International Journal for Quality research
UDK- 502.175
Original Scientific Paper (1.01)

MULTICRITERIA APPROACH FOR ASSESSMENT OF ENVIRONMENTAL QUALITY

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Abstract: *Environment is important and inevitable element that has direct impact on life quality. Furthermore, environmental protection represents prerequisite for healthy and sustainable way of life. Environmental quality can be represented through specific indicators that can be identified, measured, analyzed, and assessed with adequate methods for assessment of environmental quality. Problem of insight in total environmental quality, caused by different, mutually incomparable, indicators of environmental load and difficult expression of overall environment quality, can be solved with multicriterial assessment. This paper presents appliance of multicriterial methods for analysis of indicators that represent environmental quality for several sites.*
Keywords: *multicriterial analysis, environment, indicators*

1. INTRODUCTION

The problem with the insight of overall quality of the environment that is affected by many factors is primarily the nature of different factors and different measurement units in which they are expressed. In these cases, the overall environmental quality can not be expressed by simple addition, it requires a complex method for evaluation of selected elements of environmental quality.

Multicriterial evaluation in environmental protection is used in cases where there are several alternatives, variations, locations or processes that have to be assessed by their total environmental load or quality. The common result of multicriterial evaluation methods is dimensionless number that indicates the degree of environmental load of alternatives that are valued. In addition to indicators that represent the environmental impact it is possible to include indicators that have economic, social, and technological character.

The paper describes two methods of multicriteria analysis, analytic hierarchy process (AHP) and TOPSIS method. Presented example gives application of multicriteria analysis in evaluating environmental quality. Multicriteria analysis was conducted on six localities of the city of Novi Sad. For weighting of indicators of environmental impact AHP was used, and for determining of environmental quality TOPSIS method was used.

2. ANALYTIC HIERARCHY PROCESS

Analytic hierarchy process (AHP) is used for decision making when a decision (choice of some of the available alternatives, or their ranking) is based on several attributes that represent criteria. [4] Solving complex decision problems using AHP method is based on their decomposition in a hierarchical structure whose elements are goal (objective), criteria (sub-criteria) and alternatives. An important component of the AHP method is a mathematical model by which priorities of elements are calculated (weighted), for elements that are on the same level hierarchical structure.

AHP was successfully used in environmental impact assessment for determining of weights for impact categories in paper [1]. In paper [3] AHP was used for verification of results gained by quantification of environmental aspects and impacts.

Application of AHP method can be explained in four steps:

(1) Setting a hierarchical model of decision problems in order with goal on the top criteria and sub-criteria at lower levels, and alternatives at the bottom of the model (Figure 1).

(2) At each level of hierarchical structure each elements of the structure are compared in pairs, whereby the decision makers express their preferences with the help of appropriate scale which has 5 degrees and 4 sub-degrees of verbally described intensities and the corresponding numerical values for them in the range from 1 to 9 (Table 1).

(3) Local priorities (weights) of criteria, sub-criteria and alternatives at same hierarchical structure level are calculated through appropriate mathematical model and afterwards they are synthesized in total priorities of alternatives.

(4) Implementation of the sensitivity analysis for final decisions.

In the second step weights (priorities) w are determined for n criteria (or alternatives) based on valuation of their actions that are indicated with $a_{ij}= w_i/w_j$. If the matrix A is formed by measure of the relative importance of a_{ij}, for case of consistent estimations where $a_{ij} = a_{ik}a_{kj}$ is true, matrix A satisfies the equation:

$$Aw=nw \quad (1)$$

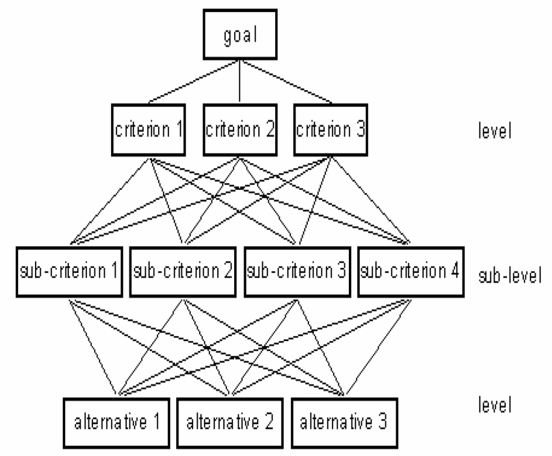

Figure 1 – General hierarchical model in AHP

Table 1 - Saaty evaluation scale [4]

Numerical values	Verbal scale	Explanation
1	Equal importance	Two elements are identical in significance compared to objective
3	Week dominance	Experience or reasoning slightly favor one element over another
5	Strong dominance	Experience or reasoning significantly favor one element over another
7	Very strong dominance	Dominance of one element is confirmed in practice
9	Absolute dominance	Highest degree of dominance
2, 4, 6, 8	Intermediate values	Need for compromise or further division

The matrix A has special features (all of its rows are proportional to the first row, and they are all positive and $a_{ij} = 1/a_{ji}$ is true) and because of that only one of its eigenvalue differs from 0 and is equal to n.

If the matrix A contains inconsistent estimates (in practical examples almost always), weight vector w can be obtained by solving the equation $(A-\lambda_{max} I)w=0$ with prerequisite that $\Sigma w_i = 1$, where λ_{max} is the largest eigenvalue in matrix A. Because of matrix A properties $\lambda_{max} \geq n$, the difference $\lambda_{max} - n$ is used in measuring estimations consistency.

With consistency index $CI=(\lambda_{max} - n)/(n-1)$ measure of consistency can be calculated:

$$CR=CI/RI \quad (2)$$

Table 2: The average consistencies of random matrices (RI values)

Matrix Size	1	2	3	4	5
RI	0,0	0,0	0,58	0,9	1,12
Matrix Size	6	7	8	9	10
RI	1,24	1,32	1,41	1,45	1,49

where RI is the random index (index of consistency for the matrix with n randomly generated comparisons in pairs - table 2 with calculated values).

If CR ≤ 0.10 is true for the matrix A, estimation of the relative importance of criteria (priority of alternatives) are considered acceptable. Otherwise, investigation should be conducted for the reasons why assessment has unacceptably high inconsistency.

3. TOPSIS METHOD

TOPSIS method (Technique for Order Preference by Similarity to Ideal Solution) is based on the concept that the chosen alternative should have the shortest distance from the ideal solution and the longest from the anti-ideal solution. [2, 4]

It is assumed that each criterion has increase or decrease of monotonous tendency, so it is easy to find "ideal" solution which is composed of all the best criterion values that are reached, and "anti-ideal" solution which is composed of worst values.

The first condition is that the selected alternative has the smallest Euclidean distance from the ideal solution in geometric term, and at the same time, the other condition is that it has the greatest distance from the "anti-ideal solutions.

Sometimes the chosen alternative, which has the minimum Euclidean distance from the "ideal" solution, has a shortest distance to the "anti-ideal solutions than other alternatives.

TOPSIS consists of 6 steps [2, 5]:

1. Normalization of the performance matrix. The matrix of performance ("payoff", "rating" or "decision matrix") has number values r_{ij} that in general have different metrics.

Each matrix row corresponds to one alternative, and each column to a single criterion; element r_{ij} is the rating (performance) of alternative A_i with respect to the criterion C_j. For m criteria (C_1, C_2, ..., C_m) and n alternatives (A_1, A_2, ..., A_n) performance matrix has the form $R_{(n,m)}$, and values ($w_1, w_2, ..., w_m$) registered above matrix represent the criteria weight defined by decision-maker, or some other way, the sum of criteria weights is 1 Therefore, elements normalization is performed by relation (3) to obtain normalized matrix X in which all elements are dimensionless.

$$x_{ij} = r_{ij}\left[\sqrt{\sum_{i=1}^{n} r_{ij}^2}\right]^{-1} \quad (3)$$

2. Normalized payoff matrix multiplied with criteria weight.

Weighted normalized performance matrix $V = (v_{ij})$ has v_{ij} elements where each v_{ij} represents product of normalized performance of alternatives X and the corresponding weighting criteria coefficient.

3. Determining the ideal solution. The ideal solution A^* and anti-ideal solution A^- are determined by relations (4) and (5)

$$A^* = \{(\max v_{ij} \mid j \varepsilon G), (\min v_{ij} \mid j \varepsilon G'), i = 1,..., n\} = \{v_1^*, v_2^*, ..., v_m^*\} \quad (4)$$

$$A^- = \{(\min v_{ij} \mid j \varepsilon G), (\max v_{ij} \mid j \varepsilon G'), i = 1,..., n\} = \{v_1^-, v_2^-, ..., v_m^-\} \quad (5)$$

where:

G = {j = 1, 2,..., m │ j belongs to criteria that have to be maximized}

G' = {j = 1, 2,..., m │ j belongs to criteria that have to be minimized}

The best alternatives that have the greatest v_{ij} for criteria that have to be maximized and the minimum v_{ij} for the criteria that has to be minimized. A^* indicates the best alternative - the ideal solution, and with the same logic, A^- indicates the anti-ideal solution.

4. Determination of alternative distance from the ideal solution. In this step, using the relation (6) and (7) n-dimensional Euclidean distance for all alternatives from the ideal and anti-ideal solutions is calculated.

$$S_i^* = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^*\right)^2}, \quad i = 1,..., n \quad (6)$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^-\right)^2}, \quad i = 1,..., n \quad (7)$$

5. Determination of the relative proximity of an alternative to ideal solution. For each alternative relative distance is determined by equation (8).

$$Q_i^* = \frac{S_i^-}{S_i^* + S_i^-}, \quad i = 1,..., n \quad (8)$$

where $0 \leq Q_i^* \leq 1$. Alternative A_i is closer to ideal solution if Q_i^* is closer to value 1, or at the same time, if S_i^* is closer to 0.

6. Ranking alternatives. Alternatives are ranked by descending values of Q_i^*.

4. EXAMPLE OF APPLICATION OF MULTICRITERIAL METHODS AHP AND TOPSIS FOR ASSESSMENT OF ENVIRONMENTAL QUALITY

4.1 Defining the multicriterial problem

The aim of multicriteria analysis is the assessment of environmental quality in the localities of the city of Novi Sad through indicators that indicate the load (potential pollution) on the environment.

Indicators (criteria) for total environmental load evaluation have physical character and quantitative values and they are related to air quality, noise level and frequency of passing vehicles in some parts of the city of Novi Sad.

Air Quality is represented by the measured values of the total dust (amount of suspended matter), the concentration of carbon monoxide CO and carbon dioxide CO_2. Frequency of passing vehicles provides information on the number of passing heavy (trucks), light (passenger cars) vehicles and motorcycles on traffic roads in the city of Novi Sad.

Measuring points for indicators are grouped in six localities in the following way:

1. Location – Salajka,
2. Location – Detelinara,
3. Location – Telep,
4. Location – Grbavica,
5. Location – Stari grad,
6. Location – Petrovaradin.

Selected indicators of environmental impact have the following column numbers that will be entered in the input matrix of performance:

1. Indicator - total dust,
2. Indicator - concentration of carbon dioxide,
3. Indicator - concentration of carbon monoxide,
4. Indicator - daily level of noise,
5. Indicator - frequency of passing heavy vehicles,
6. Indicator - frequency of passing light vehicles,
7. Indicator - frequency of passing motorcycles.

Figure 2 displays the positions of measurement sites for seven indicators and they are grouped in six locations. Measured values of the indicators are given in Table 3.

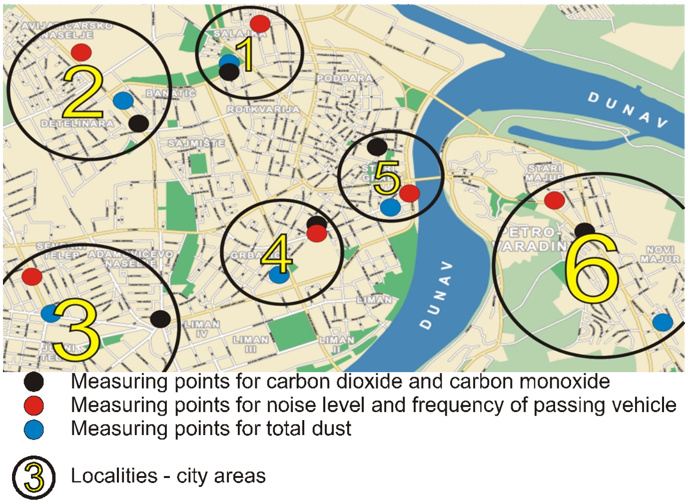

Figure 2 – Display of indicators position and measurement sites

Table 3 – Display of indicators and their measured values [6]

Locality \ Indicator	Total dust	Concentration of carbon dioxide	Concentration of carbon monoxide	Daily level of noise	Frequency of passing heavy vehicles	Frequency of passing light vehicles	Frequency of passing motorcycles
Unit	[mg/m^2]	[mg/m^3]	[mg/m^3]	[dB]	[-]	[-]	[-]
1	94,3	879,35	0,29	73	39	652	3
2	96,7	851,31	1,07	70	28	305	2
3	135,8	815,29	0,00	65	6	251	2
4	457,6	981,34	6,60	69	18	424	2
5	290,	1519,50	0,72	70	20	456	3
6	96,8	943,72	3,16	68	16	315	3

Results of measured indicators have been taken from Eco-bulletin for March 2008 and it is published by the Novi Sad City Head Office for Environmental Protection. [6].

4.2 Multicriterial analysis of environmental quality

Analytic hierarchy process is used for determination of indicators (criteria) weights that will be implemented in TOPSIS method. Figure 3 shows goal of multicriteria analysis, indicators, and localities hierarchically ordered by AHP in "decision tree".

According to Figure 3, the aim of multicriteria analysis (environmental quality), is located at the top of the hierarchy and it is not compared with other elements of the hierarchy. Indicators and localities are divided into two levels of hierarchy. At the second level of the hierarchy are the indicators (criteria), and on the last level of the hierarchy are the environment localities.

All comparison of two hierarchy elements is done using Saaty scale and the results of comparing elements of a certain hierarchy level are placed in the appropriate comparison matrix. First, the upper part of the matrix is being filled (Table 4), above the diagonal, so that the indicator from current row is compared with the indicator in the column above. Reciprocal values are placed below diagonal at the lower part of the matrix and thus form a matrix of comparisons (Table 4). Comparison of the criteria themselves one another results with equal importance, i.e. value 1 in the performance matrix, so the matrix diagonal is always formed with number 1.

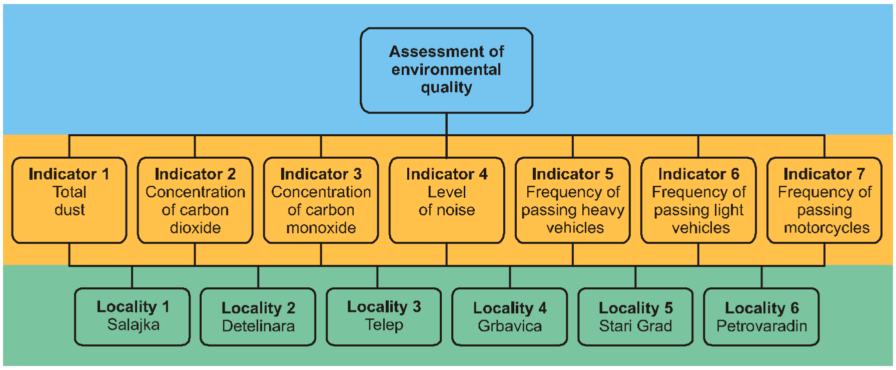

Figure 3 – AHP „decision tree“

Table 4 - AHP performance matrix for the indicators

Indicator / Indicator	1	2	3	4	5	6	7	Indicator weight
1	1,00	2,00	2,00	0,20	0,33	0,50	3,00	0,10
2	0,50	1,00	2,00	0,33	0,50	2,00	5,00	0,14
3	0,50	0,50	1,00	0,20	0,20	0,33	2,00	0,05
4	5,00	3,00	5,00	1,00	2,00	2,00	5,00	0,30
5	3,00	2,00	5,00	0,50	1,00	0,33	5,00	0,18
6	2,00	0,50	3,00	0,50	3,00	1,00	5,00	0,19
7	0,33	0,20	0,50	0,20	0,20	0,20	1,00	0,04

Last column of Table 4 shows weights assigned to indicators by AHP method. This order of importance of indicators for evaluating environmental quality through indicators that point to the environmental load of Novi Sad, is subjective and expected by decision maker. According to decision-maker, the most important indicators are frequency of passage of heavy, light vehicles and motorcycles, while the indicators such as the concentration of carbon monoxide and carbon dioxide are considered as least important indicators. From this it follows that the values of indicators such as frequency of passage of heavy, light vehicles and motorcycles will have major influence on the final value of assessment criteria for total environmental load.

After obtained indicators weight analysis of the consistency is made and the degree of consistency is calculated by equation 2, where the random index RI is obtained from Table 2:

$$CR = \frac{CI}{RI} = \frac{0{,}12}{1{,}32} = 0{,}09 < 0{,}1 \qquad (9)$$

The obtained index of consistency is less than 0,1 and there is no need for calculation repeat. Using the measured values from Table 3 input matrix R is formed for TOPSIS method. As indicators weight w for TOPSIS method, weights given in table 4 obtained by AHP are used. After calculations by TOPSIS methodology, basic TOPSIS analysis results are obtained:

- normalized matrix X, shown in table 5 and by diagram on Figure 4 and
- assessment criteria Q shown in table 6 and by chart on Figure 5

Table 5 - Values in normalized matrix X obtained by TOPSIS method

Locality \ Indicator	Total dust	Concentration of carbon dioxide	Concentration of carbon monoxide	Daily level of noise	Frequency of passing heavy vehicles	Frequency of passing light vehicles	Frequency of passing motorcycles
1	0.064	0.350	0.039	0.431	0.677	0.631	0.480
2	0.066	0.338	0.144	0.413	0.486	0.295	0.320
3	0.923	0.324	0.000	0.383	0.104	0.243	0.320
4	0.311	0.390	0.888	0.407	0.312	0.410	0.320
5	0.197	0.604	0.097	0.413	0.347	0.441	0.480
6	0.066	0.375	0.425	0.401	0.278	0.305	0.480

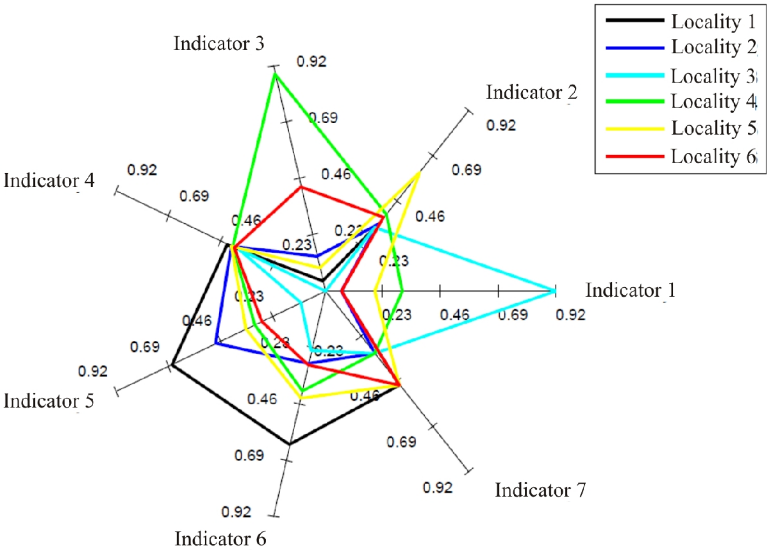

Figure 4 - Spider plot of matrix X

Spider chart was selected because of good abilities to display data on many axes. However, restriction for spider diagram appliance is the existence of a minimum three diagram axis for an adequate data view.

Spider diagram distinctly shows the difference of character of environmental load for certain localities. For example, Telep (site 3) has high amount of total dust (indicator 1) that "peeks" from other measured values, while in Grbavica (site 4) high concentrations of carbon monoxide (indicator 3) are measured. If two sites had similar values of pollution, their "stars" in the spider diagram would have similar shapes.

Table 6 – Assessment criteria Q for the six localities in the city of Novi Sad

Locality	Assessment criteria Q_i
1 – Salajka	0,56
2 – Detelinara	0,36
3 – Telep	0,38
4 – Grbavica	0,41
5 – Stari Grad	0,40
6 - Petrovaradin	0,23

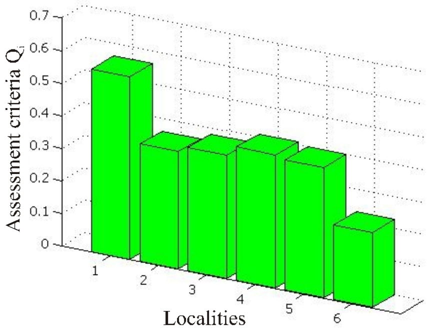

Figure 5 – Graphical overview of assessment criteria Q by localities

5. CONCLUSION

The results of multicriteria analysis are clearly presented in tables and graphs. It can be especially pointed out that this paper shows convenient application of spider diagram for a summary review of normalized matrix *X*.

Assessment criteria *Q* values from Table 6 indicate that the overall environmental load is generally equal for all sites except for Salajka (site 1), Telep (site 3) and Petrovaradin (site 6). Finally, it can be concluded that in Novi Sad for March 2008, according to the multicriterial analysis with AHP and TOPSIS method, for considered indicators of environmental impact, site 3 - Telep has the lowest environmental load, while the largest is on locality 1 - Salajka.

One of the contributions of this paper is the possibility for combining AHP and TOPSIS multicriterial methods for evaluation of environmental quality through indicators that represent the environmental load.

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Received: 23.12.2009 Accepted: 25.05.2010 Open for discussion: 1 Year