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TOWARDS CLASSIFICATION OF GROUNDWATER LEVEL DEPTH PATTERNS ON FOREST FRESH SITES

PRÓBA KLASYFIKACJI ZALEGANIA WODY GRUNTOWEJ NA LEŚNYCH SIEDLISKACH ŚWIEŻYCH

Summary. The scope of the research described in this paper is to classify groundwater level depth patterns on forest fresh sites. The approach has been employed with the view to facilitate explaining interactions between physiographic characteristics and groundwater dynamics. The methods, which have been employed so far, for explanation of groundwater level dynamics interactions with local physiographic conditions, do not allow to draw firm conclusions. The classification of groundwater dynamics patterns requires employing more sophisticated methods, because of relatively extensive range of groundwater dynamics variability site-to-site expressed e.g. by amplitude and cycle period. The methods of groundwater patterns classification proposed in literature based either hydrogeological attitude or, if related to forest ecosystems, focused on water balance elements. The area selected for the investigation represented typical features for the Northern European Lowland forests defined by soil and form of terrain pattern shaped by the last glacial period (Vistulian glaciation) and dominant share of Scots pine (*Pinus sylvestris* L.) in stand species composition. The research period covered the 2002-2007 hydrological years. The measurement used in analysis covered 35 sites equipped with measurement wells.

Key words: groundwater level depth, forest fresh sites, canonical variate analysis

Introduction

The knowledge concerning influence of forest considered as a uniform type of land-cover on water balance elements is quite well established. Nevertheless, there is still no broader explanation on how different forest ecosystems or different forest ecosystem characteristics within a particular ecosystem modulate water balance elements (ANDRESSIAN 2004). The main obstacle in gaining more exact answers can be put to complexity and diversity of relations between particular forest ecosystems characteristics and hydrologic processes or water balance elements. These relations are usually interdependent and altered by forest management operations in managed forests.

Important issue that has to be additionally considered is seasonal and long-term dynamics of forest ecosystems and heterogeneity of site conditions. Thus the detailed attention should be put to solving problems with defining the influence of some external or interfering factors that may affect the results of field investigations due to heterogeneity of site.

The scope of the research described in this paper is to test classification methodology of groundwater level patterns over the investigated area. The approach has been employed with the view to facilitate explaining interactions between physiographic characteristics and groundwater dynamics. The methods, which have been employed so far, for explanation of groundwater level dynamics interactions with local physiographic conditions do not let to state firm conclusions (GRAJEWSKI and OKOŃSKI 2007, OKOŃSKI et AL. 2008). The classification of groundwater dynamics patterns requires employing more sophisticated methods, because of relatively extensive range of groundwater dynamics variability site-to-site expressed e.g. by amplitude and cycle period length. The methods of groundwater dynamics patterns classification proposed comprehended either hydrogeological attitude or, if related to forest ecosystems, focused on water balance elements (ŻURAWSKI 1968, SULIŃSKI 1995, GRAF 1999).

Materials and methods

The research area was located in western part of the Polish Lowland (part of the Northern European Lowland). The research sites were set in the Puszcza Zielonka forest, ca 6 km NE of Poznań, Poland, over forest area ca 150 km^2 delimited by geographical coordinates (52°28'01"-52°37'34"N, 16°58'57"-17°13'26"E). The area selected for the investigation represented typical features of the Northern European Lowland forests defined by soil and form of terrain pattern shaped by the last glacial period (Vistulian glaciation) and dominant share of Scots pine (*Pinus sylvestris* L.) in stand species composition.

Annual rainfall (P) and temperature (t) for the area are 522 mm, and 8.1°C. Evapotranspiration (E) and climatic water balance (CWB) equal 506 mm and 11 mm. Climatic water balance over the area is frequently negative owing to high level of evapotranspiration. Vegetation period lasts from the end of March till the beginning of November.

The criteria employed for selection of experimental plots and locations of groundwater measurement wells within investigated area were both representativness of forest stand and habitat characteristics and spatial homogeneity of the ecosystem over larger units (Fig. 1, Table 1).

Forest stand sites with dominant Scots pine (*Pinus sylvestris* L.) and oaks (sessile and pedunculate oak) (*Quercus petraea* Liebl., *Q. robur* L.) were investigated. Selected types of habitats according to Polish silviculture taxonomy were fresh broadleaved, fresh mixed broadleaved and fresh mixed coniferous forest habitats. These are the forest habitats with moderately moist soil. The phytosociological equivalents for these

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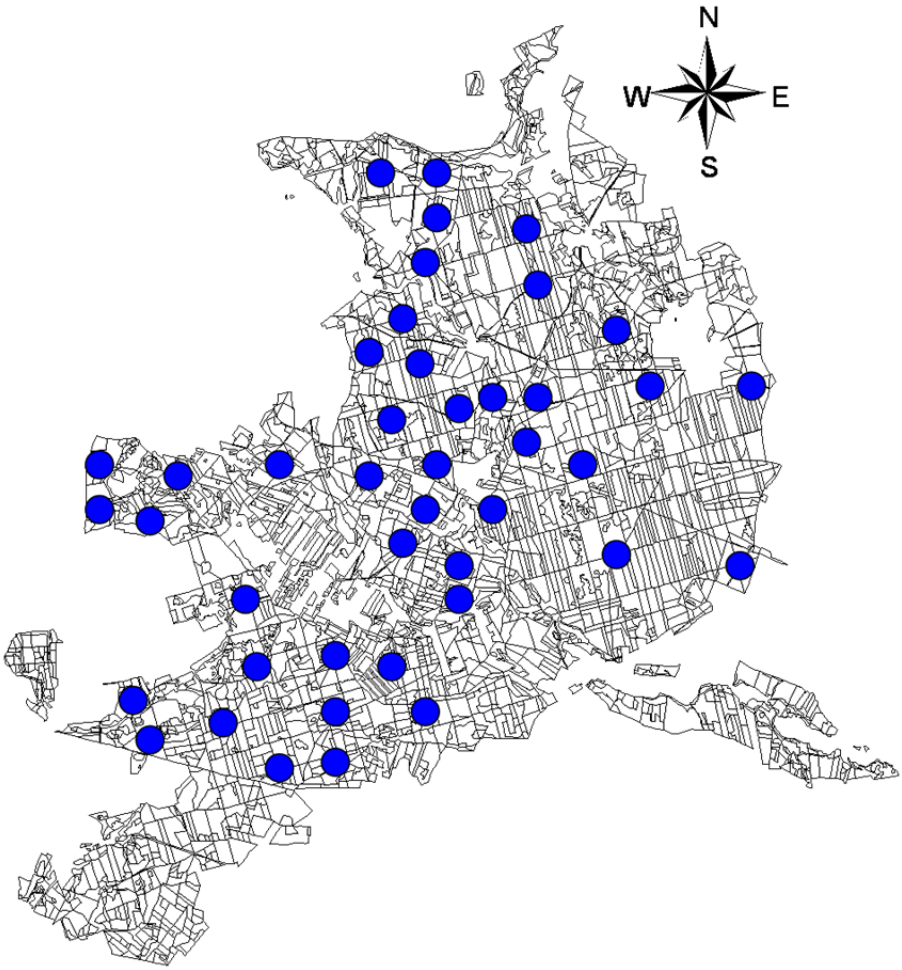

Fig. 1. Location of groundwater level depth measurement sites in the investigated forest area
Rys. 1. Położenie powierzchni monitorowania poziomu wody gruntowej na obszarze badań

forest habitats are associations with dominant Scots pine in Central Europe, e.g. *Querco roboris-Pinetum* J.Mat. 1988 or *Peucedano-Pinetum* W.Mat. 1973.

The groundwater level depth measurements were performed on weekly basis with 1 cm accuracy in 43 monitoring wells installed in experimental plots on forest fresh sites, of which 35 were located in pine and the rest in oak stands. Average monthly groundwater level depth values were employed for data analysis. The research period covered the 2002-2007 hydrological years (Fig. 2).

The physiographical site characteristics were intentionally excluded from the analysis. This assumption enabled focusing on groundwater level depth changes solely to work out groundwater dynamics patterns and classification scheme.

Okoński B., Grajewski S., Kayzer D., 2012. Towards classification of groundwater level depth patterns on forest fresh sites. Nauka Przyr. Technol. 6, 1, #6.

Table 1. Selected characteristics of forest stands and sites for groundwater level depth measurement sites
Tabela 1. Wybrane cechy drzewostanowo-siedliskowe dla stanowisk monitorowania stanu wód gruntowych

No. Lp.	Forest division Nadleśnictwo	Forest sub-compartment address Wydzielenie	Area Obszar (ha)	Dominant species Gatunek panujący	Tree age (years) Wiek drzewa (lata)	Stand stratification Struktura pionowa	Dominant species share Udział gatunku panującego (%)	Crown closure Zwarcie korony	Forest site type Typ siedliskowy lasu	Soil type Typ gleby	Soil texture Gatunek gleby	Landform feature Forma terenu
1	2	3	4	5	6	7	8	9	10	11	12	13
1	Zielonka	112a	15.98	Sessile/ common oak Dąb bezszypułkowy/ szypułkowy	98	1-storeyed stand Drzewostan 1-piętrowy	60	Closed Umiarkowane	Fresh broad-leaved forest Las świeży	Brown podzolic Rdzawe	Clayey sand Piasek gliniasty	Plateau Wysoczyzna
2	Łopuchówko	119i	3.39	Sessile/ common oak Dąb bezszypułkowy/ szypułkowy	19	1-storeyed stand Drzewostan 1-piętrowy	50	Closed Umiarkowane	Fresh broad-leaved forest Las świeży	Brown Brunatne	Sand on silty sandy gravel Piasek na żwirze pylastopiaszczystym	Plateau Wysoczyzna
3	Łopuchówko	94o	2.73	Sessile/ common oak Dąb bezszypułkowy/ szypułkowy	123	1-storeyed stand Drzewostan 1-piętrowy	70	Broken Przerywane	Fresh broad-leaved forest Las świeży	Brown Brunatne	Clayey sand on silt and clay Piasek gliniasty na pyle i glinie	Depression Zagłębienie bezodpływowe
4	Łopuchówko	96j	7.13	Sessile/ common oak Dąb bezszypułkowy/ szypułkowy	93	1-storeyed stand Drzewostan 1-piętrowy	50	Broken Przerywane	Fresh broad-leaved forest Las świeży	Brown Brunatne	Clayey sand on sandy gravel Piasek gliniasty na żwirze piaszczystym	Plateau Wysoczyzna
5	Łopuchówko	126b	3.58	Scots pine Sosna zwyczajna	83	2-storeyed stand Drzewostan 2-piętrowy	90	Broken Przerywane	Fresh broad-leaved forest Las świeży	Brown Brunatne	Sand on sandy gravel Piasek na żwirze piaszczystym	Depression Zagłębienie bezodpływowe
6	Zielonka	82g	4.21	Scots pine Sosna zwyczajna	73	1-storeyed stand Drzewostan 1-piętrowy	100	Closed Umiarkowane	Fresh coniferous forest Bór świeży	Podzolic Bielicowe	Sand Piasek	Plateau Wysoczyzna
7	Zielonka	13f	5.34	Scots pine Sosna zwyczajna	98	1-storeyed stand Drzewostan 1-piętrowy	100	Closed Umiarkowane	Fresh coniferous forest Bór świeży	Podzolic Bielicowe	Sand Piasek	Plateau Wysoczyzna
8	Zielonka	28h	2.98	Scots pine Sosna zwyczajna	108	1-storeyed stand Drzewostan 1-piętrowy	100	Broken Przerywane	Fresh coniferous forest Bór świeży	Podzolic Bielicowe	Sand on sandy gravel Piasek na żwirze piaszczystym	Plateau Wysoczyzna
9	Zielonka	60d	3.25	Scots pine Sosna zwyczajna	128	1-storeyed stand Drzewostan 1-piętrowy	100	Closed Umiarkowane	Fresh coniferous forest Bór świeży	Podzolic Bielicowe	Sand Piasek	Plateau Wysoczyzna
10	Zielonka	61a	0.85	Scots pine Sosna zwyczajna	39	1-storeyed stand Drzewostan 1-piętrowy	100	Closed Umiarkowane	Fresh coniferous forest Bór świeży	Podzolic Bielicowe	Sand on clayey sand Piasek na piasku gliniastym	Plateau Wysoczyzna

Okoński B., Grajewski S., Kayzer D., 2012. Towards classification of groundwater level depth patterns on forest fresh sites. Nauka Przyr. Technol. 6, 1, #6.

Table 1 – cont. / Tabela 1 – cd.

1	2	3	4	5	6	7	8	9	10	11	12	13
11	Zielonka	70i	4.52	Scots pine Sosna zwy-czajna	158	1-storeyed stand Drzewostan 1-piętrowy	60	Broken Przery-wane	Fresh mixed broadleaved forest Las mieszany świeży	Brown Brunatne	Clayey sand Piasek gliniasty	Depres-sion Zagłębie-nie bezodpły-wowe
12	Zielonka	41l	3.46	Scots pine Sosna zwyczajna	98	1-storeyed stand Drzewostan 1-piętrowy	100	Broken Przery-wane	Fresh mixed broadleaved forest Las mieszany świeży	Brown podzolic Rdzawe	Clayey sand Piasek gliniasty	Plateau Wysoczy-zna
13	Zielonka	46a	2.98	Scots pine Sosna zwyczajna	98	1-storeyed stand Drzewostan 1-piętrowy	100	Broken Przery-wane	Fresh mixed broadleaved forest Las mieszany świeży	Brown podzolic Rdzawe	Sand on clayey sand Piasek na piasku gliniastym	Valley Dolina rzeczna
14	Łopu-chówko	155d	7.58	Scots pine Sosna zwyczajna	131	2-storeyed stand Drzewostan 2-piętrowy	100	Broken Przery-wane	Fresh mixed broadleaved forest Las mieszany świeży	Brown podzolic Rdzawe	Sand on sandy gravel Piasek na żwirze piaszczystym	Valley Dolina rzeczna
15	Łopu-chówko	156a	4.18	Scots pine Sosna zwyczajna	81	1-storeyed stand Drzewostan 1-piętrowy	70	Broken Przery-wane	Fresh mixed broadleaved forest Las mieszany świeży	Brown podzolic Rdzawe	Sand on sandy gravel Piasek na żwirze piaszczystym	Valley Dolina rzeczna
16	Łopu-chówko	131g	3.87	Scots pine Sosna zwyczajna	49	1-storeyed stand Drzewostan 1-piętrowy	100	Closed Umiar-kowane	Fresh mixed broadleaved forest Las mieszany świeży	Brown Brunatne	Sand on sandy gravel Piasek na żwirze piaszczystym	Depres-sion Zagłębie-nie bezodpły-wowe
17	Łopu-chówko	117j	3.87	Scots pine Sosna zwyczajna	56	1-storeyed stand Drzewostan 1-piętrowy	70	Closed Umiar-kowane	Fresh mixed broadleaved forest Las mieszany świeży	Brown Brunatne	Sand on sandy gravel Piasek na żwirze piaszczystym	Plateau Wysoczy-zna
18	Łopu-chówko	75f	3.23	Scots pine Sosna zwyczajna	57	1-storeyed stand Drzewostan 1-piętrowy	80	Closed Umiar-kowane	Fresh mixed broadleaved forest Las mieszany świeży	Brown Brunatne	Sand on sandy gravel Piasek na żwirze piaszczystym	Depres-sion Zagłębie-nie bezodpły-wowe
19	Łopu-chówko	45d	4.69	Scots pine Sosna zwyczajna	44	1-storeyed stand Drzewostan 1-piętrowy	80	Broken Przery-wane	Fresh mixed broadleaved forest Las mieszany świeży	Brown Brunatne	Sand on sandy gravel Piasek na żwirze piaszczystym	Depres-sion Zagłębie-nie bezodpły-wowe
20	Łopu-chówko	69g	1.61	Sessile/ common oak Dąb bezszy-pułkowy/ szypułkowy	121	1-storeyed stand Drzewostan 1-piętrowy	80	Broken Przery-wane	Fresh mixed broadleaved forest Las mieszany świeży	Brown Brunatne	Clayey sand Piasek gliniasty	Plateau Wysoczy-zna
21	Zielonka	45o	2.83	Sessile/ common oak Dąb bezszy-pułkowy/ szypułkowy	113	1-storeyed stand Drzewostan 1-piętrowy	70	Closed Umiar-kowane	Fresh mixed broadleaved forest Las mieszany świeży	Brown Brunatne	Clayey sand Piasek gliniasty	Valley Dolina rzeczna

Okoński B., Grajewski S., Kayzer D., 2012. Towards classification of groundwater level depth patterns on forest fresh sites. Nauka Przyr. Technol. 6, 1, #6.

Table 1 – cont. / Tabela 1 – cd.

1	2	3	4	5	6	7	8	9	10	11	12	13
22	Zielonka	87g	7.11	Sessile/ common oak Dąb bezszy-pułkowy/ szypułkowy	148	1-storeyed stand Drzewostan 1-piętrowy	50	Closed Umiar-kowane	Fresh mixed broadleaved forest Las mieszany świeży	Brown Brunatne	Sand Piasek	Depres-sion Zagłębie-nie bezodpły-wowe
23	Zielonka	106f	2.53	Scots pine Sosna zwyczajna	73	1-storeyed stand Drzewostan 1-piętrowy	100	Closed Umiar-kowane	Fresh mixed broadleaved forest Las mieszany świeży	Brown Brunatne	Clayey sand Piasek gliniasty	Plateau Wysoczy-zna
24	Zielonka	78j	1.11	Black locust Robinia grochodrzew	84	1-storeyed stand Drzewostan 1-piętrowy	90	Closed Umiar-kowane	Fresh mixed coniferous forest Bór mieszany świeży	Brown Brunatne	Sand Piasek	Plateau Wysoczy-zna
25	Zielonka	89d	2.6	Scots pine Sosna zwyczajna	58	1-storeyed stand Drzewostan 1-piętrowy	100	Full Pełne	Fresh mixed coniferous forest Bór mieszany świeży	Brown Brunatne	Sand on sandy gravel Piasek na żwirze piaszczystym	Plateau Wysoczy-zna
26	Zielonka	74a	9.22	Scots pine Sosna zwyczajna	101	1-storeyed stand Drzewostan 1-piętrowy	100	Broken Przery-wane	Fresh mixed coniferous forest Bór mieszany świeży	Brown Brunatne	Sand Piasek	Plateau Wysoczy-zna
27	Zielonka	16o	1.78	Scots pine Sosna zwyczajna	118	1-storeyed stand Drzewostan 1-piętrowy	50	Broken Przery-wane	Fresh mixed coniferous forest Bór mieszany świeży	Brown Brunatne	Clayey sand Piasek gliniasty	Plateau Wysoczy-zna
28	Zielonka	10d	2.85	Scots pine Sosna zwyczajna	71	1-storeyed stand Drzewostan 1-piętrowy	100	Broken Przery-wane	Fresh mixed coniferous forest Bór mieszany świeży	Brown Brunatne	Clayey sand on sandy gravel Piasek gliniasty na żwirze piaszczystym	Plateau Wysoczy-zna
29	Zielonka	5d	12.34	Scots pine Sosna zwyczajna	103	1-storeyed stand Drzewostan 1-piętrowy	100	Broken Przery-wane	Fresh mixed coniferous forest Bór mieszany świeży	Brown podzolic Rdzawe	Clayey sand on sandy gravel Piasek gliniasty na żwirze piaszczystym	Depres-sion Zagłębie-nie bezodpły-wowe
30	Zielonka	3f	5.06	Scots pine Sosna zwyczajna	66	1-storeyed stand Drzewostan 1-piętrowy	70	Broken Przery-wane	Fresh mixed coniferous forest Bór mieszany świeży	Brown Brunatne	Clayey sand Piasek gliniasty	Valley Dolina rzeczna
31	Zielonka	12c	2.85	Scots pine Sosna zwyczajna	48	1-storeyed stand Drzewostan 1-piętrowy	100	Closed Umiar-kowane	Fresh mixed coniferous forest Bór mieszany świeży	Brown podzolic Rdzawe	Sand on sandy gravel Piasek na żwirze piaszczystym	Plateau Wysoczy-zna
32	Zielonka	31c	4.62	Sessile/ common oak Dąb bezszy-pułkowy/ szypułkowy	60	1-storeyed stand Drzewostan 1-piętrowy	50	Closed Umiar-kowane	Fresh mixed coniferous forest Bór mieszany świeży	Brown Brunatne	Sand on sandy gravel Piasek na żwirze piaszczystym	Plateau Wysoczy-zna

Table 1 – cont. / Tabela 1 – cd.

1	2	3	4	5	6	7	8	9	10	11	12	13
33	Zielonka	36f	11.54	Scots pine Sosna zwyczajna	123	2-storeyed stand Drzewostan 2-piętrowy	100	Broken Przery-wane	Fresh mixed coniferous forest Bór mieszany świeży	Brown Brunatne	Clayey sand Piasek gliniasty	Plateau Wysoczy-zna
34	Zielonka	26Ah	5.04	Scots pine Sosna zwyczajna	42	1-storeyed stand Drzewostan 1-piętrowy	100	Full Pełne	Fresh mixed coniferous forest Bór mieszany świeży	Brown Brunatne	Clayey sand Piasek gliniasty	Plateau Wysoczy-zna
35	Łopu-chówko	51f	4.38	Scots pine Sosna zwyczajna	59	1-storeyed stand Drzewostan 1-piętrowy	90	Broken Przery-wane	Fresh mixed coniferous forest Bór mieszany świeży	Brown podzolic Rdzawe	Sand on sandy gravel Piasek na żwirze piaszczystym	Plateau Wysoczy-zna
36	Łopu-chówko	48h	1.79	Scots pine Sosna zwyczajna	56	1-storeyed stand Drzewostan 1-piętrowy	80	Broken Przery-wane	Fresh mixed coniferous forest Bór mieszany świeży	Brown podzolic Rdzawe	Sand on sandy gravel Piasek na żwirze piaszczystym	Plateau Wysoczy-zna
37	Łopu-chówko	178d	0.58	Scots pine Sosna zwyczajna	26	1-storeyed stand Drzewostan 1-piętrowy	90	Full Pełne	Fresh mixed coniferous forest Bór mieszany świeży	Brown podzolic Rdzawe	Sand Piasek	Plateau Wysoczy-zna
38	Zielonka	134a	11.27	Scots pine Sosna zwyczajna	43	1-storeyed stand Drzewostan 1-piętrowy	100	Full Pełne	Fresh mixed coniferous forest Bór mieszany świeży	Brown Brunatne	Clayey sand on sandy gravel Piasek gliniasty na żwirze piaszczystym	Plateau Wysoczy-zna
39	Zielonka	130c	12.08	Scots pine Sosna zwyczajna	72	1-storeyed stand Drzewostan 1-piętrowy	100	Closed Umiar-kowane	Fresh mixed coniferous forest Bór mieszany świeży	Brown Brunatne	Sand on sandy gravel Piasek na żwirze piaszczystym	Plateau Wysoczy-zna
40	Łopu-chówko	10c	12.77	Scots pine Sosna zwyczajna	62	1-storeyed stand Drzewostan 1-piętrowy	100	Closed Umiar-kowane	Fresh mixed coniferous forest Bór mieszany świeży	Brown podzolic Rdzawe	Sand on sandy gravel Piasek na żwirze piaszczystym	Depres-sion Zagłębie-nie bezodpły-wowe
41	Zielonka	45Al	0.72	Scots pine Sosna zwyczajna	57	1-storeyed stand Drzewostan 1-piętrowy	100	Closed Umiar-kowane	Fresh mixed coniferous forest Bór mieszany świeży	Podzolic Bielicowe	Sand on sandy gravel Piasek na żwirze piaszczystym	Valley Dolina rzeczna
42	Zielonka	92a	23.27	Scots pine Sosna zwyczajna	71	1-storeyed stand Drzewostan 1-piętrowy	100	Broken Przery-wane	Fresh mixed coniferous forest Bór mieszany świeży	Brown Brunatne	Sand on sandy gravel Piasek na żwirze piaszczystym	Plateau Wysoczy-zna
43	Zielonka	86t	4.54	Scots pine Sosna zwyczajna	71	1-storeyed stand Drzewostan 1-piętrowy	100	Closed Umiar-kowane	Fresh mixed coniferous forest Bór mieszany świeży	Brown Brunatne	Clayey sand on sandy gravel Piasek gliniasty na żwirze piaszczystym	Plateau Wysoczy-zna

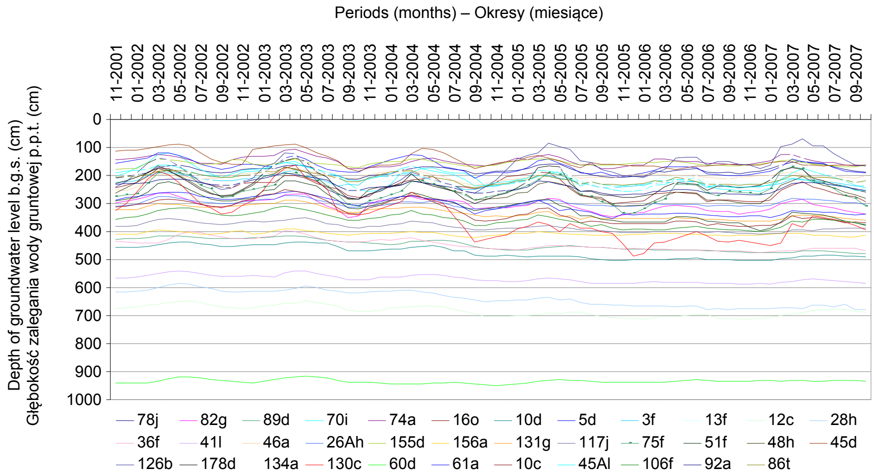

Fig. 2. Dynamics of groundwater level depth for the experimental plots in the hydrological years 2002-2007

Rys. 2. Zmienność zalegania wody gruntowej na powierzchniach badawczych dla lat hydrologicznych 2002-2007

For analysis of groundwater level depth patterns, differences were calculated between average groundwater level depth values. The Mahalanobis squared distance method was employed as a measure of groundwater level depth differences between investigated sites. The method is utilized in analysis of multidimensional populations, differentiates the influence of each component and employs correlations between them (MORISSON 1967, KRZYŚKO 2000). In this case, components are groundwater level depths values for each months of hydrological year. The dispersion matrix for Mahalanobis squared distance of groundwater level depths was set for two-factor experiment in cross classification with even observation number in subclasses (SEARLE 1971). The dispersion matrix included variability of groundwater measurement site location and temporal groundwater level depth (SEBER 1984).

The results were illustrated in the space of canonical variates. Canonical variate analysis is the method which enables graphical presentation of multidimensional experiment results (LEJEUNE and CALIŃSKI 2000). The method includes the transformation of groundwater level depth effects matrix into a set of new variables matrix, which carry similar information, but is distributed in the multivariate Euclidean space. Groundwater level depth matrix is defined by difference between average groundwater level depths for individual monitoring wells and the general means. The distance between origin point of the Cartesian coordinate system and any point related to groundwater level depth for particular site can be interpreted as the Mahalanobis squared distance of each site to the general mean values.

Results and discussion

Graphical configuration of points was obtained as a result of the conducted decomposition of the matrix illustrating the investigated monitoring wells in respect of groundwater level depths in the two-space of two first canonical variates (Fig. 3).

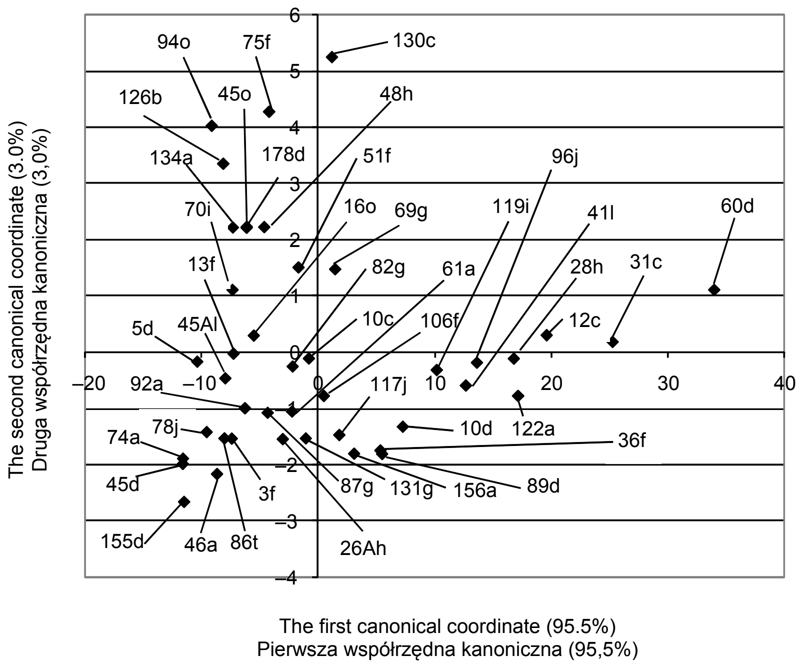

Fig. 3. Position of selected monitoring wells in relation to groundwater level depth in the space of two first canonical variates

Rys. 3. Położenie wybranych studzienek pomiarowych w odniesieniu do głębokości wody gruntowej w przestrzeni dwóch pierwszych zmiennych kanonicznych

It was found that first canonical variable carries 95.5% of variability, the second 3.0% and the other variables 1.5% variability. Since the variation percentage preserved by this transformation (transition from the twelve-dimensional space into the one-dimensional space) equals 95.5%, the loss of information concerning the transferred variation between average groundwater level depths does not have an effect on the interpretation of results. Calculated values of the first canonical coordinates allowed employing ordering pattern of wells according to groundwater level depths (Table 2). The wells located in the research sites 60d, 31c manifested the highest values of the first canonical coordinate. These wells represent the highest values of groundwater level depths below ground surface. The wells located in the research sites 74a, 155d and 45d have the lowest value of the first canonical coordinate. These are the wells which have the lowest groundwater level depths below ground surface.

Table 2. Values of the first canonical coordinate (φ_1)
Tabela 2. Wartości pierwszej współrzędnej kanonicznej (φ_1)

Research site Powierzchnia badawcza	φ_1	Research site Powierzchnia badawcza	φ_1	Research site Powierzchnia badawcza	φ_1
45d	–11.64	45o	–6.16	117j	1.79
74a	–11.62	178d	–6.15	156a	3.05
155d	–11.53	16o	–5.55	36f	5.31
5d	–10.39	48h	–4.66	89d	5.46
78j	–9.59	87g	–4.36	10d	7.23
94o	–9.16	75f	–4.24	119i	10.15
46a	–8.70	26Ah	–3.07	41l	12.64
126b	–8.17	61a	–2.27	96j	13.59
86t	–8.07	82g	–2.21	28h	16.76
45Al	–8.00	51f	–1.71	112a	17.12
3f	–7.43	131g	–1.08	12c	19.58
70i	–7.37	10c	–0.83	31c	25.23
134a	–7.34	106f	0.46	60d	33.94
13f	–7.28	130c	1.16		
92a	–6.31	69g	1.43		

Calculated values of Mahalanobis squared distances for the selected research sites 60d, 155d and 74a located in pine forest stands are presented in Table 3. These sites represent on the average the highest and lowest values of the canonical coordinate for pine forest stands.

Calculated values of Mahalanobis squared distances for the selected research sites 31c and 94o located in oak forest stands are presented in Table 3. These sites represent on the average the highest and lowest values of the canonical coordinate for oak forest stands.

According to the values of Mahalanobis squared distances, the most similar to well located in the research site 60d (pine forest stand) is the well located in the research site 31c (oak forest stand) and the least similar are the wells located in the research sites 45d and 74a (pine forest stands). The similar pattern occurs for well placated in the research site 45d. The most similar are the wells located in the research sites 74a, 155d, 78j (research sites located in pine forest stands), but the least similar are the wells located in the research sites 60d and 31c.

In addition, the analysis of Mahalanobis squared distances between the well located in the site 106f and the other locations, showed the highest dissimilarity for wells located in the sites 60d and 31c. The dissimilarity can be ascribed to outlaying pattern of groundwater level depth in the wells representing sites 60d and 12c in comparison with the wells located in other sites. The most similar wells are 10c, 117j, 131g and 69g located

Table 3. Mahalanobis squared distances between the measurement wells located in the research sites 45d, 94o, 106f, 31c, 60d and the other measurement wells calculated according to average groundwater level depths
Tabela 3. Odległości Mahalanobisa pomiędzy studzienkami pomiarowymi umiejscowionymi na powierzchniach badawczych 45d, 94o, 106f, 31c, 60d oraz pozostałymi studzienkami pomiarowymi wyznaczonymi według przeciętnych głębokości zalegania wód gruntowych

Research site Powierzchnia badawcza	45d	94o	106f	31c	60d	Research site Powierzchnia badawcza	45d	94o	106f	31c	60d
78j	6.5	34.4	104.1	1 218	1 905	117j	183.6	154.2	5.1	552.9	1 041
82g	94.1	67.8	12.3	754.7	1 311	94o	48.1	0	123.3	1 201	1 871
89d	294.4	251.9	27.4	396.8	822.1	96j	641.9	536.5	176.5	137.8	418.3
70i	32.4	20.4	69.8	1 072	1 716	75f	100.2	32.8	55.7	889.4	1 471
74a	2.5	43.4	151.3	1 363	2 086	51f	115.5	67.8	13.4	729.7	1 274
16o	47.3	34.1	46.4	951.1	1 565	48h	68.1	30.1	36.9	899.6	1 494
10d	357.5	301.3	48.2	328.6	721.6	45d	0	48.1	150.6	1 368	2 091
5d	10.4	24.7	123.5	1 271	1 969	69g	184.1	127.1	7.7	572.7	1 062
3f	20.9	38.3	65.6	1 071	1 720	126b	49.2	12.0	102.4	1 130	1 782
13f	27.3	25.8	64.8	1 058	1 702	178d	53.3	17.4	57.5	991.2	1 612
12c	980.6	845.6	367.5	35.4	210.0	134a	40.5	13.8	74.6	1 067	1 707
31c	1 368	1 201	618.9	0	77.6	130c	224.2	120.1	40.6	614.7	1 102
28h	811.6	692.8	269.6	72.9	298.6	60d	2 091	1 871	1 129	77.6	0
36f	289.4	247.5	25.5	402.6	830.2	61a	91.2	77.9	10.5	760.1	1 318
41l	593.7	500.2	151.6	159.9	457.0	10c	123.3	92.0	4.7	680.2	1 212
46a	13.4	43.4	89.9	1 158	1830	45o	49.7	18.0	56.4	991.6	1 612
26Ah	75.6	72.6	14.7	805.0	1 378	45Al	19.4	25.3	78.4	1 106	1 763
112a	830.0	716.9	279.9	67.5	287.7	87g	58.6	57.5	27.8	881.5	1 476
155d	5.2	54.4	150.9	1 360	2 083	106f	150.6	123.3	0	618.9	1 129
156a	220.5	187.0	12.1	496.2	963.1	92a	31.4	38.2	47.7	998.0	1 626
131g	115.6	101.0	7.1	696.4	1 235	86t	15.8	36.4	75.6	1 113	1 773
119i	482.2	395.7	99.9	232.6	574.0						

in pine forest stands. Analysing the investigated wells set in Table 3, it shows that the most similar to well 31c are wells 112a, 12c, 28h, 60h of which the first is located in pine forest stand and the others in oak forest stands. The most similar to well located in the site 94o are 126b, 178d and 134a (pine forest stands) and the least similar are the wells in the research sites 60d and 31c.

The comparison of average values of groundwater level depth was performed for an oak forest stand against the average values of groundwater level depth for pine forest stands. The average groundwater level depth values below ground surface for oak forest stands are higher than for pine forest stands, e.g. for May 121 cm and October 130 cm, respectively.

The graphical illustrating research sites in respect to groundwater level depth appears to be useful analysis tool for ordering. The pattern of site distribution on the plot enables assessment of similarities. The method can be considered as an instrument to facilitate explaining interactions between physiographic characteristics of forest fresh sites and groundwater regimes.

In this case, the advantage of Mahalanobis squared distance method, in compression to the methods basing on Euclidean distances, is employing relations between groundwater level depths of each month, however the method does not include the dynamic aspect of groundwater changes more extensively.

Conclusions

1. Groundwater level depth measurement wells in fresh forest stands can be ordered with utilization of canonical variet analysis method.
2. Mahalanobis squared distances method enables finding similar wells for each measurement well according to its groundwater level depth pattern in longer periods.
3. The measurement wells with the highest groundwater level depth below the ground surface were located in the research sites 60d and 31c under the pine and oak forest stands, respectively. The measurement wells with the lowest groundwater level depth below the ground surface were located in the research sites 45d and 74a under the pine forest stand.
4. The average groundwater level depth values below ground surface for each month were larger by ca 120 cm in oak forest stands on fresh forest sites than in pine forest stands over the entire research area.

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PRÓBA KLASYFIKACJI ZALEGANIA WODY GRUNTOWEJ NA LEŚNYCH SIEDLISKACH ŚWIEŻYCH

Streszczenie. W pracy podjęto próbę klasyfikacji zmienności zalegania wody gruntowej na leśnych siedliskach świeżych. Klasyfikacja zalegania wody gruntowej umożliwia objaśnienie interakcji pomiędzy cechami fizyczno-geograficznymi a dynamiką wody gruntowej. Dotychczas stosowane metody objaśniania związków między zmiennością wody gruntowej i cechami środowiska nie upoważniały do formułowania jednoznacznych wniosków ze względu na dużą zmienność dynamiki wody gruntowej, m.in. różną amplitudę, różną długość cykli, stąd zastosowano bardziej złożoną metodykę z wykorzystaniem odległości Mahalanobisa i analizy zmiennych kanonicznych w celu zilustrowania wyników. Podawane w literaturze sposoby klasyfikacji reżimów wody gruntowej wykorzystywały podejście hydrogeologiczne lub w przypadku ekosystemów leśnych skupiały się na elementach bilansu wodnego. W pracy wykorzystano pomiary głębokości zalegania wody gruntowej pod poziomem terenu dla charakterystycznego dla Niżu Polskiego obszaru młodoglacjalnego pokrytego drzewostanem sosnowym i dębowym w Puszczy Zielonka koło Poznania. Rozpatrywano pomiary prowadzone w latach hydrologicznych 2002--2007 w 43 studzienkach pomiarowych zlokalizowanych na powierzchniach badawczych. Zastosowana metoda badawcza pozwoliła uszeregować głębokości zalegania wody gruntowej w poszczególnych punktach pomiarowych, dając podstawę do oceny wpływu poszczególnych cech środowiska leśnego na dynamikę wody gruntowej.

Słowa kluczowe: głębokość zalegania wody gruntowej, leśne siedliska świeże, analiza zmiennych kanonicznych

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