ANALYTIC HIERARCHY PROCESS IN SELECTING BEST GROUNDWATER POND

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Summary

Decision support method known as Analytic Hierarchy Process (AHP) is used to evaluate and rank urban groundwater ponds with respect to prescribed criterions. Three major ponds of the city of Novi Sad in Yugoslavia were subjected to 7 criterions with diverse metrics. Ranging from 'pond capacity' to 'environmental impacts', criterions defined by an expert serve as multiobjective decision environment where only sophisticated method such as AHP may play a proper role and consistently lead toward the final decision – here selection of the best groundwater pond.

Keywords: decision-making, hierarchy, groundwater, pond

1. INTRODUCTION

Selecting of the best source/pond for water supply from aquifer systems may be understood as ultimate decision-making after systematic evaluation of appropriate alternatives is performed and related decision space is created. To choose the one for specific situation in a region and to claim that it is the best or at least the favorite one, systems approach appears necessary to be applied. The main reason is that it preserves important issues are included such as: ponds' capacities, water quality, technical accessibility, protection and environmental impacts, exploitation economy, sociological influences etc. Besides, systems approach assures consistency of applied evaluating technique with decision-making process itself. In fact, the major issue is how to relate a variety of factors, i.e. to recognize their impacts and importance in real field conditions, and finally to determine dominance of one factor to another by investigating different dominant/weak structures.

The Analytic Hierarchy Process (AHP) (*Saaty,1980,1986,1992*) appears to be a flexible decision making tool for multiple-criterion problems such as selection of the best groundwater supply pond. It enables decomposition of a problem into hierarchy and assures that both qualitative and quantitative aspects of a problem are incorporated in evaluation process. AHP has been successfully applied in recent case study for evaluating and selecting the best one among three major groundwater ponds in the city of Novi Sad, capital of Vojvodina Province in Yugoslavia. All ponds are in the Danube river valley. For evaluating procedure total of 7 criterions is adopted after discussion with an expert in hydrogeology. Brief description of AHP is followed by results obtained, and discussion concludes the paper.

2. ANALYTIC HIERARCHY PROCESS IN BRIEF

The method Analytic Hierarchy Process (AHP) is mathematically simple matrix-based technique, but it is also powerful decision supporting tool. The best description of this method is probably the one given by Forman (*1983*): 'AHP is a compensatory decision methodology because alternatives that are efficient with respect to one or more objectives can compensate by their performance with respect to other objectives. AHP is composed of several previously existing but unassociated concepts and techniques such as hierarchical structuring of complexity, pairwise comparisons, redundant judgments, an eigenvector method for deriving weights, and consistency considerations. Although each of these concepts and techniques were useful in and of themselves, Saaty's synergistic combination of the concepts and techniques (along with some new developments) produced a process whose power is indeed far more than the sum of its parts.'

Like many other methods, AHP allows decision makers to create a model of a complex problem as a hierarchical structure with the goal at the top and objectives (criterions), sub-objectives (sub-criterions), and alternatives at levels in drop-down manner. Hierarchical approach is common to most multiple-objective decision-making methods because in reality decision makers and decision analysts approach the decision problems exactly this way:

1. The most general, overriding objective is specified first as a goal, on the top of hierarchy;
2. It is then progressively broken down into more specific objectives that can, in turn, be broken down into sub-objectives;
3. At the fingertips of the hierarchy lie the attributes.

Note that in decision theory, depending on the nature of a problem, dual notation may be found: (a) criterions/alternatives and (b) objectives/attributes. Herein the first couple will be used, as indicated at Fig. 1.

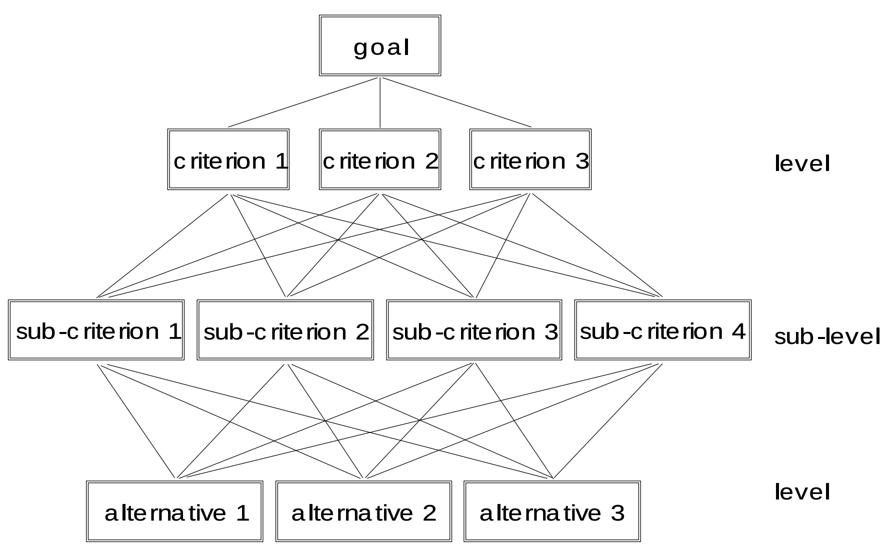

Figure 1. Hierarchy in AHP

A criterion and sub-criterion hierarchy ensures that the alternatives are appropriately related to an overall goal. A good example is natural resource management situation where the most general criterion may be stated as sustainable development or quality of life, and then divided into sub-criterions that have economic, social and environmental metrics. Alternatives should be weighted with respect to criterions and (if any) sub-criterions and in up-ward direction considered as ranked with respect to overall goal.

In most cases it is possible to apply weights to the criterions, and this opportunity should be addressed to real decision makers such as stakeholders or executive directors and managers. On the other hand, placing weights on alternatives tends to be a more scientific or technical task that is undertaken by experts or the decision analyst.

AHP allows for the application of data, experience, insight, and intuition in a logical and thorough way within a hierarchy as a whole. In particular, AHP as weighting method enables decision-maker to derive weights as opposed to arbitrarily assign them. AHP not only supports decision-maker by enabling him to structure complexity and exercise judgment, but also allows him to incorporate both objective and subjective considerations in the decision process itself (*Forman, 1983*).

3. AHP CASE STUDY

3.1. Groundwater ponds

There are three major and two secondary groundwater ponds for supplying fresh water to the city of Novi Sad, capital of Vojvodina Province, Yugoslavia. Major ponds are known as Strand, Petrovaradinska ada and Ratno ostrvo. Those three ponds are in full 24-hour operation. Their exploitation is supported on a temporary and intervening base by two other ponds known as Kamenjar and Detelinara. For certain reasons the last two ponds were not considered in this study.

All three major groundwater ponds are located near the shoreline of the Danube River. Since Danube passes almost through the center of the city, ponds are really within the core city area. Two ponds, Strand and Ratno ostrvo, are located on the left river side at 5.5 km distance from each other. Strand pond is more upstream and is located just near the University of Novi Sad Campus. The third pond, Petrovaradinska ada, is located at the opposite river side, approximately across the Ratno ostrvo pond.

3.2. Evaluating criterions

In order to compare characteristics and rank three major ponds, it was decided to consult experienced expert in groundwater hydrology, and ask him to derive proper set of criterions that should be used in evaluation procedure. After short discussion the following set of criterions was adopted: capacity, water quality, cost of water, natural protection, recharging capabilities, technical accessibility, and environmental impacts.

Capacity of a pond is defined as total well's capacity installed. Water quality is understood as necessity for water treatment. The unit cost of water is defined as cost of m^3 of installed pump capacity. As far 'natural protection' criterion is considered it was assumed, for example, that low-permeable layers such as clays or sandy clays should cover water-bearing layers with the underlying logic in evaluations by AHP: the more massive protecting layers are – the better natural protection of the pond is. Recharging capability aggregates both natural and artificial recharging possibilities that exclude any hazardous pollution. Technical accessibility of the pond is global measure of technical characteristics of wells, pumps, local infrastructure etc. Finally, 'environmental impacts' is an important criterion that serves to include interrelations between ponds, water factories, society interests and other environment factors; certain psychological issues are considered to be included in evaluations under this criterion, too.

3.3. AHP statement of the problem

To correlate above-mentioned elements with AHP terminology, decision problem here is to evaluate three major city groundwater ponds and derive their global weights with respect to certain qualitative, quantitative and mixed criterions.

Namely, here we have:

Alternatives (ponds):
1. Petrovaradinska ada
2. Strand
3. Ratno ostrvo

Criterions:
1. Capacity
2. Water quality
3. Cost of water
4. Natural protection
5. Recharging capabilities
6. Technical accessibility
7. Environmental impacts

Hierarchy of the problem has two levels, Fig. 2. To determine ponds' ranks, a number of pairwise comparisons are necessary to perform in two stages. First, each pair of criterions is mutually compared with respect to the goal. Second, each pair of alternatives is compared with respect to each criterion at upper level of the hierarchy. In straightforward manner weighting coefficients for all alternatives are derived by AHP with respect to the goal: 'Identify the best pond'. Weighting coefficients for all criterions with respect to the goal are derived in turn as a sub-result of the procedure.

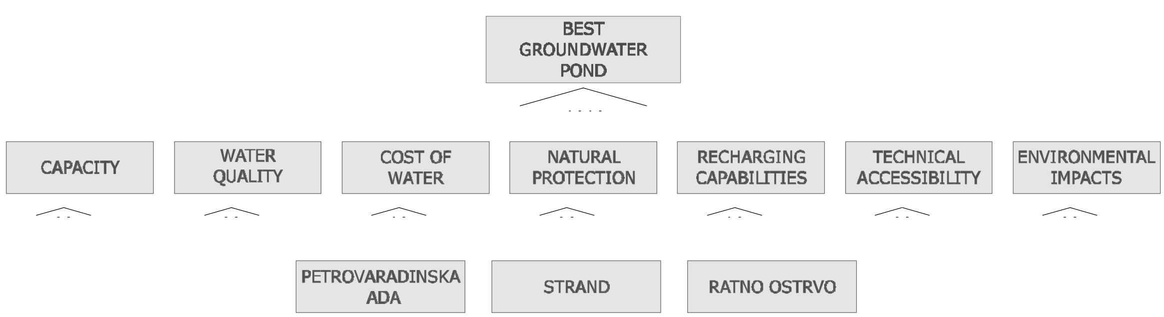

Figure 2. Hierarchy of the problem

3.4. AHP at work

Comparisons of all elements of the hierarchy (criterions with respect to goal, and ponds with respect to criterions) are made on both levels of hierarchy, by using Saaty's scale of pairwise comparisons given in Tab. 1.

Table 1. Saaty's scale of pairwise comparisons

$$S = \left\{ \frac{1}{9}, \frac{1}{8}, \frac{1}{7}, \frac{1}{6}, \frac{1}{5}, \frac{1}{4}, \frac{1}{3}, \frac{1}{2}, 1, 2, 3, 4, 5, 6, 7, 8, 9 \right\}$$

Importance	**Definition**	**Explanation**
1	Equal importance	Two elements have equal importance regarding the element in higher level
3	Week dominance	Experience or judgement slightly favours one element
5	Strong dominance	Experience or judgement strongly favours one element
7	Demonstrated dominance	Dominance of one element proved in practise
9	Absolute dominance	The highest order dominance of one element over another
2,4,6,8	Intermediate values	Compromise is needed

Pairwise comparisons of 7 criterions with respect to the goal should first be made. After 21 comparisons, (7x6)/2=21, made on computer by using EcPro (*Forman & Saaty, 1998*), the following comparison matrix is obtained, Fig. 3.

	CAPA	**QUAL**	**COST**	**PROT**	**RECH**	**ACCE**	**ENVI**
CAPA	**1**	1	2	1/3	2	5	5
QUAL	1	**1**	7	1	2	4	5
COST	1/2	1/7	**1**	1/4	1/5	1	3
PROT	3	1	4	**1**	1	5	3
RECH	1/2	1/2	5	1	**1**	7	4
ACCE	1/5	1/4	1	1/5	1/7	**1**	3
ENVI	1/5	1/5	1/3	1/3	1/4	1/3	**1**

Figure 3. Comparison matrix: criterions vs. goal

Dimension of the matrix is 7x7, because one column and one row correspond to each criterion. If this matrix is denoted as $A=\{a_{ij}\}$, all it's entries are obtained by inscribing relative importance of each criterion over another with respect to goal. Entries for each pair of criterions relate to certain row and column cross-sections. For example, if the one believes that criterion 1 (CAPACITY) has strong dominance over criterion 6 (ACCESSIBILITY), then entry a_{16} of the matrix should be put to the value of 5. To keep the thinking consistent, the entry a_{61} is 1/5. Intelligible, all entries at the main diagonal are equal to 1.

After comparison matrix for criterions vs. goal is created, weighting coefficients and ranks of criterions are calculated following the procedure described in (*Saaty, 1980*). The result is given in Tab. 2. Weighting coefficients represent relative importance of each criterion in making a decision which groundwater pond is the best, and ranks represent order of their importance.

Table 2. Weighting coefficients of criterions with respect to goal

Criterion	Weighting coeff.	Rank
Capacity	0.188	3
Water quality	0.240	1
Cost of water	0.058	5
Natural protection	0.238	2
Recharging capabilities	0.187	4
Technical accessibility	0.051	6
Environmental impacts	0.037	7

Following the same procedure, groundwater ponds were compared in pairs with respect to each criterion. After 7X3=21 comparisons, the following 7 matrices were generated, Fig. 4. Note that rows and columns in these matrices correspond to groundwater ponds in order: 1–Petrovaradinska ada, 2–Strand, and 3–Ratno ostrvo.

CAPA

1	2	1/2
1/2	1	1/3
2	1	1

QUAL

1	2	1
1/2	1	1/2
1	2	1

COST

1	1/4	3
4	1	5
1/3	7	1

PROT

1	4	2
1/4	1	1/5
1/2	5	1

RECH

1	3	4
1/3	1	2
1/4	1/2	1

ACCE

1	1/3	2
3	1	3
1/2	1/3	1

ENVI

1	1/4	3
4	1	5
1/3	1/5	1

Figure 4. Comparison matrices: ponds vs. criterions

3.5. Results

As described in (*Srdjevic et al, 2000*), AHP computes weights for each groundwater pond with respect to 7 criterions. Different vectors correspond to each of 7 matrices given in Fig. 4; each vector consists of ponds' weights. In other words, for each element (here criterion) at higher level, there is one vector of weighting coefficients for each of 3 ponds.

The overall vector of ponds' weighting coefficients is the final result of comparisons made on both levels of hierarchy. It is now related to the goal and is given in Tab. 3.

Table 3. Weighting coefficients of groundwater ponds with respect to goal

Groundwater pond	Weighting coeff.	Rank
Petrovaradinska ada	0.429	1
Strand	0.229	3
Ratno ostrvo	0.343	2

Table 3 shows that the best groundwater pond for supplying city of Novi Sad with fresh drinking water is Petrovaradinska ada. Out of 100 points, it takes 43. The second best is groundwater pond Ratno ostrvo with 34 points. The last one in the row is Strand with 23 points.

3.6. Consistency

If it would be possible to calculate precisely weighting coefficients for all elements at the same level of hierarchy, assuming elements are compared mutually by use of Saaty's scale, then weighting coefficients obtained would be truly consistent (*Saaty, 1980, 1986*). This is, unfortunately, impossible to achieve in real situations. For example, if one claims that A is much more important than B, B slightly more important than C, and C slightly more important than A, judgment is inconsistent and decisions made are less trustworthy. It is obvious that 1–9 scale in AHP leads to inconsistency a priori. Same doubts in consistency would appear if different scales (1-5 or 1-7) were used. Discussions on this topic are controversial worldwide. All participants are, luckily, aware of the fact that inconsistency is part of the human nature and that in reality it is enough just somehow to measure degree of inconsistency. This way appears to be the only one so results could be defended and justified in front of public (scientists, investors, colleagues, etc.).

As a measure of inconsistency, AHP uses originally defined method of calculating index of inconsistency (*Saaty, 1980; Karlsson, 1998*). It is deduced that the values of inconsistency index lower than 0.10 are acceptable (10% of inconsistency). Although higher value of inconsistency index requires re-evaluation of pairwise comparisons, decisions obtained in that kind of situation could also be taken as 'the best alternative' (*Karlsson, 1998; Jandric & Srdjevic, 2000*). It should also be noted that one of the advantages of AHP is that it is low sensible to judgment errors and that there is small risk of inconsistency. This could be explained by the redundancy of pairwise comparisons.

Inconsistency index obtained here was 0.07. Only slight corrections were made in micro–decisions, i.e. pairwise comparisons, so it may be said that the whole AHP session was pleasant experience with encouraging results obtained.

4. CONCLUSIONS

This paper presents selected results of recent research in groundwater management in Yugoslavia. In specific, The Analytic Hierarchy Process is applied to evaluate three urban groundwater ponds with respect to certain criterions defined by an expert in hydrogeology. Available pertinent literature and authors' knowledge indicate that this is probably the first AHP application in groundwater ponds evaluation. At least, it demonstrates ease in providing full and creative cooperation of groundwater expert and specialists in the field of system analysis and mathematical techniques for multiple-criterion, computer supported, decision making. There is a strong motivation to continue research in this field, and certain results are expected to be published soon.

Paper does not investigate nor discuss some doubts related to the problem formulation or AHP postulates. For example, AHP has no effect on how the criterions are chosen, or how hierarchy is created. That is the job of the decision maker or decision analyst. Here it was done by decision analysts (authors of the paper) with a great help of highly respected groundwater expert.

AHP achieves satisfactory consistency if basic rules of utility theory are applied. It was here fully provided and results may be accepted as trustworthy.

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