountains. However, the Kujawy region is characterized by the lowest values of precipitation stability index (Table 1).

We observed 70 years of trends in *RR*. At Kujawy, a slight decrease in precipitation is noted (–3.4 mm per 10 years); the trend is statistically not significant at the 90% probability level. In comparison, at the seashore and in the mountains, the *RR* trends were statistically significant at the 95% level and their values were +13.5 mm and +17.0 mm per 10 years, respectively (Fig. 2).

Table 1 Characteristics of precipitation in various regions of Poland, 1931–2000.

Region	*RR*max (mm)	*RR*min (mm)	*RR*avg (mm)	d*RR*max (mm)	d*RR*min (mm)	*RRS*	*IHR*
Kujawy	760	245	512	395	–335	0.99	1.42
Seashore	915	396	662	425	–395	1.28	1.24
Mountains	1009	486	718	365	–317	1.32	0.98

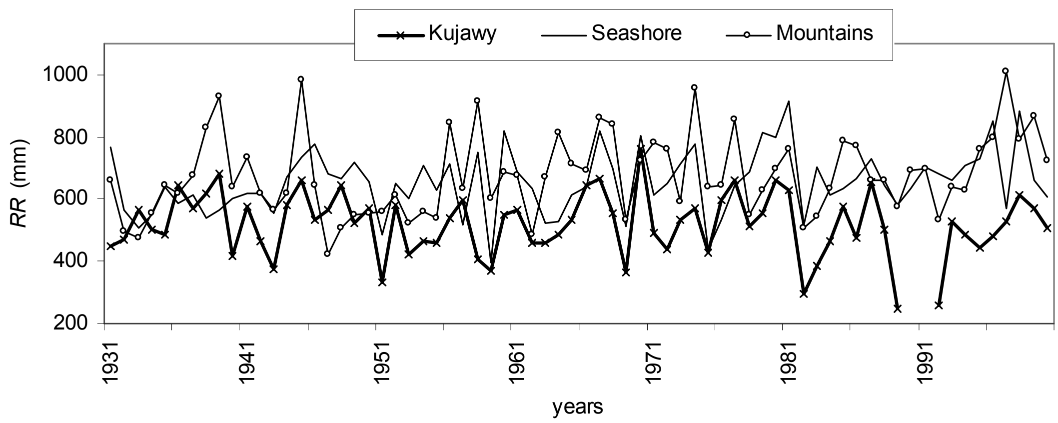

Fig. 2 Fluctuations in annual precipitation totals (*RR*) in several regions of Poland, 1931–2000.

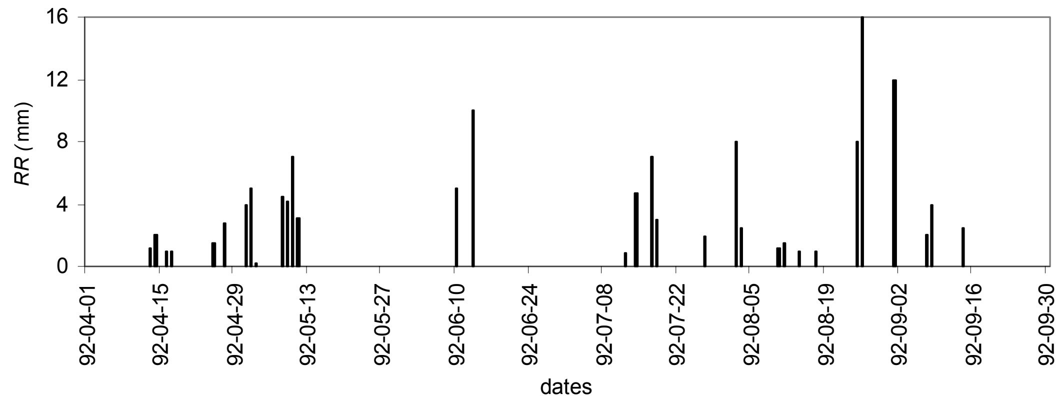

Fig. 3 Course of daily precipitation totals (*RR*) in the upper Notec valley in Poland in the growing season of 1992.

Weak stability of precipitation at Kujawy is one of the causes of the unstable hydrological regime of this region. The d*RR* values varied from –335 to 395 mm. A similar range of d*RR* values was observed at the seashore. By comparison, in the mountains, year-to-year fluctuations in precipitation were considerably lower. The highest *IHR* values are noted at Kujawy. However, the mountains have the most stable hydrological regime (Table 1).

The precipitation total in the upper Notec valley in 1992 was 259 mm and in the growing season (April–September) it was 130 mm. This year was extremely dry and hot and long-lasting (26–30 days) periods without precipitation occurred twice in the growing season (Fig. 3).

The course of groundwater table depth in the studied soil complexes indicates changes in soil moisture. There is sufficient soil moisture when the groundwater table is between 40 (*Z*2) and 80 cm (*Z*3) in the periodically dry peat–moorsh soil and between 30 (*Z*2) and 50 cm (*Z*3) in the dry peat–moorsh soil. The duration of insufficient soil moisture amounts to three months (55% of the growing period) in the BC complex soil and over 4.5 months (82%) in the C complex soil. In the latter soil, the insufficient soil moisture started at the beginning of May and lasted to the end of the growing season (Figs 4 and 5; Table 2). According to Kaca *et al*. (2003), the mean duration (for the years 1972–2002) of sufficient soil moisture in the upper Notec valley was longer than in the examined dry year (1992) and lasted over three months at both the examined sites.

Subirrigation from ditches was carried out at the study sites during 9–11 June, 16–23 June and 27–28 July. No effect of irrigation on the groundwater table depth in the dry C complex soil was observed. During the meteorological and soil droughts, the groundwater table depth lowered, the capillary rise was broken and then groundwater feeding was stopped. In the BC complex soil, the groundwater table depth rose as a result of irrigation. The hay yield from meadows of the BC complex soil was about 6–7 t ha^{-1} and evapotranspiration was about 450–490 mm in the growing season. On the C complex soil 4–5 t ha^{-1} of hay yield was observed and about 400–450 mm of evapotranspiration. This means that the rainfall deficit for grass, calculated as the difference between evapotranspiration and precipitation, was 320–360 mm at the first site and 270–320 mm at the second one.

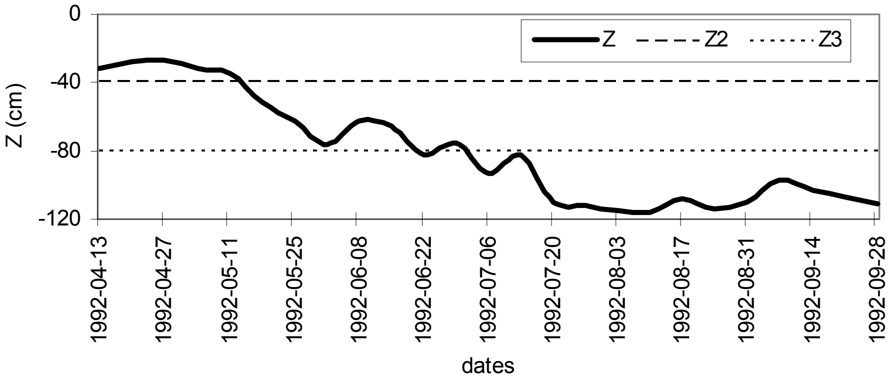

Fig. 4 Groundwater table depth (*Z*) in the peat–moorsh soil of the periodically dry complex BC under grassland in the growing season 1992 in the upper Notec valley in Poland. (*Z*2: minimum groundwater table depth ensuring 8% of air (volume) in the root zone of grasses, *Z*3: maximum admissible groundwater table depth ensuring efficient capillary water rise to the root zone of grasses.)

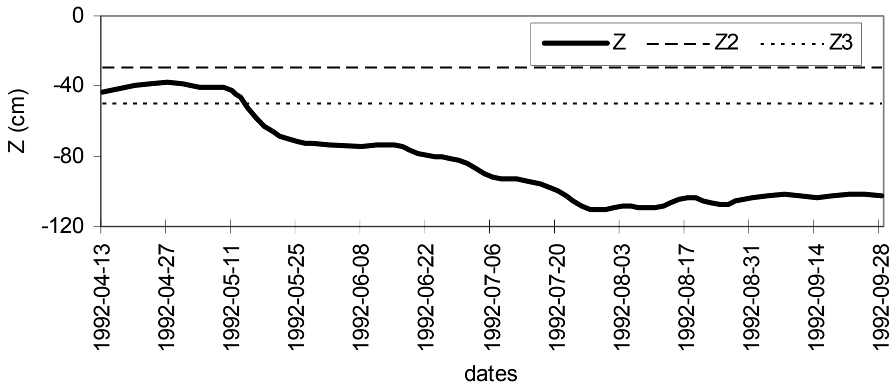

Fig. 5 Groundwater table depth (*Z*) in the peat–moorsh soil of the dry complex C under grassland in the growing season 1992 in the upper Notec valley in Poland (for explanation, see Fig. 4).

Table 2 Duration (% of the growing season) of different soil moisture states in the root layer in the two kinds of peat–moorsh soils in the upper Notec valley in Poland in 1992.

Soil moisture	Periodically dry BC:		Dry C:	
	1992	1972–2002*	1992	1972–2002*
Excessive	18	25	0	25
Sufficient	27	61	18	55
Insufficient	55	15	82	21

* mean values for organic soil without feeding and groundwater table depth on 1 April, $Z = 0$ cm, according to Kaca *et al.* (2003)

DISCUSSION AND CONCLUSIONS

Irrigation in the Notec valley plays an important role in mitigating the effects of drought on crop production. Under the climatic, soil and economic conditions of the Kujawy region, the systems of gravitational irrigation are applied on the grassland river plain. According to Kaca *et al.* (2003), the mean duration (1972–2002) of sufficient soil moisture in the upper Notec valley was longer than in the examined dry year (1992) and lasted over three months at both study sites. The duration of periods of insufficient soil-moisture can be reduced by proper water management and a properly functioning sub-irrigation system.

In dry years in the Notec valley, the effects of water scarcity are greater in dry soils (the C complex with worse retention properties) than in the periodically dry ones (the BC complex). Lowering of the groundwater table depth caused a reduction in water used for evapotranspiration and of hay yield from meadows. Irrigation plays an important role in mitigating the effects of droughts on crop production. In recent years the role of irrigation in supplying water to maintain proper moisture conditions for conservation of grassland ecosystems has been stressed. Controlled runoff from cultivated peatlands should be the simple method commonly used to ensure sufficient soil moisture for crop production, as well as for conservation of grassland ecosystems (Labedzki, 2003). The modernization, rehabilitation, proper operation and maintenance of the existing sub-irrigation systems are essential to ensure that the required moisture conditions are maintained for the protection of grassland ecological systems.

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