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AN ATTEMPT TO CLASSIFY GROUNDWATER LEVEL DEPTH IN PINE FOREST STANDS ON FRESH SITES

Summary

The aim of the research described in this paper is to classify groundwater level patterns in pine stands of forest fresh sites. The approach has been employed with the view to facilitate explaining interactions between physiographic characteristics and groundwater dynamics in prospective research. The methods which have been employed so far for explanation of groundwater level dynamics interactions with local physiographic conditions do not let to draw firm conclusions. The classification of groundwater dynamics patterns requires employing more sophisticated methods, because of a relatively extensive range of groundwater dynamics site-to-site variability expressed, e.g., by amplitude and cycle period. The methods of groundwater patterns classification proposed in the literature focused either on hydrogeological criteria or, if related to forest ecosystems, focused on water balance elements in forest habitats.

The area selected for 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 dynamics, forest fresh sites, classification of groundwater depth level

INTRODUCTION

Climate is a main factor affecting water balance and hydrological processes at the scale of large spatial units. However properties of local physiographic, non-climatic conditions, including properties of landcover modulate hydrological conditions for particular location and gain importance over less extensive spatial units.

Forest ecosystems affect water balance by stimulation of evapotranspiration due to substantial uptake of water from root zone and interception of rainfall by vegetation cover. Forest ecosystems modulate infiltration and filtration process, some forms of water storage and outflow processes.

The knowledge about influence of forest considered as a uniform type of landcover 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 particular ecosystem modulate water balance elements (Andressian 2004). The main obstacle in gaining more exact answers can be put to the complexity and diversity of relations between particular forest ecosystem 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 site heterogeneity. 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 ambition of the research described in this paper is to classify groundwater level patterns over investigated area. The approach has been employed with the view to facilitate explaining interactions between physiographic characteristics and groundwater dynamics in prospective research. 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 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 in literature comprehended either hydrogeological attitude or, if related to forest ecosystems, focused on water balance elements (Żurawski 1968, Graf 1999, Suliński 1995).

2. MATERIALS AND METHODS

The research area was located in western part of 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 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.

Annual rainfall and temperature for the area are 522 mm, and 8.1 ºC, respectively. Evapotranspiration and climatic water balance equal, respectively, 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 to beginning of September.

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

Forest stand sites with dominant Scots Pine (*Pinus sylvestris* 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 moderate soil moisture content. The phytosociological equivalents for these 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 stands. Average monthly groundwater level depth values were employed for data analysis. The research period covered 2002-2007 hydrological years (Fig. 2).

The physiographic 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.

Let $\mathbf{Y}_{i,j} = \begin{bmatrix} Y_{i,j,1} & Y_{i,j,2} & \cdots & Y_{i,j,12} \end{bmatrix}'$ denotes the vector of groundwater level depth in the i-th research site ($i = 1, \ldots, 35$) in the j-th hydrological year ($j = 1, \ldots, 6$), and let $\mathbf{Y}_{i\bullet} = \frac{1}{6}\sum_{j=1}^{6}\mathbf{Y}_{i,j}$ denotes the vector of mean groundwater level depth values for i-th site. In this case, vector coordinates $\mathbf{Y}_{i,j}$ are groundwater level depth values for each month of hydrological year. For analysis of groundwater level depth, differences were calculated between average groundwater level depth values. The squared Mahalanobis distance method was employed as a measure of groundwater level depth differences between the investigated sites. The squared Mahalanobis distance between i-th and k-th research sites is presented in the form (1):

$$D_{i,k}^{2} = \left(\mathbf{Y}_{i\bullet} - \mathbf{Y}_{k\bullet}\right)' \mathbf{S}^{-1}\left(\mathbf{Y}_{i\bullet} - \mathbf{Y}_{k\bullet}\right). \tag{1}$$

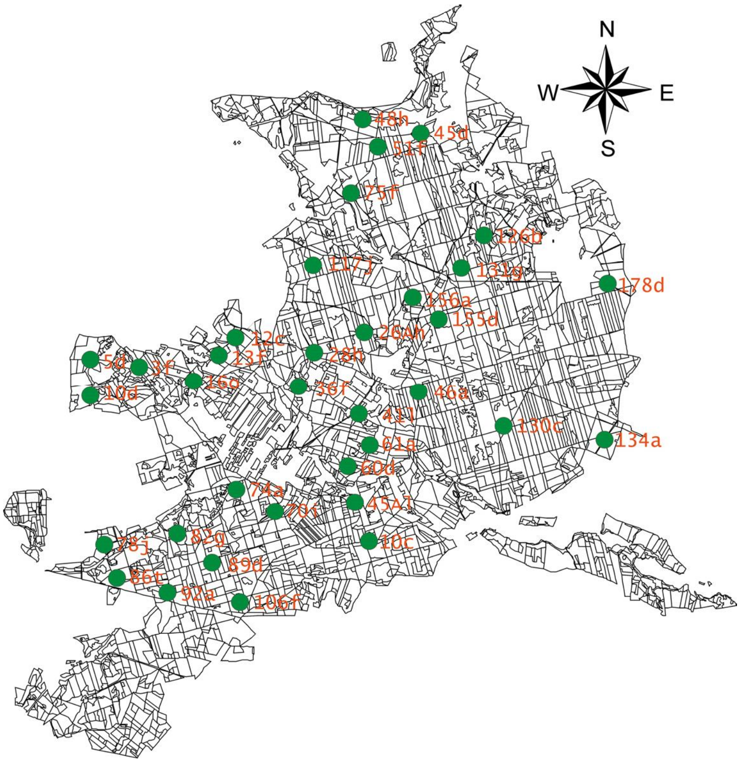

Figure 1. Location of groundwater level depth measurement sites in the investigated forest area.

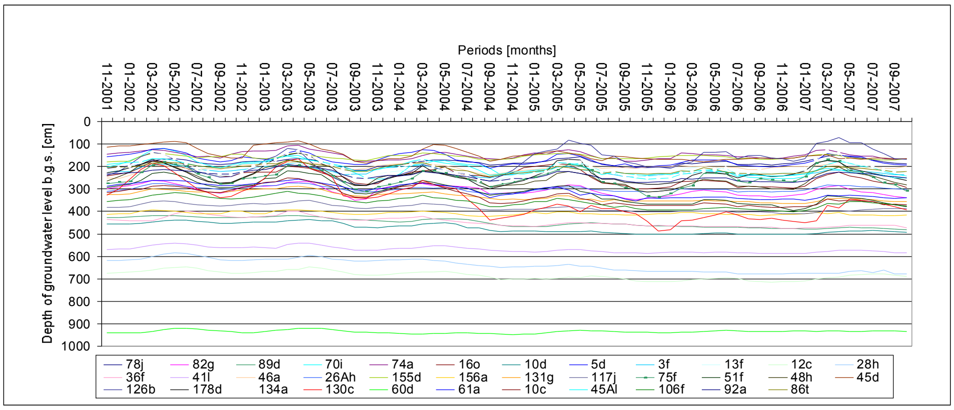

Figure 2. Dynamics of groundwater level depth in the experimental plots in the hydrological years 2002–2007

The dispersion matrix **S** for the squared Mahanalobis distance of groundwater level depths was set for two-factor experiment in cross-classification with even observation number in subclasses (Seber 1984). The dispersion matrix **S** can be calculated with the formula:

$$\mathbf{S} = \tfrac{1}{170}\sum_{i=1}^{35}\sum_{j=1}^{6}\left(\mathbf{Y}_{i,j} - \mathbf{Y}_{i\bullet} - \mathbf{Y}_{\bullet j} + \mathbf{Y}_{\bullet\bullet}\right)\left(\mathbf{Y}_{i,j} - \mathbf{Y}_{i\bullet} - \mathbf{Y}_{\bullet j} + \mathbf{Y}_{\bullet\bullet}\right)', \tag{2}$$

where $\mathbf{Y}_{\bullet j} = \tfrac{1}{35}\sum_{i=1}^{35}\mathbf{Y}_{i,j}$ and $\mathbf{Y}_{\bullet\bullet} = \tfrac{1}{210}\sum_{i=1}^{35}\sum_{j=1}^{6}\mathbf{Y}_{i,j}$. The dispersion matrix included variability of groundwater measurement site location and temporal groundwater level depth. The method is utilized in analysis of multidimensional populations, differentiates the influence of each coordinate and employs correlations between them (Krzyśko 2000).

The results were illustrated in the spaces of canonical variates. Canonical variate analysis is the method which enables graphical presentation of multidimensional experiment results (Lejeune and Caliński 2000). Consider a matrix $\mathbf{\Omega} = \mathbf{CY}$, where $\mathbf{Y} = \left[\mathbf{Y}_{1\bullet} \quad \mathbf{Y}_{2\bullet} \quad \cdots \quad \mathbf{Y}_{35\bullet}\right]'$ and $\mathbf{C} = \mathbf{I}_{35} - \tfrac{1}{35}\mathbf{1}_{35}\mathbf{1}'_{35}$. Groundwater level depth effects matrix $\mathbf{\Omega}$ is defined by difference between average groundwater level depths for individual monitoring wells and the general means. The method includes the transformation of matrix $\mathbf{\Omega}$ into a set of new variables, which carry similar information, but have been distributed in the multivariate Euclidean space.

Following the transformation, the matrix $\mathbf{\Omega}$ is presented in the form: $\Omega = \sum_{p=1}^{12_1}\lambda_p^{-1/2}\psi_p\varphi'_p$, where the vectors $\boldsymbol{\psi}_p$ and $\boldsymbol{\varphi}_p$ and scalars λ_p are determined from equations of the form (Lejeune and Caliński 2000):

$$\mathbf{\Omega S}^{-1}\mathbf{\Omega}'\left\lfloor\tfrac{1}{6}\left(\mathbf{I}_{35} - \tfrac{1}{35}\mathbf{1}_{35}\mathbf{1}'_{35}\right)\right\rfloor^{-}\boldsymbol{\psi}_p = \lambda_p\boldsymbol{\psi}_p, \tag{3}$$

$$\mathbf{\Omega}\left\lfloor\tfrac{1}{6}\left(\mathbf{I}_{35} - \tfrac{1}{35}\mathbf{1}_{35}\mathbf{1}'_{35}\right)\right\rfloor^{-}\mathbf{\Omega}'\mathbf{S}^{-1}\boldsymbol{\varphi}_p = \lambda_p\boldsymbol{\varphi}_p, \tag{4}$$

The vector $\boldsymbol{\psi}_p$ is called the *p*-th canonical coordinate, and the vector $\lambda_p^{-1/2}\boldsymbol{\varphi}_p$ is called the *p*-th dual canonical coordinate. The squared distance between the origin point of the Cartesian coordinate system and any point related to groundwater level depth for particular site can be interpreted as the squared Mahalanobis distance of each site to the general mean values.

3. RESULTS AND DISCUSSION

Graphical configuration of points was obtained as a result of the conducted decomposition of the matrix **Ω** illustrating the investigated forest area in respect of groundwater level depths in the two-dimensional space of canonical coordinates (Fig. 3).

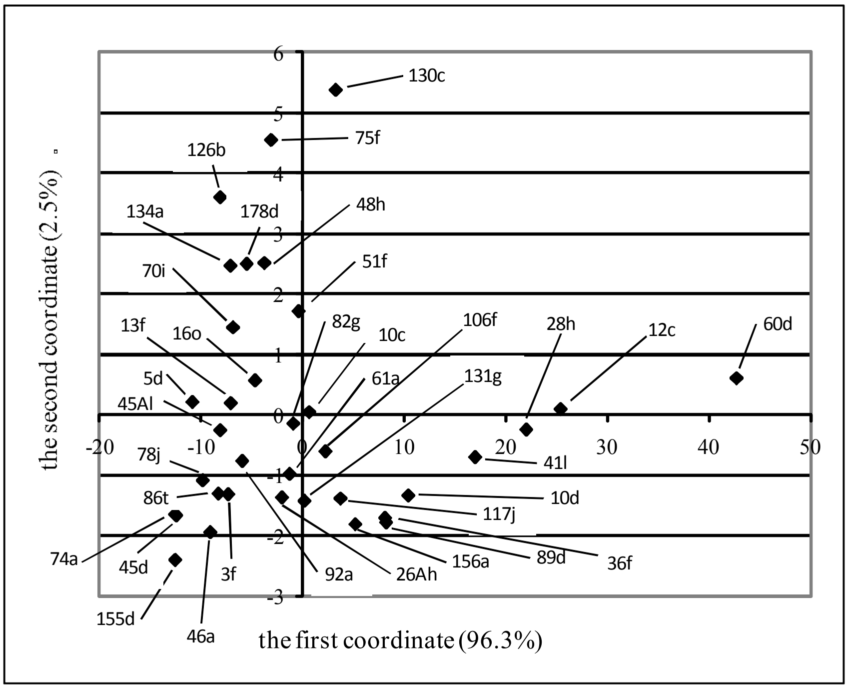

Figure 3. Position of the research sites in relation to groundwater level depth in the space of two first canonical variates.

It was found that the first canonical variable preserves 96.3% of information about groundwater level depths, the second 2.5% and the other variables 1.2% variability. Since the variation percentage preserved by this transformation (transition from the twelve-dimensional space into the one-dimensional space) equals 96.3%, 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 coordinate allowed employing ordering pattern of wells according to groundwater level depths (Table 1).

Table 1. Values of the first canonical coordinate (φ_1)

Research site – measurement well/ first canonical coordinate (φ_1)																	
78j	82g	89d	70i	74a	16o	10d	5d	3f	13f	12c	28h	36f	41l	46a	26Ah	155d	156a
-9.87	-0.96	8.19	-6.89	-12.6	-4.71	10.4	-10. 9	-7.35	-7.12	25.4	21.98	8.08	17.0	-9.13	-2.08	-12.6	5.15

Measurement well/ first canonical coordinate (φ_1) continued																
131g	117j	75f	51f	48h	45d	126b	178d	134a	130c	60d	61a	10c	45Al	106f	92a	86t
0.15	3.70	-3.14	-0.43	-3.79	-12.5	-8.15	-5.55	-7.15	3.22	42.7	-1.32	0.59	-8.14	2.22	-5.99	-8.32

Table 2. Squared Mahanalobis distances between measurement wells located in research sites 60d, 131g, 74a and the other measurement wells calculated according to average groundwater level depths

	Measurement well																	
Measurement well	78j	82g	89d	70i	74a	16o	10d	5d	3f	13f	12c	28h	36f	41l	46a	26Ah	155d	156a
60d	2769	1908	1199	2469	3063	2251	1052	2873	2510	2483	304.2	432.1	1206	665.3	2693	2010	3065	1416
131g	103.4	5.3	65.8	65.1	163.6	34.2	105.4	126.1	57.7	56.9	639.6	479.7	64.5	283.7	88.0	7.1	163.8	26.4
74a	10.0	138.7	433.4	48.3	0	72.9	527.9	9.5	29.5	35.9	1445	1199	429.2	874.4	13.9	112.2	1.7	316.3

	Measurement well, continued																
Measurement well	131g	117j	75f	51f	48h	45d	126b	178d	134a	130c	60d	61a	10c	45Al	106f	92a	86t
60d	1816	1525	2121	1864	2168	3053	2598	2334	2490	1592	0	1943	1775	2587	1645	2374	2608
131g	0	13.1	48.9	11.4	33.2	163.0	98.6	53.3	71.7	64.2	1816	4.1	3.6	72.2	9.0	39.6	72.7
74a	163.6	266.6	131.5	161.9	97.0	2.4	51.9	71.0	49.6	306.7	3063	128.9	179.0	22.9	224.5	45.9	19.4

The wells located in research sites 60d, 12c, 28h, 41l and 10d manifested the highest values of the first canonical coordinate. These locations represent wells of the highest values of groundwater level depths below ground surface. The wells located in research sites 74a, 155d, 45d and 5d have the lowest value of the first canonical coordinate. These are the wells which have the lowest groundwater level depths below ground surface.

Calculated values of the squared Mahanalobis distance for selected measurement wells 60d, 144g and 74a are presented in Table 2. These wells represent the highest average and lowest values of the canonical coordinate. According to the values of the squared Mahanalobis distance, the most similar to the well located in the research site 60d is the well located in research site 12c and the least similar are the wells located in the research sites 74a, 155d, 45d. The similar pattern occurs for well located in research site 74a. The most similar are the wells located in research sites 155d, 45d and 5d and the least similar are the wells located in research sites 60d and 12c.

In addition, the analysis of the squared Mahanalobis distances between the well located in the site 144g and the other locations showed the highest dissimilarity for wells located in the sites 60d and 12c. 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 graphical illustrating of measurement wells in respect to groundwater level depth appears to be useful analysis tool for ordering the wells. The pattern of well distribution on the plot enables assessment of similarities between wells. 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 the squared Mahanalobis distance method in comparison to the methods basing on Euclidean distances can be ascribed to employing relations between groundwater level depths of each month, however the method does not include the dynamic aspect of groundwater changes more extensively.

6. CONCLUSIONS

1. Application of canonical variate analysis allowed ordering the measurement wells according to groundwater level depth.

2. The case of 96.3 % of information related to groundwater level changes preserved by the first canonical coordinate could be considered as an interesting result of the analysis. The result could be explained by relative similarity of groundwater level depth changes in forest fresh sites over investigated area regardless of groundwater level depth.

3. Application of squared Mahanalobis distances let find similar wells for each measurement well in respect to groundwater level depth.

REFERENCES

Andreassian V. Waters and forests: from historical controversy to scientific debate. Elsevier. Journal of Hydrology, 2004, 291: 1–27.

Grajewski S., Okoński B. 2007. Variability of groundwater level depth in uneven-aged forest stands of marshland habitats. KTIW PAN 3. Kraków: 41-48.

Graf R. 1999. Conditions of recharge and discharge groundwater (first level) in aquifers of Wielkopolska region. (Warunki zasilania i sczerpywania wód podziemnych pierwszego poziomu w wybranych zlewniach niziny Wielkopolskiej), PTPN, Prac. Kom. Geograf-Geolog, t. 24. Poznań. (in Polish).

Lejeune M., Caliński T. 2000. Canonical analysis applied to multivariate analysis of variance. Journal of Multivariate Analysis 72: 100-119.

Krzyśko M. 2000. Multivariate statistical analysis (Wielowymiarowa analiza statystyczna). Rektor Uniwersytetu im. Adama Mickiewicza, Poznań, (in Polish).

Okoński B., Krzyszkowska J., Grajewski S., Moliński K. 2008. Groundwater Depth Dynamics of Fresh Forest Sites. Vol. 1. Sec. 1: Environ. Prot. Proc. Of 7th Int. Conference. VGTU: 256-260.

Seber G. A. F. 1984. Multivariate Observations. Wiley. New York.

Suliński J. 1995. Factors diversifying values of water balance elements in clearfelled forest stands (Czynniki różnicujące wartości składowych bilansu wodnego drzewostanów zagospodarowanych zrębowo). Sylwan, 11, 1995, p. 49-65. (in Polish).

Żurawski M. 1968. An attempt to classify zones of groundwater first level of in Wielkopolska Lowland (Próba wydzielenia stref pierwszego poziomu wód podziemnych na Nizinie Wielkopolskiej), PTPN, Prace Komisji Geogr.-Geolog., T. 7, Z. 2, Poznań. (in Polish).

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