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Risk assessment of forest decline by application of geostatistics and multi-criteria analysis

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Abstract: In this paper, the risk zone mapping of declining lowland forests belonging to „Morović", management unit „Varadin-Županja" (northern Serbia) is performed using geostatistics analysis. Based on the monitoring of groundwater level, the Kriging method has been performed for the spatial distribution of groundwater level for a multiyear period (2010–2013) – reference level and characteristic levels for the wettest and the driest year during the analyzed period. Risk assessment was determined by the variance of characteristics compared to reference levels. Then, multi-criteria decision analysis methods (AHP, PROMETHEE II) were applied to define the rank of each department (smaller forest management units) located in the research area. These analyses are very important because they enable to locate of the area with a high risk of forest decline and to rank departments using criteria: deviation from water level recorded during dry periods, species demand for water, conservation status and purpose of the unit (seed stands or technical wood). The proposed methodology is usable for the determination of the primary localities for the application of management measures conducting on the level of lower planned units (departments) and thus lead to the successful planning and more efficient forest management. Obtained results at the researched area showed that a negative influence on the watering regime has groundwater level decreasing compared to the reference level because it directly affects available water for the plants. Based on multicriteria analysis methods, it was deduced that the most endangered parts are located at the edge, while this risk is much lower in the central part of the management unit. A combination of applied methods (geostatistics and multicriteria analysis) is of great importance for forestry management.

Keywords: The risk from forest decline; Groundwater monitoring; Geostatistics analysis; Multi-criteria analysis.

INTRODUCTION

In the belt of lowland (hygrophilous) forests, the water is of the greatest importance to its normal functioning. Significant changes in water quantity cause successive changes inside the ecosystem. Pedunculate oak decline is present in many European countries, so it represents a serious global problem. Research of pedunculate oak sites in Europe and its watering regime is the most important ecological factor of lowland forests. This issue is one of the first steps in order to solve complicated processes related to the decline of forest ecosystems in this area. Knowing of the watering regime in concrete site conditions, and the relation of plant associations to extremely wet or dry habitats is very important, not only for normal growth and development of phytocenosis but also for effective application of management measures. If the study area is exposed to various negative influences, not only of natural (climate changes) but also of anthropogenic factors (embankment building), then the intensity of these influences effect has to be spatially considered (Nikolić, 2017). The assessment of risk zones from forests decline should be performed and some other criteria (forest and soil type, stand structure, unit selected for some concrete purpose) should be determined for ranking of selected planned units (departments) for more successful planning and management.

Considering species whose development and survival mostly depends on water (the most important ecological factor in hygrophilous forests) big attention should be paid to the watering regime. Many authors (Donaubauer, 1998; Shume, 1992; Varga, 1987) found that the main reason for the disordered watering regime in pedunculate oak hygrophilous forests is a human factor. Gradual decline and devastation of pedunculate oak are mostly related to small water quantity that the plant can uptake during long dry periods, but it also could be partly caused by a lot of precipitation during longer wet periods.

Pedunculate oak forests in the area of northern Serbia covers about 40.000 ha and they are, from an ecological and economical point of view, one of the most valuable forest ecosystems. During the second half of the 20th century, forests in Serbia have been exposed to a huge human and extreme climate influence. The more intensive process of pedunculate oak decline in Serbia has been recorded during the period 1910–1925, and after 1950 and in the period 1983–1986 (Medarević et al., 2009). According to the mentioned author, the decline process included about 2,500,000 m^3 of trunks.

It should be emphasized that the watering regime at the researched area depends a lot on local hydrogeological conditions. Analysis of available references related to pedunculate oak decline indicates the complex influences of biotic and abiotic factors that additionally complicates the implementation of protective measures for saving these forests.

The main scope of the research is defining the most endangered areas (departments) based on the criteria that will clearly define the application of silvicultural and management measures for the protection of these ecosystems. Defining of the most endangered areas should be conducted due to data related to groundwater monitoring, using the Kriging method and Promethee method.

Multi-criteria decision analysis (MCDA) approach is a beneficial tool for researchers, decision-makers and practitioners in the area of soil and water resource management (Ameri et al., 2018; Vulević et al., 2015; Vulević and Dragović, 2017; Welde, 2016), as well as forest management for solving problems related to sustainable forest management planning (Balana et al., 2010; Sheppard and Meitner, 2005).

MATERIAL AND METHODS

Study area

The researched area belongs to the greatest lowland complex of pedunculate oak forests in Europe. Forest complex that includes the management unit „Varadin-Županja" is situated in the area of Srem in the northern part of Serbia (Fig. 1). Forest unit „Sremska Mitrovica", with its forest enterprise „Višnjićevo", manages with these forests. Forests belonging to the management unit „Varadin-Županja" are located in a non-flooded area between Sava and Bosut rivers. The relief is flat with a small difference between the highest and the lowest positions. Elevation ranges between 81 and 83 m above sea level. The geological basis is the alluvial deposition of the sand with a different structure. The most widespread soils are gley, humogley, and cambisol. The watering regime directly influences the productive potential of these soils. The main purpose of the forests belonging to this management unit is technical timber production and seed stand. The most widespread forest type in this management unit is pedunculate oak, hornbeam and ash forest type (Carpino-Fraxino-Quercetum roboris caricetosum remotae) on humogley in the non-flooded area and it covers 41.80% of the whole afforested area. According to data from General Plan for Forest Management, a structure of the forests in Srem related to its origin is: high natural stands of hardwoods cover 61.1%, while artificially established stands cover about 38.9%. As for conservation criteria, preserved stands cover 64.3%, while thinned stands include 35.7%. Pure stands cover 64.3%, while mixed stands include 35.7%.

Groundwater monitoring

In this management unit, there have been mounted objects for groundwater level monitoring (piezometers) and they are located along bioindication lines. There have been overall 9 piezometric devices mounted. They are 6 m deep and distributed along with two observing profiles, and one piezometer has been mounted at the depth of 20 m. Piezometric tubes have been mounted in a piezometric drill hole with its all constructive elements (precipitator, filter, gravel device, fulfilled above-filter tube, clay buffer, concrete insurance, and piezometric cap). Groundwater level was measured every 10 days (3 times a month) during the whole researched period (2010–2013) by the public enterprise „Vojvodinašume".

Geostatistical analysis

Geostatistic methods are of great importance for projects related to groundwater monitoring (Aboufirassi and Marino, 1983; Ahmadi and Sedghamiz, 2007; Delhomme, 1978; Desbarats et al., 2002; Dunlap and Spinazola, 1984; Knotters and Bierkens, 2001; Volpi and Gambolati, 1978). In this paper, the Kriging model for groundwater level displaying was used. Kriging includes geostatistic techniques used for determining the unknown value of a variable on the base of available data related to some variables (so-called control points) and on the base of structural features of variogram, as well (Matheron, 1962, 1963, 1965). Spatial interpolation of data related to characteristic groundwater levels at the researched area by universal kriging (Johnston et al., 2001) is applied using software ArcMap 10.6. This model uses semiovariogram analysis based on the exponential mathematical model. Nine points that represent the locations of groundwater level monitoring objects (piezometers) were used to construct the kriged surface of average groundwater levels (reference level) calculated for vegetation seasons of researched years 2010, 2011, 2012, and 2013, each separately. The next step was connected with determining of extreme years on the base of the most significant climate factors such as air temperature and rainfalls during vegetation season. Based on mentioned climate factors, 2010 was determined as the wettest, and 2012 as the driest. After that, average groundwater levels during vegetation season for these extreme years were determined, and then deviations of these medium values during extreme years from the reference level for the period 2010–2013 were recorded. It enabled the establishing of a rising of a piezometric level of groundwater during 2010 and its falling during 2012. These deviations affect hydrological site conditions and optimal providing of pedunculated oak by water.

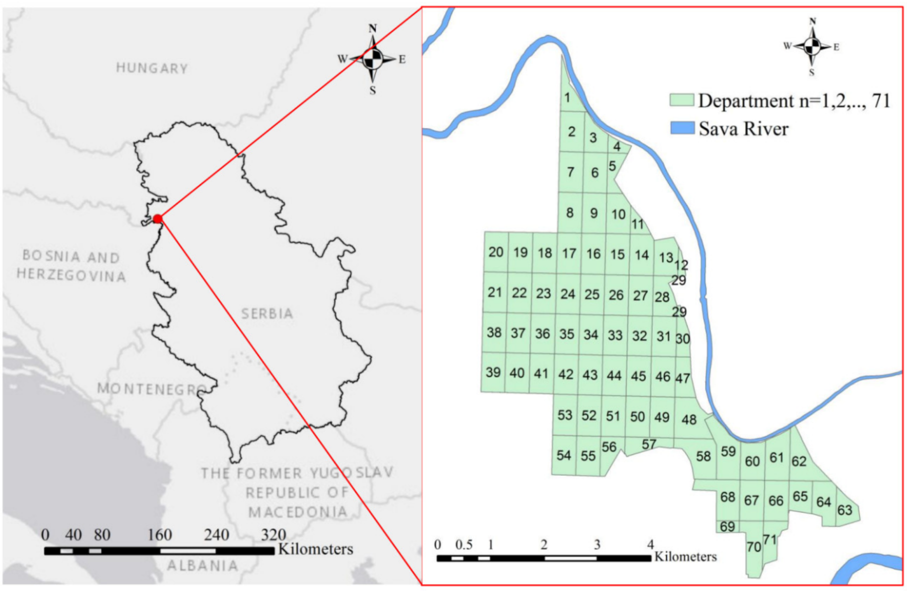

Fig. 1. Study area.

AHP method

The Analytic Hierarchy Process (AHP) is a multi-criteria decision analysis (MCDA) method developed by T. Saaty in 1980 that consists of three steps: problem structuring in the hierarchy form, assessment of preference using pairwise comparisons and aggregation of these preferences to determining the best decision.

In this paper, AHP is only used for determining the criteria weights (priorities), using the prioritization method, e.g. principal eigenvalue method (EM). According to Saaty (2003), the principal eigenvector is a priority vector of consistent matrix A (Eq. (1)):

$$A = [a_{ij}] = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix} \quad (1)$$

where a_{ij} represent the element of the judgment matrix A, and $a_{ij} = 1/a_{ij}$, $a_{ij}\ x\ a_{ij} = 1$, n = attributes of evaluations, $i, j = 1, 2, \dots, n$. This matrix is formed by comparison of every two criteria, respect to the defined goal. The comparison is carried out using a number from the 1–9 scale S, where $S = \{1, 2, 3, 4, 5, 6, 7, 8, 9\}$ to express the importance of i*th* criterion relative to the *jth* criterion. The verbal equivalents of judgments are going from the equal importance (for the judgment 1) to the extreme importance (for the judgment 9). The reciprocal value {1/9, 1/8, 1/7, 1/6, 1/5, 1/4, 1/3, 1/2} is used for the comparisons of *jth* criterion (less dominant element of the matrix A) with the *ith* criterion (more dominant element of the matrix A).

Then, the vector of the relative weights of each criterion w is calculated performing the aggregation of the pairwise comparison values from matrix A, using EM described by Saaty (Saaty 1994). The priority vector w could be obtained solving the system: $Aw = \lambda_{max}w$, $e^Tw = 1$, where A represents a judgment matrix and λ_{max} is the largest eigenvalue of A. In the next step the deviation of the judgment approximation is measured using the consistency index (CI) estimated as $(\lambda_{max} - n) / (n - 1)$ (Saaty, 1990) as well as the consistency ratio (CR) which value equal or less then 0.10 confirms that pairwise comparison matrix satisfies consistency test.

PROMETHEE method

The PROMETHEE method (Preference Ranking Organization METHod for Enrichment Evaluation) belongs to the family of the multi-criteria outranking method, conceived by Jean-Pierre Brans in 1982. PROMETHHEE II is outranking method used for the complete preorder of the action (alternatives) through the procedure described at Bezhadian et al. (2010):

1) Determination of deviations or differences between evaluations of two alternatives a and b on each criterion: $dj(a,b) = gj(a)–gj(b)$, where $dj(a,b)$ denotes deviation,

2) Application of selected preference function $Pj(a,b)$ proposed by Brans and Vincke (1985) in the order to translate the deviation $dj(a,b)$ in real number between 0 and 1, using the formula: $Pj(a,b) = Fj[dj(a,b)], j = 1,.., k$.

3) Calculation of global preference index $\pi\ (a,b)$ (Eq. (2)) as a weighted sum of preference function $Pj(a,b)$ and criterion importances-weights wj:

$$\pi(a,b) = \sum_{j=1}^{k} P_j(a,b) w_j \,. \quad (2)$$

4) Calculation of positive outranking flow $\phi^+(a)$ (Eq. (3)) and negative outranking flow $\phi^-(a)$ (Eq. (4)) as:

$$\phi^+(a) = 1/(n-1) \sum_{x \in A} \pi(a,x) \quad \text{and} \quad (3)$$

$$\phi^-(a) = 1/(n-1) \sum_{x \in A} \pi(x,a) \,. \quad (4)$$

5) Calculation of net outranking flow $\phi(a)$ (Eq. (5)) as:

$$\phi(a) = \phi^+(a) - \phi^-(a) \quad (5)$$

that enables the complete ranking of alternatives.

RESULTS

Results related to groundwater level monitoring

Results related to groundwater level monitoring have been analyzed during the vegetation period because the greatest water uptake responsible for basic functions performing occurs in that period of time. In the area of management unit "Varadin-Županja", an average groundwater level during 4 vegetation periods (2010–2013) i.e. reference level has been displayed in Fig. 2. On this map, the following zones of groundwater level are observed:

- piezometric level of groundwater in an interval from -2.6 to –2.8 m includes the area of 0,843 km^2, that is 3.77% from the study area
- piezometric level of groundwater in an interval from -2.8 to –3.0 m includes the area of 2,5896 km^2, that is 11.59% from the study area
- piezometric level of groundwater in an interval from -3.0 to –3.2 m includes the area of 18,9186 km^2, which is 84.64% from the study area.

In the paper, there has been analyzed site conditions of lowland forests with a special insight into the groundwater regime during the wettest and the driest researched period. In the area of management unit „Varadin-Županja“, interpolation of medium monthly piezometric levels during 2010 and 2012 has been performed. These years were selected as periods with the greatest and the lowest precipitation quantity during the vegetation period.

The average groundwater level during vegetation period 2010 was estimated and the following zones of groundwater level are observed:

- piezometric level of groundwater in an interval from -1.0 to –1.1 m includes the area of 0,6223 km^2, that is 4.30% from the study area
- piezometric level of groundwater in an interval from -1.1 to –1.4 m includes the area of 11,4244 km^2, that is 51.12% from the study area
- piezometric level of groundwater in an interval from -1.4 to –1.6 m includes the area of 9,3422 km^2, that is 41.80% from the study area
- piezometric level of groundwater in an interval from -1.6 to –1.8 m includes the area of 0,9603 km^2, which is 4.30% from the study area.

In the area of management unit „Varadin-Županja“, an average groundwater level during vegetation period 2012 was dis-

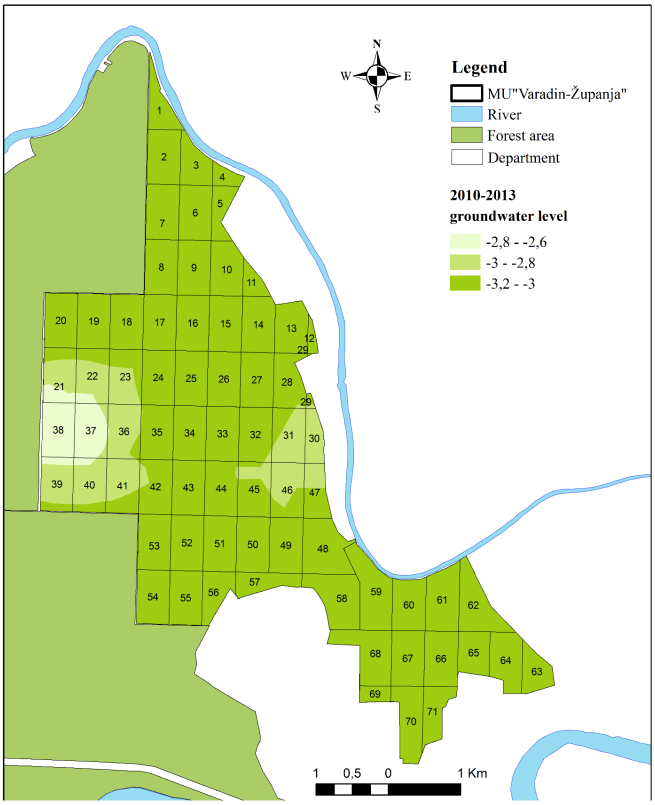

Fig. 2. Spatial distribution of groundwater level in the period 2010–2013.

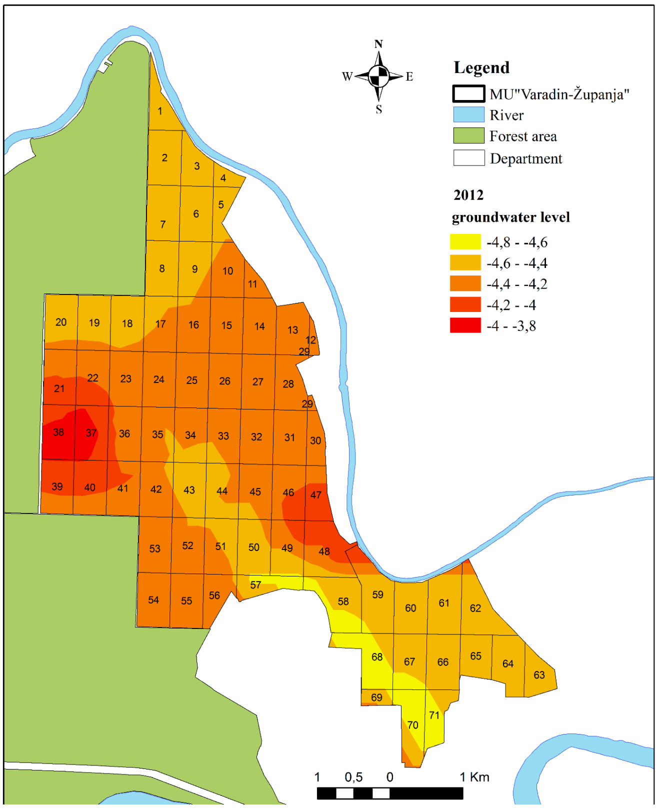

Fig. 3. Spatial distribution of groundwater level in 2012.

played in Fig. 3. On this map, the following zones of groundwater level can be observed:

- piezometric level of groundwater in an interval from –3.8 to –4.0 m includes the area of 0,5407 km^2, that is 2.42% from the study area
- piezometric level of groundwater in an interval from –4.0 to –4.2 m includes the area of 1,8206 km^2, that is 8.15% from the study area
- piezometric level of groundwater in an interval from –4.2 to –4.4 m includes the area of 10,3546 km^2, that is 46.33% from the study area
- piezometric level of groundwater in an interval from –4.4 to –4.6 m includes the area of 8,3861 km^2, that is 37.52% from the study area
- piezometric level of groundwater in an interval from –4.6 to –4.8 m includes the area of 1,247 km^2, which is 5.58% from the study area.

Obtained results at the area of MU „Varadin-Županja“ for 2010 display increased groundwater level compared to the reference level, which positively affects site conditions and vegetation development of hygrophilous woods. Considering that the scope of the paper is determinating the risk zones, further research should be focused on the analysis of the changes that occur during dry periods when groundwater level falls under reference level because these conditions negatively affect vegetation survival in this area. In order to define areas with more or less significant fluctuations compared to the reference level, a map that displays groundwater level deviation during dry 2012 from the reference level is produced. According to the decreased groundwater level compared to the reference level, the following risk zones have been determined (Fig. 4):

- piezometric level of groundwater in an interval from 0.4 to 0.6 m includes the area of 6,0065 km^2, that is 26.88% from the study area

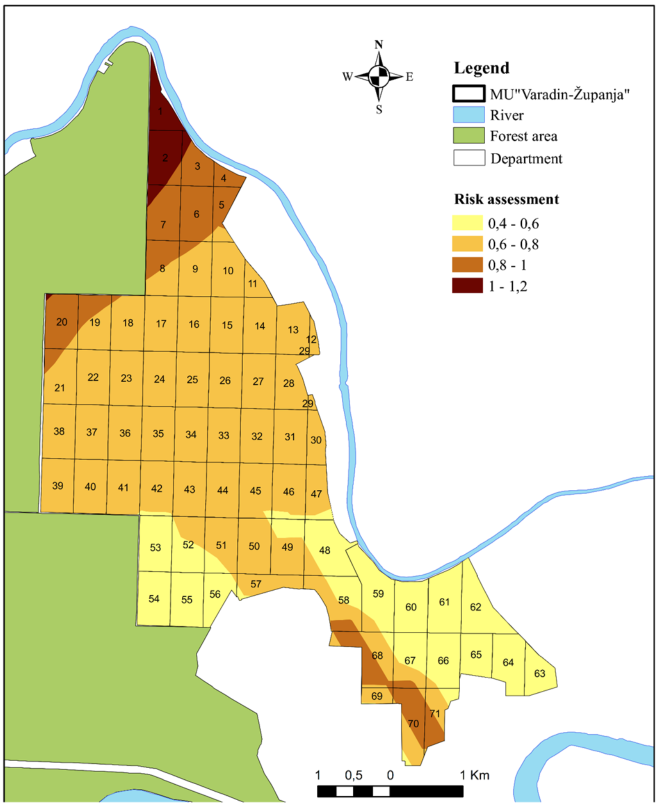

Fig. 4. Risk zones assessment in management unit „Varadin-Županja“ determined using Kriging method.

- piezometric level of groundwater in an interval from 0.6 to 0.8 m includes the area of 13,0143 km^2, that is 58.23% from the study area

- piezometric level of groundwater in an interval from 0.8 to 1.0 m includes the area of 2,7219 km^2, that is 12.18% from the study area
- piezometric level of groundwater in an interval from 1.0 to 1.2 m includes the area of 0,6065 km^2, that is 2.71% from the study area.

Based on obtained results, we can deduce that dry periods endanger the survival of these forests and these periods were recorded during vegetation period 2012.

Results of multicriteria methods application

Application of PROMETHEE method enables ranking of 71 departments belonging to MU „Varadin-Županja“ in order to define priority areas for management measures application by using Visual PROMETHEE 1.4 Academic Edition Software. Criteria used for ranking are forest conservation status (K1), deviation from water level recorded during dry periods (K2), species demands for water (K3) and purpose of the unit (K4). These criteria are expressed in different measures and their values are variable ranged, so they are transferred from numbers into intervals [1–4], where 1 is related to the greatest priority for measures application, while 4 indices the lowest priority.

The value of criterion forest conservation status (K1) was obtained for all departments based on forest conditions. If one department consists of many polygons with a different condition, an average value of criteria should be calculated as the area of department part multiplied by the purity of the department part and devided by the whole department area. Values related to the endangerment of another department have been obtained in the same way. The main rule is – if forest purity is less, its priority for protective measures is greater.

The values of criterion - deviation from water level recorded during dry periods (K2) are in intervals 0.2–0.4 m, 0.4–0.6 m, 0.6–0.8 m, and 0.8–1.0 m. The most unsuitable site conditions are in the case of the lowest water level (0.2–0.4 m), so these areas need to be marked with 1 (greatest priority for measures application). Reversely, department parts with the greatest water level (0.8–1.0 m) represent areas with the lowest priority.

According to the criterion - species demands for water (K3), species are ranged from these with the greatest water demand (ash) that have value 1 to these with the lowest water demands (black locust), which have value 4.

In order to determine values of criterion - the purpose of the unit (K4), department parts used as seed stand got value 1 (greatest priority), while areas where technical timber dominates got another 3 values – 2, 3 and 4. These values have been formed due to the price list of wood sortiments defined by PE „Srbijašume“ – the greatest price – 2, a bit lower price – 3 and the lowest price – 4. According to that price list, species present in MU „Varadin-Županja“ can be ranked in this way: pedunculate oak (the most expensive), ash (medium expensive), black locust and hornbeam (the lowest price). Based on the above mentioned, if the department is completely used as a seed stand, that department deserves value 1 for criteria purpose of the unit. If 50% of the department is with pedunculate oak and another 50% with ash, the value of these criteria for the department would be 2.5.

Average values of criteria have been obtained for each department by statistical options using in ArcMap 10.6 and they represent parameters of elevation matrix that is one of the inputs of the PROMETHEE II method (Table 1).

Table 1. Evaluations of the departments for the "Varadin – Županja" management unit.

Department	K1	K2	K3	K4	Department	K1	K2	K3	K4
D1	1.46	1.00	1.96	2.04	D37	1.35	3.00	2.53	2.53
D2	2.00	1.11	2.10	2.10	D38	1.05	3.00	2.05	2.11
D3	2.06	1.87	2.19	2.19	D39	1.48	3.00	2.71	2.71
D4	1.84	2.00	2.00	2.00	D40	1.04	3.00	1.88	2.26
D5	1.87	2.24	2.25	2.25	D41	1.99	3.00	2.07	1.35
D6	2.10	2.03	2.31	2.31	D42	1.10	3.07	2.15	1.27
D7	2.09	1.89	2.26	2.26	D43	2.15	3.00	2.18	2.73
D8	1.08	2.49	2.22	2.31	D44	2.00	3.00	1.75	2.35
D9	1.68	2.89	2.03	2.03	D45	2.00	3.03	2.01	2.01
D10	1.74	3.00	2.11	2.11	D46	1.06	3.11	2.03	2.03
D11	1.30	3.00	2.46	2.46	D47	2.09	3.15	2.45	2.45
D12	1.00	3.00	2.00	2.00	D48	1.64	3.86	3.31	3.36
D13	1.67	3.00	2.04	2.04	D49	2.00	3.32	2.83	2.83
D14	1.05	3.00	2.07	2.07	D50	2.06	3.01	3.66	3.79
D15	1.70	3.00	2.01	2.01	D51	2.06	3.19	2.18	2.18
D16	1.07	3.00	2.17	2.24	D52	2.10	3.61	2.30	2.30
D17	1.29	3.00	2.43	2.43	D53	2.06	4.00	2.37	2.37
D18	1.10	2.97	2.08	2.22	D54	1.24	4.00	1.85	2.25
D19	1.20	2.62	2.03	2.07	D55	1.00	4.00	2.00	2.00
D20	1.45	2.05	1.98	2.09	D56	1.20	3.97	2.29	2.29
D21	1.00	2.84	2.00	2.00	D57	1.14	3.07	1.92	2.20
D22	1.23	3.00	2.34	2.34	D58	1.07	3.25	2.26	2.42
D23	1.03	3.00	1.97	2.03	D59	2.47	3.90	2.15	2.15
D24	1.47	3.00	2.58	2.68	D60	2.46	4.00	2.18	2.18
D25	1.40	3.00	2.17	2.17	D61	1.90	4.00	2.22	2.22
D26	1.63	3.00	2.14	2.14	D62	2.24	4.00	2.32	2.32
D27	1.87	3.00	2.08	2.08	D63	1.53	4.00	2.00	2.00
D28	1.91	3.00	2.42	2.42	D64	1.24	4.00	2.36	2.36
D29	2.15	3.00	4.17	4.17	D65	1.75	4.00	2.26	2.29
D30	1.43	3.00	2.89	2.89	D66	2.15	3.95	2.52	2.52
D31	1.05	3.00	2.08	2.08	D67	1.89	3.53	2.03	2.03
D32	1.54	3.00	2.81	2.81	D68	2.00	2.56	2.01	2.01
D33	1.32	3.00	2.00	2.39	D69	1.00	2.98	2.00	2.00
D34	1.19	3.00	1.85	2.20	D70	1.03	2.44	2.05	2.05
D35	1.32	3.00	2.07	2.13	D71	1.34	2.75	2.32	2.32
D36	1.33	3.00	2.50	2.50					

After determining values for all 4 criteria, the type of criterion and preference function was defined. Each considered criterion is minimized because the aim is urgent protection of departments with criteria values 1. There is 6 different preference function, but in this paper linear preference, type III is used for all criteria. Based on the used preference function and differences in values between two criteria for departments that are in pairs compared (deviations), preference was obtained and its value is linearly increasing with deviation grow. If two departments have the same value as one criterion, they are of the same priority. The absolute dominance of one department compared to another exists if the difference in criteria values between these two departments is over a defined level (preference threshold). For each criterion, this preference threshold has been determined due to the guide that software offers and its values are displayed in Table 2. For each criterion and all pairs of action (departments), preference function was determined and based on this, global preference index π (a,b) was determined. In the last step, based on values of positive and negative outranking flow, the net flow $\phi(a)$ was calculated for each department (Fig. 1).

Table 2. Preference threshold for criteria used for departments ranking.

Criterion	K1	K2	K3	K4
Preference threshold *p*	1.26	0.79	0.84	0.84

If all criteria used in the analysis have the same influence on the final decision, the weights of all departments are the same. If it is not the case and decision makers prefer some criteria more, then their weights are different and it is possible to determine those weights using different methods, such as the AHP method that was used in this paper. Two scenarios have been considered: Scenario 1- the same weights of all criteria and Scenario 2 - different weights of all criteria. In the first case, all criteria have a weight value equal to 0.25, while in another case, there is a difference between weights estimated using the Saaty scale, displayed in Table 3. We ensure the reasonable level of consistency (value of CI is less than 0.10), so weight obtained in this way have been taken for analysis.

If we put in the software elevation matrix of decision making, defined type of criteria, preference function, criteria weight, preference threshold, it is possible to determine positive, negative and net outranking flow as well as the final ranking of the actions. The values of the net outranking flow $\phi(a)$ for Scenario 1 are between –0.64 and 0.42. The value of $\phi(a)$ for Scenario 2 is from –0.70 and 0.52 (Fig. 5).

Table 3. Criteria weights (Scenario 2).

	K1	K2	K3	K4	Weights *w*
K1	1	1/3	1/2	1/2	0.1238
K2	3	1	1	2	0.3659
K3	2	1	1	1	0.2778
K4	2	1/2	1	1	0.2326

CI = 0.015, RI = 0.90, CR = 0.017

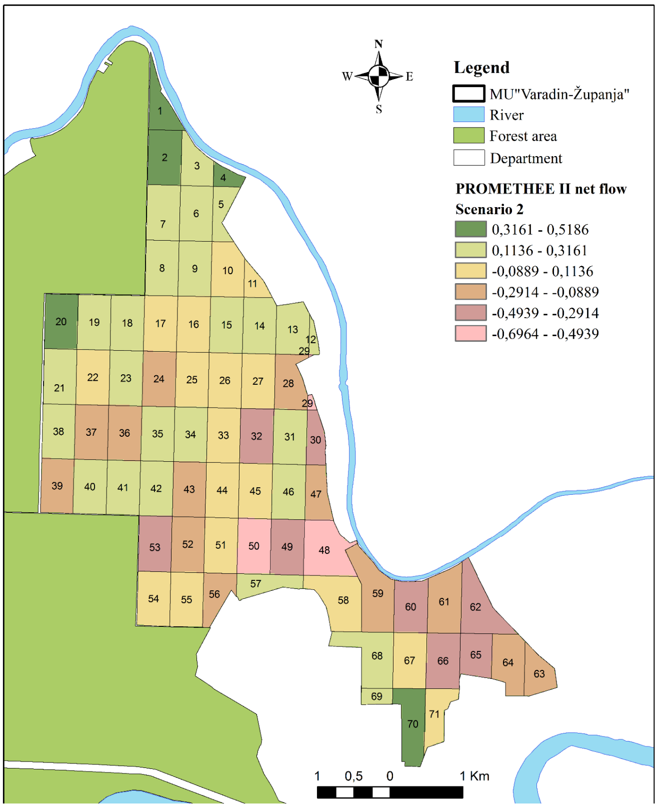

Fig. 5. Risk of forest decline obtained using PROMETHEE II (Scenario 2).

DISCUSSION

Areas of oak forests, that also include researched area of MU „Varadin-Županja", are characterized by the different spatial distribution of groundwater level, not only during wet but also during a dry period. This forest area includes hygrophilous forests of pedunculate oak whose survival, apart from precipitation, also depends on additional watering by surface or groundwater. Medium precipitation quantity on the researched area during vegetation period is 343 mm (Nikolić, 2017), which is not enough for the survival of these forest ecosystems. Embankment building in 1932 along the river Sava isolated this area from flooded water influence, so the survival and growth of these pedunculate oak forests before all depends on groundwater level fluctuations. Due to the importance of groundwater level influence on hygrophilous forests survival in Ravni Srem, further research is focused on analyzing and monitoring these fluctuations by using appropriate geostatistical methods and multicriteria methods. This analysis is focused on two directions – first is related to reference level determining that represents an average groundwater level during vegetation period 2010–2013. Deviation of an average level during vegetation period in some years from reference level tells about groundwater level influence on a watering regime. This influence can be different. During 2010, at the area of MU „Varadin-Županja", increasing of groundwater level was recorded, while during 2012 an opposite trend was found – decreasing of groundwater level compared to the reference level. Based on obtained results, it can be deduced that decreasing of groundwater level during 2012 influences a lot on the watering regime and it has a negative impact because it directly affects water quantity available to plants. Spatial defining the zones of groundwater level fluctuations is of great importance during planning documents making, and it also helps a lot during the application of silviculture measures at critical points. In the area of MU „Varadin-Županja", during 2012, 26.88% of the research area is with groundwater level in interval from 40 to 60 cm compared to reference level, then, 58.23% belongs to the zone with an interval from 60 to 80 cm, 12.18% of the territory to the interval from 80 to 100 cm and finally 2.71% of the study area has groundwater interval between 100 and 120 cm compared to reference level. Vrbek et al. (2006) established a relationship between the radial increment of pedunculate oak and a minimal level of groundwater during vegetation period in Kalje forest, and in period 1978–1985 occurred significant decreasing of radial increment due to groundwater level decreasing, so there is some similarity to groundwater level decreasing in Gornji Srem. Monitoring of ground and surface water in Slavonija forests (Croatia) established that lack of water is the main cause of the pedunculate oak decline. Stojanović et al. (2014) considered the influence of water level of the river Danube on increment and vitality of the stands belonging to mixed forests consisted of pedunculate and turkey oak in forest units „Odžaci“ and „Sombor“ by using dendrochronological methods. They found a decreasing trend of increment in a few past decades, and also a significant correlation between the water level of the river Danube and growth rings width. According to our results, the values of net outranking flow obtained using the PROMETHEE II method show that the greater value of this parameter means the greater priority for the application of management measures. According to these results, 7 departments are among the first 10 due to both considered scenarios – D1, D19, D20, D21, D42, D69, and D70 – so they demand the urgent application of management measures. The greatest compatibility shows the results of PROMETHEE II using Scenario 2 (Fig. 5) with determined risk zones due to the groundwater level decreasing (Fig. 4). As for the most endangered departments, obtained results are compatible (D1, D2, D4, D20, and D70). Areas that are medium endangered due to risk according to groundwater level decreasing (D18 – D 47) are also medium endangered by using the PROMETHEE II method (Scenario 2) with a small difference in values of net flow due to considering of more criteria with different importance.

Results obtained in the paper show that using of Kriging, AHP, and PROMETHEE II methods can enable determination of the most endangered areas (departments), that can contribute to the better organization of silvicultural and management measures application, and it also can contribute a lot to protecting of these ecologically and economically valuable ecosystems.

CONCLUSIONS

Based on obtained results at the area of MU „Varadin-Županja“, it can be deduced that negative influence on the watering regime has groundwater level decreasing compared to the reference level because it directly affects available water for the plants.

In the area of MU „Varadin-Županja“, during the dry period, all departments have different risk of endangerment: very high (2.71%), high (12.18%), medium (58.23%), and low (26.88%).

Using of multicriteria method, AHP and PROMETHEE II method, it is possible to improve the results of a previous geostatistical analysis. AHP method enables determining the importance of different criteria, while the PROMETHEE II method determines the ranking of alternatives. Departments with the greatest priority by using multicriteria analysis methods are located at the edge of the management unit, while the greatest, central part is at the medium risk of endangerment.

Spatial defining of the fluctuation zones of the groundwater level is of great importance during planning documents making and during the application of appropriate silvicultural measures at critical points. In addition to results related to the spatial display of endangered sites, it is also important that multicriteria analysis enables determining of other criteria influence (for example, the technical value of timber) on primary locations selection for adequate management measures application on the level of smaller planned units such as departments.

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