SYLWAN 168 (3): 184-197, March 2024
https://doi.org/10.26202/sylwan.2024002
Journal homepage: https://sylwan-journal.pl

ORIGINAL PAPER

Changes in groundwater levels in the Wielkopolski National Park

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ABSTRACT

Groundwater levels are subject to cyclical changes associated with variations in meteorological conditions. Groundwater levels were measured between 2015 and 2022, at 17 sites placed throughout the Wielkopolski National Park (WPN). Using a numerical terrain model with a resolution of 5 m, topographic catchments were determined for each of the sites where the levels were measured. The topsoil cover is mainly composed of loose sands and weak loamy sands. Forest habitat types are dominated by mixed fresh forest and fresh forest. The average depths of the groundwater table for each site ranged from 0.89 m to 17.92 m below the land surface. The analyses carried out showed a gradual lowering of the groundwater table at all the analyzed sites. The average annual decline in groundwater levels, as determined by Sen's estimator, ranged from 3.0 cm to 21.9 cm.

KEY WORDS

climate change, forests, groundwater level fluctuations, Wielkopolski National Park

Introduction

The condition of forests is significantly affected by a number of environmental factors, and one of the most significant of these is the availability of water (Glanville *et al.*, 2023). Forests are affected by both short-term and long-term environmental changes (Boisvenue and Running, 2006). Observed climate changes affect the reduction of precipitation amounts and, at the same time, their temporal distribution (Dai, 2011; IPCC, 2014; Miler *et al.*, 2015; Boczoń *et al.*, 2016). The observed increase in air temperature during growing seasons increases potential evaporation (Kasper *et al.*, 2022). On the other hand, during winter periods, it may result in a reduction or complete lack of snow retention, allowing wooded areas to be replenished during periods of early spring (Contosta *et al.*, 2019; Matiu *et al.*, 2020).

Groundwater represents a critical water source for plants, especially during drought, with continuous groundwater availability widely associated with the presence of ecological refugia and the preservation of biodiversity during periods of adverse conditions (Glanville *et al.*, 2023). Depth to groundwater was identified as a factor for forest species distribution pattern (Peters *et al.*,

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Received: 25 January 2024; Revised: 4 April 2024; Accepted: 5 April 2024; Available online: 10 May 2024

2008). The groundwater recharge under forests in Northern Germany significantly decreased from 1958 to 2007. This reduction was caused in roughly equal measure by changes in the climate and changes in forest structure (Nathkin *et al.*, 2012).

Trees of temperate zone forests are considered particularly susceptible to soil desiccation because they are adapted to a moisture-balanced environment, with usually assured water availability and no seasonal droughts (Leuschner and Ellenberg, 2017). Forests were shaped by past climate, and even slight changes in climate can significantly affect them (Bhatti *et al.*, 2006; Fettig *et al.*, 2013). One of the factors influencing species changes in forests is the varying drought resistance of different tree species (Leuschner, 2020). Different tree species may differ in their response to changes in groundwater levels. Šenfeldr *et al.* (2021) showed that *Fraxinus angustifolia* Vahl. is more sensitive than *Quercus robur* L. to fluctuations in groundwater levels, both on a short- and long-term scale.

The changes taking place affect not only the state of vegetation, but also the conditions for the development of fauna. Amphibian representatives are among the most endangered species (Wake and Vredenburg, 2008). This is also confirmed by studies conducted in Poland (Pabijan *et al.*, 2023). Declining groundwater levels are causing the disappearance of small water bodies that are an essential element in the two-phase life cycle.

Global environmental changes significantly affect the functioning of forest ecosystems and their biodiversity (Sala *et al.*, 2000). Environmental degradation and ongoing climate change may reduce the biodiversity of forest ecosystems on a global scale (Hooper *et al.*, 2012), but also affect the movement of zones where particular species find optimal growth conditions (Fettig *et al.*, 2013). This may cause species changes and the gradual displacement of native species, which will be detrimental in areas of particularly valuable protected areas. These processes affect not only flora, but also fauna (Huntley *et al.*, 2008; Lawler *et al.*, 2009). Hence, attempts are being made to develop forest management strategies that increase forest biodiversity (Hisano *et al.*, 2018). Climate change may increase both biotic and abiotic risks to forests an forestry (Venäläinen *et al.*, 2020).

Forests support biologically diverse ecosystems (Pimm *et al.*, 2014), but also provide socially valuable services (Nesbitt *et al.*, 2017; Grammatikopoulou and Vačkářová, 2021). Quantitative assessment of changes in landscape and wildlife habitat allows for sustainable development and protection of these areas also for commercial forests (Hashida *et al.*, 2020).

The purpose of this study was to assess changes in groundwater levels in the Wielkopolski National Park (WPN), observed in 2015-2022, and to identify trends in changes as one of the factors affecting the environment.

Material and methods

The study used measurement data of daily measurements of groundwater levels made available by the Wielkopolski National Park. Measurements were made in 17 sites in the period from November 2015 to October 2022 (Fig. 1).

The area of the WPN is about 76 km^2. The top layers of the soil cover are dominated by post-glacial sandy formations. The dominant habitat type is fresh broadleaved forest found on 56% of the forested area. In contrast, mixed fresh broadleaved forest accounts for 26% and mixed fresh coniferous forest for 12.2% of the area. Other habitats include riparian forest, alder forest, wet broadleaved forest, mixed wet broadleaved forest and mixed swamp forest (Wielkopolski Park Narodowy, 2023).

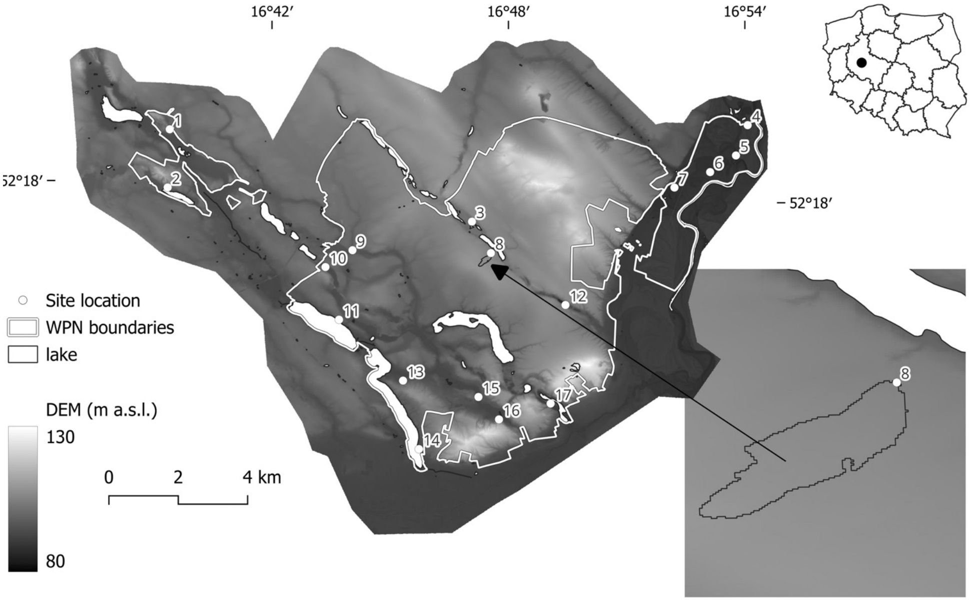

Fig. 1.
Distribution of measurement points against the background of the Digital Elevation Model of the Wielkopolski National Park. The arrow indicates the location of the enlarged sample catchment area of point 8 on the DEM

To describe the variability of meteorological conditions, daily data from the IMGW station Poznań-Ławica, located about 20 km from the analysed area, were used. The average air temperature for 1981-2020 was 8.9°C, and the average annual precipitation was 523 mm.

The relief of the land surface was determined based on a 5 m resolution DEM map made using LiDAR aerial data made available as a LAS file by the Wielkopolski National Park (Fig. 1). In order to determine the impact of land adjacent to the water level measurement points, topographic catchments of points located outside alluvial areas (P1 to P3 and P8 to P17) were determined using multiple flow direction method (an example catchment area of site P8 is shown in Figure 2). For points P4, P5, P6 and P7 located in alluvial areas, areas delineated by a circular buffer of 50 m radius were taken as areas that may affect water levels. To describe the physiography of each catchment, the following parameters were determined using the SAGA GIS program: average land slope, average SAGA Wetness Index value, dominant topsoil cover texture and dominant forest habitat type. In turn, the local values of the following parameters were determined for each of the groundwater depth measurement sites: general curvature, Multiscale Topographic Position Index (TPI) and TPI Landform.

The SAGA Wetness Index (SWI) is a modification of Topographic Wetness Index that implement multiple direction flow algorithm that iteratively modifies the catchment area based on a function of local slope and the flow accumulation of pixels adjacent to each pixel (Winzeler *et al.*, 2022). The SWI concept assumes that adjacent cells interact through ‘suction’ or lateral movement of moisture, and that this influence increases in flat terrain where small changes in elevation cause random distribution of runoff paths (Böhner and Selige, 2002; Riihimäki *et al.*, 2021).

The Topographic Position Index (TPI) compares the elevation of each cell in a DEM to the mean elevation of a specified neighborhood around that cell (Weiss, 2002). Positive TPI values

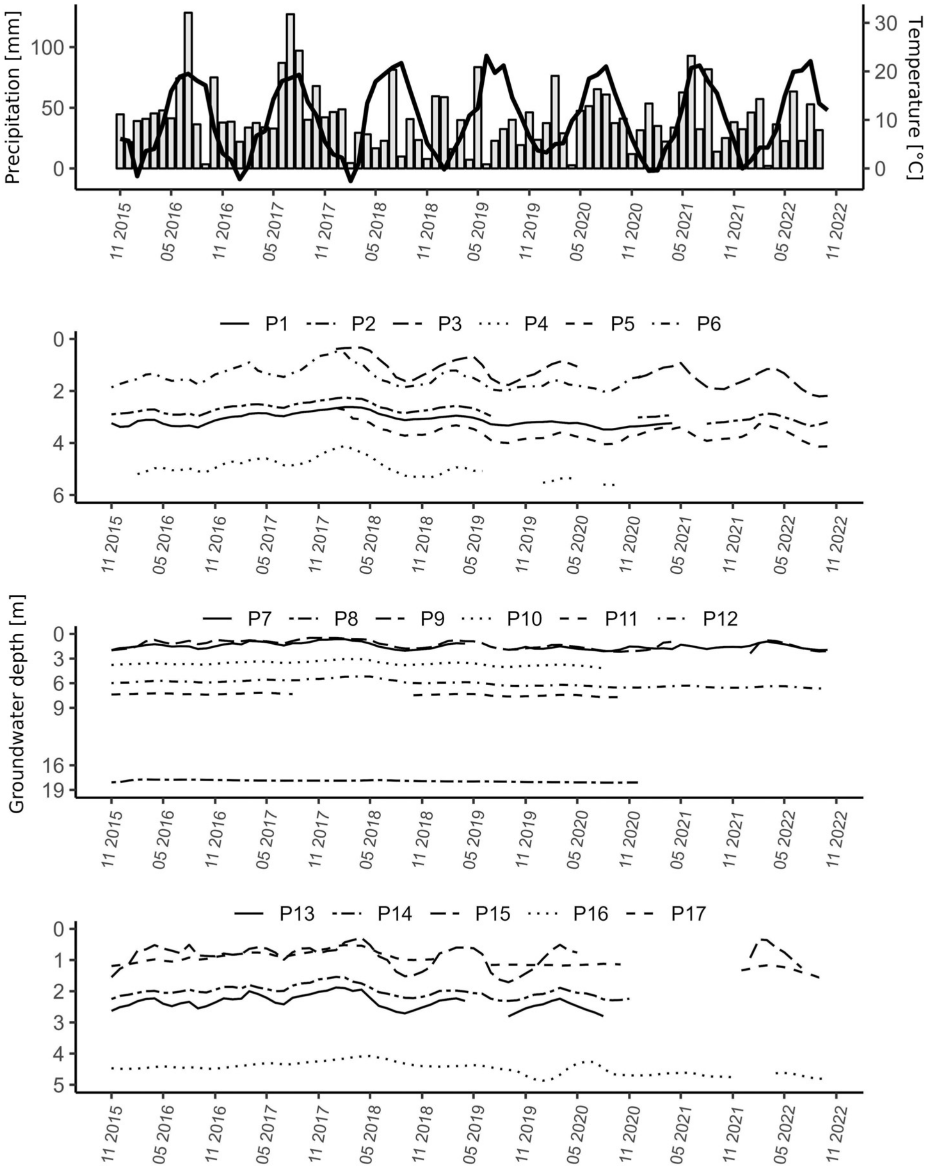

Fig. 2.
Groundwater level depth in the analyzed sites against the background of meteorological conditions

indicate that the central point is located higher than its average surroundings, while negative values indicate a position lower than the average. The classification of landforms was made according to the method proposed by Weiss (2002), which classifies the landscape into discrete slope position classes using the standard deviation of TPI. Terrain slopes and slope curvatures were determined using the method presented by Zevenbergen and Thorne (1987).

In order to analyse temporal trends in changes in the depth of the groundwater table, periodic gaps occurring in the data sequences were filled using the Seasonal Decomposition algorithm included in the R 'imputeTS' library (Moritz and Bartz-Beielstein, 2017). Trend parameters of temporal changes in groundwater table depth were determined using the Mann-Kendall test and Sen's estimator.

Analyses of environmental parameters, statistical calculations and visualization of results were performed using SAGA GIS programs (Conrad *et al.*, 2015) and R in version 3.2 (R Core Team, 2023).

Results

The topographic catchment areas of the analyzed groundwater depth measurement points range from 0.3 ha for point P13 to 5.7 ha for the catchment area of point P8 (Table 1). On average, the size of the catchment area was 1.7 ha. Average land slopes range from 1.6% for the largest catchment of point P8 to 25.9% for the catchment of point P16. The average for all catchments is 9.3%. The average moisture conditions for each of the catchments were determined using the SAGA Wetness Index (Table 1, Fig. 3). The lowest values of the index, indicating the best water runoff conditions, were obtained for the catchment of point P1, where it was 5.25, while the highest SAGA WI values of 11.2 were obtained for the catchment of point P8, indicating possible water accumulation in the area. The top layers of the soil cover of the analysed catchments are dominated by light loamy sands (7 catchments) and loose sands (5 catchments) (Fig. 4, Table 1). The remaining catchments have clayey sands (2 catchments) and sandy silt, silt and sandy loam. In 5 catchments the dominant forest habitat type is fresh broadleaved forest, in 4 catchments mixed fresh broadleaved forest and mixed fresh coniferous forest, in 3 catchments it is riparian forest, and in 1 catchment it is wet forest.

In addition to the catchment features, local landform characteristics for each groundwater depth measurement point were determined using SAGA GIS software, which allowed us to

Table 1.
Topography description of the groundwater depth measurement points

Site	Area [ha]	Mean slope [%]	Mean SAGA WI	Soil type	Forest habitat types	General curvature	Multiscale TPI	TPI landform code
P1	0.5	16.4	5.25	1	2	0.0139	–2.24	5
P2	1.4	15.3	5.85	3	2	–0.0036	–0.74	3
P3	0.6	6.0	8.41	2	3	–0.0079	–1.30	4
P4	0.9	4.9	8.50	1	1	0.0031	0.29	3
P5	0.9	3.8	9.86	4	5	0.0056	0.44	3
P6	0.9	4.1	8.43	5	5	–0.0030	–0.15	3
P7	0.9	3.7	9.39	2	5	0.0014	0.10	4
P8	5.7	1.6	11.19	2	3	0.0043	0.49	5
P9	0.7	6.8	7.37	3	4	–0.0076	–0.95	2
P10	0.7	13.1	7.24	2	2	0.0074	0.77	5
P11	0.5	6.4	7.65	1	1	–0.0014	1.79	1
P12	4.7	10.2	8.17	2	3	0.0076	0.60	4
P13	0.3	8.5	6.39	6	3	–0.0089	–2.38	4
P14	1.3	4.2	8.29	1	1	–0.0035	–0.18	2
P15	4.7	7.2	8.13	2	2	0.0015	–0.05	4
P16	0.8	25.9	5.32	1	1	–0.0039	–0.84	4
P17	3.1	20.7	5.99	2	3	–0.0096	–3.19	4

Soil type: 1 – loose sand, 2 – light loamy sand, 3 – loamy sand, 4 – sandy silt, 5 – silt, 6 – sandy loam; Forest habitat types: 1 – fresh mixed coniferous forest, 2 – fresh mixed broadleaved forest, 3 – fresh broadleaved forest, 4 – wet broadleaved forest, 5 – riparian forest; TPI lanform code: 1 – midslope ridges, 2 – open slopes, 3 – plains, 4 – valleys, 5 – midslope drainages

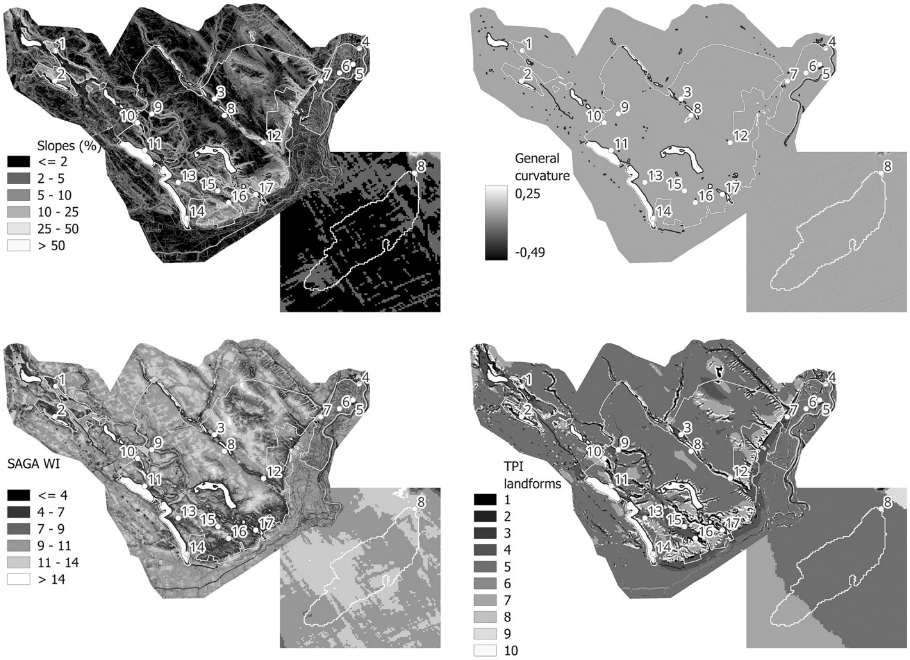

Fig. 3.

Maps of topographical indices

TPI landforms: 1 – high ridges, 2 – midslope ridges, 3 – local ridges, 4 – upper slopes, 5 – open slopes, 6 – plains, 7 – valleys, 8 – upland drainages, 9 – midslope drainages, 10 – streams

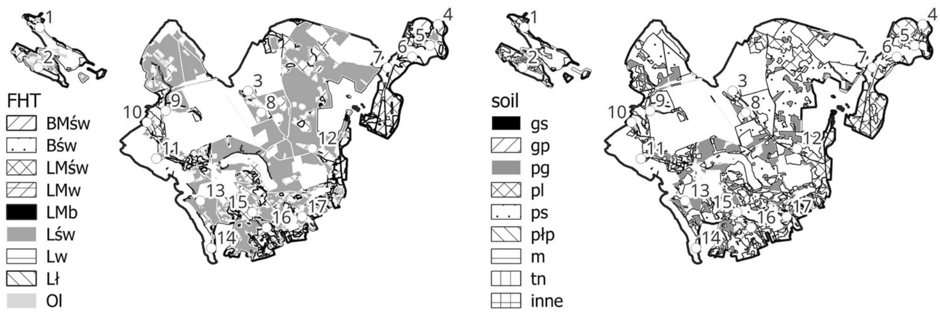

Fig. 4.

Maps of forest habitat types (FHT) and forest soils for afforested areas

FHT: BMśw – fresh mixed coniferous forest, Bśw – fresh coniferous forest, LMśw – fresh mixed broadleaved forest, LMw – moist mixed broadleaved forest, LMb – swamp mixed broadleaved forest, Lśw – fresh broadleaved forest, Lw – moist broadleaved forest, Lł – riparian forest, Ol – alder and alder-ash forest; soil: gs – medium clay, gp – sandy loam, pg – clay sand, pl – loose sand, ps – light clay sand, płp – sandy silt, m – alluvia, tn – turf, inne – other

determine the curvature of the terrain and the location of the analyzed points (Table 1, Fig. 3). According to the TPI Landform, 8 of the water level measurement sites are located on valley terrain, 4 are located on flat terrain, and 2 each are located on the open slope and drained middle parts of the slope.

The average depths of the ground water table, measured in 2015-2022, at 17 sites in the WPN range from 0.89 m at well P15 to 17.92 m at well P8 (Table 3, Fig. 5). At the same time, water levels at the P8 site show the least variability in water levels, with the smallest amplitude of levels, at 0.44 m, and the lowest value of standard deviation among all analyzed sites. The depth of the

Table 2.
The descriptive statistics of groundwater depth [m]

	Mean	sd	Median	Min	Max	Range	Skew	Kurtosis
P1	3.12	0.23	3.14	2.60	3.51	0.91	–0.47	–0.62
P2	2.79	0.26	2.78	2.23	3.39	1.16	0.02	–0.59
P3	1.25	0.46	1.28	0.30	2.17	1.87	–0.3	–0.67
P4	4.97	0.41	4.98	4.09	6.32	2.23	0.37	1.06
P5	3.64	0.30	3.67	2.48	4.12	1.64	–1.10	1.68
P6	1.51	0.38	1.56	0.42	2.05	1.62	–0.83	0.16
P7	1.49	0.38	1.55	0.54	2.16	1.62	–0.49	–0.63
P8	17.92	0.11	17.88	17.69	18.13	0.44	0.14	–1.19
P9	1.28	0.52	1.25	0.14	2.47	2.33	0.14	–1.24
P10	3.63	0.25	3.64	3.05	4.23	1.18	–0.30	–0.13
P11	7.43	0.14	7.39	7.16	7.74	0.58	0.56	–0.57
P12	6.04	0.39	5.99	5.16	6.63	1.47	–0.38	–0.90
P13	2.39	0.23	2.38	1.79	2.86	1.06	–0.15	–0.58
P14	2.03	0.19	2.05	1.51	2.33	0.82	–0.56	–0.10
P15	0.89	0.38	0.77	–0.32	1.74	2.06	0.59	–0.36
P16	4.48	0.19	4.44	4.06	4.88	0.81	0.08	–0.69
P17	1.01	0.22	1.03	0.44	1.48	1.04	–0.46	–0.43

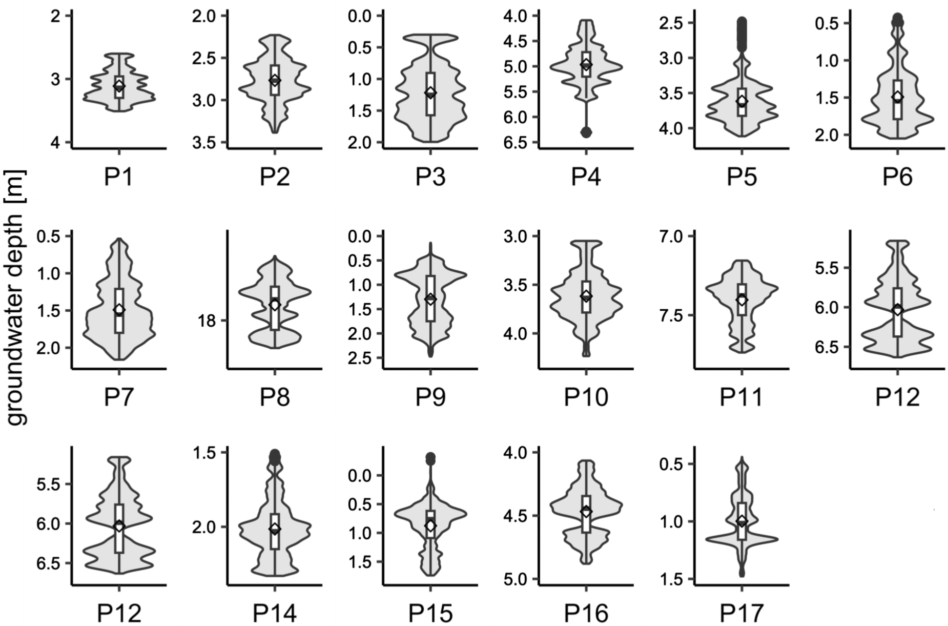

Fig. 5.
Variation of the groundwater depth in the measurement points

groundwater table at site P8 results from its location near a high, steep slope leading to the lake. Due to the very well-drained, light loamy sands in this area, this causes strong drainage of the area. At the same time, the large depth of groundwater means that changes in water levels are most influenced by processes related to the flow of groundwater, and the impact of atmospheric precipitation is much smaller compared to places with a shallower groundwater depth.

Analysis of groundwater table depth distributions performed with the Shapiro-Wilk test showed that for no measurement site did the distribution of water levels meet normality conditions. The calculated Spearman correlation coefficients indicate strong relationships between water levels measured at all wells (Table 3). The lowest value of the correlation coefficient was obtained for the relationship between water states in P2 and P8, for which the value of r=0.02, with a significance level of $p<0.05$. At the same time, this is the only relationship with a negative correlation. For the rest of the relationships of water states, the significance level is $p<0.0001$. It can be noted the lower values of the correlation coefficient of water states at the P8 site with the other measurements. This is due to the large difference in the depth of the groundwater table measured at site P8, averaging almost 18 m, and the other sites, for which the average depths range from 0.9 to 7.4 m. This results in different rainfall supply conditions.

The trend parameters of the average monthly water levels measured in the period November 2015 - October 2022 determined by the Mann-Kendall test indicate that the depths of the groundwater table at almost all sites show an increasing trend (Table 4). The slope values of the trend line, determined by Sen's parameter, range from $0.81 \cdot 10^{-4}$ m·day^{-1} for site P1 to $6.00 \cdot 10^{-4}$ m·day^{-1} for site P3, which corresponds to an average lowering of the water table from 3.0 cm to 21.9 cm·year^{-1}, respectively. Only at site P6 no trend was found. At the same time, an increase in mean yearly air temperatures can be observed for the analyzed period. The calculated Sen's parameter is 0.025°C for the year. However, in the case of yearly sums of precipitation, a decreasing trend was observed, and Sen's parameter was 7.3 mm·year^{-1}. The greatest decline in the groundwater table can be observed in fresh broadleaved forest habitat (sites P3, P8, P12, P13, P17), where it amounted to 11.8 cm·year^{-1}, then in wet and riparian forest sites (P5, P6, P7, P9) – 9.9 mm per year, and the lowest in mixed forest sites – 7.1 cm·year^{-1}.

Discussion

During the analysed period of 2015-2022, water levels are gradually decreasing at almost all sites. This process is noticeable not only in the Wielkopolski National Park, but is also observed in

Table 3.
Spearman correlation of groundwater depth

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16
P2	0.96															
P3	0.83	0.94														
P4	0.80	0.82	0.79													
P5	0.87	0.86	0.86	0.93												
P6	0.81	0.87	0.84	0.86	0.96											
P7	0.81	0.72	0.69	0.88	0.85	0.95										
P8	0.40	0.02*	0.36	0.53	0.64	0.47	0.47									
P9	0.77	0.74	0.84	0.83	0.84	0.83	0.83	0.65								
P10	0.90	0.95	0.91	0.90	0.95	0.91	0.90	0.53	0.85							
P11	0.65	0.53	0.88	0.71	0.94	0.77	0.78	0.71	0.78	0.92						
P12	0.83	0.90	0.78	0.87	0.70	0.73	0.61	0.73	0.72	0.93	0.96					
P13	0.77	0.87	0.93	0.77	0.90	0.92	0.94	0.36	0.88	0.88	0.70	0.69				
P14	0.80	0.88	0.91	0.85	0.92	0.93	0.91	0.46	0.89	0.87	0.73	0.76	0.93			
P15	0.53	0.46	0.80	0.56	0.75	0.69	0.76	0.39	0.78	0.73	0.71	0.40	0.82	0.77		
P16	0.68	0.89	0.65	0.72	0.55	0.48	0.47	0.47	0.55	0.61	0.48	0.85	0.33	0.51	0.31	
P17	0.90	0.96	0.84	0.93	0.76	0.88	0.67	0.58	0.75	0.92	0.69	0.93	0.77	0.83	0.44	0.79

Table 4.
Trend parameters of groundwater depth

Sampling point	Z	τ	Sen's slope [·10^{-4} m·day^{-1}]
P1	3.06	0.23	0.81
P2	7.16	0.53	2.22
P3	8.00	0.62	6.00
P4	6.99	0.54	3.40
P5	7.58	0.59	5.67
P6	–0.10	0.01	0.00
P7	2.40	0.18	1.30
P8	10.19	0.79	1.66
P9	4.48	0.33	3.86
P10	7.47	0.58	3.32
P11	9.28	0.71	2.08
P12	7.86	0.59	4.05
P13	6.77	0.52	2.31
P14	5.66	0.44	1.26
P15	2.43	0.18	0.98
P16	5.08	0.38	1.58
P17	7.80	0.58	2.23

other areas of Poland and Europe. Based on the calculated Sen's coefficient for the change trend, it can be assumed that during the analyzed 7-year research period, water levels decreased on average for the entire study area by 0.78 m. However, these changes show high variability even within the same habitat. At site P6, located in a riparian forest, no trend was found, while at site P5, located nearby, the water table decreased by 1.4 m. A gradual decrease in the groundwater levels in the Zielonka Forest, located at a distance of about 50 km from the WPN, is already observed in the years 1970-2009 (Miler *et al.*, 2015). Korytowski *et al.* (2017) showed that in the period 2000-2009, water levels in forests located in southern Wielkopolska decreased by 0.75 m in fresh mixed coniferous forest habitats, by 0.53 m in fresh mixed broadleaved forest habitats, and by 0.53 m in wet mixed broadleaved forest habitats by 0.77 m. A similar trend of decreasing groundwater levels between 1980 and 2010 is observed in Fennoscandia. At the same time, the authors emphasize the significant acceleration of the pace of change starting in 2001 (Nygren *et al.*, 2020).

Changes in meteorological conditions observed in recent years indicate a gradual decrease in the water resources available to vegetation. The increasing water deficit is due not only to declining precipitation totals, but also to increasing air temperatures, resulting in increased evaporation. According to the Köppen-Geiger classification, seasonal, within-year variation in soil water resources has been influenced by winter snow retention, spring snowmelt, summer periods of precipitation or high evapotranspiration, and autumn rains (Beck *et al.*, 2018). The changes taking place are reducing the impact of snow retention on groundwater resources in favor of precipitation in winter periods and high evapotranspiration instead of snowmelt in spring periods (Sultana and Coulibaly, 2011; Scheliga *et al.*, 2018). The impact of decreasing rainfall amounts on lowering groundwater levels is indicated by the results of several decades of research conducted in the Zielonka Forest by Grajewski *et al.* (2013) and also by Nygren *et al.* (2020) in Fennoscandia.

It should also be noted that in the analyzed 7-year period, the average groundwater table was the shallowest in the fresh mixed broadleaved forest (site P15) and fresh broadleaved forest (sites P15 and P17), and not in the wet forest (site P9) or adjacent to water bodies riparian forests as assumed by the forest habitat moisture variants (IUL, 2012). A similar situation is indicated in their research by Orzepowski *et al.* (2004) and Korytowski *et al.* (2017), who point to the topography of the area as the main factor causing such a pattern of groundwater levels.

Decreasing precipitation and increasing air temperature result not only in a decrease in the depth of the groundwater table, but also in a decrease in soil moisture in the aeration zone. These changes can lead to species changes in stands due to differential resistance to water deficits (Klein *et al.*, 2014; Brinkmann *et al.*, 2016; Boczoń *et al.*, 2018). This may hinder efforts in the ESL to restore the 'natural' species composition of forest stands. Most of Poland's forests are covered with pine *Pinus sylvestris* L., considered a fairly drought-tolerant species (Boczoń *et al.*, 2016). Beech *Fagus* L. and linden *Tilia* L., on the other hand, show lower resistance to water deficit conditions compared to oak *Quercus* L. (Kasper *et al.*, 2022). Mathematical modeling can be used to assess the impact of changes in groundwater levels on the development of stand biodiversity (Schwaiger *et al.*, 2018).

Conclusions

The analysis of changes in the groundwater level depth measured over the 7-year period indicates a gradual decline in the groundwater level in almost the entire area of the Wielkopolski National Park. The average annual rate of water table depth decrease measured in 16 sites located throughout the WPN ranges from 3.0 to 21.9 cm per year. Only in one site no trend of change was found. The processes taking place, affecting the decrease in ground retention, should be associated with the observed decrease in precipitation and rising air temperatures. In the analyzed period, an average annual increase in air temperatures of 0.025°C was observed, while annual precipitation sums decreased by 7.3 mm. Given the relatively short period of observation of water levels, it is necessary to continue the study to determine how the observed changes in water conditions will affect the condition of the protected areas of the Wielkopolski National Park.

Authors' contribution

M.F. – conceptualization, methodology, literature review, manuscript preparation, statistical analyses; A.Z. – statistical analyses, manuscript review.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgements

The article used data provided by the Wielkopolski National Park: Woda w środowisku przyrodniczym. Portal informacyjno-edukacyjny Wielkopolskiego Parku Narodowego (Water in the natural environment. Informational and educational portal of the Wielkopolski National Park) https://ebd.web.amu.edu.pl.

Data from the Institute of Meteorology and Water Management – National Research Institute were processed.

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STRESZCZENIE

Zmiany stanów wody gruntowej na terenie Wielkopolskiego Parku Narodowego

Na stan lasów wpływa szereg czynników środowiskowych, z których jednym z najbardziej istotnych jest dostępność wody. Wpływ na lasy mają zarówno krótko-, jak i długookresowe zmiany stanów wody gruntowej związane z cyklicznymi zmianami wynikającymi ze zmienności warunków meteorologicznych. Drzewa lasów strefy umiarkowanej uważane są za szczególnie wrażliwe na wysychanie gleby, ponieważ są przystosowane do charakteryzującego miniony klimat zrównoważonego wilgotnościowo środowiska, z zapewnioną zazwyczaj dostępnością wody i brakiem sezonowych susz. Zachodzące zmiany wpływają nie tylko na stan roślinności, ale także na warunki rozwoju fauny. Stopniowe obniżanie się lustra wody gruntowej prowadzi do zaniku niewielkich śródleśnych zbiorników wodnych stanowiących miejsca rozmnażania się i bytowania wielu gatunków płazów.

Celem pracy było poznanie zmian stanów wody gruntowej na terenie Wielkopolskiego Parku Narodowego obserwowanych w latach 2015-2022 i określenie trendów zmian, jako jednego z czynników wpływających na środowisko naturalne. W pracy wykorzystano dane pomiarowe głębokości wody gruntowej udostępnione przez Wielkopolski Park Narodowy. Pomiary wykonywane były codziennie w 17 studzienkach rozmieszczonych na terenie całego WPN (ryc. 1), w okresie od listopada 2015 r. do października 2022 r. Zmienność danych meteorologicznych opisano z wykorzystaniem pomiarów miesięcznych sum opadów atmosferycznych i średnich temperatur powietrza prowadzonych na stacji IMGW Poznań-Ławica. Do opisu topografii terenu wykorzystano numeryczny model terenu o rozdzielczości 5 m, stworzony z danych LiDAR udostępnionych przez WPN (ryc. 1). Wyznaczone powierzchnie obszarów zasilania miejsc pomiaru stanów wody wynosiły od 0,3 do 5,7 ha, a ich średnie spadki terenu od 1,6 do 25,9% (tab. 1; ryc. 3). Na terenie WPN przeważającym typem siedliskowym jest las świeży, następnie las mieszany świeży i bór mieszany świeży (ryc. 4). Pokrywa glebowa zbudowana jest głównie z piasków słabogliniastych i piasków luźnych. Miejsca pomiaru głębokości poziomu wody gruntowej położone są w zróżnicowanych ze względu na rzeźbę terenu lokalizacjach (tab. 1).

Średnia głębokość lustra wody gruntowej wynosi od 0,89 m dla miejsca P15 do 17,92 m dla miejsca P8 (tab. 2). Równocześnie głębokość lustra wody w miejscu P8 charakteryzuje się najmniejszą zmiennością (tab. 2; ryc. 5). Uzyskane wyniki badań wskazują na istnienie w okresie badań trendu obniżania się lustra wody gruntowej we wszystkich analizowanych miejscach (ryc. 2). Obliczona wartość estymatora Sena odpowiada średniemu obniżaniu się lustra wody gruntowej w analizowanych lokalizacjach od 2,9 cm do 21,6 cm w ciągu roku (tab. 4). Wiązać to można z obserwowanymi równocześnie trendami obniżania się rocznych sum opadów i jednoczesnym wzrostem

średnich temperatur powietrza (ryc. 1). W analizowanym okresie zaobserwowano silną korelację stanów wody gruntowej w prawie wszystkich miejscach pomiaru stanów wody, z wyjątkiem miejsca nr 8 (tab. 3). Wynika to głównie z głębokiego, w porównaniu do pozostałych, położenia lustra wody w tej lokalizacji. Należy zauważyć, że z uwagi na stosunkowo krótki okres obserwacji stanów wody konieczna jest kontynuacja badań, która pozwoli określić, jak obserwowane zmiany warunków wodnych będą wpływać na stan chronionych obszarów Wielkopolskiego Parku Narodowego.