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Intra-annual groundwater levels and water temperature patterns in raised bogs affected by human impact in mountain areas in Poland

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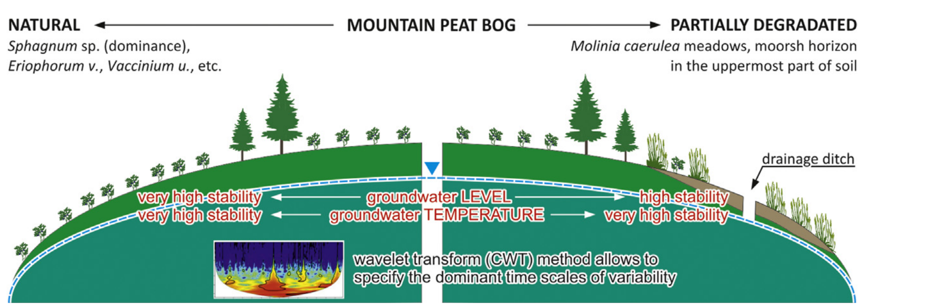
HIGHLIGHTS

- Wavelet analysis was applied to examine time series.
- Wavelet coherence between hydrological and meteorological variables were quantified.
- Peat bogs display high stability of groundwater level and water temperature.
- Water table fluctuations are closely linked to weather conditions in summer and autumn.

GRAPHICAL ABSTRACT



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ABSTRACT

Over the last century, the vast majority of peatlands in Europe have experienced substantial transformation as a result of drainage works that led to an imbalance in the natural hydrologic regime as well as changes in vegetation composition. The ongoing study aims to reconstruct the natural hydrologic regime of peatlands and restore their typical vegetation communities. In this study, we examine the variability of groundwater levels and groundwater temperature in raised bogs located in the Bieszczady Mts. in southern Poland. Both groundwater table levels and groundwater temperature serve to characterise the hydrology of peatlands, which in turn is critical for plant growth and rates of relevant biochemical processes. Our objective is to determine the predominant scale of intra-annual variability in time series and identify their potential sources by assessing the adaptive response of peat bogs to key changes in weather conditions. For this purpose, data obtained from 9 monitoring wells located in peat bogs, with a varying degree of degradation, were used. Fluctuations in time series and potential linkages between selected variables were analysed in the frequency domain using the continuous wavelet transform. The results show that peat bogs exhibit a relatively high stability of groundwater table levels and groundwater temperature despite meaningful changes in weather conditions. The most visible response of peat bogs to weather conditions was observed in summer and autumn. Our study demonstrates that degraded peat bogs experience the largest decrease in groundwater table levels and more frequent fluctuations. In contrast, groundwater temperature remained stable throughout the year at all the studied bog sites.

1. Introduction

From a hydrologic point of view, peatlands are classified somewhere between aquatic and terrestrial ecosystems (Holden et al., 2004). Peat material as a whole contains up to 95% water (by volume); however,

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for the most part, only water accumulated in the surface layer of the bog takes part in runoff and evapotranspiration (Ilnicki, 2002). Furthermore, raised bogs are of particular interest in catchment water management due to their pattern of resupply that is dominated by rainwater. Egglesmann (1993) and Verry (1988) note that undrained parts of ombrotrophic peat bog domes are constantly saturated with water. For this reason, meltwater and rainwater flow across the surface of peat and accumulate in the marginal part of the peat bog. In peatlands located in mountain areas, this pattern is intensified by the gradient of the slope. Consequently, natural raised peat bogs do not retain the excess of precipitation and do not affect the reduction in maximum runoff in streams (Ilnicki, 2002).

The hydrologic regime of raised peat bogs may be impaired by technical works (e.g. lowering the groundwater table level) aimed at transforming a wild natural resource (unproductive land) into agricultural land. An examination of the groundwater table level in peat bogs is important due to the fact that a decrease in the water level – expected either as a result of climate warming (Roulet et al., 1992) or anthropogenic-type drainage – can have a number of environmental effects. The lowering of the water table level in peatland changes the aeration conditions (oxidation rate) of peat soils ('Histosols' according to soil taxonomy rules), which affects soil morphology (e.g. soil structure) as well as physical, chemical, and biological features of Histosols. Consequently, carbon dioxide and methane emissions from peat soil also change (Bridgham and Richardson, 1992; Moore and Roulet, 1993; Nedwell and Watson, 1995), which may lead to peatlands becoming net carbon sources instead of net carbon sinks (Trettin et al., 2006). Since peatlands do occupy a large surface area of the Earth (Lal, 2004; Yu et al., 2010), this change may have potential consequences on a global scale.

Groundwater levels in a peat bog affect a number of biotic processes. The lowering of the groundwater level can change the species composition of plants growing across a peat bog as well as vascular plant production (Potvin et al., 2015) as a result of the specific habitat requirements of plants (Proctor, 2000; Weltzin et al., 2003). In particular, changes in vascular plant production may be caused by even very small changes in groundwater levels (Wallen et al., 1988). Changes in water table levels in peat bogs are an important issue due to ecosystem respiration. Both autotrophic respiration and heterotrophic respiration in peatlands depend on thermal and hydrologic conditions (Juszczak et al., 2013).

The lowering of the groundwater table in peat bogs may alter the hydrologic regime in terms of watershed runoff quantity, timing and flow paths, and moisture storage (Holden et al., 2004) as well as the hydrochemical regime due to an increase in the extractable nutrients concentration (Devito and Hill, 1997; Holden et al., 2004). This process is very complex and depends on the microtopography of the given peat bog as well as on the type of vegetation present (Macrae et al., 2013; Strack et al., 2006).

Particularly interesting are studies concerning the groundwater table as well as water temperature dynamics in peat bogs, as they follow a specific water regime (Ilnicki, 2002) and have a lower content of nutrients (Bridgham et al., 1996). Given the above, the aim of this study was to assess the variability of groundwater table levels as well as groundwater temperature during a period of one year in relation to changes in weather conditions and the rate of peat bog degradation.

2. Research sites and methods

2.1. Study area and sites

The Bieszczady Mts., located in Central Europe (Fig. 1), are characterised by a number of distinct features compared with other mountain ranges in the Carpathian mountain chain. This mountain area stands out in terms of low groundwater retention, long and snowy winters, and high amounts of precipitation. As a result of its heterogeneity of terrain and the hydrogeologic parameters of its rocks (flysch formation: mainly sandstones and shales), the water retention conditions in the Bieszczady vary (Rzonca and Siwek, 2011). Increased flows and floods occur between March and May, and occur most frequently in the early spring and last for a comparatively short time. The average long-term flow in the period 1985–1994, measured at sites on the San River at Zatwarnica and Dwernik, was 10.05 $m^3\ s^{-1}$ and 7.60 $m^3\ s^{-1}$ respectively (Rzonca and Siwek, 2011). In the study area, the mean annual air temperature (MAT) is approximately 4 °C, with the highest temperatures occurring in July and August (mean temperature: 13.6 °C), and the lowest temperatures in January (mean temperature: −4.8 °C). Mean annual precipitation (MAP) may reach 1300 mm and snow cover persists from mid-October till mid-May (155 to 180 days per year) (Nowosad, 1995).

There are many relatively large peat bogs in the Bieszczady Mts. These are natural ecosystems, but they largely have been transformed

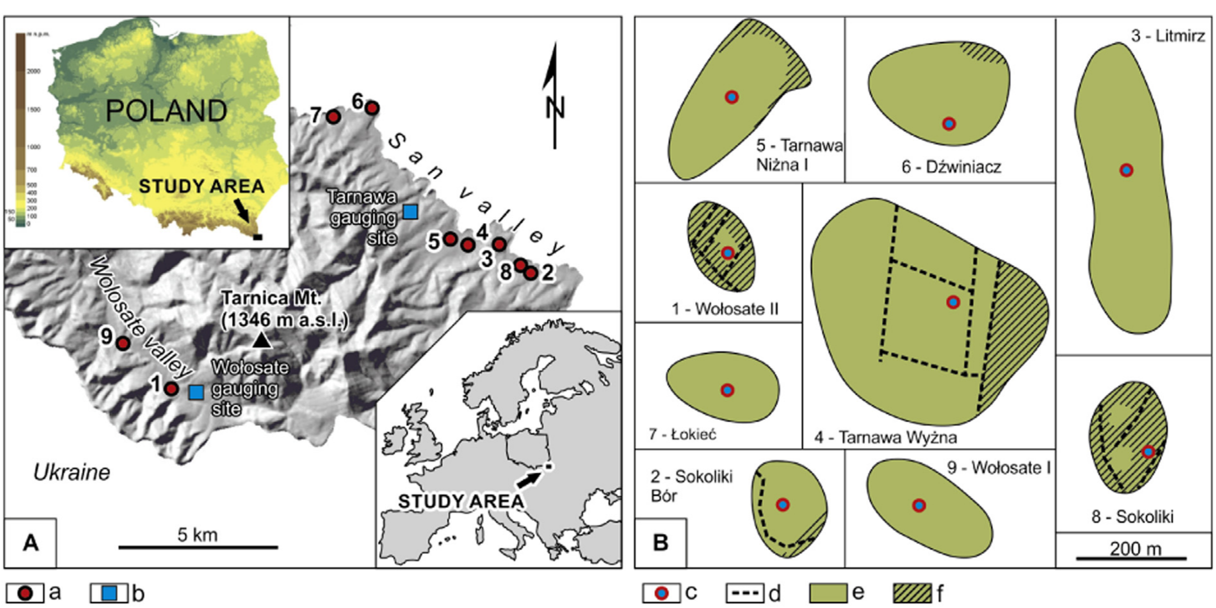

Fig. 1. Study area: A) location of studied sites: a – studied peat bogs, b – gauging sites, B) location of piezometers in the studied peat bogs (numbers of bogs according to A) c – piezometers, d – drainage ditches, e – natural peat bog vegetation, f – *Molinia coerulea* meadows (locally other meadows).