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Original Research Article

Hydrogeological study of groundwater-dependent ecosystems—an overview of selected methods

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ABSTRACT

Hydrogeological studies, their methods and results are an integral part of a broader scope of environmental research, particularly environmental protection. The hydrogeological studies conducted in recent years indicate the need for a more interdisciplinary approach and integration of various fields of natural sciences. Here, hydrogeological studies of *groundwater-dependent ecosystems* (GDEs) conducted in the middle Vistula River valley, Kampinoski National Park, Poland, are used as an example. The hydrogeological survey integrated with the results from other disciplines such as environmental engineering, hydrologic engineering, hydrology, geology and geophysics, forestry, agriculture, soil science and environmental biology provides an informed output that can in turn form an important input to various environmental studies.

1. Introduction

Hydrogeological studies conducted in recent years in wetland areas, which are so-called groundwater-dependent ecosystems (GDEs), indicate the need for a more interdisciplinary approach and integration of the environmental studies. Here, we present examples of hydrogeological research and practice that form an input to an interdisciplinary environmental science and the future pathways for the development of ecohydrology. These studies, research methods, and their results are used in the interdisciplinary research, particularly in the field of environmental protection.

Preservation of the existing wetland ecosystems and renaturalization of the selected degraded areas constitute important elements of the strategy of eco-development, biodiversity, and shaping of water resources (Hobbs and Norton, 1996; Harmsworth, 2002; Anderson and Barbour, 2003; Ramsar Convention on Wetlands, 2003; Harris et al., 2006; Acreman et al., 2007; Sommerwerk et al., 2010; Krogulec and Sawicka, 2012; Kopeć et al., 2013; Krogulec, 2013), but the key is to understand of the complexity of environmental processes (Zalewski, 2015).

Waterlogged areas, swamps, or marshes are not well defined in the Water Framework Directive (Directive 2000/60/EC), though they are recognized by an indication of their distinct functions (article 1 of WFD) and environmental goals (article 4 of WFD). Infiltration regime, hydrodynamic conditions, land use, groundwater extraction, irrigation–drainage networks and the types and aquatic needs of plant ecosystems are one of the most significant hydrogeological and environmental factors that affect the condition of GDEs. In turn, International

Abbreviations: GDEs, groundwater-dependent ecosystems; IHP, International Hydrological Program; KNP, Kampinoski National Park; WFD, Water Framework Directive; PCA, principal component analysis.

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Hydrological Programme of UNESCO for the period 2014–2021 (UNESCO, 2012) under the theme 5 "Ecohydrology, engineering harmony for a sustainable world" indicates that the key for enhancing catchment's biological productivity and biodiversity is to improve the understanding of the role of different types of wetland ecosystems distributed in the catchment on the water cycling processes and support studies on the role of hydrodynamics of the river basin in the reduction of various types of pollution.

This paper presents the consecutive steps/phases of the long-term hydrogeological studies undertaken in the area of the Kampinoski (Kampinos) National Park (KNP), in respect of the regulation of the groundwater conditions in relation to the linked groundwater dependent ecosystems (GDEs). The first phase was the long-term hydrogeological monitoring that allowed to determine the basic hydrogeological characteristics. The development of hydrodynamic model, based on the previous phase, allowed for predicting dynamic response of the groundwater system to the hydrological conditions change. Vegetation class mapping was used to counter verify the groundwater modelling results in respect to the response of the vegetation to groundwater conditions using factor analysis.

2. Study area

The research ground for the hydrogeological studies was the left side of the Vistula River valley located northwest from Warsaw, Poland, and the largest wetlands (marshes) in Central Poland covering the area of 242.3 km^2; the Vistula River is one of the largest rivers in the North European Plain with the catchment area of 194,424 km^2. The investigated section of the Vistula valley is located in the Kampinos Forest, which is almost entirely included into the Kampinoski National Park (KNP). The park was established in 1950 and occupies the area of 385 km^2; it is surrounded by a protective zone, established in 1977 (with the area of 378 km^2). It is also the NATURA 2000 site and the Biosphere Reserve (UNESCO MaB).

The hydrogeological conditions of KNP have been the subject of several research projects, including the project "Model analysis of hydrogeological conditions in wetlands" (2011–2014, funded by the State Committee for Scientific Research) and are summarized in several publications (Krogulec, 2003a,b, 2004, 2013).

The geological formation of the study site is formed by the Quaternary sediments, which constitute a main collector of groundwater. A top part of this unconfined aquifer is made of sandy and sandy-gravel deposits, and the bottom is created by sandy-silts, which makes a total thickness of the aquifer up to 50 m. The aquitard is created by glacial tills and more often Pliocene loams, and occurs in this region at elevations ranging from 2 to 54 m above sea level (a.s.l.) (Baraniecka and Konecka-Betley, 1987; Sarnacka, 1992; Krogulec, 2004). Delimitation of the main groundwater circulation systems in the Quaternary aquifer was made by Krogulec (2004) following the methods of Tóth (1963) and presents a clear dichotomy. Although general flow direction in the aquifer is north and west to the main discharge base, which is Vistula and Bzura rivers (intermediate system), groundwater circulation in GDEs areas (marsh zones) should be considered as a local system (Figs. 1 and 2).

For the purpose of systemising the hydrogeological research the zones of similar groundwater hydrodynamic conditions (so-called hydrozones) were determined. The following criteria were used to distinguish the hydrozones (Krogulec, 2004): geologic structure and geomorphology, lithology of subsurface sediments and related vegetation cover, depth of groundwater level, amplitude of water level fluctuations, and human economic activities, and the result of this multi-criteria analysis is as follows (Figs. 1 and 2):

- Vistula River floodplain terrace
- Marsh zones (northern and southern)
- Dune zones (northern and southern)
- Accumulative-erosive Warsaw-Blonie terrace, called the Blonski level (with part of the upland).

3. Monitoring studies of groundwater level

The statistical analysis of the monitoring observations most widely used in monitoring networks (Gilbert, 1987; Loaiciga et al., 1992; Davis and McNichols, 1994; Chou, 2004; Moon et al., 2004; Bidwell, 2005; Yang et al., 2008; Maheswaran and Khosa, 2013) was the basis for identifying the range of seasonal and long-term groundwater level changes. The analysis of point monitoring data enables evaluation of the trend changes at points, identification of statistical parameters, and prediction of water level changes.

The results of monitoring studies in KPN, to varying degrees, have been obtained in the course of several research projects, including the project "Model analysis of hydrogeological conditions in wetlands" (2011–2014, the State Committee for Scientific Research) and are summarized in several publications (Krogulec, 2003a, 2004, 2013). The planned re-naturalization of bogs within the area of the park requires the diagnosis of the present condition and indication of tendencies and scope of changes in water relations in these areas.

The monitoring network in KNP consists of 56 piezometers and 25 water level gauges (Fig. 1). The spatial distribution of the monitoring network measurement points was designed to take full advantage of hydrogeological analysis within the enclosed surface drainage basin and the hydrogeological system (Krogulec, 2002, 2004). A set of data from the multiyear period (1999–2013) in marsh zones (20 piezometers), which forms a database of over 7000 observations, is the basis of statistical analysis. Statistical analysis of the point monitoring data in marsh zones enabled determination of the scope of the groundwater level changes in the multiyear period, and on the annual and seasonal basis (Table 1). On the basis of these data, seasonal changes were analyzed and the range of change of groundwater levels was defined. The spatial interpretation of the hydrogeological data was carried out using the GIS software. Assessment of the quantitative state of groundwater was carried out using spatial statistical analyses as well as numerical groundwater flow modeling.