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The package "ahp" of R program for evaluating landscape management plans

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ABSTRACT
R program offers numerous packages for different types of analysis. In this paper, we demonstrate application of the R package "ahp" which fully implements Analytic Hierarchy Process (AHP) methodology and provides appealing graphical representation of results. The case study problem is focused on evaluating different management plans for the Košutnjak park-forest in Belgrade, Serbia. Four management plans for this area are assessed in multi-criteria environment, taking into account six criteria (maintaining or promoting the diversity of species; improvement of forest health conditions; maintenance or further development of sport and recreational facilities and related infrastructure; protection of cultural heritage; air quality improvement; and regulation of temperature extremes). The evaluation is organized as a decision-making process and performed by the first author. The ranking of management plans is presented and followed by analysis of consistency of the decision maker.

KEY WORDS: Program R, "ahp" package, landscape management, multi-criteria analysis

Introduction

The Analytic Hierarchy Process (AHP) is a multi-criteria method suitable for different types of analysis including assessing management strategies in landscape architecture and planning (Lakićević, 2013). There are diverse programs that support AHP methodology, such as: Expert Choice and Criterion Decision Plus. In order to apply the AHP method, one can write their own codes in a programming language; for instance, Fortran has been commonly used for this purpose (Srdjevic et al., 2019). One of the efficient computerised tools is the programming language R and its package "ahp". In this paper we demonstrate the use of this program for the evaluation and ranking of four management plans for the Košutnjak park-forest. It should be noted that the R program allows writing codes that implement AHP calculations, and that there is also another package – "MCDM" that supports calculations for several multi-criteria methods, including VIKOR, TOPSIS, WASPAS, etc. (Ceballos-Martin, 2016). Applying the "ahp" package requires basic literacy in R, and therefore can be suitable for a large group of professionals.

Program R is free software that can be applied in different tasks in area of urban ecology, as it has over 11,000 different packages available (Lakićević, 2018). The packages are suited for different scientific areas, primarily statistics, but there are also packages developed for mapping, landscape modelling, calculation of biodiversity indices, etc. which are all highly valuable for the purposes of landscape planning and landscape ecology (Lakicevic et al., 2020). In addition to that, the program supports calculations needed for applying different multi-criteria methods, and therefore is expected to be widely used in landscape management and related fields in the future.

This paper will introduce one basic example by showing a common problem in landscape management – selecting the best management plan for a particular landscape area, with respect to different criteria that can be (and usually are) mutually confronted. In these terms, the final solution is the optimal one in multi-criteria context, following the principle of Pareto optimality (Srđević, 2006). Generally, decision-making process can be performed in either individual or group context, and this paper addresses the example of individual decision making, in order to keep the explanations condense and straightforward. The aim of the paper is to promote the application of AHP method and in particular the application of the R package "ahp". The paper analyzes the main strengths and points out some of disadvantages of this R package, with regard to its possible future uses.

Method

The AHP (Saaty, 1980) is a multi-criteria method that relies on decomposing the decision-making problem into a hierarchy. Standard AHP hierarchy contains three levels: goal, criteria and alternatives (see Figure 2). Elements at given level have to be mutually (in pairs) compared with respect to elements at adjacent superior level. In other words, criteria have to be compared with respect to the goal, and alternatives have to be compared with respect to each criterion. The comparisons are usually performed by using the Saaty's scale of relative importance (Table 1).

Table 1.
Saaty's scale of relative importance
Tabela 1.
Satijeva skala relativnog značaja

Definition	Numerical value
Equal importance	1
Moderate importance	3
Strong importance	5
Very strong importance	7
Extreme importance	9
Intermediate values	2, 4, 6, 8

While making comparisons of decision elements at given level, decision maker creates so-called comparison matrix by inserting into it numerical equivalents to semantic definitions given in Table 1. If the number of compared elements is n, it is sufficient to make n(n-1)/2 comparisons and fill-in the upper triangle of the comparison matrix. Entries of the matrix in its lower triangle are filled with reciprocals, symmetrically to the main diagonal. The diagonal elements of the matrix are 1 (see Figure 3 of the case study example). From each comparison matrix the local weights (priorities) are derived, by using one of the so-called prioritisation methods (see for instance Srdjevic, 2005). The R package "ahp" uses the eigenvector method (Glur, 2018).

Synthesis of local priority vectors (i.e. weights) obtained for criteria vs. goal, and alternatives vs. each criterion, is performed by applying distributive aggregation model. This way, the final priority vector is obtained for alternatives at the bottom of hierarchy vs. goal on its top. The consistency of comparisons, made by the decision maker, is usually checked by calculating consistency ratio *CR* as suggested by Saaty (1980); the value of 10% is considered a threshold although theoretical justification for it does not exist. Worth to mention is that there are other consistency measures (such as Euclidean norm L2, or minimum violation criterion) applicable regardless which prioritization method is being used. Specific measures are also developed for several prioritization methods. More on this can be found in (Mikhailov, 2000; Aguarón and Moreno-Jiménez, 2003; Srdjevic, 2005).

The previously described procedure had been performed in R (version 3.5.3) using the package "ahp" (Glur, 2018). The application of this package requires forming the input file in the form presented in Figure 1. The example shows the comparison of criteria with respect to the goal and the remaining comparisons repeat the same pattern. The rest of procedure is rather simple and it uses commands such as "Visualize" and "AnalyzeTable".

```
Goal:
  name: Selecting MP
  preferences:
        pairwise:
        - [C1, C2, 1/2]
        - [C1, C3, 4]
        - [C1, C4, 3]
        - [C1, C5, 1/3]
        - [C1, C6, 1/2]
        - [C2, C3, 5]
        - [C2, C4, 4]
        - [C2, C5, 1/2]
        - [C2, C6, 1]
        - [C3, C4, 1/2]
        - [C3, C5, 1/7]
        - [C3, C6, 1/6]
        - [C4, C5, 1/6]
        - [C4, C6, 1/5]
        - [C5, C6, 2]
```

Figure 1. Input data for the “ahp” package
Slika 1. Ulazni podaci za “ahp” paket

Case study example

The case study example is modified from a previous research (Srdjevic et al., 2013), in which a group decision-making approach is applied in evaluating four management plans for the Košutnjak park-forest. In the previous research, the authors have used this case study to introduce a new approach to urban landscape management which is based on the AHP and the Consensus Convergence Model, and all computations were performed using the original codes written in Fortran. In this research, the decision-making problem has been modified in a following way: (1) there is one decision maker; (2) the only method used is the AHP; and (3) the hierarchy looks like presented in Figure 2.

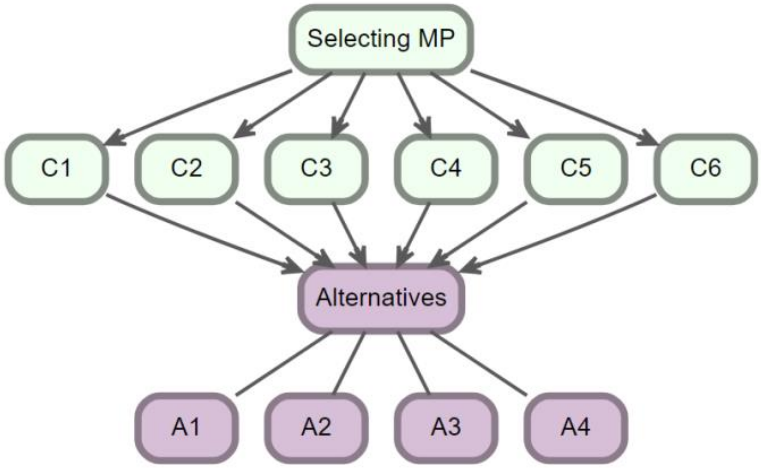

Figure 2. Hierarchy of the decision-making problem
Slika 2. Hierarhija problema odlučivanja

The AHP hierarchy of the descion-making problem can be described in a following way: the goal is stated as selecting the best management plan for the Košutnjak park-forest, the criteria set is consisted of the following elements: maintaining or promoting the diversity of species (C_1); improvement of forest health conditions (C_2); maintenance or further development of sport and recreational facilities and related infrastructure (C_3); protection of cultural heritage (C_4); air quality improvement (C_5); and regulation of temperature extremes (C_6), while alternatives include four management plans. Management plan 1 (A_1) implies keeping the current management plan without any alternations;

management plan 2 (A_2) is focused on nature protection, by reintroducing autochthonous species whose survival has been endangered, along with the removal of invasive and plants that have been affected by severe phytopathological and entomological damages; management plan 3 (A_3) should ensure rejuvenation of natural vegetation in the areas that are most affected by invasive species and improve recreation facilities in remaining areas and management plan 4 (A_4) should fully adapt this space for recreational and tourist purposes.

The first step of AHP evaluations included the pair-wise comparison of criteria with respect to the goal (Table 2).

Table 2.
Matrix of comparision of criteria with respect to the goal
Tabela 2.
Matrica poređenja kriterijuma u odnosu na cilj

Goal	C_1	C_2	C_3	C_4	C_5	C_6
C_1	1	1/2	4	3	1/3	1/2
C_2		1	5	4	1/2	1
C_3			1	1/2	1/7	1/6
C_4				1	1/6	1/5
C_5					1	2
C_6						1

The next step implied the evaluation of alternatives (management plans) with respect to each criterion (Figure 3).

C_1	A_1	A_2	A_3	A_4
A_1	**1**	1/3	1/3	5
A_2		**1**	2	6
A_3			**1**	6
A_4				**1**

C_2	A_1	A_2	A_3	A_4
A_1	**1**	1/6	1/6	1
A_2		**1**	1	5
A_3			**1**	5
A_4				**1**

C_3	A_1	A_2	A_3	A_4
A_1	**1**	6	1/3	1/5
A_2		**1**	1/8	1/9
A_3			**1**	1/2
A_4				**1**

C_4	A_1	A_2	A_3	A_4
A_1	**1**	4	1/4	1/5
A_2		**1**	1/6	1/7
A_3			**1**	1/2
A_4				**1**

C_5	A_1	A_2	A_3	A_4
A_1	**1**	1/5	1/4	4
A_2		**1**	1	7
A_3			**1**	7
A_4				**1**

C_6	A_1	A_2	A_3	A_4
A_1	**1**	1/5	1/4	3
A_2		**1**	2	7
A_3			**1**	6
A_4				**1**

Figure 3. Decision making matrices with respect to criteria
Slika 3. Matrice poređenja alternativa u odnosu na kriterijumime

Results and Discussion

The input data presented in Table 2 and Figure 3 were processed in the R program, and had lead to the final results – ranking of alternatives (management plans) with respect to the set of selected criteria. Figure 4 presents the final results – priority (weight) for each criterion, and the final priorities for each alternative (management plan). Results also include analysis of consistency for each matrix of performed pair-wise comparasons.

	Priority	A1	A2	A3	A4	Inconsistency
Selecting MP	100.0%					1.3%
C1	12.6%	16.4%	45.9%	32.6%	5.2%	6.3%
C2	20.6%	7.4%	42.3%	42.3%	8.1%	0.2%
C3	3.7%	13.7%	3.8%	30.7%	51.8%	6.0%
C4	5.3%	12.0%	4.9%	32.5%	50.5%	6.2%
C5	35.6%	12.1%	43.0%	40.1%	4.8%	4.4%
C6	22.1%	11.1%	50.9%	32.7%	5.3%	3.8%

Figure 4. Final ranking of alternatives and consistency ratio
Slika 4. Konačno rangiranje alternative i stepen konzistentnosti

The results in Figure 4 show that two highest ranked criteria are: C_5 – air quality improvement (priority is equal to 35.6%) and C_6 – regulation of temperature extremes (priority is equal to 22.1%). The highest ranked management alternative is A_2 that implies re-naturalisation of the park-forest area by introducing autochthonous species whose survival has been endangered, along with the removal of invasive species and plants affected by severe diseases and pests. The results also show that the consistency for the entire evaluation process has been within tolerable limits (<10%). The values for consistency are additionally highlighted with red colour, so that the inconsistent evaluations can be easily spotted. It should be noted that if the values of the consistency exceed the threshold value of 10% the program adds an exclamation mark ("!") next to the value of consistency ratio.

The R package "ahp" allows different graphical representation of the results. For example, table presented by Figure 4 can be additionally modified, and the criteria and alternatives can be ordered based on the priority values, usually in the descending order (from the highest to the lowest values). Figure 5 shows the modified table with the descending order of elements.

	Weight	A2	A3	A1	A4	Inconsistency
Selecting MP	100.0%	41.5%	37.2%	11.5%	9.8%	1.3%
C5	35.6%	15.3%	14.3%	4.3%	1.7%	4.4%
C6	22.1%	11.3%	7.2%	2.4%	1.2%	3.8%
C2	20.6%	8.7%	8.7%	1.5%	1.7%	0.2%
C1	12.6%	5.8%	4.1%	2.1%	0.7%	6.3%
C4	5.3%	0.3%	1.7%	0.6%	2.7%	6.2%
C3	3.7%	0.1%	1.1%	0.5%	1.9%	6.0%

Figure 5. Final ranking of alternatives and consistency ratio (descending order)
Slika 5. Konačno rangiranje alternative i stepen konzistentnosti (opadajući niz)

Figure 5 shows re-aranged results from the table presented by previous figure. This representation makes the final results – ranking of alternatives, easily readable.

Even though, the "ahp" programs has a clear graphical representation of the results, one shortcut of this package is lack of possitibility for a sensitivity analysis. Software Expert Choice, as well as software CDP (Criterion Decision Plus) offer a possibility for sensitivity analysis, i.e. the check to which extent the alternation of input data affects the final results.

Conclusion

Decision making in landscape planning can rely on multi-criteria analysis, and especially on the AHP method. In order to apply the AHP, different software products exist, and some of them are being commercialized (e.g. Expert Choice or Criterion Decision Plus). The R package "ahp" is considered as an appropriate, and free of charge, substitute. In order to demonstrate some of the capacities of this package, the paper presents its application on the example of evaluating and selecting the most appropriate management plan for the Košutnjak park-forest in the Serbian capital – Belgrade. The decision problem is structured in three hierarchy levels: goal, six criteria and four alternatives (management plans). Individual (single) decision-making process is being performed and the results are described. The future research will expectedly demonstrate a successful application of the "ahp" package in a group decision-making context. The main strengths of this package are: easy procedure of processing the input data and clear graphical representation of the results. The main shortcut of the package is the missing option for performing sensitivity analysis. Despite of that, a general recommendation would be to apply R program and its packages for diverse types of tasks in domain of landscape planning.

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Paket "ahp" programa R u vrednovanju planova upravljanja predelima

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SAŽETAK
R program nudi brojne pakete za različite vrste analiza. U radu je prikazana primena R paketa "ahp" koji u potpunosti realizuje metodologiju analitičkog hijerarhijskog procesa (AHP) i omogućuje kvalitetne grafičke prikaze rezultata. Studija slučaja je vrednovanje različitih planova upravljanja park-šumom Košutnjak u Beogradu u Srbiji. Četiri plana upravljanja za ovo područje vrednovana su u odnosu na šest kriterijuma: očuvanje i unapređenje raznolikosti vrsta; unapređenje zdravstvenog stanja šuma; unapređenje i dalji razvoj opreme za sport i rekreaciju i prateće infrastructure; zaštita kulturnog nasleđa; unapređenje kvaliteta vazduha i regulacija temperaturnih ekstrema. Vrednovanja je izvršio prvi autor rada. Pored rangiranja planova upravljanja park-šumom u Beogradu paralelno je proveravana konzistentnost donosioca odluka.

KLJUČNE REČI: Program R, "ahp" paket, upravljanje predelima, višekriterijumska analiza

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