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Original Research Article

Risk of groundwater drought in groundwater-dependent ecosystems in the central part of Vistula River Valley, Poland

Ewa Krogulec

Department of Geology, University of Warsaw, Żwirki i Wigury 93, 02-089 Warsaw, Poland

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ABSTRACT

This study was focused on assessing the dynamics of groundwater-level fluctuations in shallow hydrogeological systems, that is, groundwater-dependent ecosystems (GDEs). Assessment of the range of dynamics of groundwater-level fluctuations allows for correct local water resource management, as well as aids the agricultural organizations and development/planning authorities to improve their understanding of sustainable groundwater resource management. Analysis of the dynamics of groundwater-level fluctuations in GDEs in multiannual and seasonal scales, determination of the fluctuation trends, and the values of characteristic levels allows for the identification of risks and the occurrence of groundwater (hydrogeological) drought. Observations of groundwater levels were conducted in the central part of Vistula Valley in 17 piezometers of the monitoring network (about 6600 observations). The piezometers of the monitoring network are located such that they are not under the direct influence of anthropopression, which allows for the interpretation of the results as the influence of natural factors on the quantitative state of GDEs. In conclusion, the present investigation showed that hydrogeological droughts, characteristic of the summer months, occur only during the years when the lowest groundwater levels were observed. Shallow hydrogeological droughts occur periodically, from summer to spring, and the average duration of shallow droughts was 8 weeks.

1. Introduction

Measurements of groundwater-level fluctuations can provide a practical means of estimating temporally and spatially variable groundwater recharge rates (Rasmussen and Andreasen, 1959; Sophocleous, 1991; Healy and Cook, 2002; Rai and Singh, 1995; Bierkens, 1998; Knotters and Bierkens, 2000; Coulibaly et al., 2001; Rai et al., 2006; Krogulec, 2016). Changes in subsurface water storage can be attributed to recharge, evapotranspiration from groundwater, and groundwater flow out of the basin (Schict and Walton, 1961). The statistical analysis of those monitoring observations most widely used in monitoring networks (Loaiciga et al., 1992; Moon et al., 2004; Bidwell, 2005; Coppola et al., 2005; Krogulec, 2004; Yang et al., 2008; Baalousha, 2010; Maheswaran and Khosa, 2013; Shiri et al., 2013a,b) was the basis for identifying the range of seasonal, annual, and long-term groundwater level changes.

Assessment of the position of the groundwater level and the dynamics of its fluctuations permit the indication

E-mail address: ewa.krogulec@uw.edu.pl.

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and the definition of the acceptable level to which groundwater is allowed to fall, while maintaining important environmental values (Murray et al., 2006) in various conditions. Results of groundwater monitoring, according to the Water Framework Directive (WFD) (EC, 2000) and Groundwater Directive (GWD) (EC, 2006), are elements of the assessment of groundwater levels and constitute the base for risk assessment of their pollution and the base to identify their pressures and influencing factors. The European legislation, aimed at the protection of the surface and groundwater, recognizes the fact that groundwater-dependent ecosystems (GDEs) are influenced by changes of the quantitative and qualitative status of groundwater and groundwater bodies. Hydrogeological and environmental factors influencing the status of GDEs generally include: regime of infiltration recharge, landscape development, groundwater recharge, irrigation-melioration networks, and types and water demands of plant ecosystems. The role of particular factors is variable depending on the location of protected ecosystems (Boulton and Hancock, 2006; Murray et al., 2006), but they also influence, among many other factors, groundwater level fluctuations. Analysis of trends of groundwater level fluctuations in GDEs is considered in the framework of the Source-Pathway-Receptor paradigm (EC, 2000) for threats related to groundwater quantity (Kløve et al., 2014) at different scales, varying from individual dependent surface water or terrestrial ecosystems to aquifer scale. For each objective, the risks of not meeting that objective should be assessed. The results of the analysis, particularly the indication of fluctuation trends and values of hydrogeological drought may be applied in sustainable use and ecosystem services. It should be emphasized that groundwater level changes may be caused by natural factors, anthropopression, but also recent large-scale projects of restoration and rehabilitation of damaged GDEs, considered as some of the most threatened ecosystems in the world (Bobbink et al., 2006; Brönmark and Hansson, 2002; Amezaga et al., 2002; Wagner et al., 2008). Trend analysis of groundwater-level fluctuations should lead to their classification into hydroperiods, which allows the identification of hazards and working out methods of protecting GDEs. Four types of hydroperiods can be distinguished (Alfaro and Wallace, 1994):

- Periodic: usually a clear seasonal pattern, average discharge climatically controlled (precipitation/evapotranspiration changes);
- Intermittent: great variability in flow;
- Episodic: completely irregular flow, occurring only when water levels in the aquifer are very high; and
- Perennial: continuous source year-round.

2. Material and methods

2.1. Study area

Studies were conducted in the central part of the Vistula Valley, a large river of the North European Plain. The examined section of the Vistula Valley is mostly located in the Kampinos National Park (KNP), which is spread over an area of 385 km^2. The investigated GDEs: northern southern marsh zones cover 176.9 km^2 (Fig. 1).

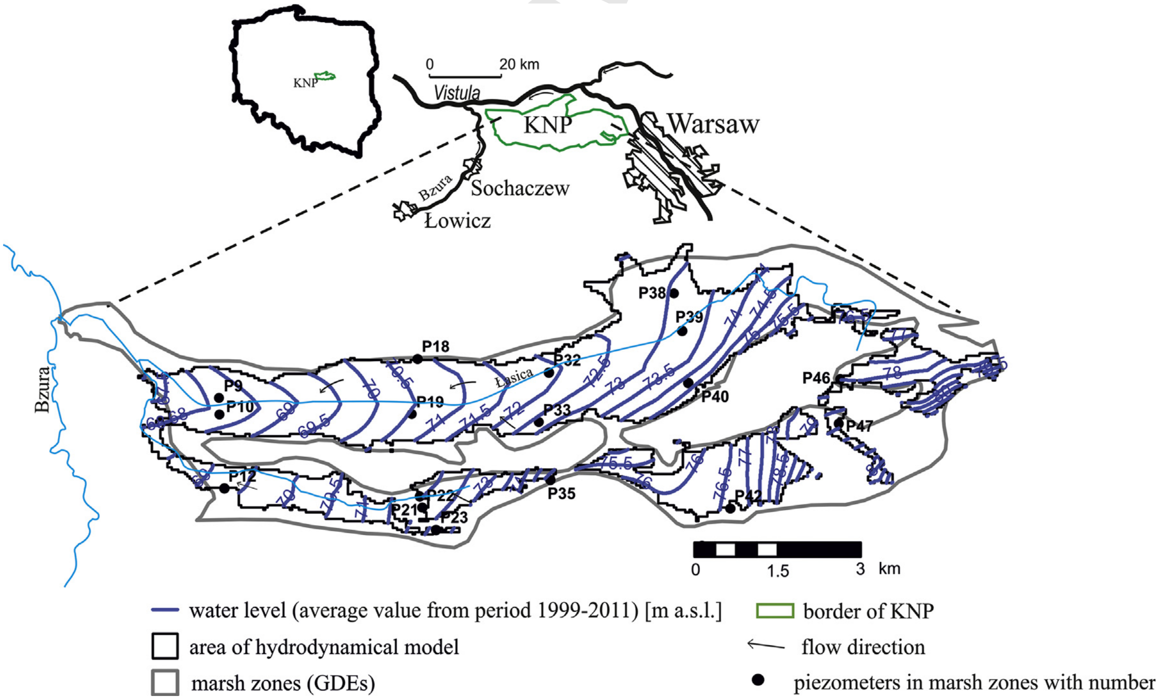

Fig. 1. Hydroisohypses of the quaternary aquifer feeding GDEs areas (average annual state).

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