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Prioritizing the Strategies and Methods of Treated Wastewater Reusing by Fuzzy Analytic Hierarchy Process (FAHP): A Case Study

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ABSTRACT

According to an estimate, one-third of the world's population suffers from moderate-to-high water stress and this menace may worsen in the coming years. In the present research, the methods related to reuse of the treated wastewater in Hamadan province in the west of Iran have been prioritized using Fuzzy Analytical Hierarchy Process (FAHP) technique according to Extent Analysis (EA). Based on the results of the studies related to environmental evaluation and also library studies, ten alternatives were chosen, which were prioritized based on the opinions of 20 experts through relevant questionnaires, employing eight criteria. The applied technique was implemented in Visual Basic environment. The relevant data were controlled through sensitivity analysis using Evangelos Triantaphyllou technique. Based on the results, the inconsistency rate related to questionnaires was confirmed. The experts believed that the criterion of health has the highest priority between other criteria. In this research, the alternatives "reusing of Hamadan treated wastewater in order to Artificial Forest foundation" obtained first rank among the alternatives. It can be concluded that a greater focus is needed on this alternative.

Key Words: Fuzzy AHP; FAHP; Environmental management; Treated wastewater reuses

INTRODUCTION

Increasing demands on water resources for agricultural, commercial, industrial and domestic purposes have made water reuse an attractive option for extending available water supplies (Crook & Surampalli, 1996). Water reclamation and reuse criteria are principally directed at health protection, wastewater quantities and the availability, cost of the existing sources, quality standards required, associated public health and environmental hazards, institutional and political aspects, monitoring and control requirements, social awareness and need for education and public acceptance for effluent reuse (Yiannis & Alexopoulou, 1996). Reclaimed water or treated wastewater applications range from pasture irrigation to artificial augmentation of potable water supplies (Crook & Surampalli, 1996). The rate of wastewater generation is usually between 80 and 200 liters per person per day or some 30 - 70 cubic meters per person per year. Thus in semi-arid areas with a water demand of; for example, 2 m per year (the range is commonly 1.5 - 3 m per year), one persons wastewater could be used to irrigate 15 - 35 square meters of land. In other words, a city of one million people will produce enough wastewater to irrigate approximately 1500 - 3500 ha (WHO, 1989). Treated wastewater reusing is a logical action and this necessitates to priorities strategies of treated wastewater reusing and persuades us to consider our opportunities and limitations to make efforts to provide a bright future accompanied by food security and a healthy environment for future generations.

Hamadan city is located in the west of Iran, 320 km far from Tehran with a population of about 420,000. Due to the low investments in industrial activities, the development of the studied area is built upon the improvement of agriculture and aquaculture (Khoram *et al*., 2004). This research was performed in Hamadan city of Iran in 2004 for prioritizing the methods of treated wastewater reusing by the Fuzzy Analytic Hierarchy Process (FAHP) with the aim of optimization management of treated wastewater in the area under study.

MATERIAL AND METHODS

In the present research, the methods of reusing the treated wastewater in the study area were prioritized using FAHP technique according to extent analysis (EA). The Analytical Hierarchy Process (AHP), introduced by Saaty (Saaty, 1980), is the most famous decision making. Fuzzy theory was presented by Iranian researcher, Zadeh Lotfi, which was developed and influenced the management and decision making during the recent years (Azar & Faragi, 2002). Researchers from the Netherlands presented a technique, which was a combination of AHP and fuzzy theory and then was called FAHP technique (Laarhoven &

Pedrycz, 1983). In a new paradigm, FAHP introduced by change and developed by Zhu (Chang, 1996; Zhu *et al*., 1999) was known as EA method in literature. Today, FAHP technique is used widely as an advance technique in decision making process (Azar & Faragi, 2002). The specific steps involved in the development and analysis of FAHP were as follows:

Design of hierarchy structure model. Initially, it is necessary to present the schematic technique based on the numbers of criteria and alternatives.

Determination of δ value (degree of fuzziness). The practical result indicates that: $0.5 < \delta < 1$ is more suitable (Zhu *et al*., 1999).

Construct a pair-wise comparison matrix at different hierarchical levels. The pair-wise comparisons are described by values taken from a pre-defined set of ratio scale values (Table II). The ratio comparison between the relative of elements indexed *i* and *j* on a criterion (Tang & Beynon, 2005). Then an element of M_{IJ} (i.e., a comparison of the *i*th decision alternatives with *j*th decision alternatives in regard to a specific criterion) is a fuzzy number defined as $M_{IJ} = (l_{ij}, m_{ij}, u_{ij})$, where l_i, m_{ij} and u_{ij} are the upper, modal and lower values for M_{IJ}, respectively.

Determine the fuzzy synthetic extent value. As mentioned, in the pair-wise comparison matrix, each element is considered as a Triangular Fuzzy Number (TFN). Each TFN is shown by three values, *l* and *u* are the lower value and upper value, respectively and *m* is the mid-value of TFN. Generally, TFN is denoted as (*l, m, u*) (Zhu *et al*., 1999). Based on this fact, if M considered as one element of pair-wise comparison matrix, then *l*, *m* and *u* are the values of M. This means that triangular fuzzy number M could be shown as *M (l, m, u)* (Chang, 1996).

Calculation of the weight vectors. In this part, it is necessary to consider of comparison for fuzzy synthetic extent value (Chang, 1996). For example, for tow fuzzy synthetic extent values M_1 and M_2, the degree of possibility of $M_1 \geq M_2$ is obtained. Also, the degree of possibility for a fuzzy synthetic extent value M to be greater than the number of *k* fuzzy synthetic extent values M_i (*i* = 1, 2, 3,…*k*) can be given by the use of the operations max and min and can be defined by

$$V(M \geq M_1, M_2, ..., M_K) = V[(M_i \geq M_1) and (M_I \geq M_2) and ... and (M_I \geq M_K)] = \min V(M \geq M_K) \quad (1)$$

Assume that:

$$d'(A_i) = \min V(M_i \geq M_k) \quad (2)$$

Where, K = 1, 2,….n; $k \neq I$ and $d'(A_i)$ value represents the relative preference of each decision alternatives (Triantaphyllou & Sanchez, 1997).

Then a weight vector related to each matrix is given by:

$$W' = (d'(A_1), d'(A_2), ..., d'(A_m)) \quad (3)$$

Case study. In this research, first the methods of treated wastewater reusing in Hamadan have been implemented, then methods have been prioritized by use of FAHP technique.

Implementiation. Based on the results of the studies related to environmental evaluation of Hamadan (Khoram *et al*., 2004) and also library studies, the first draft related to determining criteria and alternatives was prepared. This draft included ten alternatives and eight criteria. Criteria proposed in this questionnaire were related to economy, health, environment, meteorological characteristic, development province axis, religious laws, wastewater treatment plant facility and water needs. Alternative was proposed in this questionnaire contents as follows: uses in industry and agriculture, fish product, artificial forest foundation, pasture irrigation, non-potable water supply, disposal in river, artificial recharge, potable water supply and recreational uses.

It was necessary to have viewpoints of the experts. So, this draft in the form of questionnaires (based on research) was sent to 20 specialists and experts. Collective opinion of all experts revealed that 2 alternatives of wastewater reuse were not accepted. Therefore, Potable water supply and recreational uses were eliminated in second questionnaire, which was designed as nine matrixes. The experts were asked for prioritizing the alternatives based on the criteria by completing the matrix via pair-wise comparisons. After that the filled in questionnaire were collected and analysis was done. The strategies were prioritized in six steps:

(1). Design the hierarchy structure model. It has been drawn in order to give a framework of the research (Fig. 1). On the top of this diagram is the most important research objective, while the criteria that are effective in prioritization process come next.

(2). Determine the δ value. the value of δ select as o.67 (Zhu *et al*., 1999).

(3). Construct a pair-wise comparison matrix at different hierarchical levels. The prioritization has been made by pair-wise comparison matrix. Hence the questionnaire was designed based on the viewpoints of specialists and experts. This questionnaire includes nine empty matrixes. The first matrix was used for prioritization of criteria and the other eight for prioritization of strategies based on the criteria of this research. Scale 1 - 9 has been used to determine the numerical quantity and prioritize one strategy (Table I) to the other or prioritize one criterion to the other (Saaty, 1980).

(4). Determine the fuzzy synthetic extent values (S). The matrix information gathered from the questionnaires completed by specialists and experts were transferred as Excel spread sheet. Using facilities of Excel spread sheet, the geometrical mean related to all of the matrices elements were calculated. Finally, the fuzzy synthetic extent values were determined using Equation 1.

Table I. Scale of relative importance basd on saaty (Saaty, 1980)

Level of importance		Defination
Numerical value	Fuzzy value	
1	1.00-1 -1.00	Equally preferred
2	1.33 -2- 3.67	Equally to moderately preferred
3	2.33 -3- 3.67	Moderately preferred
4	3.33 -4- 4.67	Moderately to strongly preferred
5	4.33 -5 -5.67	Strongly preferred
6	5.33 -6- 6.67	Strongly to very strongly preferred
7	6.33 -7- 7.67	Very Strongly preferred
8	7.33 -8- 8.67	Very strongly to extremely preferred
9	8.33 -9 -9.67	Extremely preferred
Reciprocals of above nonzero		If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*.

Table II. Inconsistency rate related to alternatives and criteria

NO	Name	I R
1	Economy	0.013
2	Health	0.0019
3	Environment	0.004
4	Meteorological characteristic	0.0004
5	Development province axis	0.0049
6	Religious Laws	0.0068
7	W.T.P.Facilityty	0.0032
8	Water needs	0.0089
9	Criteria	0.0002

(5). Calculation the weight vectors. In order to ensure accuracy of calculations, parts of the technique were implemented in Visual Basic programming environment. Then, the weight vector related to each matrix was calculated.

(6). Normalization. The data were normalized by performing all calculations for each of the nine matrices as explained above and integrated by weighting mean method, the importance coefficient of each strategy were calculated and then the strategies were prioritized.

Sensitivity analysis. The Sensitivity analysis was performed in order to verify the results by use of Triantaphyllou method (Triantaphyllou & Sanchez, 1997). Since the sensitivity analysis was too long and great in the above mentioned method, therefore this method was implemented in Visual Basic programming environment. After proving the accuracy of the logic of this program and making necessary controls, this program were used for sensitivity analysis.

RESULTS

Finding of this research are presented in five parts as follows:

(1). The inconsistency rate in the entire was less than 10%. As a result, consistency rates in this research are confirmed (Table II).

(2). For prioritization of alternatives, the amounts fuzzy synthetic extent values of each alternative or criterion in the related matrix were calculated. In the next step, the obtained amounts or fuzzy synthetic extent values of each pair-wise comparison matrices were transferred to the provided Visual Basic compute program in nine steps. In order to sum up and prioritize the results of this computer program, the weight vector related to each matrix was calculated (Table III). Based on these calculations, the alternatives were prioritized (Table IV).

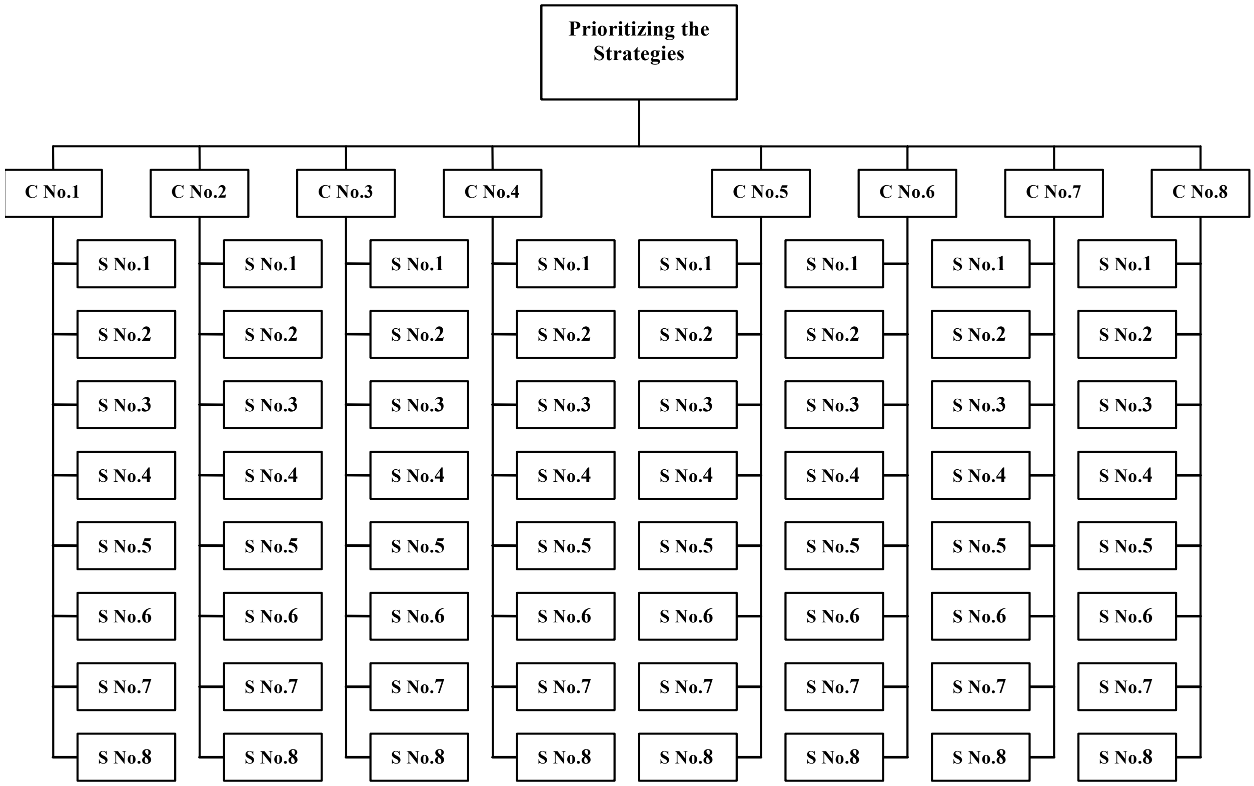
(3). In the view point of religious laws, health and wastewater treatment plant facility, the reusing of treated wastewater for artificial forest foundation, was the best method. In the view point of economy, water needs, meteorological characteristics and development province axis, the Agricultural-use was the best method. In the view point of environment criteria the Pasture irrigation was the best method.

(4). Experts and specialists believed that health has a higher priority than other criteria. Furthermore, they preferred to select and apply the artificial forest foundation as the best

Table III. Fuzzy synthetic degree values and normalized weight vector

	W.T.P.Facility			W		Economy			W
S1	0.0838	0.0938	0.1049	0.055	S1	0.1532	0.172	0.1963	0.113
S2	0.1812	0.2024	0.2263	0.258	S2	0.2411	0.2774	0.3133	0.379
S3	0.0277	0.0303	0.0332	0.115	S3	0.0405	0.0454	0.0511	0.162
S4	0.1882	0.2088	0.2315	0.302	S4	0.1055	0.1183	0.1348	0.034
S5	0.1503	0.1658	0.1828	0.013	S5	0.1197	0.1357	0.1551	0.019
S6	0.0454	0.0502	0.0556	0.118	S6	0.0456	0.0512	0.0581	0.157
S7	0.1118	0.1246	0.1385	0.067	S7	0.0365	0.0405	0.0458	0.007
S8	0.1123	0.1242	0.1373	0.072	S8	0.1389	0.1595	0.1807	0.129
	Health			W		Environment			W
S1	0.1427	0.1593	0.179	0.035	S1	0.1359	0.1512	0.168	0.078
S2	0.1751	0.1955	0.2197	0.055	S2	0.1462	0.1634	0.1821	0.014
S3	0.0285	0.0313	0.0347	0.074	S3	0.0365	0.0403	0.0445	0.123
S4	0.2118	0.2389	0.2669	0.354	S4	0.1839	0.2037	0.2258	0.049
S5	0.17	0.1936	0.2178	0.041	S5	0.2358	0.2617	0.2899	0.336
S6	0.0374	0.0415	0.464	0.198	S6	0.0592	0.0656	0.0727	0.142
S7	0.0324	0.0359	0.0407	0.131	S7	0.037	0.0408	0.045	0.122
S8	0.0932	0.104	0.117	0.112	S8	0.0657	0.0733	0.083	0.136
	Meteorological characteristic			W		Development province axis			W
S1	0.1295	0.1437	0.1595	0.105	S1	0.1419	0.1576	0.1776	0.143
S2	0.1906	0.2139	0.2388	0.343	S2	0.3372	0.3849	0.4295	0.346
S3	0.0454	0.0498	0.055	0.127	S3	0.0528	0.0581	0.065	0.014
S4	0.143	0.1602	0.1781	0.064	S4	0.1023	0.1141	0.1287	0.081
S5	0.1168	0.1294	0.1441	0.012	S5	0.1203	0.1335	0.1501	0.088
S6	0.0739	0.0817	0.0911	0.119	S6	0.0387	0.0416	0.0464	0.097
S7	0.0746	0.0822	0.0913	0.12	S7	0.0351	0.0386	0.0431	0.115
S8	0.1255	0.1391	0.1542	0.112	S8	0.0644	0.0717	0.081	0.116
	Water needs			W		Religious Laws			W
S1	0.1069	0.1196	0.1384	0.142	S1	0.1763	0.1958	0.2173	0.015
S2	0.2578	0.2928	0.3308	0.367	S2	0.0985	0.1107	0.124	0.124
S3	0.0362	0.0401	0.0449	0.15	S3	0.024	0.0262	0.0288	0.125
S4	0.0874	0.0993	0.112	0.074	S4	0.2156	0.2388	0.2674	0.402
S5	0.0863	0.0958	0.1074	0.007	S5	0.1479	0.1643	0.1824	0.065
S6	0.0748	0.0833	0.0929	0.094	S6	0.0338	0.0373	0.0413	0.176
S7	0.0364	0.0403	0.0451	0.15	S7	0.0911	0.1016	0.1135	0.004
S8	0.2074	0.2289	0.2549	0.016	S8	0.1133	0.1253	0.1386	0.089
	Criteria			W					
S1	0.1033	0.116	0.1302	0.01					
S2	0.2955	0.3265	0.3605	0.363					
S3	0.0358	0.0396	0.0441	0.011	S1-S8 : Fuzzy synthetic degree values				
S4	0.131	0.1457	0.1623	0.133					
S5	0.2173	0.2403	0.2654	0.094					
S6	0.0438	0.0491	0.0549	0.152	W : Normalized weight vector				
S7	0.0263	0.0291	0.0324	0.089					
S8	0.0476	0.0536	0.0606	0.148					

Fig. 1. Hierarchy structure model



method (Table V).

(5). The sensitivity analysis related to criteria was performed by use of Triantaphyllou method. A high amount of sensitivity coefficient was related to the environmental criterion.

Having applied the obtained results and amended the environmental criterion, data normalized by new results showed a change in weight criteria but no change was seen in the prioritization of criteria. Using the introduced method, the sensitivity analysis was performed, while a great amount of sensitivity coefficient was calculated and related to environment criterion. Having applied the obtained results and amended the strategy and final normalized results, showed no change in the results of prioritizations.

DISCUSSION

This study showed that, the experts believed the reusing of Hamadan treated wastewater for Artificial Forest Foundation was the best method. In this situation the alternative of artificial Forest foundation was selected as the best method for reusing of treated wastewater in the study area. Other alternatives such as reusing of wastewater in farming (agricultural use) and non-potable water supply are second and third criterion respectively (Table V). The use of wastewater in forestry can also bring considerable environmental benefits to the surrounding cities. In many developing countries, these areas suffer from deforestation

Table IV. Final data obtained related to criteria and alternatives

(ALS)	**ECO**	**H**	**REL**	**WAN**	**ENV**	**WTF**	**MEC**	**DPA**	
(CRS)	**0.01**	**0.363**	**0.011**	**0.13**	**0.094**	**0.15**	**0.089**	**0.148**	**Total**
(INU)	0.11	0.035	0.015	0.14	0.078	0.055	0.105	0.143	0.079
(AGU)	0.38	0.055	0.124	0.38	0.014	0.258	0.341	0.346	0.197
(FIP)	0.16	0.074	0.125	0.15	0.123	0.115	0.127	0.014	0.092
(AFF)	0.03	0.354	0.402	0.07	0.049	0.302	0.064	0.081	0.213
(PAI)	0.02	0.041	0.065	0.01	0.336	0.013	0.012	0.088	0.064
(NPW)	0.16	0.198	0.176	0.09	0.142	0.118	0.119	0.09	0.143
(DIR)	0.01	0.131	0.004	0.15	0.122	0.067	0.12	0.115	0.116
(ARR)	0.13	0.112	0.089	0.02	0.136	0.072	0.112	0.116	0.096

(CRS): Criterion | (ECO) :Economy
(INU):Industrial used | (H) : Health
(AGU):Agricultural used | (REL): Religious Laws
(FIP): Fish product | (WAN): water needs
(AFF):Artificial Forest foundation | (ENV): Environment
(PAI): Pasture irrigation | (WTF): Wastewater treatment plant Facility
(NPW): Non potable water supply | (MEC):Meteorological characteristics
(DIR): Disposal in river | (DPA): development province axis
(ARR): Artificial Recharge | (ALS): Alternatives

Table V. ranking of alternatives in this research

Alternatives	**Ranking**
Forest foundation	1
Agricultural used	2
Non potable water supply	3
Disposal in river	4
Artificial Recharge	5
Fish product	6
Industrial used	7
Pasture irrigation	8

and the resulting environmental degradation caused by the fuel demand. In arid zone, tree belts help to stabilize the desert around cities and control dust storms, while at the same time improving the environment and providing a valuable crop (WHO, 1989).

Standards in Saudi Arabia for effluent are stringent and impose un-necessary limitations on disposal and reuse of wastewater (Abu-Rizaiza, 1999). These standards may actually prevent agricultural uses and impose near drinking water quality on reuse of water. Conflicts between official standards and practical considerations cause confusion and inaccurate accounting. Also Yiannis and Alexopoulou (1996) reported that in the Athens Metropolitan area, use of various wastewater included crop irrigation, irrigation of forests areas, industrial water supply and domestic non-potable use. Twelve different reuse schemes were evaluated. These conclusions are of great interest, since the quantities of the available effluent are enormous and allow the development of an overall reuse strategy for a typical Mediterranean metropolitan area like Athens. In one of the Italian studies cited in Municipal-treated wastewater reuse for plant nurseries irrigation, it was noted that, no major limitations to the use of a tertiary effluent as an irrigation source in an ornamental plant nursery (Lubello *et al*., 2004). FAHP technique has been frequently used in different cases, for instance in capital investment study (Tang & Beynon, 2005), to select a provider for specific service (Mikhailov & Tsvetinov, 2004), to evaluate success factors of e-commerce (Feng & hongyan, 2005) and to prioritize and rank the influencing factors of public work's quality (Yang, 2006).

It can be concluded that, the frequent use of FAHP show that this technique can be effectively used in evaluation and ranking the alternatives. The FAHP technique would be applicable for prioritizing the methods of treated wastewater reusing and other case related to ranking the strategies and this technique can be more developed in near future.

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